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Mesozoic stratigraphy of the Chama Basin. Second-day road log from Ghost Ranch to Tierra Amarilla and Chama

Spencer G. Lucas, Andrew B. Heckert, Kate E. Zeigler, Donald E. Owen, and Adrian Hunt

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MESOZOIC STRATIGRAPHY OF THE CHAMA BASIN
SECOND-DAY ROAD LOG FROM GHOST RANCH TO TIERRA AMARILLA AND CHAMA

SPENCER G. LUCAS, ANDREW B. HECKERT, KATE E. ZEIGLER,
DONALD E. OWEN, AND ADRIAN HUNT

Assembly Point: Parking lot at headquarters of Ghost Ranch Conference Center

Departure Time: 7:30 AM

Distance: 49.4

Four stops

SUMMARY

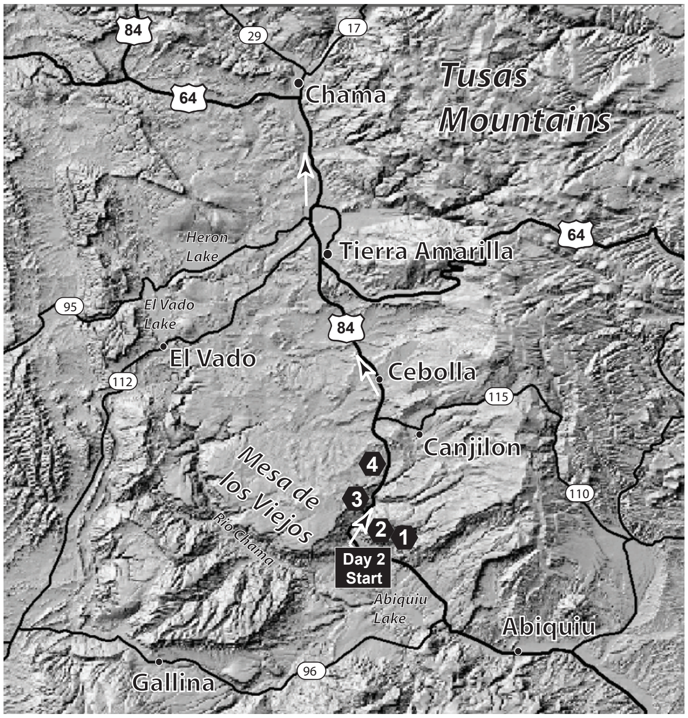
The second day trip focuses on Triassic, Jurassic and Cretaceous strata of the Chama Basin, especially on their depositional systems and paleontology. Just north of Ghost Ranch, the first stop examines the taphonomy of the Canjilon quarry, a bonebed of Late Triassic phytosaurs and other animals discovered and first collected in the late 1920s. Stop 2 returns to Ghost Ranch to hike the trail to Chimney Rock. Here, we examine the Middle Jurassic Entrada and Todilto formations, with a focus on the evolution of the Todilto depositional system. From Ghost Ranch we proceed north to the Late Triassic Snyder quarry in the Painted Desert Member of the Petrified Forest Formation, essentially at the same stratigraphic level as the Canjilon quarry. The hypothesis that a Late Triassic wildfire killed the animals in the Snyder bonebed is the focus of this stop. On the highway north to Chama, the fourth and last stop examines a section of Upper Jurassic and Cretaceous rocks, with discussion of their regional stratigraphy, sedimentation, and economic geology.

0.0 Begin at Ghost Ranch Conference Center headquarters parking lot. **Proceed west** on unpaved road toward highway. *0.2*

0.2 **Turn right** on private drive. *0.1*

0.3 Road forks, **bear right**. *0.3*

0.6 Upper Triassic Chinle Painted Desert Member badlands on right. *0.6*



1.2 STOP 1 - Canjilon Phytosaur Quarry
Pull off on right.

Walk to Canjilon phytosaur quarry. This quarry is one of the mass death assemblages of Late Triassic fossil vertebrates that have made the Chama Basin such an important vertebrate fossil-collecting area. See the accompanying minipaper for discussion of the history of collecting and taphonomy of the Canjilon quarry. *0.2*

END OF STOP 1
Continue on dirt road.

1.4 Georgia O'Keefe house on left. *0.1*

1.5 Road forks, **go right** and then left. *0.1*

1.6 **Turn left,** then retrace route to Ghost Ranch. *1.3*

2.9 **Turn left** on main dirt road. *0.2*

3.1 **Turn left** on road to campground. *0.1*

Road log continues on page 43

FOSSILS AT GHOST RANCH: THE RUTH HALL MUSEUM OF PALEONTOLOGY COLLECTION

Andrew B. Heckert[1], Spencer G. Lucas[1], Alex Downs[2] and Adrian P. Hunt[1]
[1]New Mexico Museum of Natural History, 1801 Mountain Road NW, Albuquerque, NM 87104-1375
[2]Ruth Hall Museum of Paleontology, Ghost Ranch Conference Center, HC 77 Box 11, Abiquiu, NM 87510-9601

The Ruth Hall Museum of Paleontology at the Ghost Ranch Conference Center contains a small but important collection of fossil vertebrates that well represent, in microcosm, the fossil record of Ghost Ranch's 21,000 acres and the surrounding area. The largest and most important portion of this collection is the block from the Upper Triassic *Coelophysis* quarry and other vertebrates from that site. Second in terms of both size and importance are the Upper Triassic vertebrates from the Painted Desert Member of the Petrified Forest Formation of the Chinle Group. Of lesser importance are a fish from the Middle Jurassic Todilto Formation and fragmentary dinosaur bones from the Upper Jurassic Morrison Formation.

Ghost Ranch's best and most important fossils come from the *Coelophysis* quarry, which is located in the Rock Point Formation on the grounds of Ghost Ranch itself. The Ghost Ranch block from the *Coelophysis* quarry is on permanent display at the Ruth Hall Museum of Paleontology, although several key fossils have been removed for research and separate display. This was the last block defined in the quarry during the Carnegie excavations of 1981 and 1982, although the block was not removed from the quarry until fall of 1985. Interestingly, its western face actually adjoins the block under preparation at the New Mexico Museum of Natural History and Science in Albuquerque (Colbert, 1989, fig. 6). The Ghost Ranch block has yielded an important fauna consisting not only of numerous specimens of *Coelophysis* (including at least two juvenile skulls) but also a strange aquatic archosauromorph apparently related to *Vancleavea* and a pectoral girdle of a drepanosaurid (Downs and Davidge, 1997; Downs, 2000; Harris and Downs, 2002; Hunt et al., 2002). Other fossils on display at the Ruth Hall Museum of Paleontology from the *Coelophysis* quarry include phytosaur postcrania most reasonably assigned to *Redondsaurus* and bones of a *Hesperosuchus*-like sphenosuchian.

The older, Painted Desert Member fauna from Ghost Ranch and vicinity was first collected by the museum's inspiration and namesake, Ruth Hall, principally in the 1960s and 1970s. Hall collected frequently at the Canjilon quarry (Hunt and Downs, 2002; Martz, 2002; see also Martz and Zeigler, this volume) and other localities at or near the same stratigraphic level. Particularly noteworthy is an incomplete, but originally articulated, phytosaur from the base of Orphan Mesa. This specimen, informally dubbed "Old Phytie" by Hall, was discovered by a Bob Hunt and excavated by Hall, with the help of A.W. Crompton of Harvard, in 1970 (Fig. 2.1). "Old Phytie" is important because (1) it is a relatively rare occurrence of an articulated phytosaur; and (2) we now know that it came from the same stratigraphic interval as the Canjilon quarry, Snyder quarry, Hayden quarry (see below), Sullivan et al.'s (1996) Orphan Mesa localities, and several other vertebrate occurrences. Unfortunately, some time after Hall's passing the collections fell into disrepair and most original associations

FIGURE 2.1. A-B, Excavations of "Old Phytie" near the base of Orphan Mesa, 1970 (photographs courtesy of Ghost Ranch). A, Ruth Hall with the articulated skeleton. B, A.W. Crompton working on the pedestal.

have been lost, so that many labels only identify specimens as from the "Chinle Formation, Rio Arriba County, New Mexico."

More recently, one of us (AD) has undertaken excavations at the Canjilon quarry and other areas at the same stratigraphic level. Excavations at the Canjilon quarry have yielded a typical fauna for the interval, including a well-preserved skull of *Pseudopalatus buceros*, interpreted as a female by Zeigler et al. (2003a). In 2001, Kirby Soderburg found another, large pseudopalatine skull near Orphan Mesa that is now in the Ruth Hall Museum of Paleontology's collections. This is probably a large adult male of *P. buceros* (Fig. 2.2). Since 2002, the newly discovered Hayden quarry has been the focus of most of the Ruth Hall Museum of Paleontology's efforts. This quarry appears to be extremely similar to the Snyder quarry (Day 2, stop 3), and yields a tetrapod fauna consisting of phytosaurs, the aetosaur *Typothorax coccinarum*, fragmentary dinosaurs, and other taxa currently under study by Downs and Martz.

Among the other vertebrates housed at the Ruth Hall Museum of Paleontology are a fish from the Todilto Formation near Chimney Rock (Stop 2, Day 2; see Hunt et al., this volume) and several fragmentary bones of dinosaurs collected from Morrison Formation exposures on the ranch grounds. The Todilto fish is an important record, as the Todilto vertebrate fauna, while locally rich, is always of low diversity, consisting mostly of the fishes *Todiltia* and *Hulettia* (Koerner, 1930; Dunkle, 1942; Schaeffer and Patterson, 1984; Lucas et al., 1985). The best Morrison Formation fossil at the museum is a dinosaurian distal femur collected from the Brushy Basin Member north of the ranch.

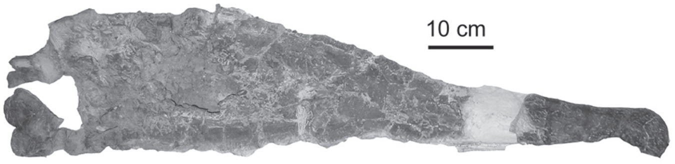


FIGURE 2.2. Lateral view of male skull of *Pseudopalatus buceros* from the base of Orphan Mesa in Ghost Ranch collection.

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TAPHONOMY AND SEDIMENTOLOGY OF THE UPPER TRIASSIC CANJILON QUARRY (PAINTED DESERT MEMBER OF PETRIFIED FOREST FORMATION, CHINLE GROUP), CHAMA BASIN, NORTH-CENTRAL NEW MEXICO, AND A COMPARISON WITH THE SNYDER QUARRY

Jeffrey W. Martz[1] and Kate E. Zeigler[2]
[1]Department of Geosciences, Texas Tech University, Lubbock, TX, 79409
[2]Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM, 87131

The Canjilon quarry, located just west of Ghost Ranch in north-central New Mexico, has been one of the most prolific Upper Triassic bonebeds discovered in the region. It lies in the Painted Desert Member of the Petrified Forest Formation of the Chinle Group, which is stratigraphically below the more famous nearby Ghost Ranch *Coelophysis* quarry in the Rock Point Formation (Dubiel, 1989; Lucas and Hunt, 1992; Lucas et al., 2003). The vast majority of the fossil material was collected by Charles Camp, who first visited the site in 1928, and returned in 1930 and 1933 (Lawler, 1974; Long et al., 1989; Martz, 2002). Although material was recovered during the excavations of 1928 and 1930, the 1933 expedition, which lasted from May 23rd to July 27th, was

FIGURE 2.3. Excavation at the Canjilon quarry by University of California field party, 1928.

a much larger scale undertaking that removed the remains of at least a dozen animals (Figs. 2.3-2.4). The nearby Snyder quarry, excavated by workers from the New Mexico Museum of Natural History and the University of New Mexico, is roughly equivalent stratigraphically and sedimentologically, but differs somewhat in the faunal content and the degree of disarticulation of the material (Zeigler, 2003; Zeigler et al., 2003a).

Field maps (in varying degrees of clarity) of the Canjilon quarry for most of the productive grid squares are available in the field notes of Camp and his students. Additionally, there is a larger quarry map drawn (in pencil) on rough brown paper in the UCMP collection. The "brown paper map" was probably the basis for the quarry maps published by previous authors, and contains additional information on the quarry layout not found in the field notes. The notes and maps show that the Canjilon quarry specimens range from almost fully articulated skeletons to associated but completely disarticuled skeletons to isolated elements (Fig. 2.4). This is in contrast to the Snyder quarry material, which is almost all associated but disarticulated specimens and isolated elements (Zeigler, 2003).

Canjilon quarry represents an extremely low diversity assemblage. Most of the material recovered can be referred to the phytosaurs *Pseudopalatus buceros* and *P. pristinus* (which are likely sexual dimorphs of the same species), and the aetosaur *Typothorax coccinarum*. The only other identifiable material consists of a few probable metoposaur vertebrae (Lawler, 1974; Martz, 2002; Zeigler, 2002). This is in contrast with the nearby Snyder quarry, which contains the remains of at least six vertebrate taxa, including those at Canjilon Quarry (Zeigler et al., 2003b).

The specimens at Canjilon quarry were recovered primarily from two distinct levels, both of them thin (30 cm thick or less) conglomerates, separated by about half a meter of reddish mudstone (Hunt and Downs, 2002; Martz, 2002). The Painted Desert Member of the Petrified Forest Formation has been interpreted as the deposits of a major meandering river depositional system (Dubiel, 1989), but the Canjilon conglomerates are not part of a point bar sequence and were therefore probably not deposited in a meandering river channel. It is likely therefore that they instead represent smaller, bedload-dominated streams feeding the major meandering channels in which flow was ephemeral with occasional flooding events. The same interpretation has been made for the Snyder quarry, and these floods were probably responsible for the distribution of most of the material at both localities (Hunt and Downs, 2002; Zeigler et al., 2003a).

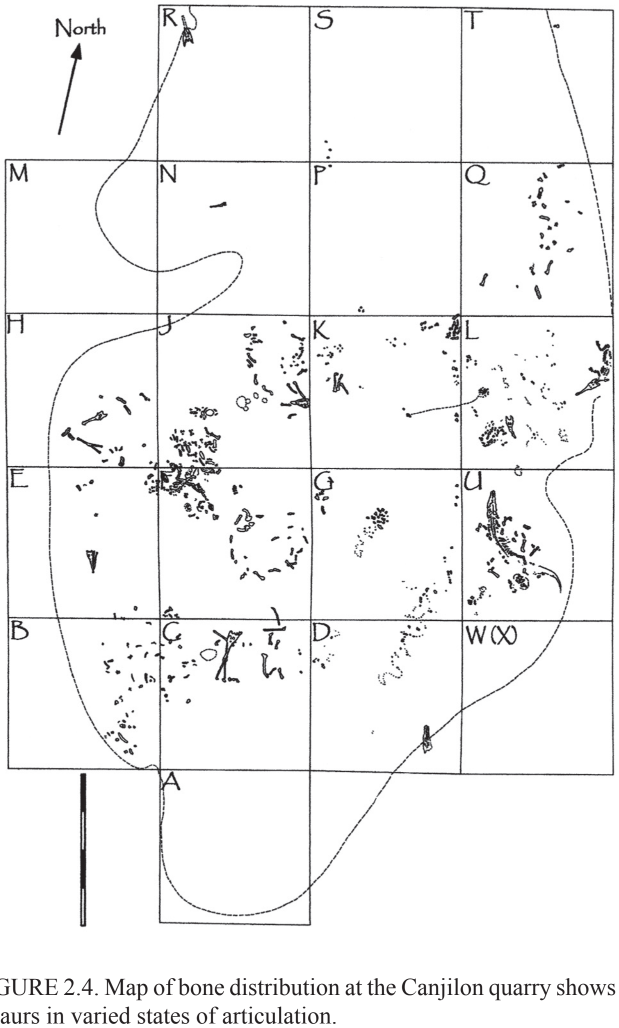

FIGURE 2.4. Map of bone distribution at the Canjilon quarry shows phytosaurs in varied states of articulation.

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3.2 STOP 2. Chimney Rock

Park in lot.

Walk trail to Chimney Rock to examine Jurassic section (Figs. 2.5-2.7).

Ghost Ranch and the surrounding area were mapped at the 1:24,000 scale by Smith et al. (1961), although this map predates the filling of Abiquiu Reservoir, so the distribution of roadways now is markedly different. Smith et al. (1961) subdivided the Mesozoic on the Ghost Ranch quadrangle into a Triassic System consisting of a "lower sandstone" and "upper shale" members of the Chinle Formation, a Jurassic System consisting of the Entrada, Todilto, and Morrison formations (the latter divided into a lower sandstone and upper Brushy Basin Member), and Cretaceous strata termed "Dakota?" Formation. In the vicinity of Ghost Ranch, Smith et al.'s (1961) "lower sandstone member" of the Chinle corresponds to the Poleo Formation and, locally, Mesa Montosa Member of the Petrified Forest Formation of Lucas et al. (2003). Lucas and Hunt (1992; Hunt and Lucas, 1993; Lucas et al., 2003) subdivided Smith et al.'s (1961) upper shale member of the Chinle into a bentonitic Painted Desert Member of the Petrified Forest Formation and an upper, non-bentonitic Rock Point Formation.

The Entrada Formation of Smith et al. (1961) is essentially identical to current usage, with the caveat that we equate the Entrada at Ghost Ranch to the Slick Rock Member of the Entrada elsewhere in New Mexico and the Four Corners region (e.g., Lucas and Anderson, 1997, 1998; Lucas and Heckert, 2003).

The Todilto Formation as used here and mapped by Smith et al. (1961) are essentially identical units. Note that the limestone of the Todilto (Luciano Mesa Member of Lucas and Anderson, 1997) is ubiquitous atop the Entrada in this area. The gypsum (Tonque Arroyo Member of Lucas and Anderson, 1997), however, pinches and swells considerably, thickness changes that probably reflect sediment loading and/or tectonic forces, not original deposition. The Todilto was deposited in a vast, paralic salina that was followed by a smaller evaporitic basin (Lucas et al., 1985; Kirkland et al., 1995). Ahmed Benan and Kocurek (2000) argued for geologically instantaneous flooding of the Entrada dune field to produce the Todilto salina, based largely

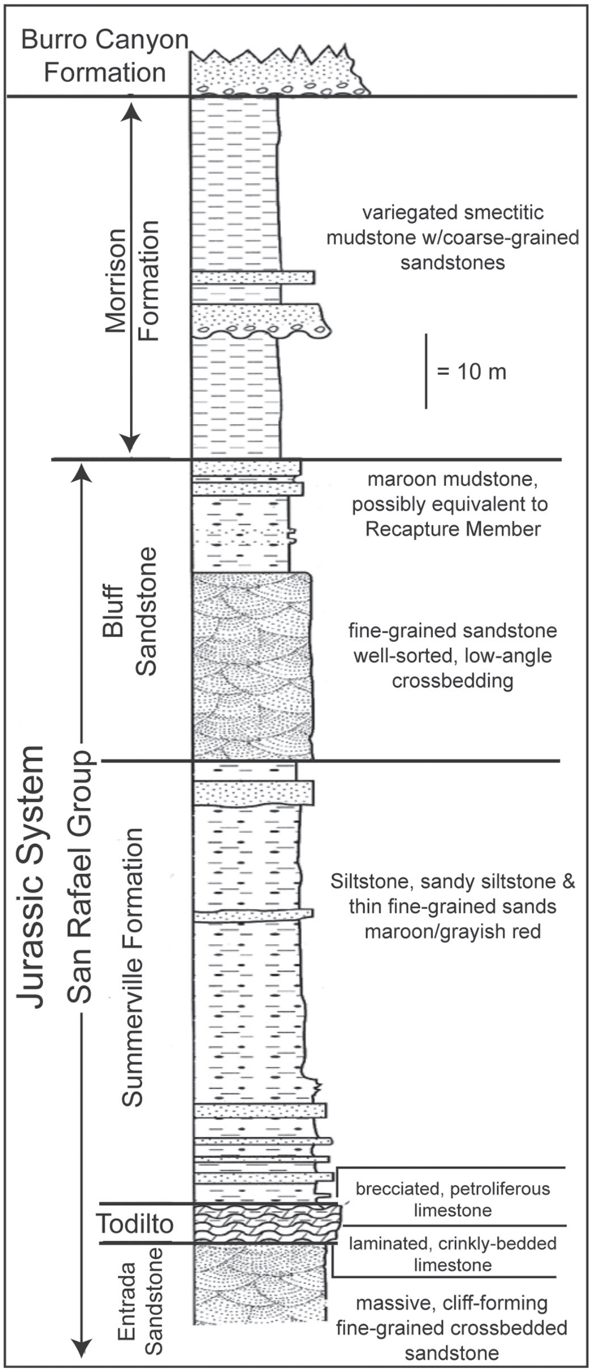

FIGURE 2.5. Measured section of Jurassic strata in Chimney Rock area (after Lucas and Anderson, 1998).

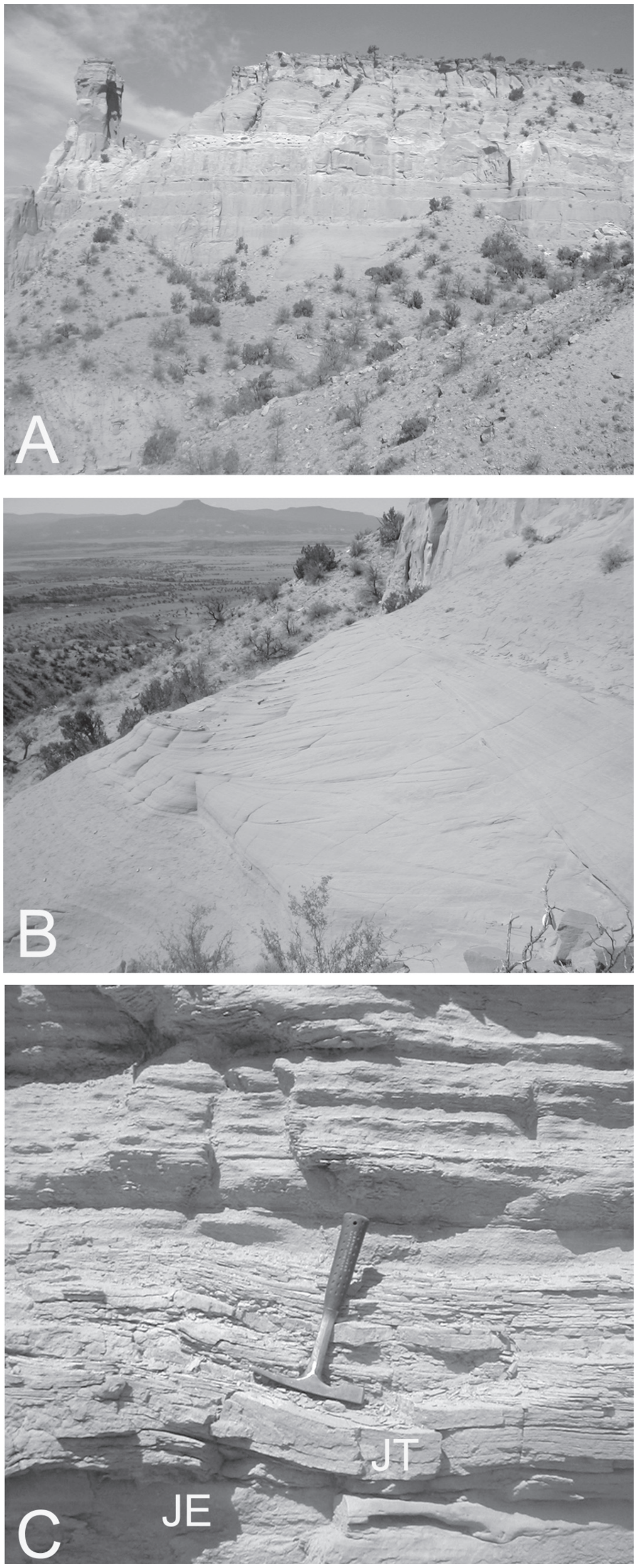

FIGURE 2.6. Photographs of selected Jurassic strata at Chimney Rock. A, Overview of Entrada Sandstone (Slick Rock Member) capped by Todilto Formation. B, Characteristic SW-dipping crossbeds in the Slick Rock Member of the Entrada Sandstone. C, Sharp contact of Todilto Formation (JT) on Entrada Sandstone (JE).

on their studies of the Todilto outcrops in the Ghost Ranch area.

The lower portion of Smith et al.'s (1961) "lower member of the Morrison Formation" is actually the Middle-Upper Jurassic Summerville and Bluff formations (Anderson and Lucas, 1992). Locally, the top of the "lower member" may correspond to the Salt Wash Member of the Morrison Formation (Anderson and Lucas, 1995, 1996, 1998). The Brushy Basin Member as used here is the same as described by Smith et al. (1961). The Dakota? of Smith et al. (1961) is, as they suspected, actually the Lower Cretaceous Burro Canyon Formation (Saucier, 1974). *1.3*

END OF STOP 2

Turn right onto main road out of ranch that leads to US 84.

4.5 Intersection with US 84 pavement begins, **turn right** and proceed north on US 84. The Painted Desert strata to left are faulted down relative to the road surface (Smith et al., 1961, pl. 5). The Hayden quarry, a recently discovered bonebed in the Painted Desert Member of the Petrified Forest Formation, is just west of a fault to the west of the highway. The drainage here is part of Arroyo Seco. *0.1*

4.6 Poleo Formation sandstones in roadcuts. *1.2*

5.8 Mile marker 226. *0.4*

6.2 Former Ghost Ranch living museum on right (formerly run by a private entity for the US Forest Service but now closed). *1.0*

7.2 Past cattle crossing sign, **turn left** onto Monastery Road (Forest Road 151). *0.1*

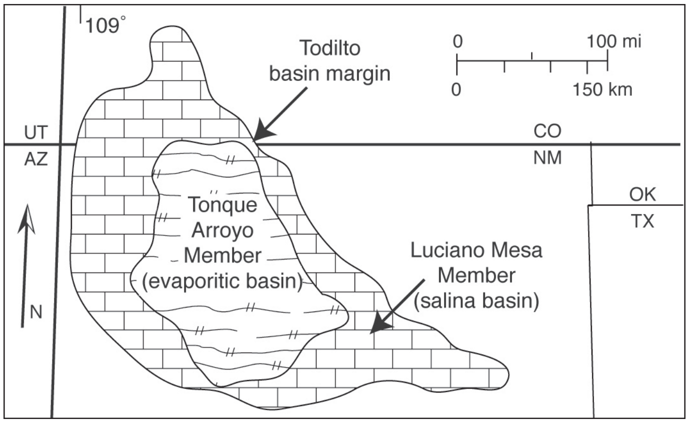

FIGURE 2.7. Distribution of the two members of the Todilto Formation in northern New Mexico and southwestern Colorado.

NEW FOSSIL FISH LOCALITY IN THE MIDDLE JURASSIC TODILTO FORMATION AT GHOST RANCH, NORTH-CENTRAL NEW MEXICO

Adrian P. Hunt[1], Spencer G. Lucas[1] and Alex Downs[2]
[1]New Mexico Museum of Natural History, 1801 Mountain Road N. W., Albuquerque, NM 87104
[2]Ruth Hall Museum of Paleontology, Ghost Ranch Conference Center, HC77, Box 11, Abiquiu, NM 87510

The Middle Jurassic (Callovian) Todilto Formation crops out throughout much of northwestern and east-central New Mexico and southwestern Colorado from north of Durango to Santa Rosa (Lucas et al., 1985; Kirkland et al., 1995). It records deposition in a vast, paralic salina that had little connection to the contemporaneous Jurassic seaway to the northwest, which was in east-central Utah. In the central part of its basin of deposition, the Todilto is composed of a lower, Luciano Mesa Member dominated by laminated limestone and an upper, Tonque Arroyo Member composed of gypsum. The base of the Todilto is a regional unconformity correlative to the J-3 unconformity of Pipiringo and O'Sullivan (1978). The Todilto at Ghost Ranch is underlain by the Middle Jurassic Entrada Sandstone and is overlain by the Middle Jurassic Summerville Formation.

The Luciano Mesa Member of the Todilto Formation locally contains a low diversity holostean fish fauna consisting of three species, *Hulettia americana*, *Todiltia schoewei* and *Caturus dartoni* (Schaeffer and Patterson, 1984; Lucas et al., 1985). These fish are known from several localities in New Mexico, including: (1) Bull Canyon, east of Santa Rosa; (2) Warm Springs, north of San Ysidro; (3) Lamy; (4) Montezuma; (5) Suwanee near Grants; (6) La Liendre near Las Vegas; (7) Echo Amphitheater, south of Chama; and (8) probably near Acoma (Lucas et al., 1985). Despite the number of localities, only the Bull Canyon area in Guadalupe County has produced significant numbers of fish fossils.

We have discovered a new locality for holostean fish (Fig. 2.8) from the Luciano Mesa Member of the Todilto Formation adjacent to Ghost Ranch in Rio Arriba County. This locality is next to the Chimney Rock trail and a fossil fish was discovered here by Shane Burt, a fifth grader from Enos Garcia Elementary School in Taos. Subsequently, one of us (APH) collected an additional specimen. The Luciano Mesa Member is 4.55-m thick at this location. Fish fossils occur 2.1 m above the lower contact with the Entrada Sandstone in a 10-cm thick bed of limestone that forms a slope break. The fossiliferous matrix is a varved, organic-rich limestone. Beds above and below the fish-level exhibit microfolding ("crinkly" bedding), which is characteristic of parts of the Luciano Mesa Member.

This new fish locality has not been excavated. Surface collection has yielded two specimens that are at the Ruth Hall Museum of Paleontology at Ghost Ranch. Both specimens are laterally compressed, and the cranial and some other areas are covered by matrix. Based on the morphology of the tail and dorsal fin and the fact that only three species of holostean fish are known from the Todilto, we are confident in assigning these specimens to *Todiltia schoewei*. This new fish locality has great potential to be a significant source of additional Jurassic fossil fish specimens from the Todilto Formation and merits further excavation.

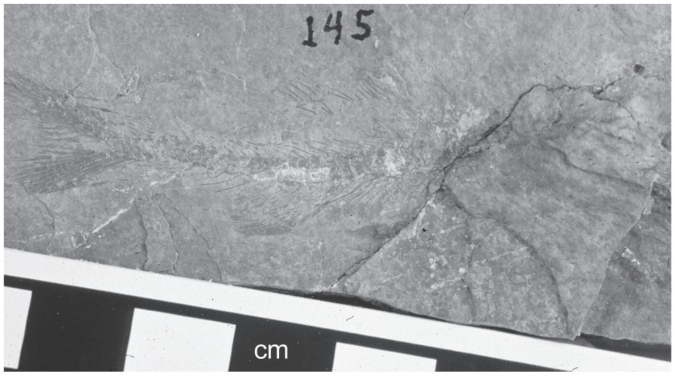

FIGURE 2.8. Specimen of *Todiltia schoewei* (Ruth Hall Museum of Paleontology specimen 145) from the Todilto Formation at Chimney Rock near Ghost Ranch.

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7.3 STOP 3: Snyder Quarry.

Pull off on left and walk to quarry.

Here we will discuss Triassic strata and fossils (Figs. 2.9-2.10). The Snyder quarry is, quite simply, the richest and most diverse Upper Triassic vertebrate locality discovered in the American Southwest in the past 50 years. The quarry was discovered by Mark Snyder and brought to the attention of the New Mexico Museum of Natural History by Alex Downs of Ghost Ranch in the summer of 1998. UNM graduate students Andrew Heckert and Kate Zeigler led excavations at the quarry for the NMMNH in 1998, 1999, 2000, and 2001, and the NMMNH has continued to revisit the site. The 1998-2001 excavations were extensive, covering an estimated 30 m^2, yielding 64 plaster jackets, 3000+ pounds of matrix for screenwashing and thousands of isolated bones, with almost all of the labor (well in excess of 3000 person hours) provided by volunteers with the New Mexico Friends of Paleontology. Approximately 30 of those jackets have been prepared and these, isolated elements, and preliminary screenwashing have yielded over 1,200 catalogued specimens at the NMMNH. The quarry is situated relatively high in the Painted Desert Member of the Petrified Forest Formation, and the presence of the phytosaur *Pseudopalatus* and the aetosaur *Typothorax coccinarum* indicate a Revueltian (early-mid Norian, approximately 215 Ma) age.

The flora and the fauna of the quarry have been published principally in the NMMNH bulletin series (Heckert et al., 2000, Zeigler et al., 2002a,b; Zeigler et al., 2003a) and have been the subject of both a master's (Zeigler, 2002) and a senior (Jenkins, 2004) thesis. Highlights include abundant carbonized (charcoalized) wood (Zeigler, 2002, 2003), an invertebrate fauna consisting of unionid bivalves and the new crab *Rioarribia schrammi* (Lucas et al., 2003; Rinehart et al., 2003) and an exceptionally rich vertebrate fauna. The vertebrates include abundant phytosaurs, aetosaurs, and dinosaurs as well as less common sharks, bony fish, primitive reptiles, sphenosuchians, rauisuchians, and a diverse microvertebrate fauna (see Heckert and Jenkins, this volume). What makes this fauna so important is its combination of abundance, excellent preservation, new taxa and records, and apparent catastrophic origin. Fossil remains are abundant---excavations are known to have already yielded all or part of 11 phytosaur skulls and thousands of isolated elements, and Zeigler (2002) reported bone densities as high as 69/m^2, counting solely bones > 5 cm length and exposed in the field. Locally, the density of fossil bones and teeth may double that number. Many of the specimens are preserved in exquisite detail, including pristine outer surfaces and, locally, bones less than 1 mm thick. In addition to the new crab mentioned previously, a new aetosaur, *Desmatosuchus chamaensis* (Zeigler et al., 2002a) and a probable new dinosaur (Heckert et al., 2000, 2003) have been found at the quarry.

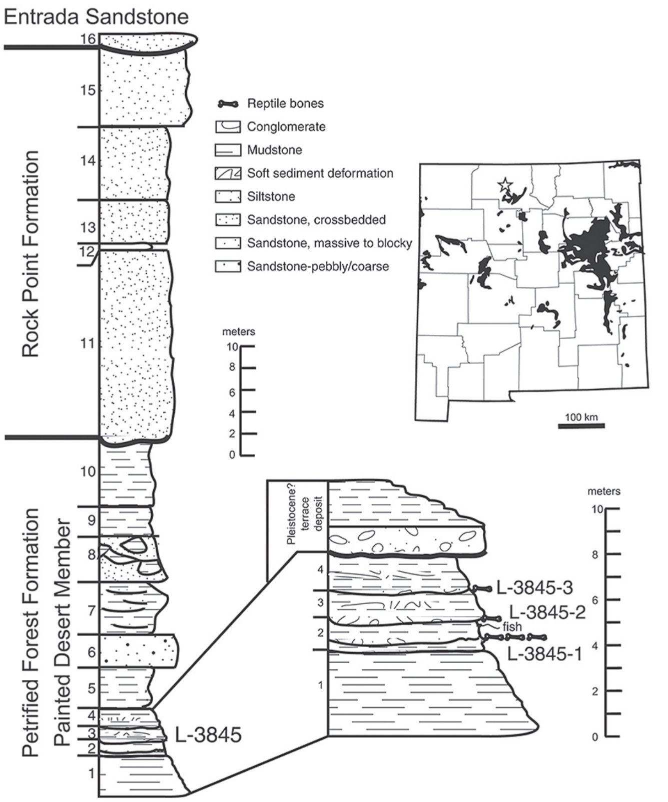

FIGURE 2.9. Measured stratigraphic section at the Snyder quarry (New Mexico Museum of Natural History locality 3845).

It now appears certain that the Snyder quarry was deposited in the aftermath of a large wildfire (Zeigler, 2002, 2003) (Fig. 2.11; see accompanying minipaper). Although it is effectively impossible to implicate the fire in the death of the fauna, the evidence is better than circumstantial. Zeigler (2002, 2003) documented abundant charcoalified wood at the Snyder quarry, and indeed in a 400 m radius at the same stratigraphic horizon. Similarly preserved wood has been observed as far east as Orphan Mesa (10 km southeast of here). Furthermore, the Snyder quarry, the Canjilon quarry (Stop 2 earlier today) and Orphan Mesa (seen on Day 1) as well as Ghost Ranch's Hayden quarry and several other localities, are all at the same stratigraphic level, and most contain the same wood. It is, of course, possible that a paleo-wildfire simply altered depositional conditions, and thus facilitated preservation of vertebrates, but it is still clear that several of these quarries represent catastrophic accumulations (Hunt and Downs, 2002; Zeigler, 2002, 2003; Zeigler et al., 2002b). Thus this interval of the Painted Desert Member yields one of the richest assemblages of tetrapods known of this age, and, in addition to the stratigraphically higher *Coelophysis* quarry, provides world-class opportunities to study Upper Triassic vertebrate paleontology. *0.1*

END OF STOP 3

Retrace route to US 84.

7.4 **Turn left** at stop sign at US 84 to continue north on the highway. Arroyo Seco drainage parallels highway on right. *1.6*

9.0 Echo Amphitheater turn on left (Fig. 2.13). *1.4*

10.4 Colluvium on right. *0.7*

11.1 Mile marker 231 on right. Jurassic Entrada and Todilto formations on left (Fig. 2.14) *0.2*

Road log continued on page 51

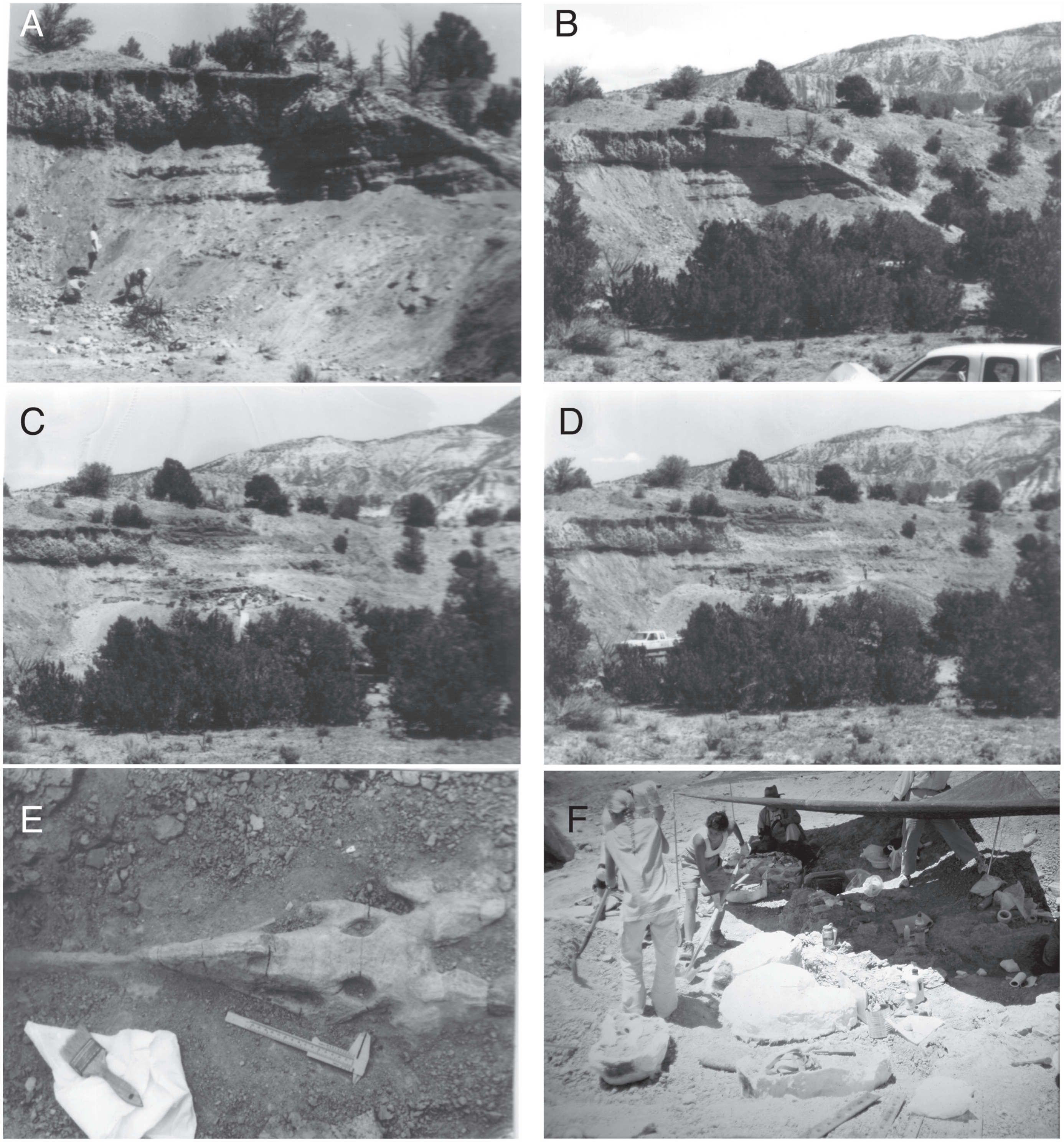

FIGURE 2.10. Vertebrate fossil excavations at the Snyder quarry. A, Discoverer Mark Snyder and others examine the quarry as it appeared on 13 May, 1999, all excavation to that point had been conducted under the cliff wall in the shade of the right side of the photo. B, Quarry as it appeared prior to bulldozing, 13 May, 1999. C, Quarry on 18 May, 1999. D, Temporary closing of the quarry at the conclusion of the May dig, 31 May, 1999. E, Subadult male skull of the phytosaur *Pseudopalatus buceros* (NMMNH P-31292), as seen in the field circa 27 May, 1999, calipers measure to 15 cm (~6 in). F, Crew at work in early July, 2000; note two flipped and two unflipped plaster jackets in foreground, ongoing excavations under the tarps in background.

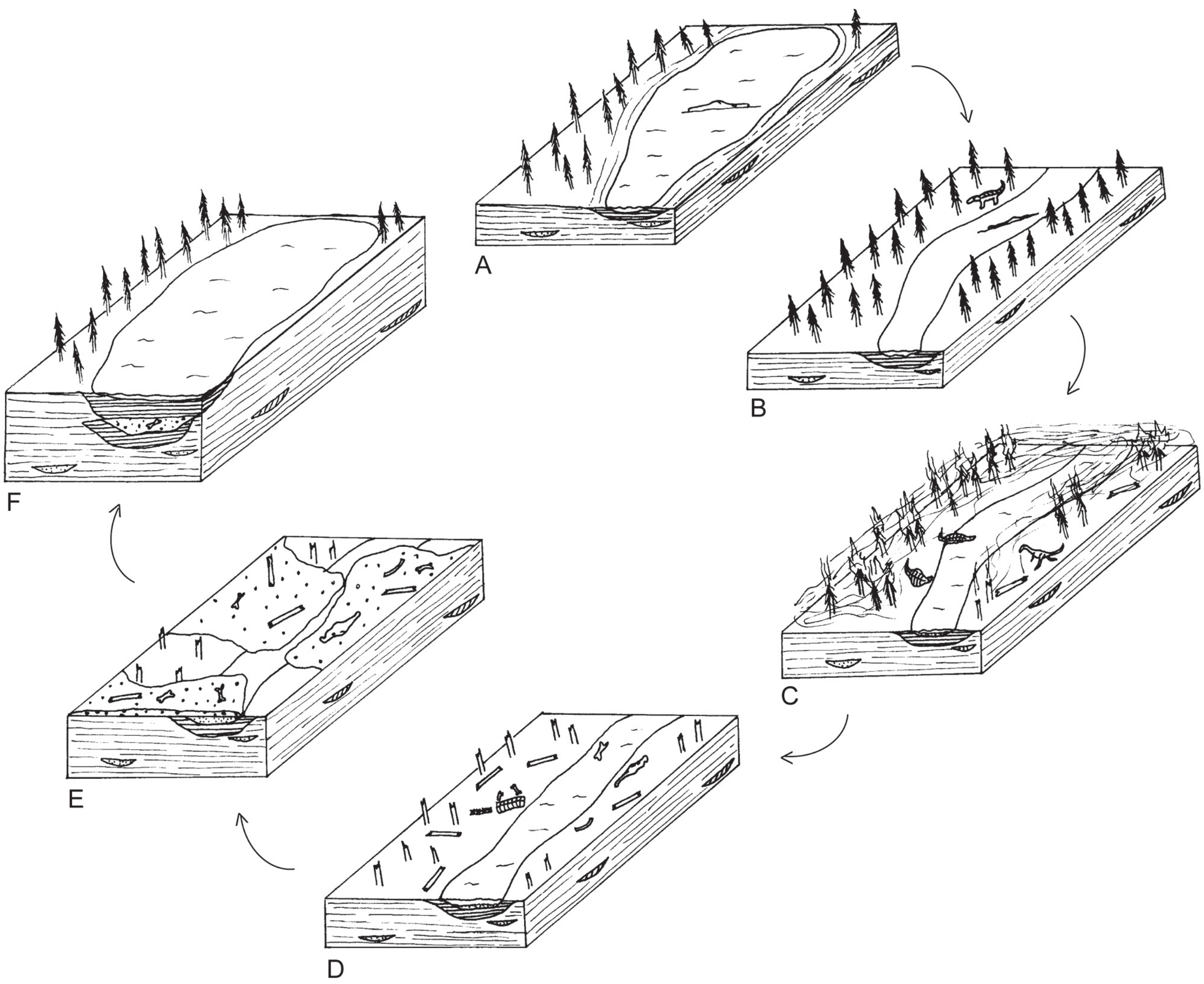

FIGURE 2.11. Depositional model for the strata and fossils of the Snyder quarry. A, Aggradation of the flood basin sediment surface took place during periods of rising base level. Highstands of base level were times of ponding and lacustrine sedimentation. B, Falling base level led to pedogenic reworking of the sediment surface and to fluvial incision, which remobilized pedogenic/lacustrine carbonate sediments. C, A catastrophic wildfire swept through the area, destroying vegetation and possibly leading to mass mortality of the local fauna. D, Following the wildfire, the floodplain was largely unvegetated and littered with downed trees and animal carcasses. E, Torrential rains caused a hyperconcentrated flood event that remobilized floodplain sediments, charred trees, and carcasses, depositing much of this sediment load in the topographic low of a stream channel. F, Subsequent base level rise and basin aggradation buried the hyperconcentrated food deposits/bone bed.

THE SNYDER QUARRY: A FIRE-RELATED UPPER TRIASSIC FOSSIL ASSEMBLAGE IN NORTH-CENTRAL NEW MEXICO

Kate E. Zeigler
New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104

The Snyder quarry is a Upper Triassic bonebed located near Ghost Ranch in north-central New Mexico. The locality is stratigraphically high in the Petrified Forest Formation of the Chinle Group. Tetrapod biostratigraphy places the quarry in the Revueltian land-vertebrate faunachron, which is mid-Norian (~210–215 Ma) (Lucas, 1998, 1999). This locality has yielded the fossil remains of a wide variety of vertebrate organisms, including a xenacanthid shark, semionotid and redfieldiid fish, a metoposaurid amphibian, a procolophonid, a cynodont, a lepidosauromorph, the phytosaur *Pseudopalatus*, the aetosaurs *Typothorax coccinarum* and *Desmatosuchus chamaensis*, the rauisuchian *Postosuchus*, a sphenosuchian and the theropod dinosaur *Eucoelophysis* (Zeigler et al., 2003a, b; Heckert et al., 2003a, b). Invertebrate fossils include unionid bivalves, a conchostracan and a decapod (Lucas et al., 2003; Rinehart et al., 2003). There is also an abundance of charcoalified plant material. Given the richness and diversity of fossil material found in the Snyder quarry, this bonebed represents a means of better understanding the mechanisms by which such an accumulation of biological material could occur.

A taphonomic analysis of the skeletal and plant material, as well as the sedimentology of the quarry, reveals that this deposit is the result of a catastrophic mass mortality event (Zeigler, 2002, 2003). The sediments of the deposit contain fine-grained mud rip-up clasts from the surrounding floodplain. The majority of the long bones and wood fragments longer than 5 cm are strongly aligned to the north-northeast. When the quarry was excavated, mapping of the positions of bones revealed a high density of bones over a large area (~16 m^2). The bones that are preserved in the quarry are primarily bones that are transported by low velocity currents (referred to as Voorhies Group I; Voorhies, 1969). However, there is also a significant number of bones moved by medium to high velocity currents. Thus, the hydrodynamics of the assemblage are not simple. There is no evidence of abrasion on the bones, as might occur with lengthy transport of material, and there is a significant amount of charcoal, which is buoyant, indicating that transport time was minimal. These data (lithology, alignment, bone density and hydrodynamics) are evidence of a very rapid movement and deposition of the bones, wood and sediments. The lithology of the sediments encasing the bones, as well as the hydrodynamic behavior of the bones themselves, indicate that transport probably occurred as a hyper concentrated flow.

The skeletal material is associated, and in rare cases articulated, indicating that the animals were in a state of partial decay prior to transport and deposition. There is no evidence of weathering of the bones or of vertebrate scavenging. Both the lack of weathering and the lack of scavenging are evidence of relatively rapid burial of the carcasses. While there is a wide array of organisms present in the deposits of the Snyder quarry, most of the animals are represented by only a single bone or bone fragment or tooth. Estimates of numbers of individuals show that the bulk of the animals killed were semi-aquatic, carnivorous phytosaurs. Terrestrial animals are well-represented, but are not present in overwhelming numbers. Also, given that at least 11 phytosaur skulls were recovered, an age profile was constructed that revealed a high percentage of subadult or young adult animals. The preponderance of young adult phytosaurs is unusual, given that these individuals would be the strongest members of their community. A death assemblage that is derived from an ecosystem through attritional processes will contain the remains of the very young and the very old members, as these are the individuals that are most susceptible to disease and predation (Holz and Barberena, 1994).

The plant material found in the Snyder quarry is unusual in its state of preservation becuase it is not silicified, as is common for wood from the Petrified Forest Formation (e.g., Heckert and Lucas, 1998; Ash and Creber, 2000). Large portions of wood from the quarry are deep black in color, have a silky, fibrous texture and break into approximately cubic fragments. Scanning electron microscopy of fragments of this material revealed well-preserved internal structure that consists of long open tubes bounded by smooth-walled divisions (Fig. 2.12). In modern conifers, living plant tissue has a tripartite division of the internal cell walls: Primary and secondary walls and middle lamella. In experiments

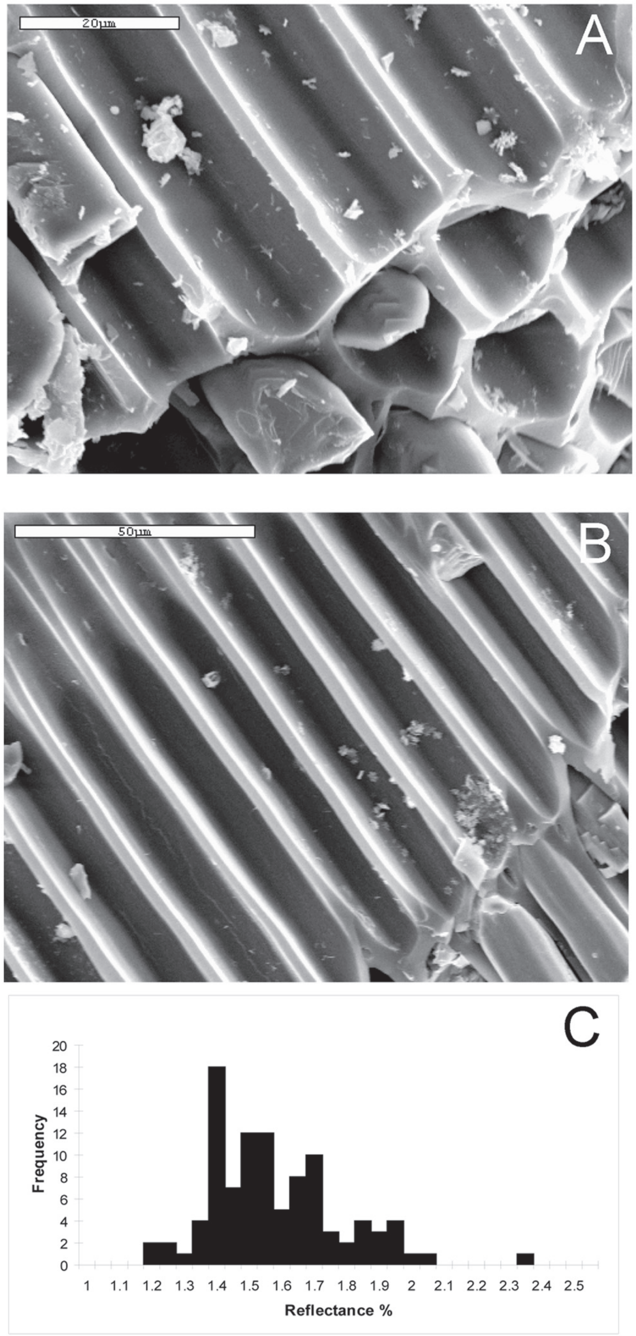

FIGURE 2.12. Scanning electron microphotographs (A-B) of charcoal from the Snyder quarry, showing completely homogenized cell walls. Histogram (C) for reflectance values of Snyder quarry charcoal fragments.

conducted on blocks of modern pine wood, cell walls become homogenized into a single structure between 280˚ and 320˚C (Cope, 1980, 1981; Jones and Chaloner, 1991; Scott, 2000). Further analysis was conducted (by Drs. A. Scott and I. Glasspool) with reflectance microscopy. Fragments of the wood were embedded in epoxy resin and polished. The average reflectance values for the wood fragments was 1.56%, which is substantially higher than reflectance values for unburned wood or for coal. This reflectance value corresponds to an approximate pyrolysis temperature of 400˚C (Jones et al., 1991).

The data from the Snyder quarry, both sedimentological and biological, points to an event that was catastrophic for the animal community and occurred relatively rapidly. While a catastrophic flood event could just as easily explain the bulk of the data, the presence of the charcoal leads to a different interpretation of events:

1) A high-temperature ground fire moves through the area. Terrestrial and semi-aquatic animals are asphyxiated, succumb to high air temperatures or are partially charred.

2) The fire passes, leaving a devastated landscape and corpses and burned plants begin to decay. Charred carcasses probably disintegrated faster than uncharred ones.

3) Rain falls on the now hydrophobic ash-laden soils and much higher run-off rates and substantial erosion are the result.

4) Carcasses, downed trees and burned tree limbs are swept up in a hyper concentrated flow and deposited in a topographic low in the area, resulting in the rapid burial of the organic material.

In addition, the nearby Canjilon and Hayden quarries, which are stratigraphically equivalent to the Snyder quarry, contain the same fauna and many of the same sedimentological and biological characteristics (e.g., Hunt and Downs, 2002; Martz, 2002; Zeigler et al., 2003d). It is highly likely that these two quarries also represent the same fire event, which increases the aerial extent of this paleowildfire. The Snyder quarry thus represents one of the few death assemblages in the fossil record to be directly tied to a wildfire. While there is no direct evidence for the mortality of the animals, the abundance of evidence from both biological and sedimentological material makes it difficult to propose an alternative scenario.

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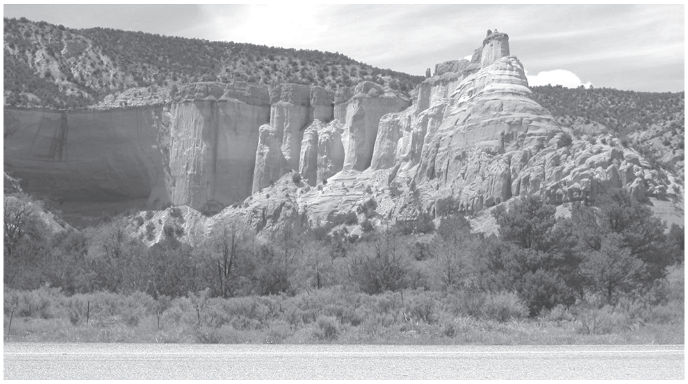

FIGURE 2.13. The Entrada Sandstone at Echo Amphitheater. The amphitheater is to the left, eroded from the thick cliff of Slick Rock Member of Entrada Sandstone. Todilto Formation gypsum here is relatively thin and overlain by very colluviated slopes of Summerville and Morrison formations.

11.3 Highway runs along Arroyo Seco on the right. *0.7*

12.0 Pass over Jurassic Todilto Formation on right. *0.1*

12.1 Mile marker 232; good view on right of Jurassic Summerville and Morrison formations. *0.8*

12.9 Summerville Formation on right is pale purple/gray sandstone overlain by green claystone of Jurassic Morrison Formation (Brushy Basin Member). *0.8*

13.7 Note Brushy Basin Member claystones on left in road cuts for next 0.3 miles. *0.6*

14.3 Top of Jurassic Morrison Formation on left. *0.7*

FIGURE 2.14. Entrada and Todilto formations at mile 11.1. Note how thick the Todilto gypsum is here, compared to its thickness a short distance back at Echo Amphitheater.

15.0 STOP 4: Navajo Canyon

Pull off (very carefully!) on left.

Cretaceous Burro Canyon and Dakota formations (Figs. 2.15-2.16). Walk downhill along the highway across Navajo Canyon to the base of the Cretaceous section.

Exposed at this stop on the west side of the road are two sequence boundaries: the shallow-channeled K-1 unconformity separating the Upper Jurassic Morrison Brushy Basin Member from the pebbly sandstones of the Lower Cretaceous Burro Canyon Formation, overlain by the undulating K-2 unconformity separating the Burro Canyon from the carbonaceous sandstones of the Encinal Canyon Member of the Dakota.

A marine-flooding surface on the Encinal Canyon marks the base of the overlying Oak Canyon Member of the Dakota, which consists of marine shale with thin shoreface sandstones. The A bentonite bed, a regional marker, occurs just beneath a thin sandstone in the Oak Canyon. Two coarsening-up sandstone parasequences form the overlying Cubero Sandstone Member of the Dakota near the top of the roadcut. The receding orange-yellow sandstone weathering back above the Cubero near the abandoned old highway is the Paguate Sandstone Member of the Dakota, the Clay Mesa Shale Tongue of the Mancos, which normally separates the Cubero from Paguate, having wedged-out south of El Vado along the Chama Canyon northwest of Stop 4. *0.7*

END OF STOP 4

Continue north on US Highway 84.

15.7 Road curves left. Cubero Member of Dakota is blocky, gray-to-tan sandstone in roadcuts. Orange-yellow sandstone directly above Cubero, which recedes back from the road, is thin Paguate Sandstone Member of Dakota overlain by a tongue of Mancos Shale. *0.2*

15.9 Rio Arriba County Rd. 287 to right at Las Jollas (a misspelling of Spanish "Las Joyas," the jewels). Note low sandstone mesa with pinyon/juniper vegetation above arroyo on right, east of antique store. It is held up by an isolated lens of coarse-grained Dakota Twowells Sandstone Member equivalent that extends 3 miles east along Lopez Canyon. Canjilon Mountain at 2:00. *0.7*

16.6 Mancos Shale in gulleys on right. La Mesita to right exposes section of Carlile to Juana Lopez members of Mancos Shale. *0.6*

17.2 Mile marker 237 to right. *1.6*

18.8 Juana Lopez Member on left in roadcuts. Invertebrate fossils (bivalves and ammonites) from the Juana Lopez Member collected here are characteristic guide fossils. *0.1*

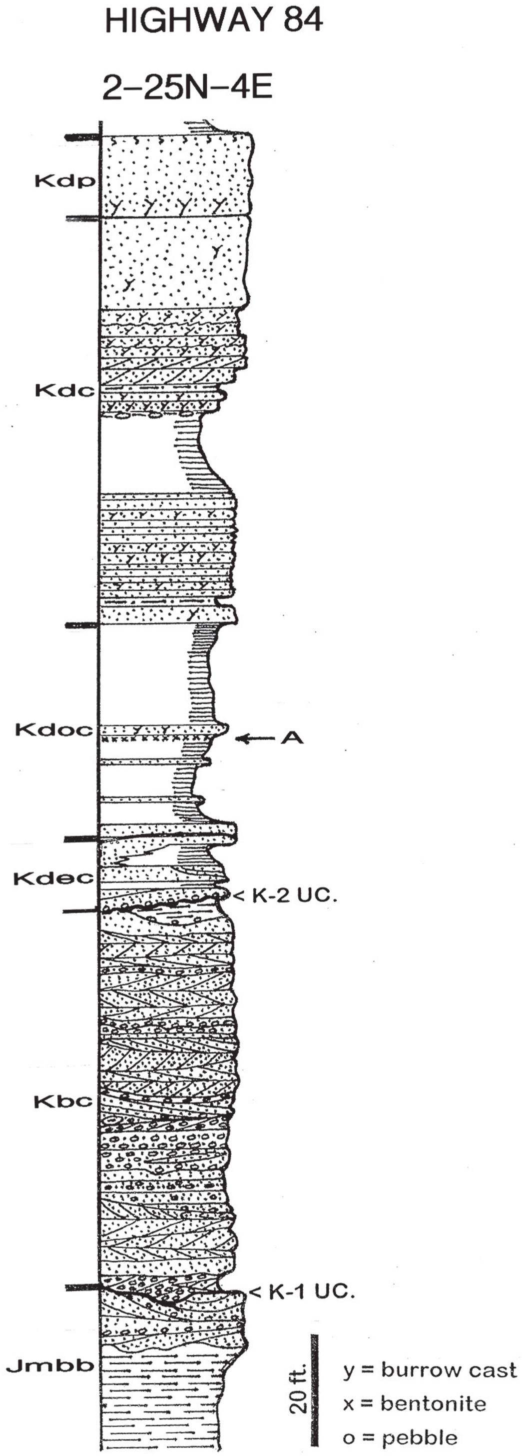

FIGURE 2.15. Measured stratigraphic section of Burro Canyon Formation and Dakota Sandstone at Highway 84 roadcut (Stop 4). Jmbb = Morrison Fm., Brushy Basin Member; Kbc = Burro Canyon Fm.; Kdec = Dakota Ss., Encinal Canyon Member; Kdoc = Dakota Ss., Oak Canyon Member; Kdc = Dakota Ss., Cubero Ss. Tongue; Kdp = Dakota Ss., Paguate Ss. Tongue. Note absence of Mancos Sh., Clay Mesa Sh. Tongue, which normally separates the Cubero and Paguate. The Paguate is a distinctive, yellow-colored, soft sandstone that weathers back from the rim of the mesas south and west (along the Rio Chama canyon) of this roadcut.

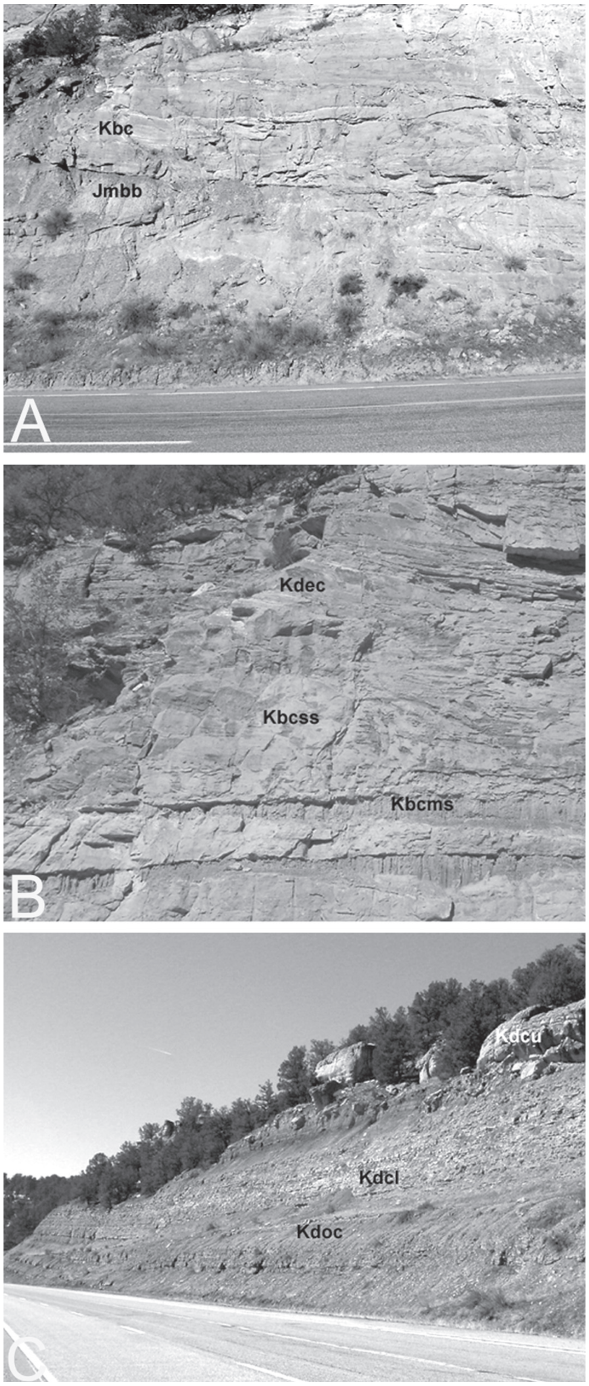

FIGURE 2.16. Photographs of selected strata at Stop 4 on west side of US 84. A, Upper part of Brushy Basin Member of Morrison Formation (Upper Jurassic) and lower part of Burro Canyon Formation (Lower Cretaceous) Jmbb = Brushy Basin; Kbc = Burro Canyon. The K-1 unconformity forms the contact, truncating the Brushy Basin mudstones and sandstones. B, Upper part of Burro Canyon Formation and lower part of Encinal Canyon Sandstone Member of Dakota Sandstone Kbcms = Burro Canyon mudstone lens; Kbcss = Burro Canyon pebbly sandstone; Kdec = Encinal Canyon carbonaceous sandstone. The K-2 unconformity forms the sandstone-sandstone contact between Burro Canyon and Encinal Canyon. C, Upper part of Oak Canyon Member of Dakota Sandstone and Cubero Sandstone Member of Dakota Sandstone Kdoc = Oak Canyon; Kdcl = Cubero Sandstone, lower parasequence; Kdcu = Cubero Sandstone, upper parasequence.

J. S. NEWBERRY AND THE GEOLOGY OF THE CHAMA BASIN

Spencer G. Lucas
New Mexico Museum of Natural History, 1801 Mountain Road NW, Albuquerque, NM 87104

Born in Connecticut, John Strong Newberry (1822-1892) (Fig. 2.17) grew up in northeastern Ohio and graduated from Western Reserve College in 1846 and from Cleveland Medical School in 1848. After additional training in Europe, he opened a successful medical practice in Cleveland in 1851. However, Newberry's passion since boyhood had been natural science, especially geology and paleontology. So, in 1855 he closed his medical practice and began a scientific career in which he participated in three of the great surveys of the western United States of the late 1800s. In 1864, Newberry was appointed Professor of Geology and Paleontology at the newly formed School of Mines at Columbia University, a position he held until his death.

In 1859, Newberry was appointed geologist of the San Juan Exploring Expedition lead by Captain J. N. Macomb (often referred to as the "Macomb Expedition"). The expedition set out from Santa Fe in early July 1859, heading to the junction of the Colorado and the Green Rivers in Utah. The expedition went up the Chama River by Abiquiu, then along Arroyo Seco and up the plateau to El Vado, Horse Lake and then on to Colorado, reaching Pagosa Springs on July 28 (Newberry, 1876; Dane, 1961). Newberry thus was the first trained geologist to examine the Chama Basin.

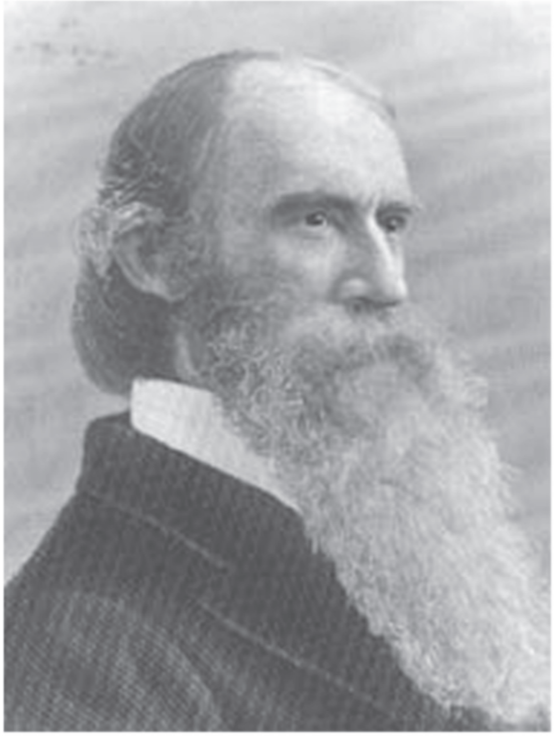

FIGURE 2.17. John Strong Newberry (1822-1892).

Newberry's (1876) geological report on the expedition identifies the bedrock strata of the Chama Basin as Triassic, Cretaceous and Tertiary rocks. In the southern portion of the basin, Newberry climbed Capulin Mountain (he called it "Abiquiu Peak") and visited the old copper mines in El Cobre Canyon. In the roof of one of the mines, Newberry collected the first Triassic plant fossils with leaves discovered in the American West (Triassic fossil wood had been discovered in the 1840s: Ash, 1974). Newberry (1876) described and illustrated these plants and recognized their similarity to Triassic plants already known from Sonora, Mexico and from Virginia and North Carolina. He thus concluded (p. 69) that "we have, therefore, in these plants evidence of the Triassic age of *all* the variegated gypsiferous rocks of northern New Mexico; for the Lower Cretaceous sandstones immediately overlie the plant-beds of the *Cobre*." Newberry was correct about the Triassic age of the plants (they are from the Upper Triassic Shinarump Formation of the Chinle Group: Lucas and Hunt, 1992), but he was incorrect that Cretaceous sandstones immediately overlie them at El Cobre Canyon; the sandstones above the plant-bearing horizon are Upper Triassic Poleo Formation of the Chinle Group. Nevertheless, based on the fossils he collected in El Cobre Canyon, Newberry assigned what are now known to be Pennsylvanian-Permian (Cutler Group), Upper Triassic (Chinle Group) and Jurassic (Entrada, Todilto, Summerville and Morrison formations) strata to his "Triassic formation."

After Newberry travelled north across the Arroyo Seco drainage, he climbed the plateau near modern-day Cebolla and travelled to the present site of El Vado. He recognized that this plateau was underlain and mantled by Cretaceous strata. Indeed, he published the first stratigraphic section measured in the Chama Basin (at the "Vada del Chama"), describing nearly 1500 ft of Cretaceous strata. Particularly significant in his section is the listing of Late Cretaceous index fossils of marine bivalves (*Ostrea, Inoceramus*) and ammonites (*Baculites, Scaphites*). Newberry's 1859 traverse from Abiquiu to El Vado thus provided the first lithostratigraphy and biostratigraphy of the bedrock strata exposed in the Chama Basin.

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18.9 Note high peaks of Brazos mountains to the north. *0.9*

19.8 Stock ponds on left and right, Rio Cebolla drainage. *0.4*

20.2 Junction 115 to Canjilon on right. *1.6*

21.8 Roadcuts in Juana Lopez Member. *0.8*

22.6 Enter Cebolla. Cebolla is Spanish for onion, and several New Mexico places have this name because of wild flowers of the onion family. However, the name also refers to sulphur water, which has an onion-like odor. The foul smelling water is the source of the name of this village of Cebolla, which has had a post office since 1907. *0.5*

23.1 Cross Rio Cebolla. *0.2*

23.3 Junction 221 to left. *1.2*

24.5 Crest hill, syncline ahead is flanked by Cretaceous Mesa Verde Group strata and floored by Lewis Shale. Brazos Mountains beyond. *1.1*

25.6 Roadside table on left. *1.1*

26.7 Cross Rio Nutrias. In Spanish, nutria refers to an otter, but in New Mexican Spanish it is used to refer to a beaver. *0.3*

27.0 Roadcuts on left are upper unit of Mancos (= Satan Tongue). *1.6*

28.6 Note flat playa lake floor here. *1.6*

30.2 Mile marker 250. *1.0*

31.2 Mile marker 251 on right. Upper Cretaceous Point Lookout Sandstone on upper part of Mancos Shale forms mesa on right (Fig. 2.18) *2.3*

33.5 Roadcuts on right in upper unit of Mancos Shale. *1.2*

34.7 Junction 162 to Tierra Amarilla on right and Historical Marker for Tierra Amarilla. Tierra Amarilla is the seat of Rio Arriba County. A townsite was first created here in 1831 and named "Las Nutrias," but since 1870 it has been called Tierra Amarilla. The name is Spanish for "yellow earth" and refers to an ochre clay used to paint the walls in adobe houses. The Tierra Amarilla land grant surrounds the town. Disagreements about Spanish land grants erupted in 1967 when the courthouse at Tierra Amarilla was taken by a band of armed men led by Reies López Tijerina (see accompanying minipaper). *0.5*

35.2 Junction 64 to Tres Piedres and Taos on right. *0.2*

35.4 Brazos Box at 3:00 (Fig. 2.19). The cliffs are a spectacular fault scarp developed in Precambrian quartzite. *0.6*

36.0 Cross Rito de Tierra Amarilla. *0.1*

36.1 Junction 531, road to El Vado. *0.8*

36.9 Highway 162 comes in from right. A second historical marker for Tierra Amarilla on right. *0.3*

37.2 Tierra Amarilla post office on left. *0.4*

37.6 Junction with Highway 112 on left. Fort Lowell historical marker on left. Fort Lowell was established in 1866 to protect the Tierra Amarilla area settlements from the Southern Utes. Originally named Camp Plummer, the post was garrisoned by a detachment of New Mexico Volunteers, some of whose descendents still live in the area. The fort was abandoned in 1869, and its log, or "fuerte buildings," were sold to local residents. *0.3*

37.9 Lava flow in roadcuts is Pleistocene Brazos flow and will be discussed at stop 2 of tomorrow's field trip. *0.8*

38.7 Junctions for Highways 95 and 514 to Los Ojos (Parkview). *0.3*

39.0 At 2:00, yellow slope is Jurassic Entrada Sandstone above Chavez Box. This smaller box is cut in Precambrian quartzite that is dipping westward into the Chama Basin, under the Mesozoic strata. *0.4*

39.4 Cross Rio de los Brazos. *0.2*

39.6 Los Brazos, founded in 1898. Rio Arriba County Road 334 to right. Los Brazos is Spanish for "the arms," and refers to the branches of the streams here. *0.8*

FIGURE 2.18. Cretaceous strata of the Mancos Shale (slope) capped by the Point Lookout Sandstone at mile 31.2.

FIGURE 2.19. The Brazos Box, a sheer cliff of Precambrian quartzite.

40.4 Junction Highway 512 to right. *2.2*

42.6 Chama River floodplain on left. Chromo Mountain at 11:00. *3.3*

45.9 Sugarloaf Mountain to right. Ridge to NW at 10-11:00 is Cretaceous Point Lookout Sandstone over Cretaceous Mancos Shale. Peak and mountains at 12-1:00 are Brazos Mountains. *1.9*

47.8 Enter Chama. Founded in 1880, the name Chama is a Spanish approximation of the Tewa word “tzama,” which was the name of a pueblo on the Chama River. Historically, Chama was a center for ranching, farming and lumber production. Today, it functions mostly as a recreation center for hunters, fisherman, hikers and those who come to ride the narrow gage railroad. *1.2*

49.0 Cross Rio Chama. *0.3*

49.3 **Turn left** at US 64/84 junction. *0.1*

49.4 **Turn right**, end at Information Center in Chama.

END OF DAY 2 LOG

THE UNSUNG REVOLT IN TIERRA AMARILLA

Donald E. Owen, Jr.
2610 Evalon, Beaumont TX, 77702

Few people passing through the quiet village of Tierra Amarilla on their way between Santa Fe and Chama know of the revolt that occurred there during 1967. Some have called it the last attempt at secession from the United States; in this case, the revolt of the Tierra Amarilla Spanish Land Grant led by Reies López Tijerina.

Reies Tijerina was born on September 21, 1926, in Fall City, Texas. Eventually, he attended the Assembly of God Bible Institute and became a traveling evangelical preacher. He helped found the “Valley of Peace” commune in Arizona with 17 other families. While there, they were antagonized by their Anglo neighbors, and their children were forced to attend public schools rather than allowing the families to educate the children themselves. While Tijerina was living in the “Valley of Peace” he learned about land grants, a controversial issue involving the rights of many Hispanics. Eventually, he became interested enough in land grants that he went to Mexico for a year to research the Treaty of Guadalupe Hidalgo, which ended the US-Mexican War during 1848. After studying the treaty, he wrote a booklet about Hispanic Americans under the treaty. In February 1963, Tijerina founded the Alianza Federal de Mercedes (Federal Alliance of Grants), an organization dedicated to giving Hispanic-American people pride in their heritage and to fighting for their rights.

Tijerina had many grievances against the Anglo oppressors. These included: (1) Hispanic and Indo-Hispanic peoples’ land was being illegally taken by the government; (2) the terms of the Treaty of Guadalupe-Hidalgo were broken; and (3) Hispanic and Indo-Hispanic children were forced through the English-language public education system, where they were not allowed to speak Spanish. Family, and especially children, were very important to Tijerina. He valued his wife and children’s safety far above his own. He also wanted the best possible education for his children and the children of the other Hispanics and Indo-Hispanics. He did not want children forced through the public education system, where he claimed that they would be brainwashed into submissiveness about the injustices happening in the Southwest.

In preparation for the upcoming 1967 Alianza annual meeting, Rio Arriba County District Attorney Alfonso Sanchez declared that the gathering was deemed an “unlawful assembly.” According to the First Amendment to the U.S. Constitution, all citizens have a right to peaceful assembly. The act declaring the meeting “unlawful” was a blatant transgression against First Amendment rights. On June 3, 1967, the Alianza meeting being held at Coyote was blocked, and District Attorney Sanchez arrested 11 members. Sanchez was marked for a citizen’s arrest by Tijerina, and on June 5, 1967, Tijerina and 19 other armed men left a picnic at Canjilon and stormed the Rio Arriba County Courthouse in Tierra Amarilla with the intent of arresting Sanchez. However, the arrest did not go as planned, and two law enforcement officers were shot, which led to a manhunt being ordered. In an interesting coincidence, the hour that Tijerina’s rebels took possession of the courthouse, Israel took the city of Jerusalem. Tijerina was eventually tried for taking the courthouse, and, in a work of legal brilliancy; he fired all his lawyers before the trial. He chose to defend himself and was acquitted of all charges. His defense was commented on as being "brilliant" in his use of the Treaty of Guadalupe Hidalgo and the U.S. Constitution to justify himself and his rebels.

Tijerina was eventually arrested during 1969 in connection with his Alianza. Tijerina was no stranger to jail time—he was imprisoned many times during his life. Most of his sentences were related to assault on officers, trespassing, kidnapping, and evasion of the law. His most notable jail sentence was in connection with his wife, Patricia. In 1969, she announced that she was going to burn a U.S. Forest Service sign, and she did. They were both arrested, and Tijerina was sentenced to nine years in prison for "aiding and abetting" his wife. However, he only served a little less than three years in prison for that sentence. Amazingly, his wife was found completely innocent of any crime, but her husband served jail time for aiding and abetting her "crime." In contrast to the Tijerinas, a Rio Arriba County Anglo man was found guilty of burning a Forest Service sign, fined $25, and set free. Tijerina cited this as yet another example of Anglo prejudice against the Hispanic and Indo-Hispanic people of the Southwest.

While the Hispanic and Indo-Hispanic people have been overlooked by the Federal court system and its injustices, the longing for justice still lives in the hearts, minds, and souls of a number of people still living in the area today. They will try their hardest to make sure that the history books never forget the name Reies López Tijerina.