Second-day road log, from Gallup to Fort Wingate, Sixmile Canyon, Ciniza, Red Rock Park, Church Rock, White Mesa, Thoreau and Grants

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SECOND-DAY ROAD LOG, FROM GALLUP TO FORT WINGATE, SIXMILE CANYON, CINIZA, RED ROCK PARK, CHURCH ROCK, WHITE MESA, THOREAU AND GRANTS

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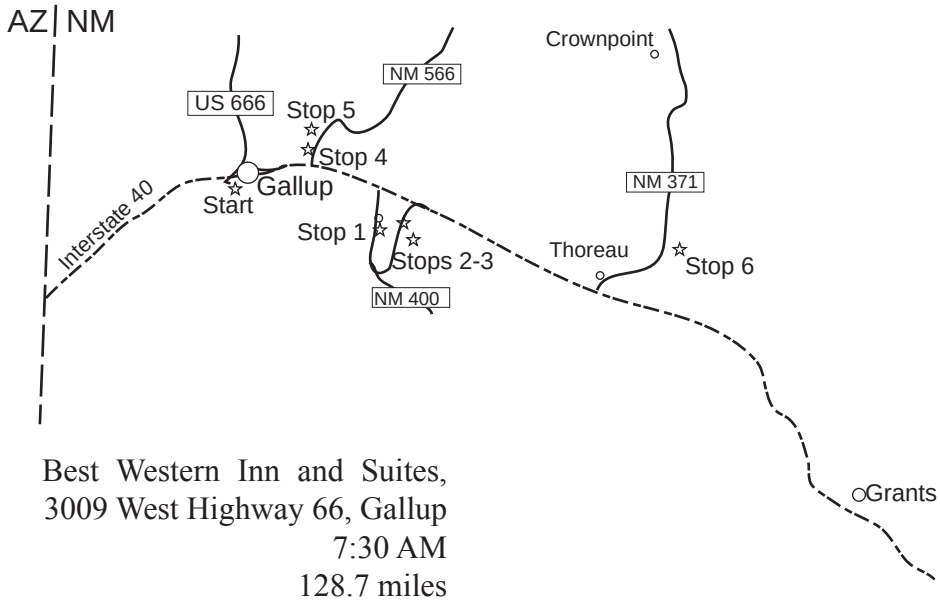

Assembly Point: Best Western Inn and Suites, 3009 West Highway 66, Gallup
Departure Time: 7:30 AM
Distance: 128.7 miles
Stops: 6

SUMMARY

The second day road log focuses on a detailed examination of the Triassic-Jurassic section of sedimentary rocks exposed on the northern flank (dipslope) of the Zuni Mountains. This is a classic section, first described in detail by Clarence Dutton in 1885. Though long studied, many aspects of these rocks remain controversial, and we explore some of these controversies.

Stop 1 dives right into debate about the base of the Chinle Group near Fort Wingate. Here, rocks of the Chinle Zuni Mountains Formation ("mottled strata") are a paleoweathering profile riddled with large, vertical, tubular structures that have been variously identified as lungfish or crayfish burrows or as rhizoliths. We let you resolve this one.

Stop 2, a few miles to the east, in Sixmile Canyon, examines an unusual feature first described by Clay T. Smith—a paleokarst developed on top of the Permian San Andres Formation and filled with Triassic Moenkopi Formation debris. This lesson in "paleogeomorphology" is followed by Stop 3, farther down Sixmile Canyon, in extensive exposures of the lower part of the Chinle Group. Topics of discussion include Chinle sedimentation, basinwide unconformities and paleontology.

Stop 4 moves us up section into the Jurassic rocks at Red Rock Park. Here, we discuss controversies regarding regional stratigraphy and sedimentation of the Wingate, Entrada, Todilto, Summerville and Bluff formations. Stop 5, a few miles north, at White Mesa, exposes the top of the Jurassic section and the base of the Cretaceous Dakota Sandstone, which here is a spectacular, incised-valley fill.

The trip then continues east to Grants, with Stop 6 north of Thoreau at a quarry developed in limestone of the Jurassic Todilto Formation. Here,

we discuss Jurassic sedimentation and industrial mineral production. The day ends at Grants.

Mileage

0.0 Start in parking lot of Best Western Inn and Suites on west side of Gallup. **Turn left** and proceed west on West Highway 66. **Get in left lane. 0.3**

0.3 Pass through traffic light at Rico Street. **0.5**

0.8 **Turn left** onto onramp for Interstate 40 East, before bridge (I-40 overpass). **0.2**

1.0 Merge left on I-40. **0.1**

1.1 Cross bridge on Interstate 40 eastbound looking down dip into the Upper Cretaceous Crevasse Canyon Formation, Bartlett Barren Member. **1.4**

2.5 Cross bridge over Rio Puerco. **0.2**

2.7 Good outcrops of the Crevasse Canyon Formation to the left next 0.2 miles. **0.6**

3.3 Coal-bearing and clinkered outcrops of the Upper Cretaceous Menefee Formation in roadcuts to left and right. **0.8**

4.1 Sign for Exit 20; hogback forms skyline ahead. More Menefee Formation outcrops to left. **0.6**

4.7 Mile marker 20. **0.5**

5.2 Exit 20, Muñoz Boulevard and US Highway 666. Roadbed on Upper Cretaceous Crevasse Canyon Formation. **1.6**

6.8 Roadcuts in Menefee Formation sandstone. **0.4**

7.2 Exit 22; Miyamura Drive on right, Miyamura Park on left. **1.2**

8.4 Road passes under powerline. Note the Hogback ahead formed at top of Gallup Sandstone with Crevasse Canyon Formation outcrops to left. **0.7**

9.1 Stop 5 from first day on left across frontage road. **0.3**

9.4 Pass through Gallup Sandstone coals in the Hogback. **0.3**

9.7 Cuesta developed in Upper Cretaceous Dakota Formation above Jurassic Morrison strata to left (Fig. 2.1). Red Rocks and Pyramid Mountain at 10:00. **0.3**

10.0 Hogback to south displays top of the Upper Triassic Chinle Group and a complete Jurassic section capped by the Dakota Sandstone. **0.6**

FIGURE 2.1. At mile 9.7, cuesta north of highway is Dakota Formation above Jurassic strata.

10.6 Exit 26 to East Gallup; leave Gallup by staying on Interstate 40. **1.1**

11.7 Cross bridge. Quaternary dunes and Rehoboth Mission on right. Note Pyramid Mountain at 10:00 (Fig. 2.2). We are driving through a strike valley developed in the upper Chinle Group that persists from here to the village of Bluewater, 25 to 30 miles to the east. Dipslopes south of the highway are generally developed in the Sonsela Member of the Petrified Forest Formation. **0.7**

12.4 Wingate Natural Gas plant on left. **0.6**

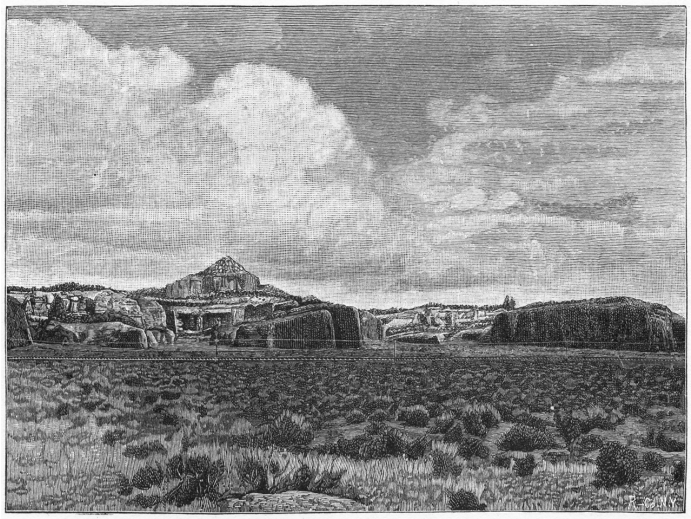

FIGURE 2.2. Dutton's (1885) woodcut photograph of Pyramid Mountain (Rock).

13.0 Cross bridge with good view to left of Red Rocks and Pyramid Mountain at 9:30, and the Jurassic section. **1.2**

14.2 Upper Triassic Owl Rock Formation roadcuts for the next 0.7 miles. **0.2**

14.4 Red Rock Park to left. **0.8**

15.2 Bridge over rail lines to Fort Wingate Army Depot. Originally a cavalry outpost established in 1862, Fort Wingate was deactivated in 1911, and was reopened as Wingate Ordnance Reserve Depot in 1918 and essentially closed again in 1992 (see Heckert et al. minipaper below). Fort Wingate is now run principally by White Sands Missile Range and serves to launch missile tests to White Sands. Note hogback exposure at 4:00. 0.5

15.7 Bridge over road to headquarters of Fort Wingate Army Depot. Note prominent tree-covered dipslope developed in the Upper Triassic Sonsela Member of the Petrified Forest Formation (Chinle Group) ahead and to the south of the highway. Strike valley is in the overlying Painted Desert Member. Dozens of above ground ammunition storage facilities called "igloos" dot the dipslope and are separated by depressions (bunkers). **1.3**

17.0 Sign for McGaffey, exit 33. **Prepare to exit to right. 1.1**

18.1 **Take exit 33**, NM Highway 400 to McGaffey. **0.2**

18.3 Stop sign. **Turn right** to go south on NM-400. **0.1**

18.4 Go straight south past turn for I-40 eastbound. **0.2**

18.6 Cross South Fork Creek. **0.7**

19.3 New entry road to Fort Wingate Army Depot on right. Drive up Sonsela dipslope. **0.3**

19.6 Crest cuesta, town of Fort Wingate ahead. Roadcuts developed in the Sonsela Member. **0.2**

19.8 Contact (Tr-4 unconformity of Lucas, 1993) between the Sonsela Member and the underlying Blue Mesa Member on right. Today's trip will focus on the Triassic section through stop 3 (Fig. 2.3). **0.2**

20.0 White sandstone to right is base of the Blue Mesa Member over redbeds of the underlying Upper Triassic Bluewater Creek Formation at the Fort Wingate Army Depot's small-arms shooting range (Fig. 2.4). **0.4**

20.4 Note Hogback near Gallup to right in distance. **0.2**

20.6 Enter town of Fort Wingate. The town (population about 950) grew up next to the military installation of the same name in the 19th century and has continued to the present, long after the fort ceased to host soldiers. The town's schools and other facilities serve the surrounding rural areas (Julyan, 1996). **0.6**

21.2 Historical marker on left for Fort Wingate. The old cavalry fort is to left behind Fort Wingate Veterans Park. Fort Wingate's history (Fig. 2.5) is detailed in the accompanying minipaper. **0.3**

FROM BEAR SPRING TO FORT WINGATE

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The area known today as Fort Wingate has had a long and complicated history of multicultural occupation and conflict. Nearby springs were frequented by traveling and war parties of Zuñi and Diné (Navajo) people, and the Zuñi referred to the place as "Anshe Kyana." Bears were often sighted at the springs as well, so this locality was known to Navajos as "Shash bitoo," and later to New Mexicans as "Ojo del Oso" (Van Valkenburgh, 1941).

The fort was first established at Bear Spring near the present-day town (mile 21.2 of the road log) and named Fort Fauntleroy by its commanding officer, Colonel Thomas T. ("little lord") Fauntleroy in 1860. When the Civil War began, however, Colonel Fauntleroy cast his lot with the Confederate Army, and the fort was quickly renamed Fort Lyon in 1862, after Brigadier General Nathaniel Lyon, an early casualty of the fighting on the Union side. Later that year the fort was abandoned, and Union troops pulled back to a site near Ojo del Gallo, about 5 mi south of present Grants, near the town of San Rafael, where they established Fort Wingate, named after Captain Benjamin Wingate, who had died earlier in the year at the Battle of Valverde, trying to repulse

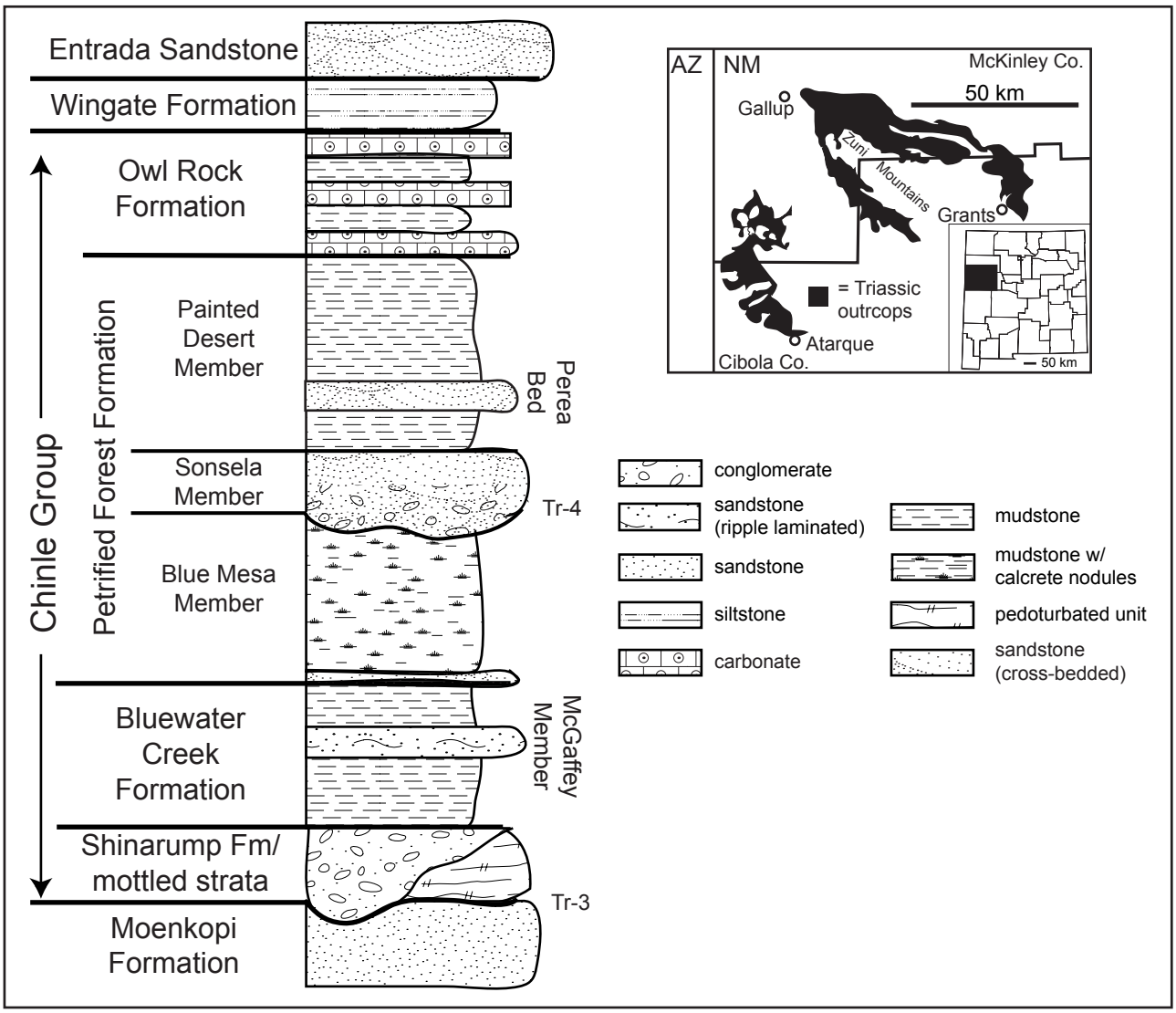

FIGURE 2.3. Generalized stratigraphy of the Upper Triassic Chinle Group in west-central New Mexico; total Chinle thickness is about 1900 ft.

the Confederate invasion of New Mexico. Ojo del Gallo had been an important watering place for centuries (it appears, for example, on the 1776 map of the Dominguez-Escalante Expedition).

FIGURE 2.4. Lower Chinle Group section at mile 20.0.

The fort at Ojo del Gallo was built a few months after the Confederate forces had been defeated and expelled from New Mexico, for the expressed purpose of dealing with the Navajo. The Navajo had used the preoccupation of the territory's military forces with the Confederates to strike at the villages, mines, and ranches of settlers they viewed as intruders. Once the Confederate threat had ended, Colonel R. S. Canby, military commander of New Mexico, began a plan to build a series of forts near Navajo territory, and to move the Navajo to a reservation far distant from the territory's population centers, both to protect New Mexicans against further raiding, and, perhaps, to prevent the Navajo from being exterminated. Before Canby could act, however, he was replaced by Brig. General James H. Carleton.

Carleton immediately implemented Canby's plan, and the construction of Ft. Wingate at Ojo del Gallo commenced. The location afforded excellent pasturage and was near the intersection of two major trails – the Spanish highway to Zuni Pueblo and the old military roads to Ft. Defiance, to the west. The site suffered, however, from its swampy surroundings and water table

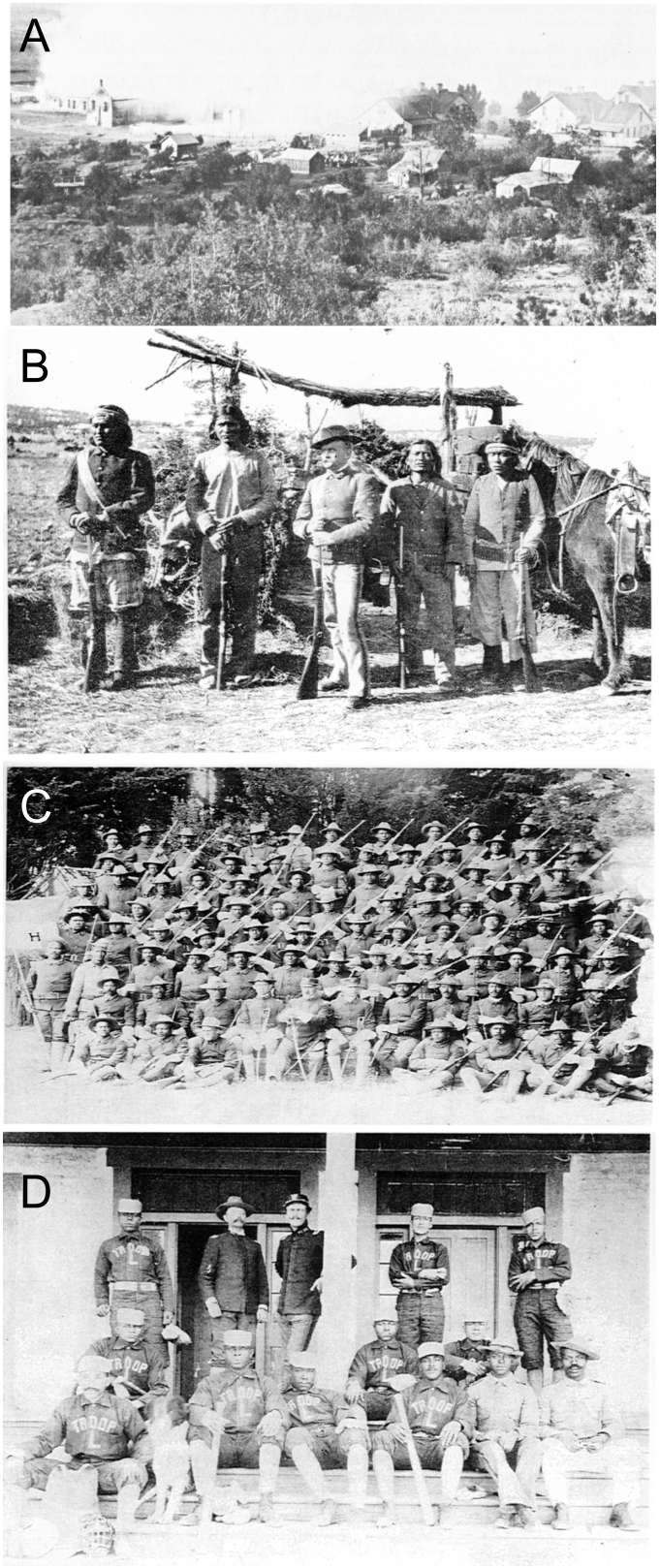

FIGURE 2.5. Historical photographs of Fort Wingate in the 19th century. A. Fort Wingate burning on July 2, 1896; B. Navajo (Diné) Scouts, Troop K, 4th Cavalry, ca. 1881-1884; C. "Buffalo Soldiers" of Troop H, 9th Cavalry, ca. 1899-1900; D. Baseball team of "Buffalo Soldiers," Troop L, 9th Cavalry, ca. 1899. Photos from Smith (1967) and Daniel (1997), Museum of New Mexico negatives 15773, 86944, 98372 and 98374.

near the surface. The fort was built of adobe, with a wooden stockade. Shortly after it was constructed, the fort served as a staging area and supply depot for Kit Carson's war against the Navajo, begun in 1863, which was designed to end the Navajo threat once and for all. His scorched-earth campaign effectively ended the Navajo resistance, and the Navajo people were forcibly resettled in the Bosque Redondo reservation near Fort Sumner, in central New Mexico, in 1864. Ft. Wingate served as a temporary detention center, from which the Navajo made "the Long Walk" to Hwéeldi, their name for Bosque Redondo. The resettlement plan was an egregious failure, and in 1868 the surviving Navajo were allowed to return to their homeland.

As the Navajo returned to northwestern New Mexico, Ft. Wingate at Ojo del Gallo was abandoned; it had fallen into decay during the Civil War and was too far removed from the new Navajo Reservation. The soldiers of Ft. Wingate moved west, to take up quarters at the site of the previous Ft. Lyon, which was then renamed Fort Wingate. There, in 1868, the fort was re-established in the present-day town of Fort Wingate, and again served as a temporary detention center for 7000 Navajos, now traveling from Fort Sumner on to Fort Defiance and the newly established Navajo Reservation.

Fort Wingate remained an important facility throughout the remainder of the 19th century. In 1877, Victorio's Chiracahua Apaches surrendered there, and in 1881-1882 Douglas MacArthur's father, Major General (at the time Captain) Arthur MacArthur commanded Company K of the 15th Infantry at the fort, and a very young Douglas (b. 1880) lived there briefly. "Buffalo Soldiers," (African-American cavalry units, with white officers, including a young John J. Pershing), principally of the 9th Cavalry, were stationed at Fort Wingate in 1876-1881 and again in 1899-1900 (Fig. 2.5C-D). With the arrival of the railroad in 1880, logging operations begun earlier by officers at the fort enjoyed great success. On July 2, 1896, much of the facility was destroyed by fire, but was rebuilt at the same site (Fig. 2.5A). Consequently, the oldest buildings at the original site only date to 1906.

One of the regular duties of the Ft. Wingate troops was to provide entertainment at the New Mexico Territorial Fair in Albuquerque. According to Fugate and Fugate (1989), in 1903 the manager of the Fair arranged a mock battle between cavalry troops and Navajo men. Both sides were issued blank cartridges, and the "battle" was scheduled for Old Town. However, some of the Navajo substituted real ammunition for the blanks, planning to shoot cavalry and escape in the confusion. The plot was discovered, however, and the Ft. Wingate contingent rode soberly back to its post. A short time later, the War Department issued orders banning any future mock battles between cavalry and Indians.

Troops were stationed at Ft. Wingate until 1911, when it was deactivated, but it was reopened in 1912 for several years in order to house about 4000 Mexican troops and their families who had fled from Pancho Villa's army into Texas during the Mexican civil war. General John J. Pershing returned to the fort during his campaign against Pancho Villa, although he was not formally stationed at Fort Wingate at that time.

In 1918, the U. S. Army Ordnance Department assumed control of the Fort for munitions storage, and by 1920 it was the largest storage facility of munitions in the world. Around 1925, Congress

appropriated $500,000 for a Navajo School; the barracks were converted to dormitories, and the parade grounds became a ball field. By the 1930s, more than 100 ordnance storage buildings were familiar sights to travelers on old Route 66, and many of the hogans and houses in the area are constructed from ammunition crates left over from that era. The present-day administrative compound for Fort Wingate (entrance under the bridge at mile 15.2 of the road log) was built in 1941, and it was during World War II that the Fort took on its present-day appearance with multiple railway spurs and hundreds of concrete "igloos" covering dipslopes developed on Chinle Group sandstones.

Fort Wingate continued to serve as a conventional ordnance storage and disposal facility throughout the Cold War. In the 1960s, the base was also used as a testing facility for rockets for the Pershing-1 missile. In the late 1980s, Fort Wingate was listed as one of the military facilities to close under BRAC (Base Realignment and Closure) 1988. As part of BRAC 1988, many munitions stored at Fort Wingate were removed and eventually disposed of in Iraqi and Kuwaiti deserts in early 1991. Others were disposed of on-site in somewhat less spectacular fashion.

Fort Wingate has long had a substantial economic impact on the region. In the 1870s and 1880s many of the officers stationed there augmented their paychecks by running logging and cattle companies. The former supplied railroad ties, and the latter often sold beef back to the government to supply the fort. Fort Wingate has long had a substantial civilian work force as well. In the 1880s, the fort employed male Navajos as scouts (Fig. 2.5B) and as laborers for facility construction, and female Navajos often worked as laundresses. Indeed, from 1868 through World War II, Navajos comprised the largest civilian workforce at Fort Wingate. During World War II the Fort employed over 1500 civilians (90% of them Navajo) loading and unloading munitions, especially TNT. By the late 1980s the fort had only a single military employee, the commanding captain, and the rest of the workforce was civilian. Since the drawing down of the facility, over $23 million has been spent to clean up a variety of "contaminants," including unexploded ordnance (UXO), explosive compounds, PCBs, heavy metals, pesticides, asbestos and (gasp!) lead-based paint. Much of this cleanup was contracted to TPL, Inc., which has a substantial facility employing as many as 85 people on-site. (Sources: WPA, 1940; James, 1967; Chilton et al., 1984; Fugate and Fugate, 1989; Julyan, 1996; Daniel, 1997; Mangum, 1997; Defense Technical Information Center, 2002; Global Security, 2002).

21.5 **Road to right** to Cibola National Forest Wingate Office; begin ascent of Chinle dipslope developed primarily on the Zuni Mountains Formation (formerly the "mottled strata") (see Heckert and Lucas, this volume). **0.3**

21.8 Outcrops of the Zuni Mountains Formation on left. **0.1**

21.9 Cattleguard. Enter Cibola National Forest. **0.2**

22.1 **STOP 1.** Pull off on dirt roads to left to look at the base of the Chinle Group.

At this stop, we focus on the early depositional history of the Chinle Group. Here, thick deposits of pedogenically modified strata overlie the unconformable surface between the Upper Triassic Chinle Group and the underlying Middle Triassic Moenkopi Formation (Fig. 2.6). These basal Chinle strata encompass a wide range of lithotypes, including conglomerates, sandstones, and mudrocks, some of which have been altered to the point where they have become "porcellanites." These strata are intensively color-mottled and turbated. Historically, these strata have been called the "mottled strata," both here and throughout their outcrop distribution from eastern Arizona to the Lucero uplift in central New Mexico (e.g., Stewart et al., 1972a; Ash, 1978; Lucas and Hayden, 1989; Heckert and Lucas, 2002a). Similar strata in east-central Utah were termed the Temple Mountain Member of the Chinle Formation by Robeck (1957). The turbation has been attributed to lungfish (Dubiel et al., 1987), crayfish (Hasiotis et al., 1993), or pedogenesis (Lucas and Hayden, 1989; Lucas and Anderson, 1993; Heckert and Lucas, 2002a). In this volume, Heckert and Lucas introduce the term "Zuni Mountains Formation" for these strata.

Here, at Stop 1, these strata are as thick or thicker than on any other locality on the southern Colorado Plateau (~65 ft). Indeed, these strata are so thick (and the underlying Moenkopi Formation so thin) that they are mapped with the Moenkopi Formation on Anderson et al.'s (2003) geologic map of the Fort Wingate quadrangle that accompanies this volume.

Our emphases here are threefold: (1) a thin remnant of the Moenkopi Formation is present; (2) above the Moenkopi Formation an unconformable surface (Tr-3 unconformity of Pipiringos and O'Sullivan, 1978) is overlain by a complex array of deposits; (3) these deposits

themselves have a complex depositional and post-depositional history.

Regarding the Moenkopi Formation, these strata are thinly bedded sicliciclastics, principally sandstones and siltstones with minor intraformational conglomerates. Moenkopi Formation strata are relatively thin (generally <30 ft) throughout the western Zuni Mountains, and typically overlie an erosional surface developed on underlying Permian strata. Indeed, there is a significant amount of paleotopography developed on the unconformable surface below Moenkopi strata regionally, so that, although the Moenkopi overlies the San Andres Formation throughout much of the Zunis, the San Andres is locally absent and Moenkopi strata rest on the underlying Glorieta Formation as well. Moenkopi Formation red beds typically weather to grayish red, with some unweathered outcrops light greenish gray. These strata are flaggy to ledgy with minor, low-angle crossbeds. Moenkopi red beds are readily differentiated from the overlying Chinle red beds by the absence of bentonitic mudstone in the Moenkopi. Locally, uppermost Moenkopi strata are pedogenically modified, with color bleaching and reduction spots, but little change in lithology or sedimentary fabric. Where changes are more profound, these strata are usually assigned to the overlying Zuni Mountains Formation.

At Stop 1, complex valley-fill deposits overlie the Tr-3 unconformity. These strata are siliciclastics that were extensively pedogenically modified. In many places this modification destroyed the primary sedimentary fabric, sometimes overprinting it with abundant rhizoliths, some of which are up to 2 m in length and as much as 20 cm in diameter. Dubiel (1987, 1989) argued that these structures were lungfish burrows, but we follow McCallister (1988) and Lucas and Hayden (1989) and consider them rhizoliths. Hasiotis et al. (1993) posited that they were instead crayfish burrows linked to the fluctuating water tables believed responsible for the color mottling. Although the simple (non-branching) nature of these structures is more similar to that of some burrows, Lucas and Hayden (1989) noted that they could well represent the non-branching roots of primitive tree-like plants such as *Neocalamites*.

Where most stratigraphers agree, however, is that whatever one terms the post Tr-3 deposits, they represent a complex valley infill of paleotopography generated between the end of Moenkopi deposition in the early Anisian and the onset of Chinle deposition during the Carnian, approximately 8 to 10 million years later. Accordingly, primary (unmodified) channel-fill fluvial deposits at the base of the Chinle are generally assigned to the Shinarump Formation (present in thin, discontinuous ribbons of conglomerate in the Fort Wingate area) or to the Zuni Mountains Formation ("mottled strata" of previous usage). There is little doubt that much of the Zuni Mountains Formation represents pedogenically modified Shinarump strata. At Nazlini near the type section of the Chinle on the Navajo Reservation there are outstanding outcrops documenting that pedogenic and diagenetic alteration of the Zuni Mountains Formation took place in Shinarump Formation deposits.

After stop return to NM-400 and continue southward. 0.2

22.3 Note outcrops of the Bluewater Creek Formation to right. **0.1**

22.4 "Monitor Butte facies" on left in roadcuts. This is lithofacies assemblage 3 of Heckert (1997) and Heckert and Lucas (2002a). **0.2**

22.6 Sandstone on left is low in Bluewater Creek Formation. A similar or equivalent sandstone to the east bears tetrapod tracks, including a footprint of an early dinosaur (Lucas and Heckert, 2002) (Fig. 2.7). **0.4**

23.0 Outcrops to right are the Bluewater Creek Formation capped by the McGaffey Member. **0.2**

23.2 McGaffey Member roadcut on left, so

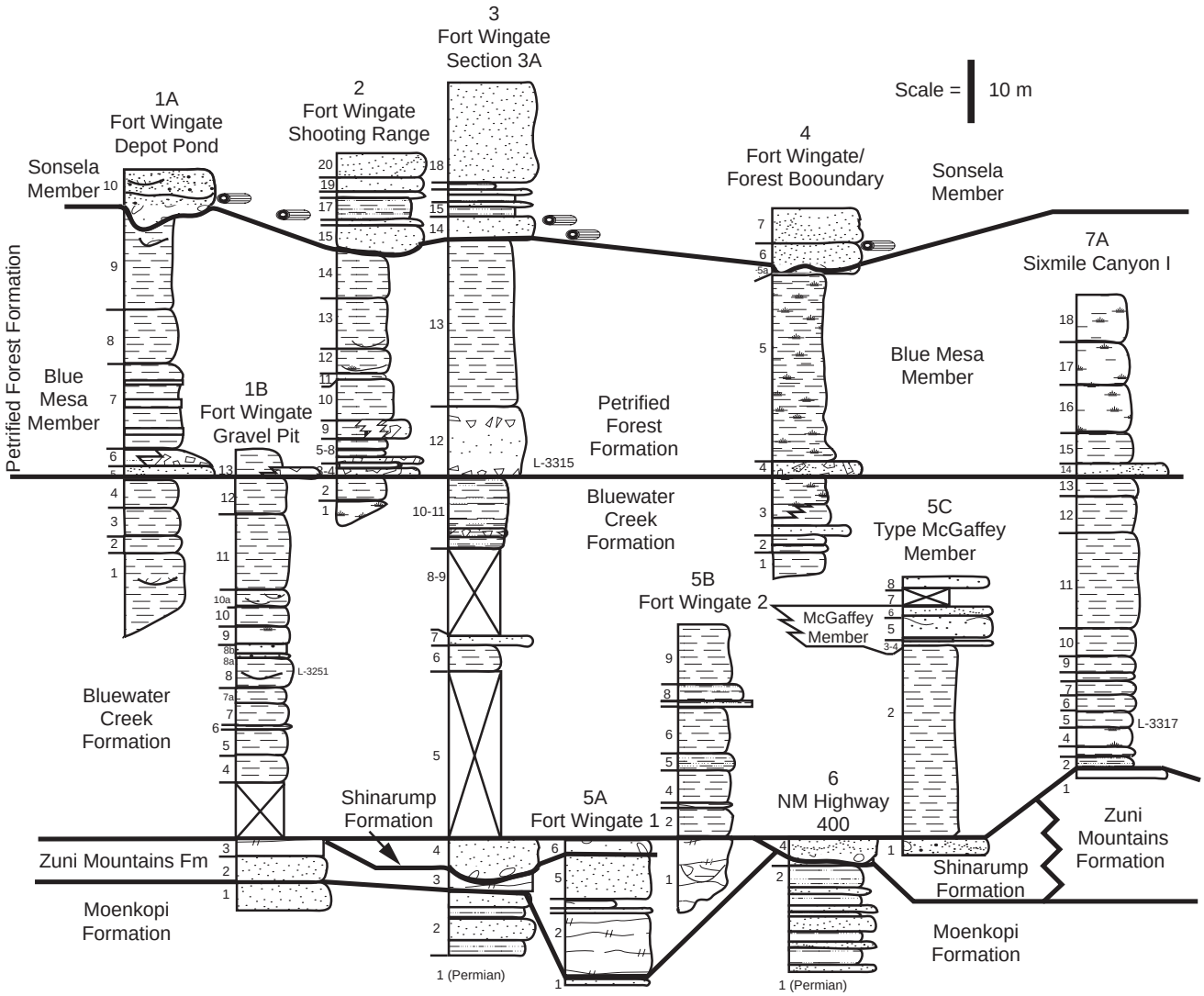

FIGURE 2.6. Lower Chinle Group stratigraphic sections in the western Zuni Mountains.

this is the top of the McGaffey cuesta. Roadbed now descends through the lower Chinle to the Middle Triassic Moenkopi Formation. **0.5**

23.7 Zuni Mountains Formation ("mottled strata") outcrops at curve in road. **0.2**

23.9 Cattleguard. **0.2**

24.1 Cibola National Forest entrance sign. Moenkopi Formation redbeds up to Shinarump Formation bench on left (Fig. 2.6, section 6). The bench below and to the right is in the Lower Permian Glorieta Sandstone. Note that the Lower Permian San Andres Formation is not present here. **0.1**

24.2 Moenkopi Formation redbeds exposed in roadcuts for the next 0.3 miles. **0.4**

24.6 Cliff to right across creek is the Glorieta Sandstone. **0.1**

24.7 Roadcuts for the next 0.2 miles are in the San Andres Formation. **0.1**

24.8 Cliff of San Andres Formation on left. Note here that patchy upper Paleozoic outcrops are present across the Zuni Mountains. Also note the equivalence of the New Mexico Glorieta with the Arizona Coconino and the New Mexico San Andres with the Arizona Kaibab. San Andres Formation outcrops on left for the next 0.2 miles. **0.9**

25.7 Zuni Mountains Formation outcrops on right. **0.2**

25.9 Milepost 3; campground on right. **0.4**

26.3 Cattleguard. We are now in ponderosa

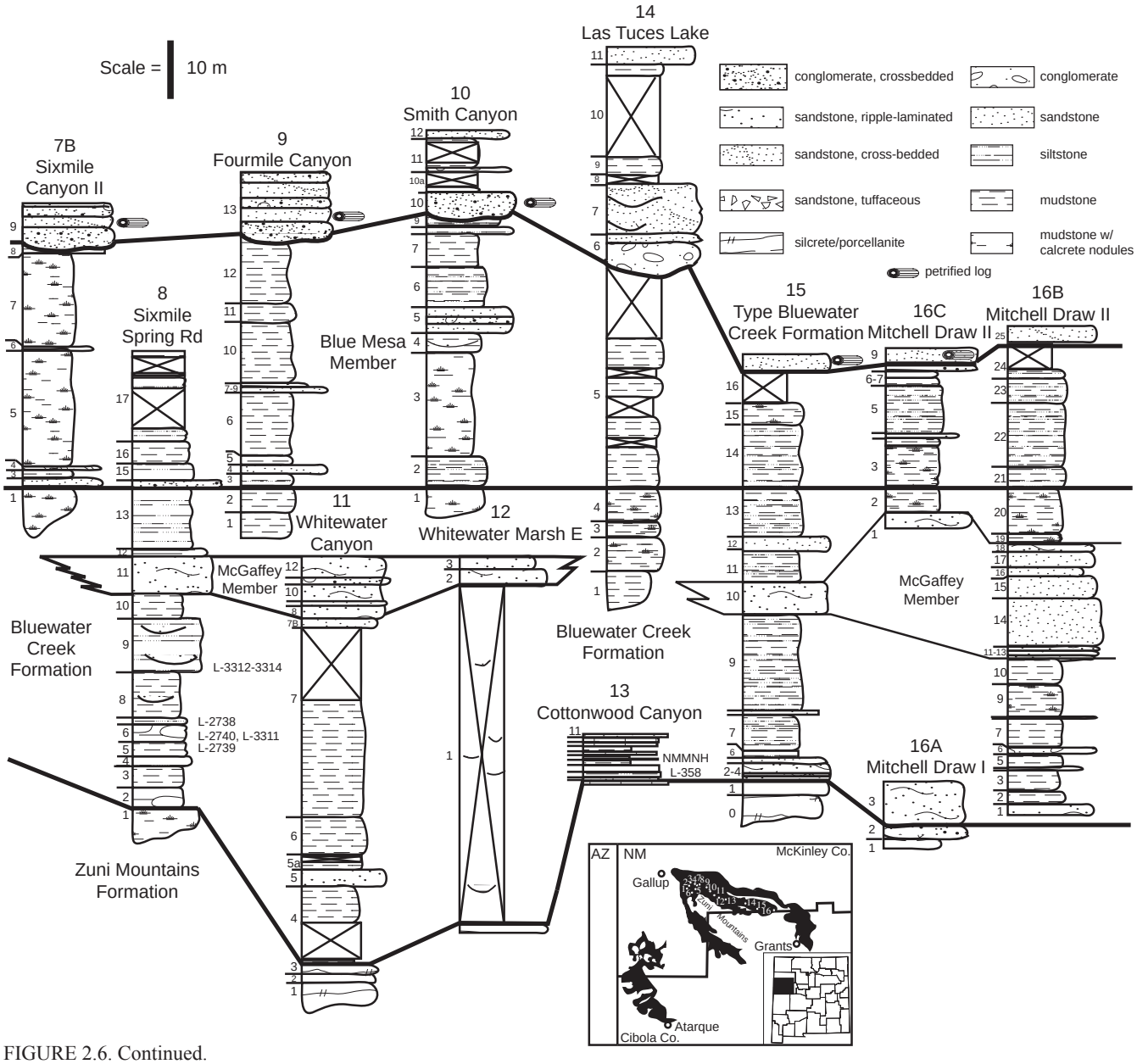

FIGURE 2.6. Continued.

pine-dominated forests. **0.1**

26.4 Quaking Aspen campground to right. **0.7**

27.1 Sign for McGaffey ahead, Grants to left. **Turn left onto dirt road and pass through gate.** (This route is closed from December 15 to March 31 each year and is nearly impassable when wet). McGaffey was established about 1903 as a timber town and was named after Amasa B. McGaffey, a trader at Thoreau who turned lumberman (Julyan, 1996). Cutting timber was a major industry in the Zuni Mountains during the late 1800s and the early 1900s. In the 1920s and 1930s, McGaffey was the largest of several Zuni Mountains lumbering towns, boasting 200 families, a five-room school, and a large town hall. It waned with the end of the lumber boom, but some residents still remain (Julyan, 1996). **0.4**

27.5 Sandstone on left is the Sonsela Member. **0.2**

27.7 Bluewater Creek Formation and Blue Mesa Member mudstone-dominated slope on left up to Sonsela Member capping ridge. **0.1**

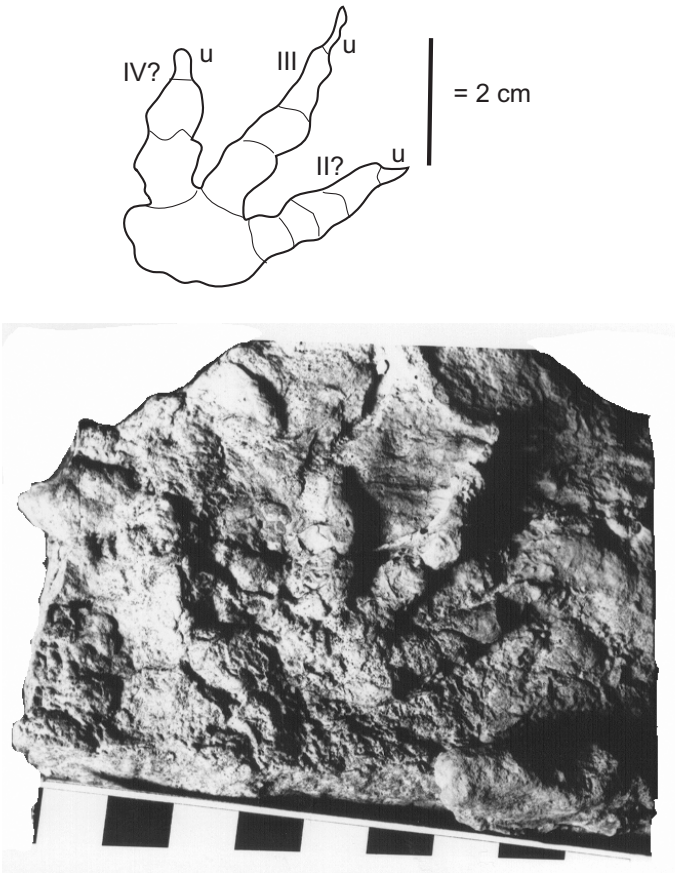

FIGURE 2.7. Dinosaur footprint from the Bluewater Creek Formation near Fort Wingate.

27.8 Blue Mesa Member bentonitic mudstones overlain by a Sonsela cuesta of tan/gray sandstones on left. **0.1**

27.9 Top of Sonsela; note its tripartite lithology—lower sandstone, middle mudstone, upper sandstone (see accompanying mini-paper). **0.2**

THE UPPER TRIASSIC SONSELA MEMBER OF THE PETRIFIED FOREST FORMATION IN THE ZUNI MOUNTAINS

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

The Sonsela Member of the Petrified Forest Formation forms the long cuesta south of Interstate 40 that stretches from the Fort Wingate Military Depot east to the community of Bluewater. This sandstone- and conglomerate-dominated unit thus forms the south wall of the Chinle strike valley between Gallup and Grants. Following Dutton (1885), Darton (1928) mistakenly thought that the Sonsela represented the base of the Upper Triassic section in the Zunis, but subsequent workers, including Cooley (1957), Foster (1957), Stewart et al. (1972a,b), Ash (1978), Lucas and Hayden (1989), Heckert and Lucas (1996, 2002a), Lucas et al. (1997a,b) and Heckert (1997a,b) all identified it as a medial sandstone in the Upper Triassic section (Fig. 2.8).

The Sonsela Member rests disconformably on the Blue Mesa Member of the Petrified Forest Formation. This is the Tr-4 unconformity of Lucas (1993), and Heckert and Lucas (1996) documented as much as 23 m of erosional relief on this contact between thicker Blue Mesa Member sections to the west near Fort Wingate and thinner sections to the east near Prewitt. The upper contact of the Sonsela with the overlying Painted Desert Member is almost always covered at the base of the Sonsela dipslope, but appears to be gradational.

Sandstones dominate the Sonsela lithosome, although conglomerates are also common. A persistent mudstone interval is sometimes exposed in the middle of the unit as well. Basal conglomerates and conglomeratic sandstones of the Sonsela Member contain many pebble-to cobble-sized clasts. These clasts may include mudstone rip-ups but more commonly are siliceous extraformational clasts, apparently derived from Paleozoic limestones presumably exposed to the south during Late Triassic time. Higher in the Sonsela section, reworked calcrete nodules are more common. Sandstones are medium- to coarse-grained subarkoses, sublitharenites, and, rarely, quartzarenites. Mudrocks are not well-exposed, but are often bluish-purple and bentonitic, thus closely resembling the mudstones of the underlying Blue Mesa Member.

Trough-crossbedding is the most common bedform in the Sonsela, with some subordinate, principally low-angle, planar crossbeds present as well. Individual sets are typically 1-1.5-m-thick, with much scour-and-fill within the bed. Most of the conglomerates are concentrated at the bases of the sets. The predominance of scour-and-fill and laterally extensive coalesced sandstone bodies strongly suggests that Sonsela deposition was by low-sinuosity streams (Deacon, 1990).

The Sonsela Member is the principal petrified wood-bearing unit at the Petrified Forest National Park (PFNP) in Arizona (Heckert and Lucas, 1998, 2002b), and logs are relatively common in the Sonsela throughout the Zuni Mountains of New Mexico. These logs tend to be shades of yellow, white, and gray, and are not as abundant, large or as colorful as the logs at the PFNP. Still, trunks up to 10 m long have been recovered in places.

Heckert and Lucas (2002b) recognized three, bed-level units within the Sonsela Member at PFNP. They termed these the Rainbow Forest, Jim Camp Wash, and Agate Bridge beds, in ascending stratigraphic order. The Rainbow Forest and Agate Bridge beds are both predominantly sandstone and conglomerate. Both bear petrified logs, especially the Rainbow Forest Bed, host to most of the major "forests" in the Park. The Jim Camp Wash bed is a mudstone-dominated interval that separates the two sandstones. Akers et al. (1958) noted a similar interval at the type section of the Sonsela in the Chuska Mountains to the northwest (see also Lucas et al., 1997b). In the Zuni Mountains, the three units are only apparent on fairly close examination, as the Jim Camp Wash Bed strata are thin and typically covered. The Rainbow Forest Bed in the Zunis tends to bear most of the petrified wood and is

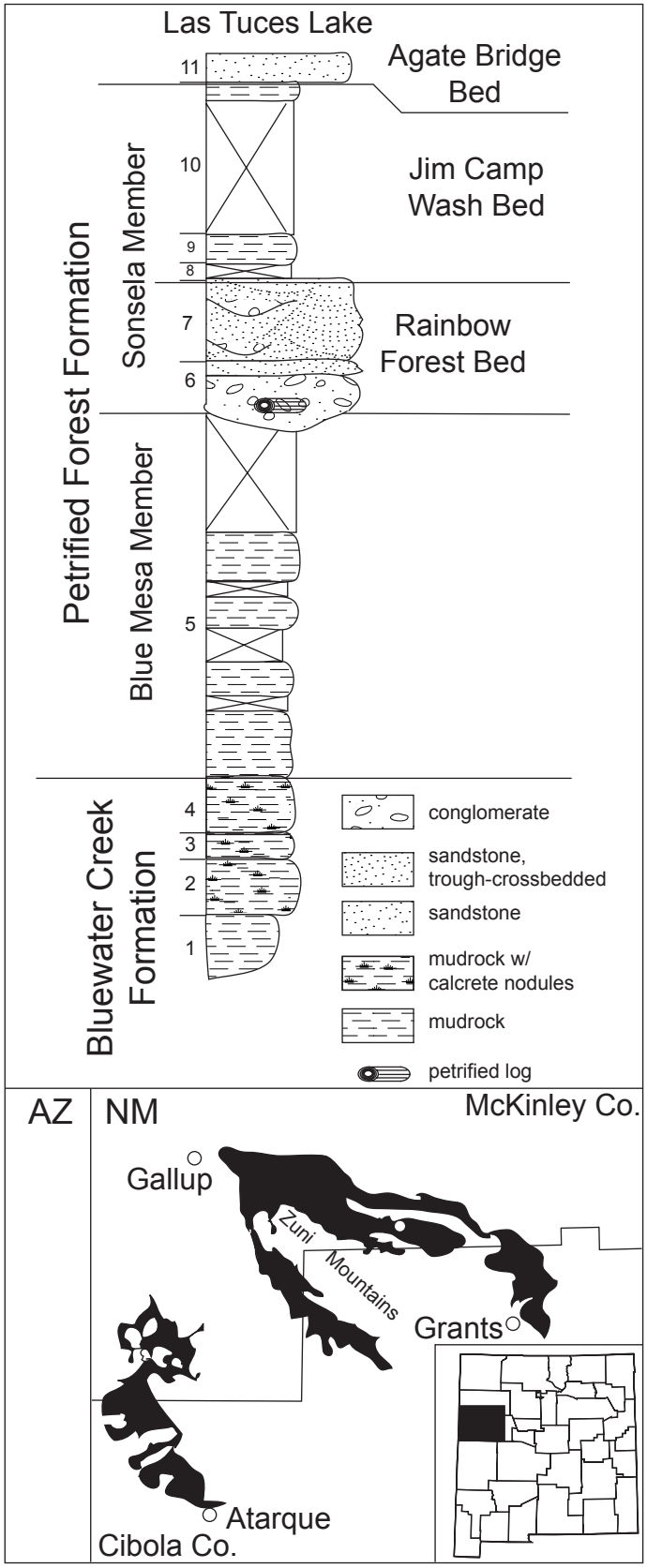

FIGURE 2.8. Representative section of the Sonsela Member in west-central New Mexico.

dominated by siliceous conglomerate clasts. The Agate Bridge Bed has less wood and more intraformational clasts.

Deacon (1990) reported paleocurrents in the Sonsela Member in the Zuni Mountains that are predominantly to the north or northeast at Fort Wingate, Continental Divide, and Bluewater. A section Deacon (1990) measured at Thoreau has easterly to southeasterly paleocurrents.

Within our broader understanding of the Chinle depositional system, Sonsela strata represent the deposits of fluvial systems draining highlands to the south (e.g., Stewart et al., 1972a; Lucas, 1993; Heckert and Lucas, 1996). These systems were themselves tributaries to a trunk drainage running southeast to northwest across the Four Corners area, where intraformational conglomerate is more common in the Sonsela interval, and correlative strata are termed the Moss Back Formation (Stewart et al., 1972a; Lucas, 1993; Lucas et al., 1997b).

Diverse lines of evidence, including palynology (Litwin et al., 1991) and tetrapod biostratigraphy (e.g., Lucas and Hunt, 1993; Lucas, 1997, 1998; Heckert and Lucas, 2002a) indicate that the Sonsela is Revueltian (early-mid Norian in age). Underlying Blue Mesa Member strata are Adamanian (latest Carnian). This contact is sharp and, locally, 1-2 m of erosional relief are visible. Heckert and Lucas (1996) and Heckert (1997a) documented as much as 23 m of erosion by comparing a 44-m-thick Blue Mesa section on the Fort Wingate Military Depot in the west to a 21-m-thick section of equivalent strata near Bluewater in the eastern Zuni Mountains. Farther to the east, in the Lucero uplift, the Blue Mesa Member was apparently removed during the development of the Tr-4 unconformity (Lucas and Heckert, 1994; Heckert and Lucas, 1996; Heckert, 1997a). This transect is one of the few well-constrained indications of the degree of erosion associated with the development of the Tr-4 unconformity.

28.1 Road forks, **go right. 0.4**

28.5 T-junction and sign; road to right goes to McGaffey, road to left to Sixmile Canyon. Debris from the Sonsela litters roadsides. Nearby McGaffey Lake (a large pond) and Forest Service campgrounds are popular fishing and camping destinations. **Turn left. 0.1**

28.6 West-dipping Sonsela Member sandstone outcrops on right; the road is on an old wagon grade used to pull logs out of the forest down to a railroad grade in Sixmile Canyon ahead. **0.3**

28.9 Cattleguard; red beds here are the Bluewater Creek Formation for next 0.3 miles. **0.4**

29.3 Sonsela Member conglomeratic debris on right. **0.1**

29.4 Blue Mesa Member mudstones in roadcuts for next 0.3 miles. **0.3**

29.7 Note slumped Sonsela up hill to left. **0.3**

30.0 Road forks; **go straight**. Sonsela cuesta at 10:00 across valley; floor of Sixmile Canyon ahead. **0.2**

30.2 "Porcellanite" of Zuni Mountains Formation on left. **0.1**

30.3 Road to left; go straight. Zuni Mountains Formation strata on right. **0.1**

30.4 Cuesta to left in Zuni Mountains Formation. **0.1**

30.5 Ripple-laminated sandstone cuesta to left is the base of Bluewater Creek Formation (lithofacies 2 of Heckert and Lucas, 1996). **0.1**

30.6 Red beds on both sides of the road are Moenkopi Formation. **0.4**

31.0 Road to right; go straight. **0.3**

31.3 Zuni Mountains Formation-Bluewater Creek Formation contact on left (red beds above blue mottled limestone). **0.3**

31.6 **STOP 2.** Typical Moenkopi sandstone on left opposite smaller road leading to east. A paleokarst is developed in the drainage here in the top of the Lower Permian (Leonardian) San Andres Formation and is filled with slumped and brecciated siliciclastic red beds of the Middle Triassic (early Anisian) Moenkopi Formation (Fig. 2.9). Smith (1954) first described and mapped this feature. The principal "dolein" is in the creek bottom just east of the road. Here, the San Andres outcrop is ~10 ft thick and consists mostly of medium light gray, thick-bedded, fossiliferous limestone; fossils are mostly heavily recrystallized shells of brachiopods and, rarely, nautiloids. Parts of this limestone, however, are brecciated, and the interstices and voids of the limestone breccia are filled with grayish red and pale reddish brown Moenkopi sandstone and conglomerate. A large boulder of this breccia sits in the arroyo floor. Just south of it is a striking red-bed fill about 6-7-ft-thick of sandstone and siltstone excavated into the San Andres bedded limestone. These features suggest that the creek bed exposes a sinkhole-like feature developed in the San Andres that has a map area of about 1800 ft^2.

Immediately east of the road are two outcrops of San Andres limestone surrounded by alluvium of the Moenkopi. These outcrops are 12 or more ft higher than the top of the San Andres in the creek bed. We suggest that this reflects paleotopography developed on top of the San Andres prior to Moenkopi deposition. The two San Andres outcrops at the road thus are "islands" surrounded by and buried over by the Moenkopi redbeds.

Here, the Moenkopi Formation is at least 20 ft thick and consists of red-bed siltstones and fluvially-deposited sandstones with minor lenses of intraformational conglomerate and conglomeratic sandstone. The Chinle Zuni Mountains Formation ("mottled strata") disconformably overlies the Moenkopi up the hill west of the road. Its base is marked by a prominent, color-mottled sandstone; colors include pale yellowish orange, very pale orange, very dusky purple and brownish gray.

Note also that the bluff to the northeast is part of the drainage divide between Sixmile and Fourmile canyons and displays red Bluewater Creek Formation overlain by purplish Blue Mesa Member capped by gray Sonsela Member on ridge crest.

After stop, continue north on main road. 0.1

31.7 Cut to right is also on the San Andres Formation (karsted) and is the location of Sixmile Spring. **0.2**

31.9 Cattleguard. **0.1**

32.0 Moenkopi on left with mottled strata above. Road to the right leads to Fourmile Canyon. **Continue straight. 0.1**

32.1 Sign for Sixmile Canyon Forest Road 547. **0.2**

32.3 Dark blue bentonitic mudstones are near the base of the Bluewater Creek Formation. Note Bluewater Creek Formation section to left. **0.9**

33.2 Note section to left of Bluewater Creek

Formation and Blue Mesa and Sonsela members of the Petrified Forest Formation. **0.2**

33.4 **Before culvert turn left onto 2-track road. 0.1**

33.5 **Stop at wash. STOP 3.** At this stop, a relatively complete lower Chinle Group section is exposed (Figs. 2.10-2.11). Only locally exposed in the valley floor are pedogenically modified siliciclastics of the Zuni Mountains Formation. The widespread red beds that are the most accessible outcrops are the Bluewater Creek Formation. Overlying the Bluewater Creek Formation are the purple, mudstone-dominated beds of the Blue Mesa Member of the Petrified Forest Formation—the contact is at the easily mapped, persistent white sandstone with abundant volcanic detritus approximately 50 m above the valley floor (Fig. 2.10). Disconformably overlying the Blue Mesa Member are the conglomerates and sandstones of the Sonsela Member.

Heckert (1997a; Heckert and Lucas, 2002) measured 50.5 m of Bluewater Creek Formation here. Throughout the Zuni Mountains the Bluewater Creek Formation consists of three primary lithofacies assemblages: (1) interbedded mudstone and siltstone with scattered calcrete nodule hori-

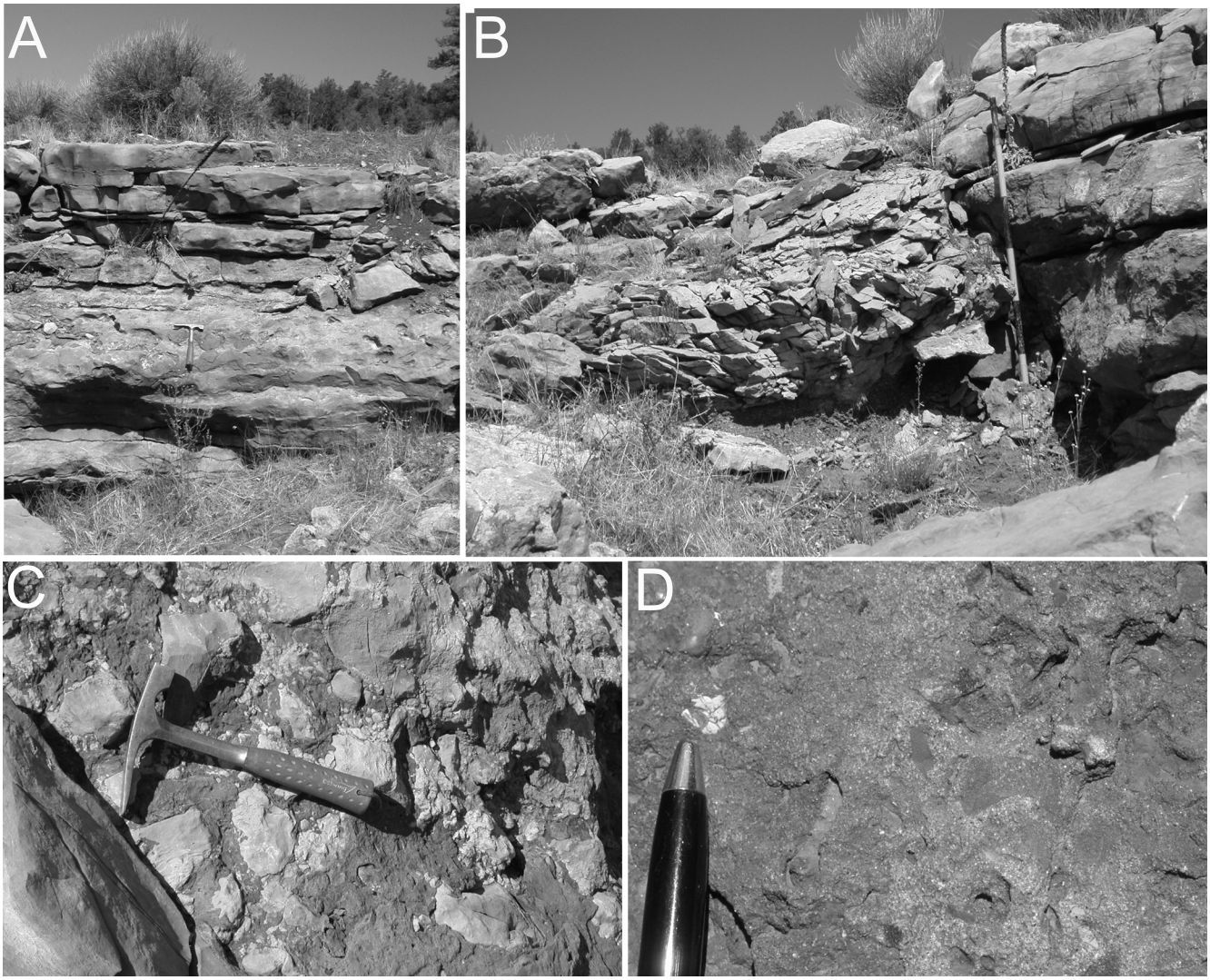

FIGURE 2.9. Photographs of Triassic Moenkopi Formation karst developed in the Permian San Andres Formation limestone at Stop 2. A-B. Overviews of the karst. C-D. Close-ups of the breccia that fills the karst. Pen in D points to a fossil bone fragment.

zons, (2) ripple laminated to plane-bedded sandstone with minor intraformational conglomerate, and (3) greenish bentonitic mudstone and black shale. These represent red-

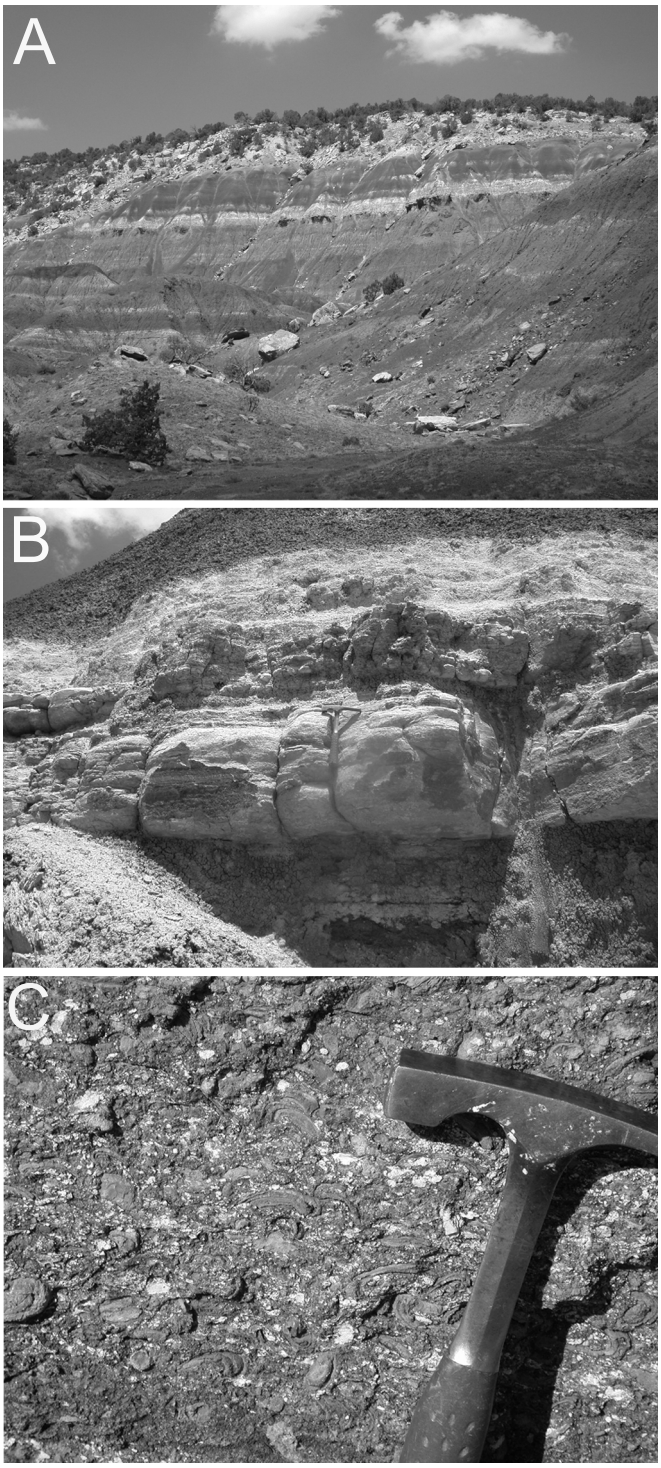

FIGURE 2.10. Lower Chinle Group outcrops at Stop 3. A. Overview of section. B. Close-up of sandstone at contact of Bluewater Creek and Petrified Forest formations. C. Unionid bivalve coquina in Sonsela Member.

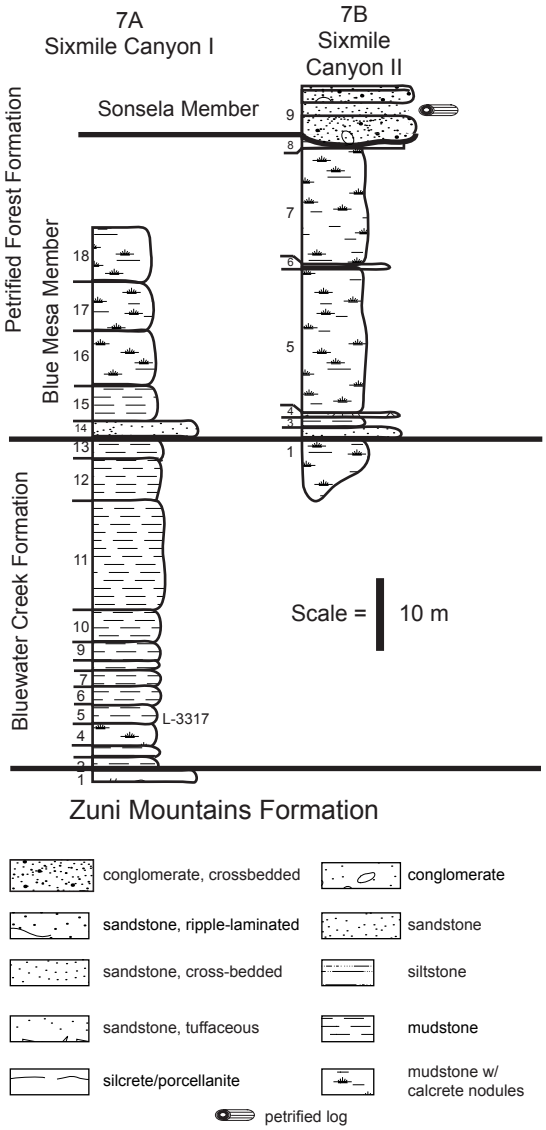

FIGURE 2.11. Stratigraphic section of the lower Chinle Group at Stop 3.

bed floodplain and overbank, low-sinuosity fluvial, and lacustrine deposits, respectively. This outcrop is relatively atypical in that it is almost exclusively the first lithofacies. However, we just drove through extensive outcrops of the third lithofacies (restricted to the bottom of the unit generally), and the second, sandstone-dominated lithofacies is evident just south of this stop where the McGaffey Member pinches out.

Throughout much of the Zuni Mountains the contact of the Petrified Forest Formation and the Bluewater Creek Formation is marked by a white, tuffaceous sandstone of the Blue Mesa Member that rests on

uppermost red-beds of the Bluewater Creek Formation (Figs. 2.6, 2.10-2.11). The upper contact is covered by colluvium here, but Heckert (1997a) measured 44 m of Blue Mesa strata north of here at his Sixmile Canyon II section (Fig. 2.6). The Blue Mesa Member clearly represents predominantly floodplain deposits, and calcrete (siderite) nodules frequently occur in discontinuous horizons, indicating paleosol development.

The top of the Blue Mesa Member is bleached out and irregularly weathered (scoured). Filling these scours are conglomerates and conglomeratic sandstones of the Sonsela Member of the Petrified Forest Formation. Lucas (1993) termed this surface the Tr-4 unconformity, and Heckert and Lucas (1996) documented 20 m of erosion on this surface across the Zuni Mountains. The Sonsela thus represents base-level recovery and the aggradation of channel deposits following this hiatus. Regionally, the Sonsela bears more petrified wood than any other Chinle unit, including the vast majority of the petrified wood at the Petrified Forest National Park (Heckert and Lucas, 1998). Here, in Sixmile Canyon the petrified wood is much less spectacular, but some logs approach 1 m in diameter and several m in length, although they are not as brightly colored as much of the wood in the Petrified Forest National Park. Although the Sonsela may appear inaccessible here, large toreva blocks litter the valley, and several of these preserve thick (0.3-0.5-m-thick) beds of unionid bivalves preserved as a sort of freshwater coquina (Fig. 2.10).

After stop turn around and go back to Forest Road 547. 0.2

33.7 Turn left onto Forest Road 547. **0.2**

33.9 Crest hill with good view of Sonsela on right. View ahead to red rock cliffs of the Entrada Sandstone in the distance. Section on left is Sonsela overlying Blue Mesa Member. **0.8**

34.7 Good view down canyon of red rock cliffs with Entrada Sandstone above Chinle Group strata. Note thick Sonsela cliffs in foreground ahead on left. **0.4**

35.1 Blue Mesa Member next to road on left. **0.6**

35.7 Road curves left; Sonsela just above road level on left. **0.3**

36.0 Sonsela to left with overturned crossbeds (Fig. 2.12). **0.1**

36.1 Road curves left; Sonsela on left with Interstate 40 traffic visible ahead. **0.2**

36.3 Road on top of Sonsela dip slope at cattleguard, looking north into entire Jurassic section up to the Upper Cretaceous Dakota Formation. Section (Fig. 2.13) is Painted Desert Member of Petrified Forest Formation (strike valley), Owl Rock Formation (pinkish bluffs low on far side of valley), Wingate Sandstone (locally exposed below Entrada), Entrada Sandstone (ribbed slopes and massive red cliffs), Todilto, Summerville, and Bluff formations (variegated slopes), overlain by Morrison Formation and capped by Dakota Formation. Here, we leave the Zuni Mounatins to travel along their northern dipslope for the rest of today's trip (Fig. 2.14). **0.1**

36.4 Jurassic section at I-40 in foreground. **0.3**

36.7 Gate and cattleguard. Leave National Forest. Note that the route we just drove through is closed from December 15 to

FIGURE 2.12. Sonsela Sandstone at mile 36.0 with overturned crossbeds (in left center of photo).

FIGURE 2.13. View north of the Mesozoic section from mile 36.3.

March 31 and is essentially impassable when wet. **0.3**

37.0 Cross major El Paso Natural Gas pipeline. **0.2**

37.2 Road turns hard right. **0.1**

37.3 Cross wash (Sixmile Canyon) at dip in road. **0.3**

37.6 Cattleguard. **0.7**

38.3 Road turns hard right. **0.1**

38.4 **Turn left onto pavement** (Whispering Cedars Road). **0.2**

38.6 Stop sign. Settlement of Ciniza on right. **Turn left** and proceed across Interstate 40 bridge. Ciniza derives its name from the Spanish word for ash, "ceniza," and is now the site of the Giant Industries oil refinery and one of the nation's largest truck stops. **0.1**

38.7 **Turn left onto Interstate 40 westbound. 0.2**

38.9 **Merge left** on I-40 westbound. **1.0**

39.9 Bridge over Sixmile Canyon. **0.8**

40.7 Midget Mesa and Mesa Butte on skyline to north. **0.9**

41.6 Exit 36 to Iyanbito--from the Diné 'Ayání bito': Buffalo Springs (Young and Morgan, 1987). 'Ayání, buffalo, literally means "the one that is always grazing." (Julyan, 1996). Type "Iyanbito Member of Entrada" (actually Wingate Sandstone) to right. **0.7**

42.3 Sonsela dipslope on left. **0.5**

42.8 Cuesta to right is developed in the Perea Bed of the Painted Desert Member of the Petrified Forest Formation. This is the type area of the Perea Bed (Cooley, 1957; Lucas et al., 1997b), discussed in the accompanying minipaper. **0.9**

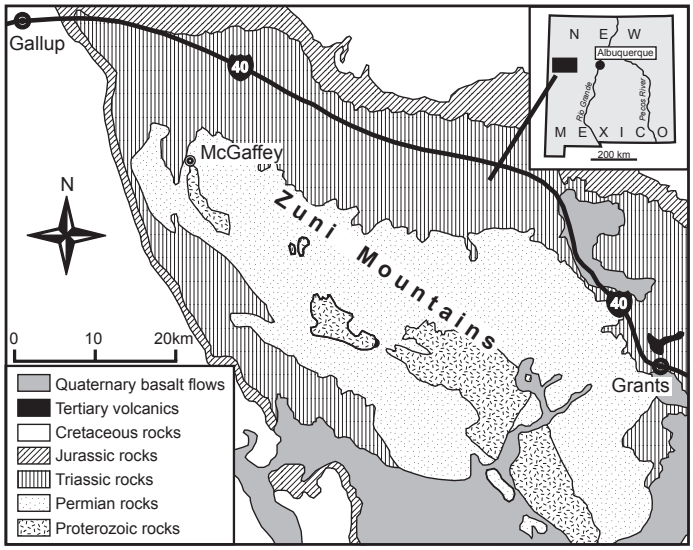

FIGURE 2.14. Simplified geologic map of the Zuni Mountains (courtesy of Karl Krainer).

THE UPPER TRIASSIC PEREA SANDSTONE BED (PETRIFIED FOREST FORMATION, PAINTED DESERT MEMBER) IN THE ZUNI MOUNTAINS

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Historically, many workers have refused to even attempt to correlate units within larger "red-bed" lithosomes such as the Chinle Group, arguing that fluvial facies are too ephemeral and laterally discontinuous to correlate across long distances. A more enlightened understanding of lithostratigraphy and sedimentation, however, recognizes that in a vast depositional system such as the Chinle basin, laterally persistent facies yield important information regarding sedimentation and base-level change, often at a regional level. Thus, Gregory (1917) was well ahead of his time when he correctly subdivided the Upper Triassic Chinle Formation into four regional subdivisions, his A, B, C, and D (in descending order). During the uranium boom of the 1950s, many other geologists made significant contributions to our understanding of Chinle lithostratigraphy, especially Cooley (1957) and Akers et al. (1958), who would further refine interval "C," the Petrified Forest Formation of current usage. Here, we build upon this work to develop a greater understanding of the Painted Desert Member of the Petrified Forest Formation.

After Akers et al. (1958) recognized the Sonsela Member (Sonsela Sandstone or Bed of their usage), the Petrified Forest Forma-

tion was informally divided into "upper" and "lower" members, and this usage persisted for more than 30 years (e.g., Stewart et al., 1972a; Lucas and Hayden, 1989). Lucas (1993) elevated the Chinle to group status, concomitantly raising members to formation rank and beds to member rank. Thus, Lucas (1993) divided the Petrified Forest Formation into the (ascending order) Blue Mesa, Sonsela and Painted Desert members. When Lucas et al. (1997a) reinvestigated the Triassic stratigraphy around Fort Wingate they identified the Perea Bed of Cooley (1957) as a valid lithostratigraphic unit in the Painted Desert Member, and designated unit 12 of Stewart et al.'s (1972a) NM-3b section as the type section (Fig. 2.15). Cooley, himself, did not actually measure the Perea near the type area, and instead relied on descriptions provided to him by J.W. Harshbarger (Cooley, 1957, p. 108).

The type section of the Perea Bed is part of a persistent cuesta arcing around the northern flanks of the Chinle outcrop belt on the Fort Wingate Army Depot. Perea itself is an abandoned railway station just north of I-40 approximately 10 mi (6 km) to the east. The name Perea is an old New Mexican family name (Julyan, 1996). Stewart et al. (1972a) documented 7 m of Perea Bed strata at the type section, and Lucas et al. (1997a) measured 4 m at another section on the Fort Wingate Army Depot. Exposed Perea strata within view of Interestate 40 are typically 4 to 8 m thick.

Regionally, there are many persistent sandstones in the Painted Desert Member. Cooley (1957) recognized several in the Petrified Forest National Park itself, named two in New Mexico (Perea and Taaiylone sandstones) and two more in Arizona outside the Petrified Forest (Chambers and Zuni River sandstones), each in a distinct outcrop belt. Laterally persistent planar-crossbedded sandstones crop out at multiple stratigraphic levels within the Petrified Forest National Park and have been referred to as "Flattops" and "Painted Desert" sandstones (Billingsley, 1985a,b; Ash, 1987) and are now formalized as Flattops and Lithodendron Wash beds (Heckert and Lucas, 2002b). These sandstones typically occur in the lower half of the Painted Desert Member and are much less common at higher stratigraphic levels. Presently, our biostratigraphic database is unable to support more detailed correlations in this interval. However, the lithologic similarity of some of these beds and their apparent homotaxial position in the lower 100 m of the Painted Desert Member suggests that at least some of them may be correlative. Specifically, the Perea Bed likely correlates to the Taaiylone bed in the south near Zuni Pueblo and to the Flattops Bed 2 and Lithodendron Wash beds in the Petrified Forest National Park (Heckert and Lucas, 2002b). The Perea may also be equivalent to Cooley's (1957) Chambers and Zuni River sandstones, but we have not reexamined those strata to the same level of detail. On an even broader scale, a similar sandstone (Saladito Point Bed) crops out low in the homotaxial Bull Canyon Formation in east-central New Mexico (Lucas et al., 2001). These strata are all stratigraphically lower than the lithologically similar Correo Bed, a persistent sandstone high in the Painted Desert that crops out throughout central New Mexico (e.g., Lucas and Hayden, 1989; Lucas and Heckert, 1994; Lucas et al., 1999).

Locally, the base of the Perea exhibits little (~1 m) stratigraphic relief. Presently we are unable to determine if there is greater stratigraphic relief on a more regional scale. The upper contact of

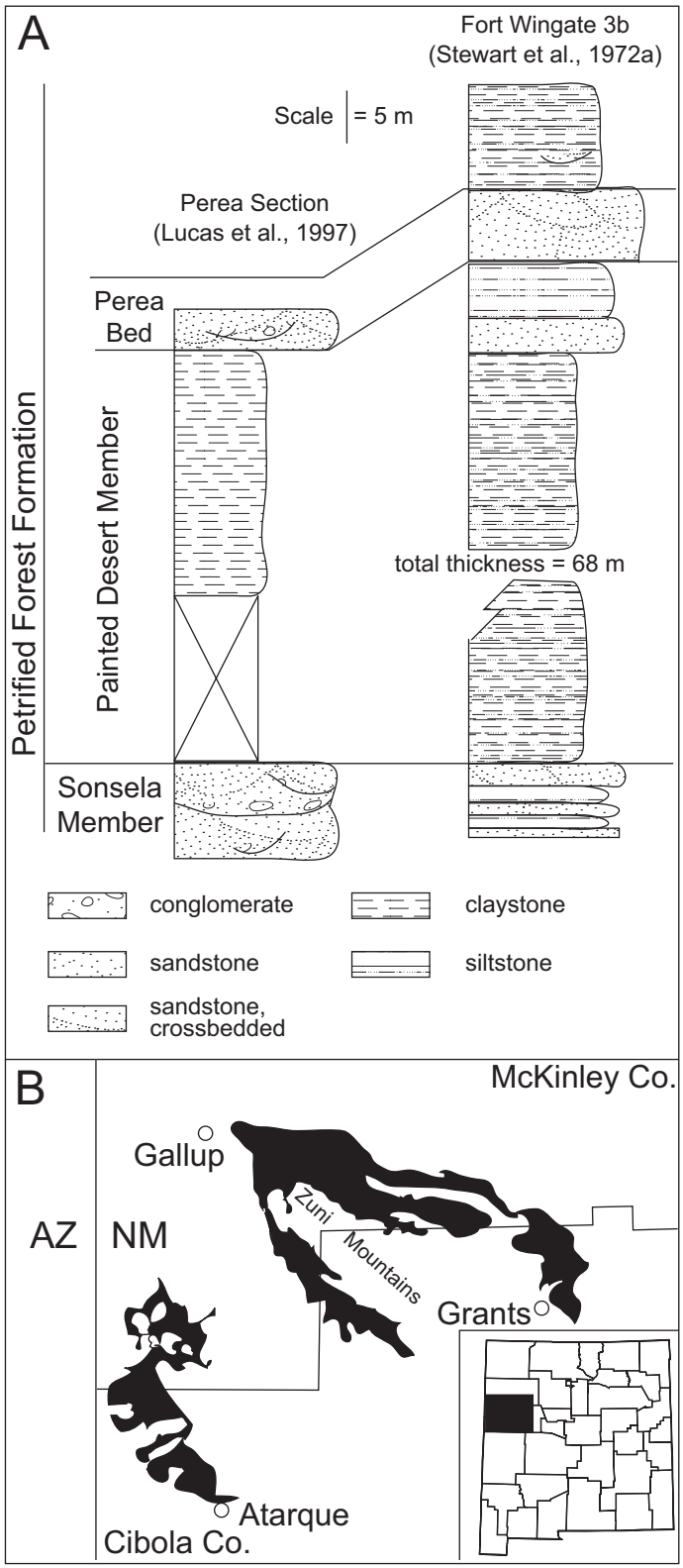

FIGURE 2.15. Measured sections of the Perea Bed of the Painted Desert Member of the Petrified Forest Formation.

the Perea Bed is, like many Chinle sand bodies, difficult to determine, as the contact is usually covered at the base of a dip slope. These sandstones appear to grade upward into the overlying mudstone-dominated interval. Perea strata are never very thick, and typical sections are only 5-10 m. The maximum thickness we have observed is approximately 12 m. Locally, the bed may pinch out.

The Perea Bed typically consists of fine- to medium-grained sublitharenites that are banded reddish brown and pale green. Conglomerates are relatively uncommon in the Perea Bed and are generally restricted to mudstone and calcrete rip-ups < 2 cm in diameter flooring individual crossbed sets. There are both planar- and trough crossbed sets in the Perea. Planar crossbeds, however, predominate, and are lithologically similar to those of the Painted Desert Member studied by Espegren (1985). The predominance of planar crossbedding suggests that a high-sinuosity fluvial system was responsible for Perea Bed deposition.

To date we have not recovered any fossils from the Perea Bed, although Stewart et al. (1972a) reported some unidentifiable bone fragments from the Perea Bed at the type section. Similar beds in the Petrified Forest National Park yield abundant unionid bivalves, but these fossils are not age-diagnostic within the Late Triassic.

We initially formalized the Perea Bed because we saw it as a useful mapping unit present on the Fort Wingate, Church Rock and Pinedale 7.5-minute quadrangles. However, reconnaissance for this guidebook revealed several additional outcrops that extend the known distribution of the Perea Bed eastward to the vicinity of Prewitt. Cooley (1957) thought that sandstone beds in the eastern portion of the Zuni Mountains might pertain to the Correo, but we note that their stratigraphic position is much more similar to that of the Perea than the Correo, so we assign them to the Perea Bed. Thus, the Perea has almost 25 mi (40 km) of strike between Gallup and Grants.

The prevalence of widespread, persistent sand bodies in the lower Painted Desert Member is an interesting phenomenon. Even if these sand bodies are not, strictly speaking, correlative, their nearly homotaxial position suggests that, early in Painted Desert time, depositional circumstances favored the widespread aggradation of sand bodies. Whether this apparent change in base level is a reflection of local, regional, or global conditions is unclear. The stratigraphically lower Sonsela Member clearly reflects base level rise following an interval of erosion and non-deposition that we suspect was driven by eustasy (Lucas, 1993, 1997; Heckert and Lucas, 1996). Whether or not the Perea Bed and its apparent correlatives represent a lower-amplitude change in base level is not clear, but possible.

To date, the Perea Bed has not held any economic significance. However, Native Americans from the Pueblo II-III periods (AD ~900-1250; Schutt, 1997) utilized the Perea both for building materials and as an elevated area above the mudstone-dominated strike valleys in the vicinity of the Fort Wingate Army Depot.

43.7 Sign for exit 33 to McGaffey. **0.6**

44.3 Roadcuts of the Perea Bed. **0.3**

44.6 **Turn right**, taking exit 33 to McGaffey. **0.2**

44.8 Stop sign. **Turn left** onto NM Highway 118 (old US Highway 66) and continue west on frontage road. **0.2**

45.0 Junction with NM-400 to left; continue straight on NM-118. **0.2**

45.2 Fort Wingate historical marker on right. **2.4**

47.6 Road to Fort Wingate Army Depot to left; continue straight. **0.5**

48.1 Cross railroad tracks. **0.1**

48.2 Cross second set of railroad tracks leading to depot. **0.7**

48.9 Owl Rock outcrop on right; see accompanying minipaper. **0.1**

DEPOSITION OF THE UPPER TRIASSIC OWL ROCK FORMATION, WEST-CENTRAL NEW MEXICO

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One of the most distinctive units of the Upper Triassic Chinle Group is the Owl Rock Formation, as much as 150 m of red-bed siltstone, sandstone and mudstone interbedded with laterally persistent limestone beds exposed on the southern Colorado Plateau. These limestones provided the primary basis for some workers (especially Blakey and Gubitosa, 1983; Dubiel, 1989a, b) to conclude that the Owl Rock Formation was deposited in an extensive lake. Dubiel (1989a) even suggested that subsidence along the "Zuni lineament" created the lake basin, and that the Rock Point Formation, which overlies the Owl Rock, represents the shoreline and landward facies that eventually prograded over the lake as it disappeared.

Lucas and Anderson (1993), however, pointed out that most Owl Rock limestone beds appear to be pedogenic calcretes, not lacustrine carbonates. Features indicative of pedogenesis in these limestones include great lateral persistence and thickness (up to 4 m thick), extreme induration, tabular to platy structure, pisolitic and multilaminar internal fabrics, common secondary silica and zones of dissolution, brecciation and recementation. Many vertical, tube-like structures in the Owl Rock limestones claimed to be lungfish burrows (e.g., Dubiel, 1989a, b) are actually rhizoliths (Tanner, 2002). Most Owl Rock limestones thus represent stage III to stage VI calcretes (Gile et al., 1966; Bachman and Machette, 1977) according to Lucas and Anderson (1993).

A more detailed analysis of Owl Rock deposition by Tanner (2002) further undermined the model of Owl Rock deposition in a large lake. Instead, Tanner (2002) concluded that Owl Rock deposition took place in a low-gradient floodbasin during a period of increasing aridity. Owl Rock limestones are pedogenic calcretes or palustrine-lacustrine limestones formed in ponds and ephem-

eral lakes that developed in topographic lows on the floodplain.

Significantly, the Owl Rock Formation lacks a fossil assemblage of a lacustrine macrofauna; indeed, few body fossils are known from Owl Rock limestones. In Moenkopi Wash, Arizona, Kirby (1989, 1991, 1993) reported a tetrapod fauna from clastic rocks in the Owl Rock Formation that is essentially identical to that of the underlying Painted Desert Member of the Petrified Forest Formation. This fauna includes the phytosaur *Pseudopalatus* and the aetosaur *Typothorax coccinarum*, both of which indicate a Revueltian (early-mid Norian) age (Lucas, 1998).

The excellent outcrop of the Owl Rock Formation in the roadcut of the I-40 frontage road just south of Red Rock Park (Fig. 2.16) was key to the conclusions of both Lucas and Anderson (1993) and Tanner (2002). The roadcut exposes ~ 8 m of Owl Rock strata that include four laterally persistent limestone beds. These beds display many of the classic diagnostic features of pedogenic calcretes, including uneven bedding, brecciation, pisolites, concentrically zoned silica replacement and a general lack of primary laminae.

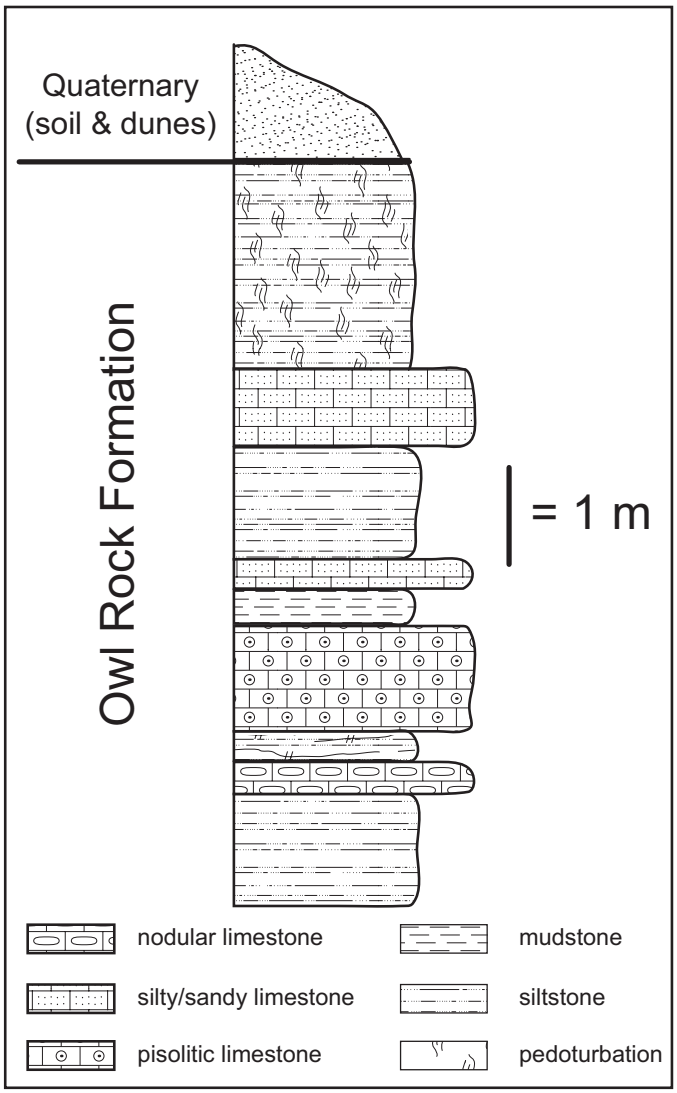

FIGURE 2.16. Measured section of Owl Rock Formation at mile 48.9.

49.0 **Turn right** on NM Highway 566, paved road to Red Rock Park. **0.1**

49.1 Bridge over railroad tracks. **0.2**

49.3 Enter village of Church Rock (population 1077 by the 2000 census; post office from 1952); chapter house on right. Church Rock, also known as Navajo Church, has long been a local landmark, even appearing on Marcou's (1858) geological map of New Mexico. Dutton (1885, fig. 12) provided a wonderful illustration of Church Rock (Fig. 2.17), noting that the rocks "are the upper members of the Jura-Trias, and strongly cross-bedded." Some Diné people referred to it as Tsé'íí'ahi, Standing Rock (Van Valkenburgh, 1941); not to be confused with the community of the same name farther north. **0.2**

49.5 **Turn left into Red Rock Park**. The park, which covers one square mile, includes

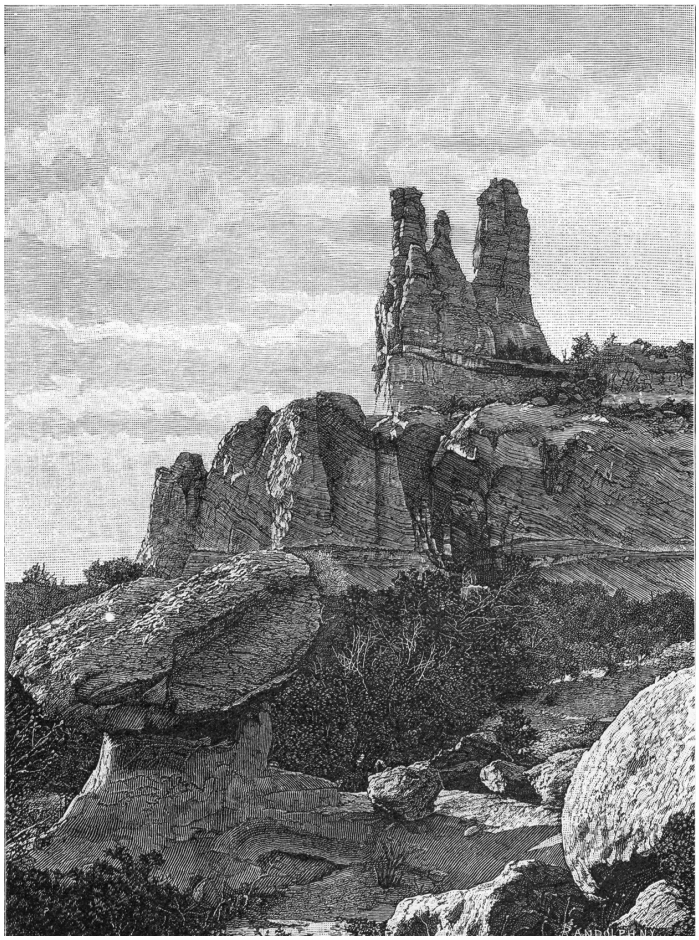

FIGURE 2.17. Dutton's (1885, fig. 12) illustration of Navajo Church.

a large arena seating 8000, an exhibition hall and arts and crafts pavilion, a convention center, auditorium, campground, and information center (see accompanying minipaper by McLemore). **0.2**

RED ROCK PARK

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Red Rock Park takes its name from the spectacular red sandstone cliffs surrounding the impressive array of public facilities, including a rodeo arena, convention center, museum, and camp grounds. The 640-acre park offers excellent scenery for balloonists, hikers, campers, and other visitors. Red Rock Park opened in 1972 as a state park at a cost of $6 million (McLemore, 1989), but in 1989 the park was turned over to the Navajo Nation.

The main attraction in Red Rock Park is an 8000-seat outdoor arena used for various events ranging from rodeos to Motocross competitions to outdoor concerts. Some 25 rodeos and numerous Native American dances are held from June until mid-November. The Inter-Tribal Indian Ceremonial and All-Indian Rodeo are held at the arena every year in August. The Lions Club rodeo in June is one of the state's finest. The Red Rock Balloon Rally in December attracts balloonists from all over the world.

Additional public facilities at the park include the Red Rock Convention Center, which can accommodate conventions, meetings, concerts, shows, weddings, and private parties. The outdoor plaza area can be used for barbecues, square dances, and trade shows. A restaurant is open on a seasonal basis and for special events. The Inter-Tribal Indian offices are housed at the convention center.

At the Red Rock Museum, visitors throughout the year can view exhibits and displays depicting the history and culture of local and regional Native American tribes, including Navajo, Rio Grande Pueblo, Zuni, Acoma, Hopi, and Plains Indians. Pottery, rugs, crafts, and paintings are on display. The museum includes a collection of Zuni Kachina dolls. Another exhibit is dedicated to the Navajo code talkers, who served as Marine Corps communication specialists during World War II (Brown, 1977). Eventually, 420 Navajos served in the group, and their code was the only one never broken by the Japanese (Paul, 1973). The museum features an art gallery where paintings by local and national artists are periodically displayed. Wild flower gardens just outside the museum offer colorful glimpses of the desert vegetation. Corn, beans, and squash are grown during the summer in a Pueblo "waffle garden," the traditional method of agriculture in the area.

Two campgrounds offer campers modern conveniences, including restrooms with showers, picnic tables, electrical and water hookups, and a sanitary dump station. Stables for boarding horses also are available. The main campground features the Outlaw Trading Post, a log cabin built in 1888 and now used as a general store, laundry, U.S. Post Office, and information center for camping arrangements and listings of daily events. Picnic areas and a playground are located at the main campground. Hiking along the one-mile nature trail north of the Outlaw Trading Post takes the visitor into undeveloped portions of the park.

Jurassic and Quaternary rocks are exposed in Red Rock Park, and Triassic rocks are seen from the park (Fig. 2.18). The oldest and most prominent rocks within Red Rock Park are the red sandstones of the Upper Triassic Wingate Sandstone and the Jurassic Entrada Sandstone. The spectacular massive cliffs forming the background for the public facilities in the park belong mostly to the Entrada. The Entrada Sandstone is divided into two members: Dewey Bridge Member and overlying Slick Rock Member. The Dewey Bridge Member consists of 40–60 ft of reddish-brown to reddish-orange silty sandstone and siltstone that form slopes at the base of the massive cliffs. The Slick Rock Member forms the spectacular cliffs and consists of 100–400 ft of reddish-orange,

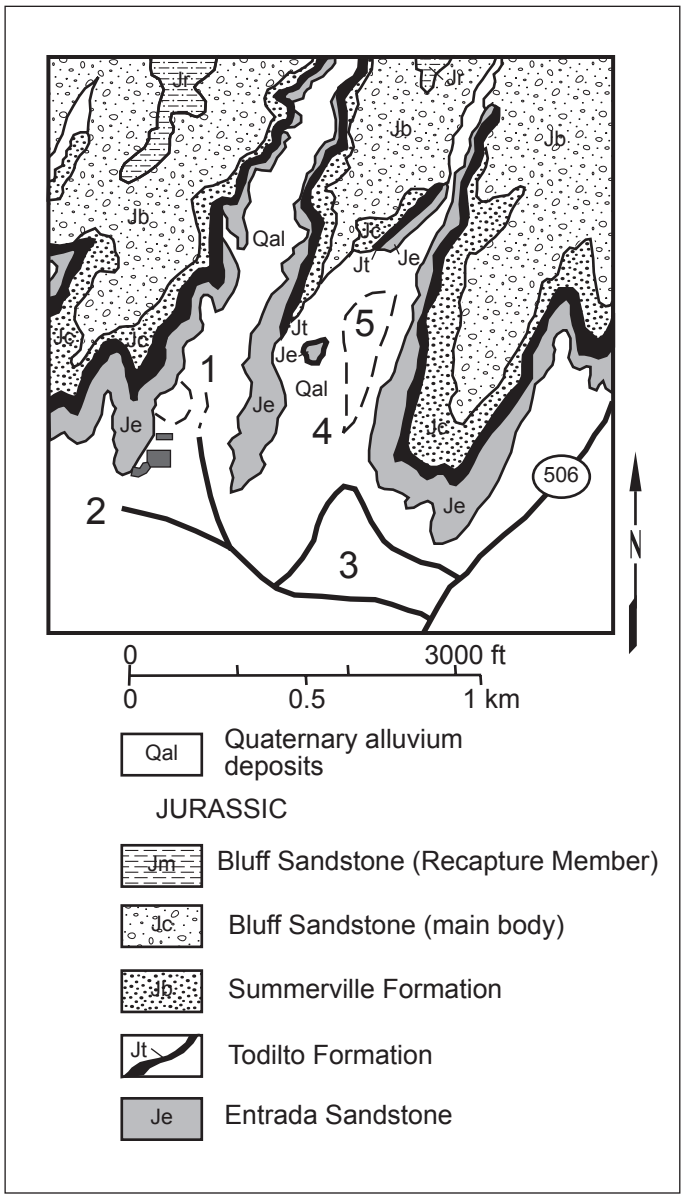

FIGURE 2.18. Geologic map of Red Rock Park.

well-cemented, thick-bedded, well-rounded sandstones, typical of ancient sand dunes. High-angle crossbeds or layers are seen in the sandstone. The sand dunes were cemented by silica and calcite from ground water and compacted to form the massive rock cliffs seen today.

The Jurassic Todilto and Summerville formations overlie the Entrada Sandstone. The Todilto Formation is the older unit and forms a thin, white to gray, resistant cap on top of the Entrada Sandstone. It consists of as much as 10 ft of fine-grained limestone that was deposited in a saline lake. Overlying the Todilto are slopes of interbedded white, pink, and reddish-brown sandstone, siltstone, and shale belonging to the Summerville Formation. The Summerville Formation is locally as much as 50 ft thick and was deposited in a shallow-water coastal plain.

The Jurassic Bluff Sandstone overlies the Summerville Formation and consists of 190 ft of green-gray to pink, well-cemented sandstone (Green and Jackson, 1975). The lower, main body, was deposited in an arid environment as sand dunes (Condon and Peterson, 1986). The overlying Recapture Member consists of 100 ft of reddish-brown to brick-red siltstone interbedded with white to green to yellow sandstone (Green and Jackson, 1975). The Recapture Member is well exposed at the base of Navajo Church, seen from the Outlaw Trading Post. The Recapture Member was deposited in both fluvial and eolian, sand-dune environments. The overlying Acoma Tongue of the Zuni Sandstone is the prominent eolian sandstone with east-dipping crossbeds at the base of Church Rock (Anderson, 1993).

The Jurassic Morrison Formation overlies the Acoma Tongue and consists of two members: Salt Wash and overlying Brushy Basin members. The Salt Wash Member is not exposed within the park boundaries, but it is visible on some of the mesas north of the park and at the top of Navajo Church. This unit consists of 130–230 ft of red to orange sandstone with thin lenses of siltstone and shale (Green and Jackson, 1975). It was deposited in a fluvial environment and is host to most of the uranium resources in the Gallup-Grants area.

The Brushy Basin Member also is not exposed within the park boundaries but crops out north of the park (Green and Jackson, 1975). It consists of green to purple to gray shale, siltstone, and sandstone.

The rocks were subsequently eroded, mainly by wind and rain, to form mesas and spires such as Navajo Church. Erosion of the rock continues today and contributes to Quaternary alluvium and unconsolidated wind-blown (eolian) sand and silt deposits in the park.

49.7 **Turn right** onto one-way "post office" road. **0.2**

49.9 **Go to right** around post office, following signs to hiking trail. **0.1**

50.0 **STOP 4.** Church Rock Post Office, trading post, and Red Rock nature trail parking lot.

At this stop we see the bold, red cliffs of the Entrada Sandstone in the vicinity of Red Rock Park. The valley here, on which the Interstate highway and railroad are built, is formed in the thick, nonresistant Chinle Group, which directly underlies the Entrada. The Wingate/Entrada contact, mostly covered here, is the J-2 unconformity.

The Church Rock trail takes us up through the Slick Rock Member of the Entrada Sandstone to closely examine the Todilto, Summerville, and Bluff formations (Figs. 2.19-2.20). Key features to note are: (1) the Todilto Formation is thin-bedded kerogenic limestone that forms a single ledge (bed) typically about 1 m thick; (2) the Summerville Formation here is very thin, about 1.5-4.0 m thick and generally poorly exposed; (3) the Summerville consists of water-laid siltstones and sandstones and shows much evidence of soft-sediment deformation; (4) the Bluff Sandstone is strikingly different from the Entrada Sandstone: Entrada bedforms are dominantly large-scale trough crossbeds

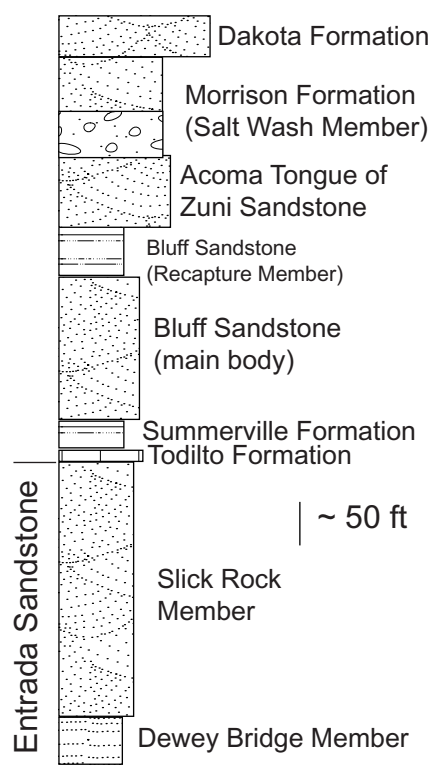

FIGURE 2.19. Schematic Jurassic stratigraphic section on Church Rock trail.

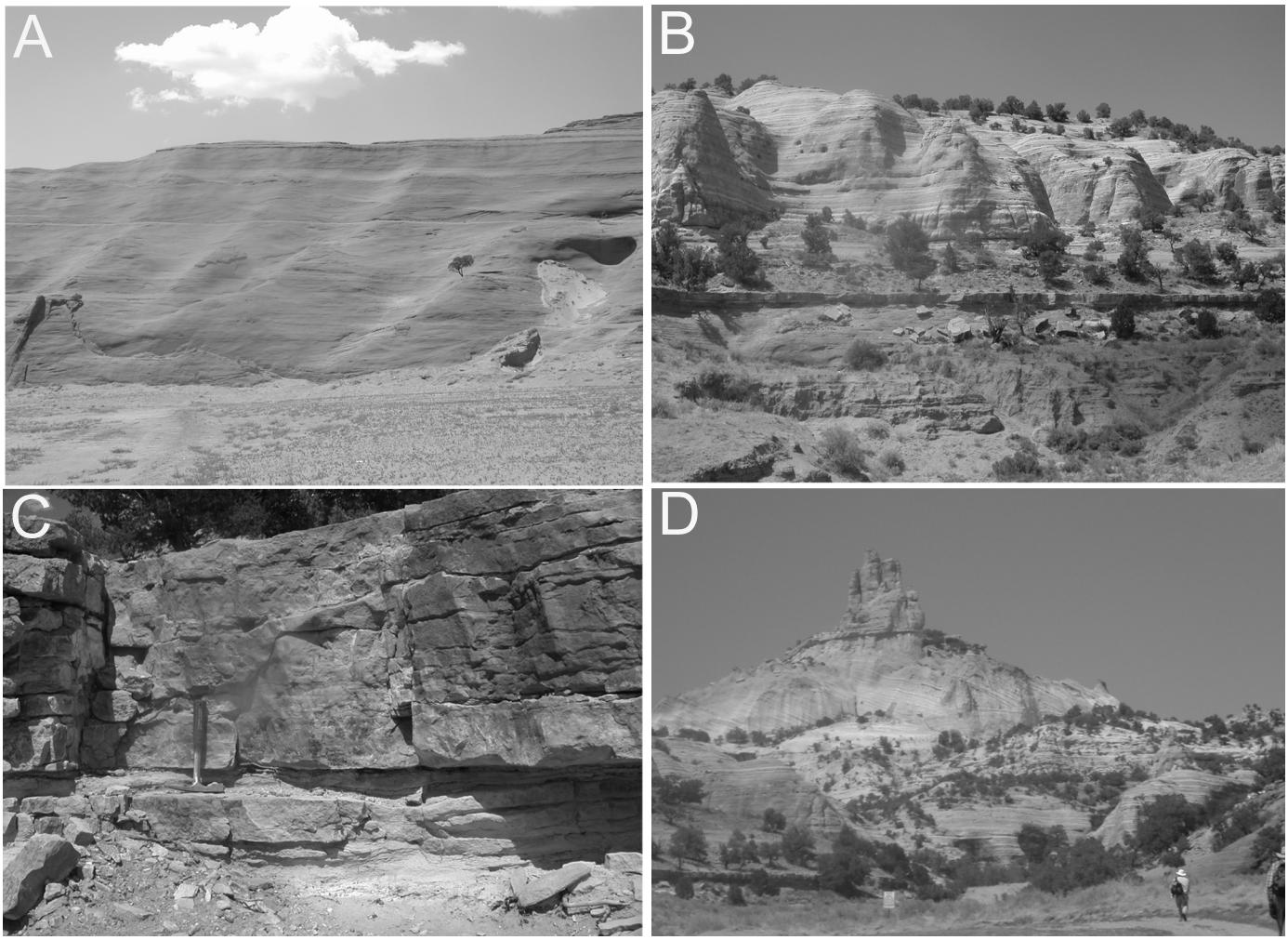

FIGURE 2.20. Photos of Jurassic outcrops on Church Rock trail. A, Crossbedded Slick Rock Member of Entrada Sandstone. B, Section Entrada-Todilto-Bluff. C, Closeup of Todilto Formation. D, Prominent Acoma Tongue of Zuni Sandstone is the crossbedded unit at the base of Church Rock.

indicative of eolian duneforms, whereas Bluff bedforms are mostly horizontal laminae in thick sets, characteristic of eolian sheet sands; (5) lower Bluff sets are broken by rhizolith horizons suggestive of a "wet" eolian system; (6) the Bluff consists of two members, a lower interval of eolian sandstone (main body) overlain by red-bed siltstone and sandstone (Recapture Member); and (7) above the Bluff is a prominent eolianite with easterly-dipping crossbeds, the Acoma Tongue of the Zuni Sandstone (Anderson, 1993).

How the red, cliff-forming, eolian sandstone here came to be called Entrada is an interesting (and confusing) story. It was originally named the Wingate Sandstone by Dutton (1885), who thought it to be of Triassic age. Stratigraphic work continued in the Colorado Plateau during the 43 years following the Wingate naming, especially in Arizona and Utah by U.S. Geological Survey geologists. In the San Rafael Swell of Utah, several groups of geologists found a red, cliff-forming, eolian sandstone unconformably overlying the Chinle Group and assumed it to be the Wingate Sandstone, as in New Mexico. They also found two other similar eolian sandstones higher in the stratigraphic column. The next higher was named Navajo Sandstone from Navajo County, Arizona, by Gregory (1915). The next sandstone above that was named Entrada Sandstone by Gilluly and

Reeside (1928), from Entrada Point in the northern San Rafael Swell, Utah. Later, Heaton (1939) correlated the Entrada of Utah through Colorado into New Mexico, where it could be traced to near the type Wingate at Fort Wingate. Baker et al. (1947) recognized that the type Wingate in New Mexico was, indeed, what had been later named Entrada in Utah, contradicting their earlier correlation (Baker et al, 1936). They proposed to solve this problem by acknowledging that the names Wingate and Entrada had been widely used for many years, and, rather than correct the miscorrelation and follow priority, recommended that the Wingate Sandstone at Fort Wingate, New Mexico and its lateral equivalents be called Entrada. They also recommended that the misidentified Wingate Sandstone of Utah and its lateral equivalents be called Wingate, although they recommended abandoning the Wingate type locality in New Mexico because the type Wingate was now called Entrada! Their recommendations have been generally followed since 1947. So, after 62 years of these red cliffs before you being the legally designated stratotype of the Wingate Sandstone, they have been called Entrada Sandstone for the last 55 years, and the Wingate Sandstone has no real stratotype! This story is perhaps the most spectacular stratigraphic nomenclature foul-up due to miscorrelation in the U.S., all courtesy of the U. S. Geological Survey.

After stop retrace route to NM-566. 0.2

CLARENCE DUTTON

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Clarence Edward Dutton (1841-1912) (Fig. 2.21) was born in Wallingford, Connecticut and graduated from Yale College in 1860. He then entered the Yale theological seminary, but the Civil War interrupted his studies when, in 1862, he joined the 21st Connecticut Volunteers and was commissioned as a second lieutenant. During the war, Dutton served at Fredericksburg, Suffolk, Nashville and Petersburg. After the Civil War, he remained in the army and ultimately advanced to the rank of major. Dutton began to study iron technology and geology in 1865, and in 1875 he began service in Major John Wesley Powell's surveys of the Rocky Mountain region, working especially on the high plateaus of central Utah and in the Grand Canyon country of northern Arizona.

Dutton's writings about this work indicate his clear interest in volcanology and seismology, and in 1882 he was able to study volcanic phenomena in the Hawaiian islands. In 1884, Dutton worked in west-central New Mexico and paid particular attention to the monoclinal flexures near Gallup and the volcanic rocks of the Mt. Taylor region.

Dutton subsequently worked in the coastal ranges of California, Oregon and Washington, and he also studied the Charleston, South Carolina earthquake of 1886. Elected to membership in the National Academy of Sciences in 1884, Dutton is most famous today for coining the term isostasy to express the idea that the crust is floating on a very plastic or liquid substratum. Indeed, this concept was a major contribution by Dutton to the late nineteenth century debate over global tectonics, most of which focused on the contraction of the planet as an underlying mecha-

FIGURE 2.21. Portrait of Clarence E. Dutton (from Merrill, 1924).

nism (Greene, 1982). Dutton's work on the Colorado Plateau was instrumental to the isostasy concept, as it was clear the Plateau had been significantly uplifted (largely, Dutton believed, because of the removal by Cenozoic erosion of thousands of cubic kilometers of sediment) without being laterally compressed, as was the case with many mountain ranges.

Dutton's 1884 work in west-central New Mexico was published in 1885 as an 85-page-long, illustrated article in the Sixth Annual Report of John Wesley Powell's young U. S. Geological Survey. It provided the first detailed description of the geology of west-central New Mexico and included: (1) a geologic map at a scale of 1:640,000 (pl. 14); (2) a series of structural cross sections through the map (pl. 18); (3) a composite stratigraphic section of the entire rock column exposed from the Zuni Mountains to the Chuska Mountains (pl. 16); and (4) a series of remarkable woodcut ("photographed on wood and engraved") images of outcrops and other geological features of west-central New Mexico (pls. 20-22, figs. 1-4, 6, 8-13, 17-25). Dutton's report thus stands as one of the first detailed studies of regional geology in New Mexico, and this classic work is the real beginning of our knowledge of the geology of the west-central portion of the state.

50.3 Stop sign; **turn left. 0.2**

50.5 Stop sign; **turn left** onto NM-566 northbound. **0.1**

50.6 Road comes in from right. Contact between Dewey Bridge and Slick Rock members of the Entrada Sandstone (white line) on left. **0.5**

51.1 Outstanding exposures of crossbeds in the Slick Rock Member on left. Note generally southwesterly dip of most Entrada crossbeds (Fig. 2.22). **0.2**

51.3 Gray limestone on left is Todilto Formation. **0.1**

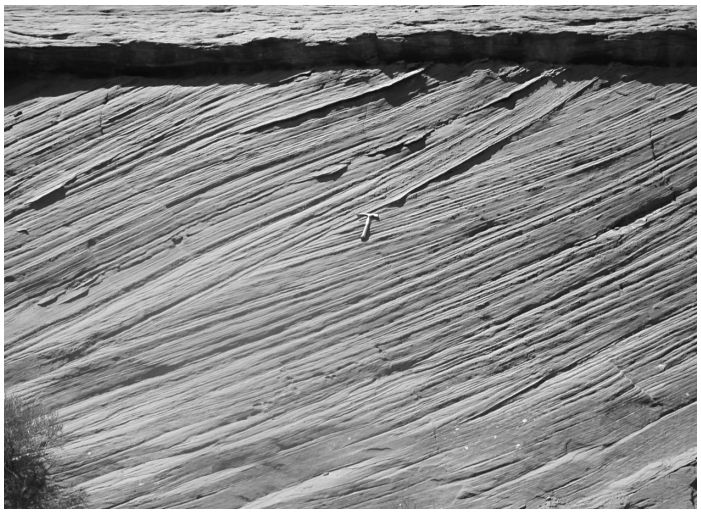

FIGURE 2.22. Southwest-dipping Entrada crossbeds at mile 51.1.

51.4 Microfaults in Bluff briefly visible high above road to left. Middle Jurassic Todilto Formation is thin limestone above well-exposed crossbeds of the Entrada Sandstone. Microfault horizon also contains sandstone pipes, generally small. **0.1**

51.5 Entrada-Todilto contact at about road level left; Bluff Sandstone outcrops overlie the Todilto. When present in this area, the Summerville Formation is a very thin (<10 ft) series of water-laid sandstones and siltstones between the Todilto and Bluff. Road continues north through Bluff Sandstone. **0.3**

51.8 Sandstone pipes in the Bluff Sandstone on left with more microfaults. **0.3**

52.1 Contact between main body of Bluff Sandstone (below) and Recapture Member of Bluff (above) on left. **0.2**

52.3 Contact between red Recapture Member and gray-green Acoma Tongue of the Zuni Sandstone on right. **0.3**

52.6 At crest of hill note inset alluvium on right; Church Rock at 9:00. White Mesa ahead at 10:00. **0.1**

52.7 Excellent exposure of Acoma Tongue on right with crossbeds. Note southeast-dipping foresets. **0.4**

53.1 **Turn left** on McKinley County Road 43 (weathered sign is barely legible). Note Acoma Tongue-Morrison contact on right before turn. **0.3**

53.4 Steeply inclined southeast-dipping foresets characteristic of the Acoma Tongue on right. At first glance this outcrop appears to be a slump, but the crossbeds are at their original attitude. **0.3**

53.7 **STOP 5.** Here, we will examine strata of the Upper Cretaceous (Cenomanian) Dakota Sandstone deposited in an incised valley in the Salt Wash Member of Morrison Formation at the west end of White Rock Mesa (Fig. 2.23). After Jurassic fluvial deposition ceased here, no sediment accumulated (or was preserved) for ~50 million years. Then, early in Late Cretaceous (Cenomanian) time, the West-

ern Interior seaway transgressed through west-central New Mexico, and the marginal marine to shallow marine Dakota sandstone was deposited. Here, we see a striking example of the Dakota-Morrison unconformity in the form of a well exposed, incised valley fill.

Note the bleached white color of the Salt Wash sandstones below the carbonaceous Dakota to the east on White Rock Mesa. The valley fill is in the part of the Dakota known as the Dakota main body. Additional valley fills and channel fills may be seen in the Dakota main body and the overlying Paguate Member of the Dakota to the east along the Second Canyon Road. Note that the Cretaceous section to the north above the marine Twowells Sandstone Tongue of the Dakota Sandstone is the lower tongue of the Mancos Shale in the valley overlain by Gallup Sandstone with interbedded Tocito Sandstone, which forms Nose Rock Point Mesa on the skyline.

After stop turn around and retrace route to highway 566. 0.6

54.3 Stop sign at intersection with NM-566. Acoma Tongue-Morrison contact ahead with brown fluvial sandstone on eolian sandstone. **Turn right** to retrace route to Interstate 40 frontage. Enjoy driving through the entire Jurassic section yet again! **0.5**

FIGURE 2.23. Incised valley in Morrison Formation filled with Dakota Sandstone at Stop 5.

54.8 Alluvium on left cut into Acoma Tongue. **0.3**

55.1 Acoma Tongue-Recapture Member contact on left. **0.1**

55.2 Recapture Member-Bluff Sandstone contact on right. **0.7**

55.9 Summerville Formation-Todilto Formation-Entrada contacts on right. **0.8**

56.7 Contact between Slick Rock and Dewey Bridge members of Entrada on right. **0.7**

57.4 Stop sign. Owl Rock Formation ahead with thick alluvial fill overlying it. **Turn left** on old U.S. 66 frontage road (NM-118). Owl Rock Formation on left (see minipaper at mile 48.9). Retrace route to McGaffey exit. 0.7

58.1 Cross railroad tracks. 0.1

58.2 Cross second set of railroad tracks. **0.6**

58.8 Entrance to Fort Wingate Army Depot on right. **2.3**

61.1 Historical marker on left for Fort Wingate. Note that cliffs to left are the section we just examined (Jurassic strata and Dakota Formation). **0.2**

61.3 **Turn right** onto NM-400, cross bridge, and prepare to turn left to go east on Interstate 40. **0.2**

61.5 **Turn left** onto Interstate 40 eastbound entry ramp. **0.2**

61.7 **Merge left** onto Interstate 40 eastbound. **0.2**

61.9 Perea Bed outcrops along highway roadcuts. **2.8**

64.7 Pass under bridge. Exit 36 to Iyanbito. **1.8**

66.5 Paralleling Sixmile Canyon road. Note bluffs to north, with a section from the upper Chinle to the Entrada. **1.0**

67.5 Exit 39 to Ciniza. Giant Truck Stop and refinery on left. **0.7**

68.2 We are driving obliquely up and across the Sonsela dipslope as we ascend toward Continental Divide. **0.7**

68.9 Cross Fourmile Canyon with good Sonsela outcrops. **1.7**

70.6 Cross Smith Canyon, also developed in

the Sonsela, with good view to left down into Painted Desert section. **0.9**

71.5 Cross Foster Canyon. Note flexure in Entrada to north. Rimrock to east of flexure is Cretaceous Dakota Formation. **1.0**

72.5 Exit 44 to Coolidge, historically the shipping point for Fort Wingate troops and infamous for its 14 rough-and-tumble saloons. Later came a guest ranch frequented by artists and ethnologists (Van Valkenburgh, 1941). **1.5**

74.0 Just before the continental divide, the peak topped with radio towers at 10:00 is Mount Powell, a Tertiary diabase intrusion above a lower tongue of the Cretaceous Mancos Shale and a complete Dakota Formation section, including the Paguate Member, which forms the rimrock. Mount Powell (K-Ar age = 32.7 $\pm$ 1.2 Ma: Robertson, 1990) may be a southern outlier of the Navajo volcanic field. **1.6**

75.6 Exit 47 to town of Continental Divide (population about 250 in 2000; post office from 1949). **0.5**

76.1 Cross physiographic continental divide; elevation 7275 feet. This pass was long called Campbell's pass, after Albert H. Campbell, the surveyor attached to the Whipple Expedition of 1853. Mount Taylor at 11:00 in distance. **3.9**

80.0 Sign for exit 53 to Thoreau. **1.0**

81.0 **Exit right** at exit 53 to Thoreau; El Paso Natural Gas station to right. **0.2**

81.2 Stop sign. **Turn left** onto frontage road. **0.1**

81.3 Stop sign, **turn left** onto NM-371 and proceed under interstate. **0.1**

81.4 Stop sign, go straight. **0.2**

81.6 Bridge over railroad tracks. **0.2**

81.8 Enter Thoreau (population 1863 by the 2000 census). Diné people refer to this locale as Dlǫ́' áyázhí, Little Prairie Dog (Young and Morgan, 1987). The arrival of the Atlantic and Pacific Railroad in 1881 marked the beginning of the town, which was originally called Chaves, after a local family who maintained a store here. In 1890, the Mitchell brothers, Austin and William, bought some 300,000 acres of timber land in the Zuni Mountains and laid out a townsite (called, of course, Mitchell), which had attracted 150 residents by 1892. The Mitchells gave up their plan to become timber barons during the Panic of 1893, and departed, but the town soon afterward became the base for the Hyde Exploring Expedition (1896-1899), which conducted the first extensive archeological excavations of Chaco Canyon. At this time, the town also developed into an extensive Indian trading center. The Hyde brothers renamed the town for the philosopher Henry David Thoreau, and the town post office changed to that name in 1899. However, local traditions claim that the name came from a resident named Thoreau, (a railroad man, army paymaster, or bookkeeper for the Mitchell brothers; accounts vary). The pronunciation is not that of Henry David, but rather "tho-ROO" or simply "THROO" (Julyan, 1996). In 1903, the American Lumber Company acquired the Mitchell Brothers' large holdings, and in partnership with the A,T & SF Railroad, resurrected the timber industry. By 1910, the firm sawed some 60 million board feet of timber, employed more than 1500 people, and an average of 100 railroad cars of timber rolled eastward from Thoreau to Albuquerque each day. However, the American Lumber Company went out of business in 1913 (Mangum, 1997). **0.2**

82.0 Post office to left; Entrada Sandstone red rock bluff in distance at 12:00. **0.7**

82.7 Leaving Thoreau; cemetery on right. **2.5**

85.2 Note section on point of mesa to left, exposing the Dewey Bridge and Slick Rock members of the Entrada Sandstone under a cap of gray Todilto Formation limestone. **0.3**

85.5 The 250-megawatt Plains Escalante Generating Station is visible at 1:00. It burns coal hauled by train from Peabody Energy's Lee Ranch surface mine 35 miles

northwest of Grants. **0.7**

86.2 Milepost 5; note Owl Rock-Wingate-Dewey Bridge-Slick Rock section exposed to left with Todilto on top. **0.7**

86.9 Red Mesa Bluffs Road on right; goes to local landfill. Continue straight. Road will now climb up through the Slick Rock Member of the Entrada. **0.8**

87.7 Outcrops of Slick Rock Member of Entrada Sandstone on left. Mesa on skyline to N at 12:00 is capped by Dakota Sandstone on Brushy Basin Member of Morrison Formation. Erosional truncation between here and STOP 6 gradually removes Brushy Basin so that basal Dakota unconformity is on Salt Wash Member of Morrison Formation. Note Dakota offset across fault (up to E) in gap with highway. **0.3**

88.0 Unpaved road to right. **Turn right. 0.1**

88.1 Enter Gallup Sand and Gravel Company Quarry. **0.1**

88.2 Road intersection; **go right. 0.1**

88.3 Road to right; go straight. **0.4**

88.7 **STOP 6.** Here, we will talk about limestone quarrying in the Todilto Formation, Summerville outcrops to the north, and Entrada stratigraphy (Fig. 2.24).

The Gallup Sand and Gravel Co. produces a variety of rock products from the Todilto Limestone. As noted in the first-day road log at Stop 2 (in Todilto Park), the Todilto Formation is an economically important unit in New Mexico. One example is the production of limestone from the lower, Luciano Mesa Member of the Todilto. The quarry visited at this stop is one of several that have been developed along the Todilto outcrop belt between Gallup and Grants. At this quarry, the Gallup Sand and Gravel Co. produces a variety of limestone rock products from the Todilto.

Quarrying begins with the removal of an average of about three ft of soil and overburden overlying the economic-grade limestone. The thickness of remaining limestone suitable for production may be up to about 15 ft. The rock is drilled and blasted and carried to a primary crusher. The crushed limestone is then screened and depending on the desired product

FIGURE 2.24. Jurassic outcrops at Stop 6. A, Cliff of Summerville and Bluff strata north of the stop. B, Limestone of the Todilto Formation at the stop. C, Wingate-Entrada section below the limestone quarry.

some may be conveyed to secondary crushers and then to a final screening.

The company adjusts the precise details of its operations according to the anticipated end uses of the limestone products. At various times the products may include riprap rock, filter rock, road metal aggregate, concrete aggregate, and various rock chip and specialty gradations. All are transported by truck from the quarry to the locations where they will be used.

We are now intimately familiar with the Jurassic section regionally. The flats below the quarry are developed in the upper part of the Triassic Owl Rock Formation. The cliff above is composed of the Wingate Sandstone and Dewey Bridge and Slick Rock members of the Entrada Sandstone (Fig. 2.24C). The quarry is developed in the Todilto Formation (Luciano Mesa Member) (Fig. 2.24B), and to the north are exposures of the Summerville Formation and Bluff Sandstone (Fig. 2.24A).

After stop, turn around and leave the quarry. 0.6

89.3 Stop sign. **Turn left. 0.5**

89.8 Crest of hill. A good view ahead of the dip slope of the Zuni Mountains. **0.5**

90.3 Note Entrada section to right. **3.9**

94.2 Highway divides; enter greater Thoreau. **0.4**

94.6 Thoreau village limit. **1.0**

95.6 Leave Thoreau. **0.1**

95.7 Bridge over railroad tracks. **0.3**

96.0 Stop sign. Go straight, under I-40. **0.1**

96.1 **Turn left** to enter I-40 eastbound onramp. **0.2**

96.3 **Merge left** onto I-40 eastbound. Mount Taylor (elevation, 11,301 ft, the highest mountain in New Mexico west of the Rio Grande) at 12:00. This mountain has tremendous cultural significance to the Diné people: it is the southern of their four principal sacred mountains, and figures prominently in many Diné creation stories and ceremonies, as well as in Navajo educational philosophy (Van Valkenburgh, 1941; Yazzie, 1971; Zolbrod, 1984; Benally, 1987; Aronilth, 1991). They refer to it variously as Tsoodził, Tongue Mountain (referring to a tongue of lava); Níłtsą́ dziil, Rain Mountain; and Dootł'izhii dziil, Turquoise Mountain (Young and Morgan, 1987).

Note Sonsela dipslope to right. The road is on colluvium near the base of the Painted Desert Member of the Petrified Forest Formation. The Sonsela in this region is an important aquifer. **3.4**

99.7 Mile marker 57. Haystack Mountain at 12:00; Mount Taylor at 1:00. Mount Taylor was named by Lieutenant James H. Simpson for Zachary Taylor, hero of the Mexican War and 12th president of the United States. In Simpson's (1850) words, this "is one of the finest mountain peaks I have seen in this country. This peak I have, in honor of the President of the United States, called Mount Taylor. Erecting itself high above the plain below, an object of vision at a remote distance, standing within the domain which has been so recently the theatre of his sagacity and prowess, it exists, not inappropriately, an ever-enduring monument to his patriotism and integrity." Although Taylor was president for only 16 months in 1849-1850, and never saw the mountain named for him, he had a profound influence on the subsequent history of New Mexico. As Julyan (1996) noted, Taylor strongly resisted attempts by Texas to annex the eastern half of New Mexico, and it was through Taylor's determination, against bitter southern opposition, that New Mexico remained a territory free of slavery. **1.0**

100.7 Mile marker 58. Note cuestas of Owl Rock Formation to left, Entrada red rock bluffs beyond, and mesas on northern skyline capped with Dakota Sandstone. **1.3**

102.0 Outcrops of upper part of Sonsela Member along road for next 1.7 miles. **3.0**

105.0 Outcrop on right of Painted Desert

Member red beds. **0.9**

105.9 Exit 63 to Prewitt (NM-412) and Bluewater State Park. Note large fault to north that cuts out the Entrada bluffs and puts the Entrada against the Morrison. The Diné name for this area is Kin łigaaí, White House; earlier it was called Naaslah, White Clay Quarry (Van Valkenburgh, 1941). The 1882 USGS Map of New Mexico marked the locality as Ojo Negra (Van Valkenburgh, 1941). The community of Prewitt (population 460 by the 2000 census) was originally called Baca, after a local family. In 1916, Bob and Harold Prewitt arrived, established a trading post, and gradually the name Prewitt replaced Baca as the name of the town. **0.5**

BLUEWATER LAKE STATE PARK

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Bluewater Lake State Park (Fig. 2.25) is one of the oldest of 31 state parks in New Mexico, becoming a state park in 1955. The park lies 7 mi west of the village of Bluewater, south of Prewitt, at an elevation of 7400 ft in Las Tuces Valley, near the Continental Divide in the Zuni Mountains. The Navajos knew the area as T'iis Ntsaa Ch'éélí, "large cottonwood trees where water flows out horizontally" (Young and Morgan, 1987; Julyan, 1996), because a forest of cottonwoods, piñon pine, and juniper surrounds the lake. Bluewater and Cottonwood (Azul) Creeks feed the man-made lake.

The lake is formed by an arched dam, which is 90 ft high and 500 ft long (Robinson, 1994), and impounds 38,500 acre-feet of water. The last time water spilled over the dam was in 1941. The dam is convex in the upstream direction for increased strength, and it is at the mouth of Bluewater Creek, a steep-walled canyon. An overlook at the end of the road from the Visitors' Center and a primitive hiking trail into the canyon offer excellent views of the dam and canyon.

The New Mexico Department of Game and Fish maintains a permanent pool of water for fish and periodically stocks the lake with rainbow trout and channel catfish. It is well known to ice-fishermen during the winter. In addition to fishing, camping, picnicking, power and sail boating, hiking, water skiing, sail surfing, and swimming are other possible recreational activities (New Mexico State Parks, 2002). Developed facilities lie on the east side of the lake, north of the dam. Facilities include day-use picnic tables, a launch ramp, drinking water, modern rest rooms with showers, camping sites (some with electrical hookups), a playground, and a dump station. Primitive camping is allowed

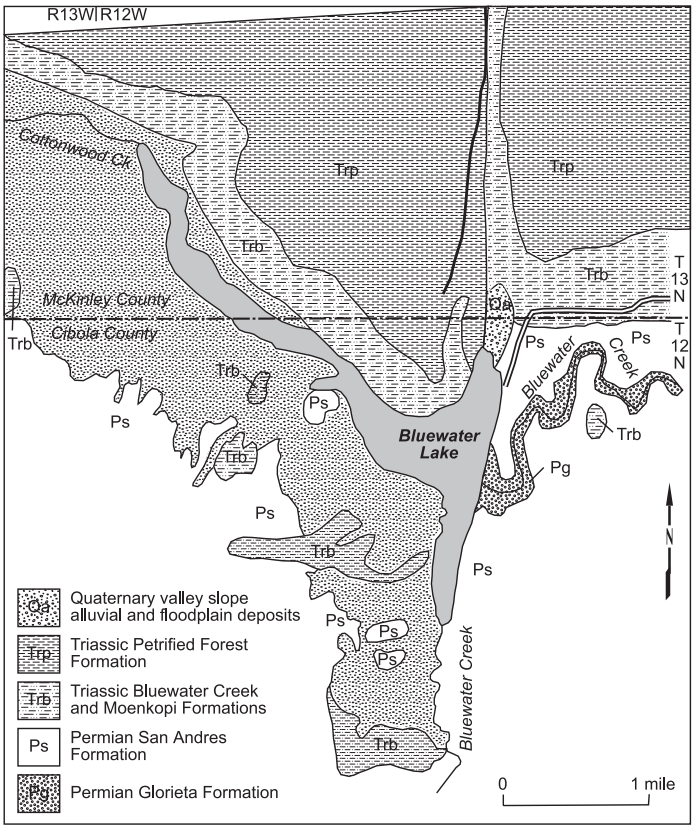

FIGURE 2.25. Geologic map of Bluewater Lake State Park (from McLemore, 1998 modified from Smith, 1954, using stratigraphic nomenclature of Lucas, 1995).

along the northwest side of the lake. A restaurant and store are available for visitors during weekends and other busy times of the year. Additional facilities are available in nearby Bluewater. Not all of the 25 mi of shoreline belongs to the state park; some land surrounding the lake belongs to private individuals, Indian tribes, and U. S. National Forest. All of the water is open to the public.

Few people permanently settled in the Zuni Mountains until the middle 1800s. Zuni, Acoma, and Navajo Indians hunted and traveled through the Zuni Mountains long before there was a Bluewater Lake. Spaniards traveled through the mountains on their way to the Zuni Pueblo. About 1756, Don Bartolome Fernandez built a ranch and settled approximately 25 mi east of Bluewater Lake. James H. Simpson of the U. S. Army and Adolph F. Bandelier traveled through the Zuni Mountains in 1849 and 1883, respectively (Robinson, 1994).

Although several earthen dams were built and rebuilt multiple times since about 1850 to impound water for local irrigation, recreational use, including hiking, picnicking, camping, swimming, fishing, boating, and water skiing, is important to most visitors today. The lake was originally impounded about 1850 by Martin Boure, a French settler, to irrigate his farm (Young, 1984); the original dam failed during a rare, torrential rain, one of a few recorded occurrences in the Zuni Mountains. In the 1870s, another Frenchman, Dumas Provencher, operated a stagecoach stop and sawmill near the present Bluewater Lake (Robinson, 1994). The settlement of Bluewater, also known as

Bluewater Valley, was established in 1880-1881 by the Atchison, Topeka, and Santa Fe Railroad and has had a post office since 1895 (Julyan, 1996). Provencher sold his operation to the Acoma Land and Cattle Co., who sold it in 1882 to James L. Latta. Latta formed the Zuni Mountain Cattle Co. in 1883 with its headquarters at Bluewater. In 1884-1885, more French settlers arrived, formed a cattle company, and built a dam at the junction of Cottonwood (or Azul) and Bluewater Creeks. That dam also failed. In 1894, a Mormon named Ernst Tietjen bought the Latta ranch, formed a partnership, the Bluewater Land and Irrigation Co., with local businessmen, and built another dam at the confluence of Bluewater and Cottonwood Creeks (Tietjen, 1980; Robinson, 1994). Other Mormon settlers soon found the area to their liking and, in 1896, established a community 3 mi west of the railroad camp called Mormontown. The railroad camp soon died, and Mormontown changed its name to Bluewater, which is still occupied.

Over the next few decades, dams were breached at least three or four times and then rebuilt at various places along Bluewater Creek (Tietjen, 1980; Robinson, 1994). Feuds occurred between the cattlemen and Mormon farmers over the destiny of the fertile valley. Finally, in 1925-1926, the Bluewater-Toltec Irrigation District was formed to build the current structure (Anonymous, 1983). About 1930, sportsmen with the help of the Game Protective Association, opened Bluewater Lake for recreational use. In 1936, the lake was stocked with trout, bass, perch, and crappie, and in 1937, the state of New Mexico purchased 160 acres along the lakeshore for recreational development (Robinson, 1994). Additional land was purchased in 1954-1955. In 1955, Bluewater Lake was added to the list of New Mexico State Parks, with a total acreage of nearly 2200 acres.

The Zuni Mountains are considered the southern boundary of the San Juan Basin and form the core of an elongated structural dome created by regional compressional tectonics during the Cretaceous and Paleogene. Rocks ranging in age from Proterozoic through Recent are exposed in and around the Zuni Mountains, but only Permian (Glorieta Sandstone, San Andres Formation) and Triassic (Moenkopi Formation and Shinarump, Bluewater Creek, and Petrified Forest formations of the Chinle Group) strata are exposed near Bluewater Lake; thin veneers of Quaternary alluvium fill valleys draining into the lake (Fig. 2.25; Smith, 1954; Hackman and Olson, 1977; Anonymous, 1983).

There is no stratigraphic evidence of a former natural lake in Las Tuces Valley; instead, it contains a thin veneer of Quaternary alluvium and finer-grained valley-fill deposits formed by ancient rivers or streams. This alluvium fills the bottom of the canyons and arroyos draining into the lake and lines some of its shores. Most of this alluvium consists of sand, silt, and clay derived from erosion of the surrounding ouctrops of the Bluewater Creek and Petrified Forest formations.

The Bluewater fault zone strikes north-south and locally separates Bluewater Creek and Petrified Forest beds from older San Andres beds. The Bluewater fault has a down-to-the-west stratigraphic throw of 100–400 ft (Smith, 1954). The dam is built along the west-facing fault-line scarp. The lake conceals portions of the en echelon fault pattern (Smith, 1954).

106.4 Roadcuts in sandstone of Painted Desert Member, possibly of the Perea Bed, on the left. **0.6**

107.0 Mount Taylor at 10:30; East Grants Ridge at 11:00; Horace Mesa at 11:00 to 12:00; and Haystack Mountain (or Butte) at 10:30. We will end day 3 near the base of Haystack Mountain at El Tintero volcano (visible as low rise capped with a small scoria cone at 11:30).

Mount Taylor forms the skyline behind El Tintero (Fig. 2.26).The right peak is Mount Taylor Peak. From the summit most of the central western part of New Mexico may be seen. The left peak is La Mosca Peak, a thick mass of latite (trachyandesite) lava that probably originated in a vent now truncated by the erosional amphitheater occupying the summit. The saddle between the two peaks is the western rim of this summit amphitheater. The profile from this angle and from the south near El Malpais is that of a mature composite volcano, a fact that did not escape Dutton (1885), who noted "…its volcanic nature is betrayed in every line and feature…"

The celebrated writer Mary Austin, in The Land of Journeys' Ending (1924), wrote this about Mount Taylor:

"Most sacred is the bulk of Tsotsil, blue as a summer rainstorm, where it watches, from its high and level plateau,

FIGURE 2.26. Mount Taylor.

the black caterpillar trains of the Santa Fé crawl across the cindery plain between the Río Grande and the Río Puerco. This is a rim-rock mesa, red sandstone, topping the softer stuff and weathering in huge blocks like a ruined wall. Like the teocalli of the Aztecs, it rises from the mesa platform, a pyramidal, solitary mass of broken cones, from whose top, streams cloud like smoke of accepted sacrifice, following the high wind river. For a whole day's travel, east and west, it dominates the landscape to the north of the railway, a semicircular volcanic mass, having a secondary cone within, one clear creek, and a giant's tongue of black lava protruded down the shallow red sandstone cañon where the railway follows the old trail past Acoma to Zuñi." **0.6**

107.6 Basalt of El Tintero volcano on both sides of road. **0.2**

107.8 Mile marker 65. Haystack Mountain at 10:00. **0.2**

108.0 Roadcuts in Sonsela Member. **0.3**

108.3 Cross wash. **0.5**

108.8 Mile marker 66. Cinder cone at 10:00 is El Tintero; Haystack Butte at 9:30. **0.8**

109.6 El Tintero (inkstand) at 9:30 is the source of the basalt flows (also known as the "Bluewater flow") that occur along the highway for the next 4 miles or so. El Tintero is a shield volcano similar to that common throughout the Southwest in which a small scoria cone is perched on the summit of a pile of lava flows. In the case of El Tintero, the regional slope away from the base of Haystack Mountain resulted in most of the flows spreading east-southeast, and south from the vent area. It is dated at between 57 ± 6 Ka (^{3}He surface dating) and 79 ka (U-series) (Laughlin et al., 1993). The younger date would imply that it is similar in age to Capulin Volcano in northeastern New Mexico, whereas the older date would imply that it is some 20,000 years older than Capulin. Judging from the overall similarity in preservation, yet drier local climate, either age is reasonable. The lava flows are tholeiites, similar in composition to the McCartys lava flow that constitutes the youngest flow within El Malpais National Monument farther east along I-40. These are the westernmost young eruptions in the Mount Taylor region. Refer to Day 3, last stop for more details. **1.1**

110.7 Lava flows of El Tintero occur along the right side of I-40. **0.7**

111.4 Pass under power line. An excellent exposure of the distal margins of the El Tintero flows is visible in the small valley on the right. Note that the valley has incised several meters subsequent to the emplacement of the flows due to constriction of the valley along the flow margin and adjacent sedimentary rock outcrops. The margin of the flow consists of a steep carapace of pahoehoe crust. Apart from loss of the glassy (tachylite) surface materials, the flow surface is eroded very little. This contrasts with the subdued appearance of the flows elsewhere, implying that mantling of fine materials blown in on top of the flow together with general accumulation of debris from the sparse vegetation account for the subdued appearance more than any actual disintegration and surface erosion. **0.4**

111.8 Cibola County line. **0.3**

112.1 Sonsela outcrops on right. **0.4**

112.5 Flats here are developed in Bluewater Creek Formation red beds. Mitchell Draw section (Fig. 2.27) to right is the easternmost Chinle outcrop in the Zuni Mountains. The red beds belong to the Bluewater Creek Formation. The substantial sandstone body in these beds is an exceptionally thick section of the McGaffey Member, as much as 60 ft thick here. The overlying Blue Mesa Member of the Petrified Forest Formation is only 63 ft thick here, about half the thickness of this unit in the western Zuni Mountains. Because underlying Bluewater Creek Formation strata have a relatively constant thickness throughout the Zuni Mountains of

about 150-180 ft, Heckert and Lucas (1996) argued that eastward thinning of the Blue Mesa Member is due to erosion at the Tr-4 unconformity, between it and the overlying Sonsela Member. **0.6**

113.1 Road cut through the basalt here reveals a soil overlying the upper vesicular zone. The upper vesicular zone of pahoehoe lava flows (Aubele et al., 1988) is characterized by a downward progression in which the average diameters of individual vesicles become larger while the number density (number per unit volume of lava) decreases. The origin of this pattern, which occurs in pahoehoe flava flows throughout the world, is a result of freezing-in of initial vesicle populations in the rapidly cooled outer portions of lava flows and continued growth and coalesence of vesicles within the flow interior. The actual volume of vesicles per unit lava flow volume decreases somewhat with depth (Cashman and Kauahikaua 1997; Crumpler et al., 1999) in accordance with ideal gas law behavior. **1.7**

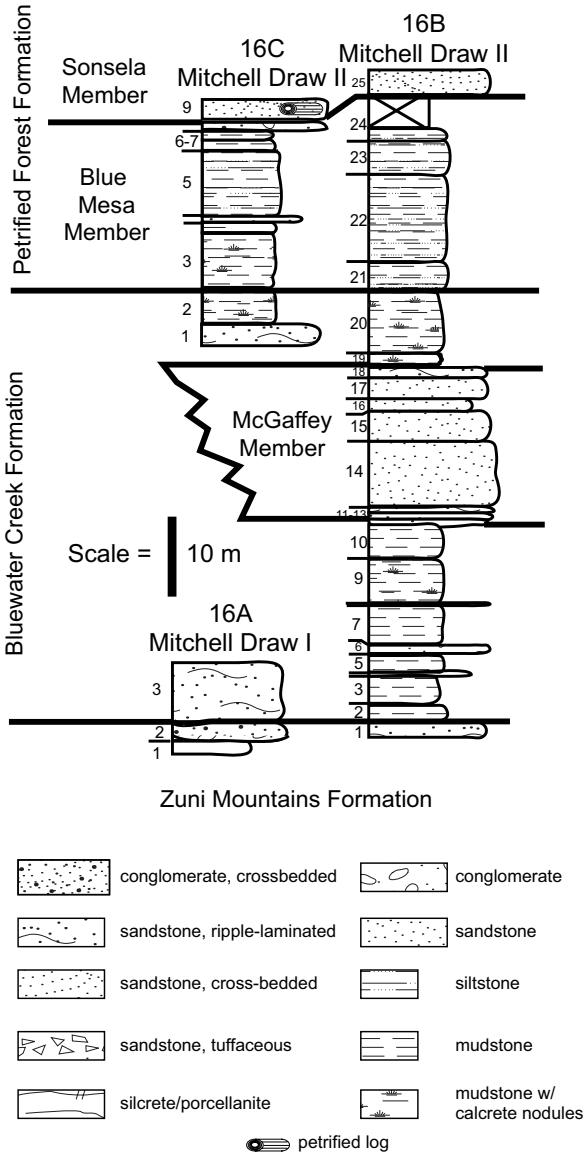

FIGURE 2.27. Mitchell Draw Chinle Group section at mile 112.5.

114.8 Exit 72 to T'iis Ntsaa Ch'éélı́, Bluewater Village (population 500 in 2000). A town near the present Bluewater grew up along the Atlantic and Pacific Railroad in 1881. Mormon settlers arrived a few years later, constructed an earthen dam at the confluence of Bluewater and Cottonwood Creeks, and by 1896 a settlement, Mormontown, had arisen about 3 mi west of the railroad town of Bluewater. The railroad town eventually died, and the farming community adopted the name. Long before the town was established, this area was known as Agua Azul (literally "Blue Water"), and it was stipulated as the southern boundary of Navajo country in the Navajo-Spanish treaty of 1819 (Julyan, 1996). The geologist James Newberry, returning from the Ives Expedition to the Colorado River in 1858, passed through the area and produced (Newberry, 1861, p. 96) a simple stratigraphic section of the units encountered from Campbell's Pass (Continental Divide) eastward to Agua Azul. He collected a few fossils from the limestones at the base of the section, which he believed to represent the "summit of the Carboniferous formation;" we now know these fossiliferous limestones are the Lower Permian San Andres Formation. **1.5**

116.3 The grassy slope on the mesa immediately in front of Mount Taylor is the west flank of a scoria cone on East Grants Ridge. This same scoria cone is naturally half-sectioned in the west side of Lobo Canyon. The high mesa in the distance at

9:30 is La Jara Mesa, the western margin of the Mount Taylor field. **0.8**

117.1 The road is now on Moenkopi Formation here, approaching the San Andres cuesta. **1.2**

118.3 Crest of hill; note Mount Taylor volcanic field to northeast. **0.4**

118.7 Begin roadcuts in Permian San Andres Formation. Note low amplitude folds in the limestone. **0.2**

118.9 Black Mesa (also known as West Grants Ridge) is at 11:00 and forms the backdrop for the towns of Milan and Grants. Its unusually symmetric map plan shape makes it a distinctive landmark from aerial and orbiting spacecraft perspectives. **0.7**

119.6 End San Andres roadcuts. Note Milan ahead with West Grants Ridge behind it. **2.1**

121.7 Exit 79 to Milan/San Mateo. Note basalt-capped West Grants Ridge (Black Mesa) to left. Milan (population 1891 by the 2000 census) developed as a result of the uranium boom of the 1950s. It is named for Salvador Milan, whose family had settled in the Gallup area in 1913 to work in the coal mines. He moved to the Grants area in 1932 and with his wife assembled large land holdings in the area. When Milan died in 1979, he had been the only mayor of the town since its incorporation in 1957 (Julyan, 1996). **2.0**

123.7 The lava flow along the margins of I-40 for the next several miles is known as either the Paxton Springs flow or the Zuni Canyon flow. The source vent is the Paxton Springs volcano, a small scoria cone located inside one of the canyons within the Precambrian crystalline terrain on the south side of the Zuni Mountains. From the Paxton Springs vent the lava flowed east to the head of Zuni Canyon, and from there northward down Zuni Canyon to emerge and spread out in the valley floor of the Rio San José. Most of the flow probably traveled within the confines of a lava tube during its traverse down Zuni Canyon. Upon emerging into the Rio San José, the flows were forced to travel in open channels and along a lower gradient. The tendency to develop a distributary lava delta at its terminus very shortly after entering the lower gradient of the Rio San José is evidence that the flow was near its maximum cooling-limited length at the time it entered the valley. Transition to aa characteristics in the valley here probably reflects the rapid emplacement. Although the Zuni Canyon flow appears to be a confused jumble of aa, from the air several distinct channels in the flow may be mapped within the terminal fan where it spread out over the valley floor. The El Calderon flow, on which the Zuni Canyon flow rests, flowed around the south side of the Zuni uplift. **0.1**

123.8 Grants city limit. **0.2**

124.0 Note aa lava to right. **0.5**

124.5 Exit 81A to San Rafael. Note Chinle outcrops to left in Grants along Santa Fe Avenue. **0.2**

124.7 Exit 81B to Grants. The highway now crosses part of the El Malpais lava field. Diné people called this flow Yé'iitsoh bídił, Giant's Blood (Young and Morgan, 1987). **0.5**

125.2 Note Jurassic-Cretaceous strata at 12:30-2:30 in distance. East Grants Ridge is at 9:00. The contrast between the white pumice of the East Grants Ridge rhyolite and the overlying dark cinder and basalt of the East Grants Ridge half-sectioned scoria cone is prominent in the distance. Mount Taylor is visible at 9:30 above Horace Mesa (9:00-11:00). **0.9**

126.1 End of Zuni Canyon lava flow. **0.7**

126.8 Impounded drainage on right. **0.2**

127.0 The El Calderon lava flow occurs adjacent to I-40 for the next several miles until the junction of I-40 and NM-117. **0.6**

127.6 **Exit 85** to Grants/Mt. Taylor; take this exit to leave I-40 and go to old 66. The Dinosaur Museum visible to the right is defunct. 0.4

128.0 Stop sign; **turn left. 0.2**

128.1 Cross bridge over I-40. **0.5**

128.6 Traffic light at intersection with Naomi Road. Continue straight. **0.1**

128.7 **Turn left** into parking lot of Best Western Inn and Suites. The town of Grants (population 8806 by the 2000 census) began as a settlement along the Atlantic and Pacific Railroad in 1881, where three brothers named Grant established a construction camp. Earlier, prior to the Civil War, Antonio Chavez had settled in the area, and it was homesteaded in 1872 by Don Jesus Blea. The settlement named Grant (the name was changed to Grants in 1935, to reflect local usage) grew slowly, as a station, depot, and coaling station on the railroad. During this time it was overshadowed by the prosperous town of San Rafael, 5 mi to the south, an agricultural and livestock community that had formed shortly after Ft. Wingate was dismantled and moved west to its present location just east of Gallup. In the 1920s, an entrepreneur named George E. Breece shifted his lumbering operations from the western side of the Zuni Mountains, where 25 years of lumbering had depleted the resource, to the untapped forest areas south of Grants, and on the west side of Grants built company housing and a railroad roundhouse to serve his spur lines into the southern Zunis. The town got water and electricity in 1929, but the timber and livestock industries were hit hard by the Depression of the 1930s. By 1941, when Grants incorporated, residents numbered about 1000. Oil from the Hospah field to the west was piped to a refinery near Grants in the early 1940s, and the Army Air Force from Kirtland Base in Albuquerque used the malpais nearby as a bombing range during World War II. Large-scale farming in the Grants area began in the 1940s, with carrots as the main cash crop, but that industry crashed in the 1950s under competition from cheaper California produce. When Paddy Martinez discovered uranium west of town in 1950, Grants boomed, its population increasing from about 2250 to more than 10,000 from 1950 to 1960 with the opening of several large mines. The influx of people, and the substantial distance of Grants from the Valencia County seat in Los Lunas, led to the creation of Cibola County from western Valencia County in 1981. Since then the fortunes of the town have waxed and waned with the level of uranium mining. The closing of the large mines in the 1980s had an adverse impact on Grants' economy, and the town has more aggressively promoted the tourist industry in recent years (Chilton et al., 1984; Julyan, 1996; Mangum, 1997).

End of second-day road log.