First-day road log, from Clayton to Seneca, Moses, Mexhoma, Kenton, Wedding Cake Butte, Travesser Park, Clayton Lake and back to Clayton

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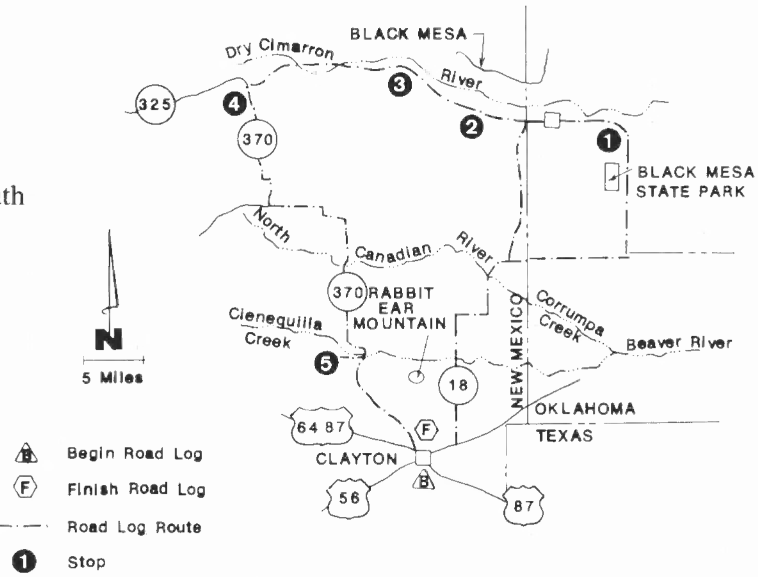
FIRST-DAY ROAD LOG, FROM CLAYTON TO SENECA, MOSES, MEXHOMA, KENTON, WEDDING CAKE BUTTE, TRAVESSER PARK, CLAYTON LAKE AND BACK TO CLAYTON

SPENCER G. LUCAS, ADRIAN P. HUNT, BARRY S. KUES and JOHN HOLBROOK

THURSDAY, SEPTEMBER 24, 1987

Assembly point: Intersection of Locust Street and South First Street, Clayton, New Mexico.
Departure time: 7:45 a.m.
Distance: 140.6 miles
Stops: 5



SUMMARY

Today's tour of the Dry Cimarron Valley of northeastern New Mexico and northwestern Oklahoma emphasizes (1) Mesozoic stratigraphy and paleontology, (2) Middle Jurassic tectonism and (3) the little-known Black Mesa Mining District.

We first proceed north and east from Clayton across the High Plains. North of Wheeless, Oklahoma we descend into the Dry Cimarron Valley to examine Lower Cretaceous strata and fossils of the Glencairn Formation. From here, we continue west through outcrops of the Morrison Formation which have produced an abundance of dinosaur fossils from several quarries in Cimarron County, Oklahoma. In the New Mexico portion of the Dry Cimarron Valley, the bedrock is largely Upper Triassic. At Stop 2 we examine a clastic plug in these strata, and the San Miguel Mine developed to extract copper from this plug. The third stop, near Wedding Cake Butte, reveals a dramatic angular unconformity between the Upper Triassic Travesser and Sloan Canyon formations and the overlying Middle Jurassic Entrada Sandstone. The tectonism responsible for this angularity and the stratigraphy of the Entrada Sandstone are the focus of discussion here. Proceeding west, to Travesser Park, we stop to examine stromatolitic bioherms in the Morrison Formation. This unique occurrence is one of several lines of evidence of a large, shallow lake extending from northeastern New Mexico into Colorado during the Late Jurassic. From Travesser Park southward, we climb the High Plains surface again, and proceed to Clayton Lake. Here, at the final stop, we examine the more than 500 dinosaur footprints in the dam spillway. These footprints, in the uppermost Mesa Rica Sandstone and overlying Pajarito Formation, are of late Albian age. Today's road log continues to Clayton, but we end here at Clayton Lake for tonight's barbecue. The historical information in this and the other road logs was derived from Miller (1952), Pearce (1965), Union County Historical Society (1980), Chilton et al. (1985) and Young (1986).

Mileage

0.0 **Turn right** at intersection of Locust Street and South First Street (US Highway 87) **and proceed N** on US-87. **0.5**

0.5 **Stop light;** junction of US Highway 87/NM Highway 18 and US Highway 56/64. **Turn right** onto Main Street **and proceed E** on US 56/64. **0.6**

1.1 **Junction** with NM Highway 538 (to S); **continue E** on US 56/84. **0.2**

1.3 Clayton historical marker on left. Clayton, the seat of Union County, was founded in 1887 and named for Clayton C. Dorsey, son of the owner of the Stephen Dorsey Ranch. **0.3**

1.6 At 9:00 Clayton basalts in the Apache Valley are visible. Beyond, at 8:30, is Rabbit Ear Mountain. **0.1**

1.7 Descend hill into valley of a tributary of Apache Creek. **0.6**

2.3 Highway crosses tributary of Apache Creek. In creekbed to right the Ogallala Formation is exposed. **1.0**

3.3 Rest stop to left with historical marker for Clayton Lake State Park which is about 8 mi NW of here. At 7:00, Rabbit Ear Mountain is visible on the skyline. **0.3**

3.6 Historical marker for Rabbit Ear Mountain to left. Rabbit Ear Mountain was named for a Comanche chief called Rabbit Ears (Orejas de Conejo) because his ears had been frozen. He was killed in battle and buried on the mountainside. **0.2**

3.8 **Junction** with NM Highway 18; **turn left and proceed N** on NM-18. **0.2**

THE VEGETATION OF NORTHEASTERN NEW MEXICO

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Prior to the mid-nineteenth century, northeastern New Mexico was biologically unknown. It was a strange land of panoramic savannah, formidable mountains and spreading grassland. In June of 1846, Dr. Aldolphus Wislizenus on a U.S. government expedition pushed his way across what is now Oklahoma and Kansas, and entered northeastern New Mexico. He was astounded by the diversity of the vegetation, and made voluminous collections of specimens. His route took him from the headwaters of the Canadian River across Ocate Creek to Wagon Mound through Mora, Las Vegas and on to Santa Fe. Virtually everything he collected was new to science. This included the now familiar species of piñon pine and hedgehog cactus. It was this expedition and the one that followed that provided us with rudimentary information on the vegetation of northeastern New Mexico. Now, 140 years later, we have a much clearer understanding of the origins, relationships and composition of the vegetation of that region. We know that the flora is the product of two great vegetation influences, namely the Rocky Mountains and the Great Plains. This Rocky Mountain influence is clearly demonstrated in the hills and mountains of western Colfax and Mora Counties, whereas the influence of short grass prairie and high plains is evident in Union and Harding Counties.

Although botanical knowledge in New Mexico has grown immeasurably since the early explorers, the definition and delineation of plant associations is still a topic of disagreement among botanists. This is particularly a problem in northeastern New Mexico where the Great Plains and Rocky Mountain megafloras meet. The attached vegetation map of northeastern New Mexico (Fig. 1.1) brings together current data on the region and projects distribution of plant groups to series-level accuracy. The data for this map have been compiled from four sources: the New Mexico Department of Natural Resources botanical

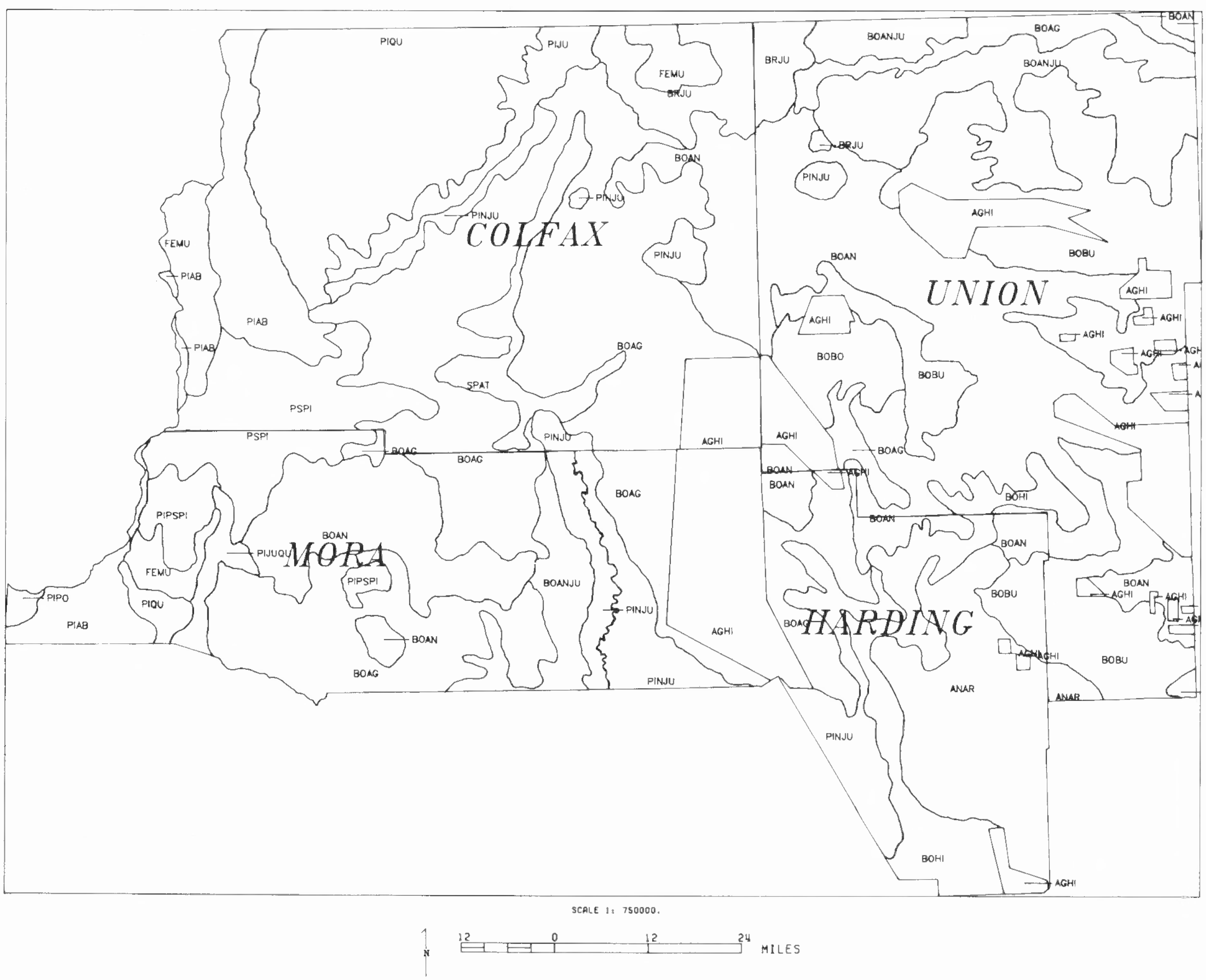

FIGURE 1.1. Vegetation map of northeastern New Mexico.

staff field-studies, the SCS map of potential vegetation of New Mexico (Donart et al., 1978), Dr. Sandy Dick-Peddie (Dick-Peddie, in press) and the Technology Application Center (Morain et al., 1977). The classification scheme used in this treatment is based on the Brown et al. (1979) system. It has been modified to include the shift in biomes encountered in New Mexico. The classification of vegetative types of northeastern New Mexico (Fig. 1.1) is as follows: **AGHI** – agriculture—human impact (man-made feature); **ANAR** – *Andropogon scoparius, A. hallii,* and *Artemisia filifolia;* little bluestem and sand bluestem grasses codominant with sand sage, along with dropseed grasses, sideoats and blue grama grasses, yucca, and other species (association level); **BOAG** – *Bouteloua gracilis* and *Agropyron smithii;* blue grama grass with western wheatgrass; associated species include bottlebrush squirreltail, threeawn, ring muhly, winterfat and fringed sage (association level); **BOAN** – *Bouteloua* spp. and *Andropogon scoparius;* dominated by various species of grama grass (especially sideoats grama) and little bluestem with some western wheatgrass, galleta grass and buffalo grass (association level); **BOANJU** – *Bouteloua curtipendula, Andropogon scoparius* and *Juniperus* spp.; dominated by sideoats grama grass and little bluestem grass, with scattered juniper. Also present are blue grama grass, black grama, New Mexico feathergrass, sand dropseed, yucca and broom snakeweed (association level); **BOBO** – *Bouteloua curtipendula* and *B. gracilis;* codominant species are sideoats grama and blue grama grasses, with sand dropseed, New Mexico feathergrass, little bluestem and scattered shrubs and juniper (association level); **BOBU** – *Bouteloua gracilis* and *Buchloe dactyloides;* dominated by blue grama with buffalo grass, galleta grass, sand dropseed and threeawn grasses; broom snakeweed and cactus species are locally abundant (association level); **BOHI** – *Bouteloua gracilis* and *Hilaria jamesii;* dominated by blue grama grass and galleta grass (association level); **BRJU** – brush and *Juniperus* spp.; bushy species are found in codominance with juniper species (series level); **FEMU** – *Festuca arizonica* and *Muhlenbergia montana;* subdominants are Arizona fescue and mountain muhly (association level); **JUPI** – *Juniperus monosperma* and *Pinus edulis;* oneseed juniper and piñon pine, with galleta grass, Indian ricegrass and grama grasses (series level); **PIAB** – *Picea engelmannii* and *Abies* spp.; Englemann spruce and fir (association level); **PIJU** – *Pinus ponderosa* and *Juniperus scopulorum;* ponderosa pine dominates and rocky mountain juniper is a subdominant; oak species, skunkbush, mountain mahogany, blue grama grass, spike muhly and needlegrass may occur (association level); **PINUQU** – *Pinus edulis, Juniperus monosperma* and *Quercus gambellii;* dominated by piñon pine with juniper a secondary dominant; gambel oak is common throughout (association level); **PINJU** – *Pinus edulis* and *Juniperus monosperma;* piñon pine and oneseed juniper with little appreciable woody understory, may include ponderosa pine at higher elevations (series level); **PIPO** – *Pinus ponderosa;* dominated by ponderosa pine with some Douglas fir and piñon pine; grassy understory includes Arizona fescue and mountain muhly (association level); **PIPSPI** – *Pinus ponderosa, Pseudotsuga menziesii* and *Pinus edulis;* ponderosa pine with some Douglas fir and piñon pine; the understory often includes mountain mahogany, serviceberry, bottlebrush, mountain muhly and Arizona fescue (association level); **PIQU** – *Pinus ponderosa* and *Quercus gambellii;* dominated by ponderosa pine with the subdominant gambel oak; other oak species and mountain mahogany are also common (association level); **PSPI** – *Pseudotsuga menziesii* and *Picea engelmannii;* Douglas fir and Engelmann spruce (association level); **SPAT** – *Sporobolus airoides* and *Atriplex* spp.; alkali sacaton and saltbush species with occurrences of western wheatgrass, blue grama and rabbitbrush (series level).

4.0 At 10:00 Rabbit Ear Mountain is visible with Clayton basalts in the Apache Valley in front of it (Fig. 1.2). **0.6**
4.6 Cross creek; prairie to right is part of the Kiowa National Grasslands. To left is a large, odoriferous feed lot. **0.3**
4.9 Entrance to New Mexico Cattle Inc. feed lot on left. **0.1**
5.0 Rabbit Ear Mountain and good view of basalt-capped cuestas on N side of Apache Valley at 10:00. **1.1**
6.1 Narrow bridge over Apache Creek. **0.7**

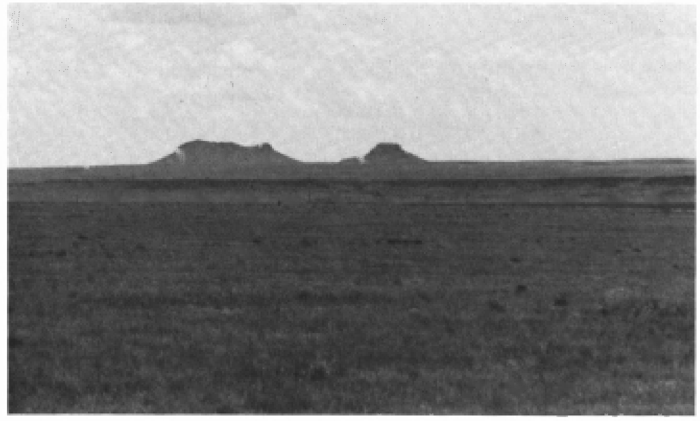

FIGURE 1.2. Rabbit Ear Mountain from mile 4.0.

6.8 Paved roads to right; continue N on NM-18. **0.4**
7.2 Deflation playa at 2:00. **0.4**
7.6 Gravel pit to left. **0.1**
7.7 Cross Goodin Draw. **1.0**
8.7 Entrance to Clayton Cattle Feeders feed lot on left. **0.5**
9.2 Highway crests hill revealing Ogallala Formation overlain by Clayton basalts. The highway is now on the basalt-covered surface. **0.5**
9.7 Clayton basalts in roadcuts as we descend into the valley of Seneca Creek. Clayton basalts of the Seneca flow define the southern edge of Seneca Creek to the left. The highway has just entered the Seneca 1:24,000 quadrangle map (Fig. 1.3). As is true of most of the southern High Plains of northeastern New Mexico, the dominant exposed bedrock is either the upper Cenozoic Ogallala Formation or basalts of late Cenozoic age. Only in deep canyons and river valleys are older, Mesozoic, strata generally exposed. Here, these older strata are confined to the Graneros Shale and Dakota Group. The Ogallala and Dakota are the principal aquifers in this area (Fig. 1.4). **1.0**
10.7 Ogallala calcrete on right of highway. **0.7**
11.4 Bridge over Seneca (Cieneguilla) Creek; at 8:00–9:00 Rabbit Ear Mountain is visible about 6 mi in the distance. The highway now ascends a terrace. **2.6**
14.0 Tiny, blue-green building on right is Seneca post office. **0.7**
14.7 Enter Seneca, a scattering of mostly abandoned houses. Before the 1930's, the Seneca school district served about 200 children. **0.2**
14.9 Abandoned Seneca school on right (Fig. 1.5). **0.9**
15.8 Highway makes **sharp right turn** to parallel Gyp Arroyo. **1.8**
17.6 At 9:00 the gravel pit at the crest of the hill is in the Ogallala Formation. **0.4**
18.0 Another gravel pit in the Ogallala at 1:00. **0.5**
18.5 Highway makes **sharp left turn. 1.5**
20.0 Corrumpa Creek visible in distance at 1:00. **0.1**
20.1 For the next 0.5 mi note Ogallala Formation overlain by stabilized dune sands on both sides of the highway. Just west of the highway is the Seneca northeast section of Leonard and Frye (1978) (Fig. 1.6). Here, a prolific fossil flora was collected in the lower part of clay-mineral zone II of the Ogallala Formation. The flora includes seven taxa, two grasses (*Stipidium grande* and *Berrioch-*

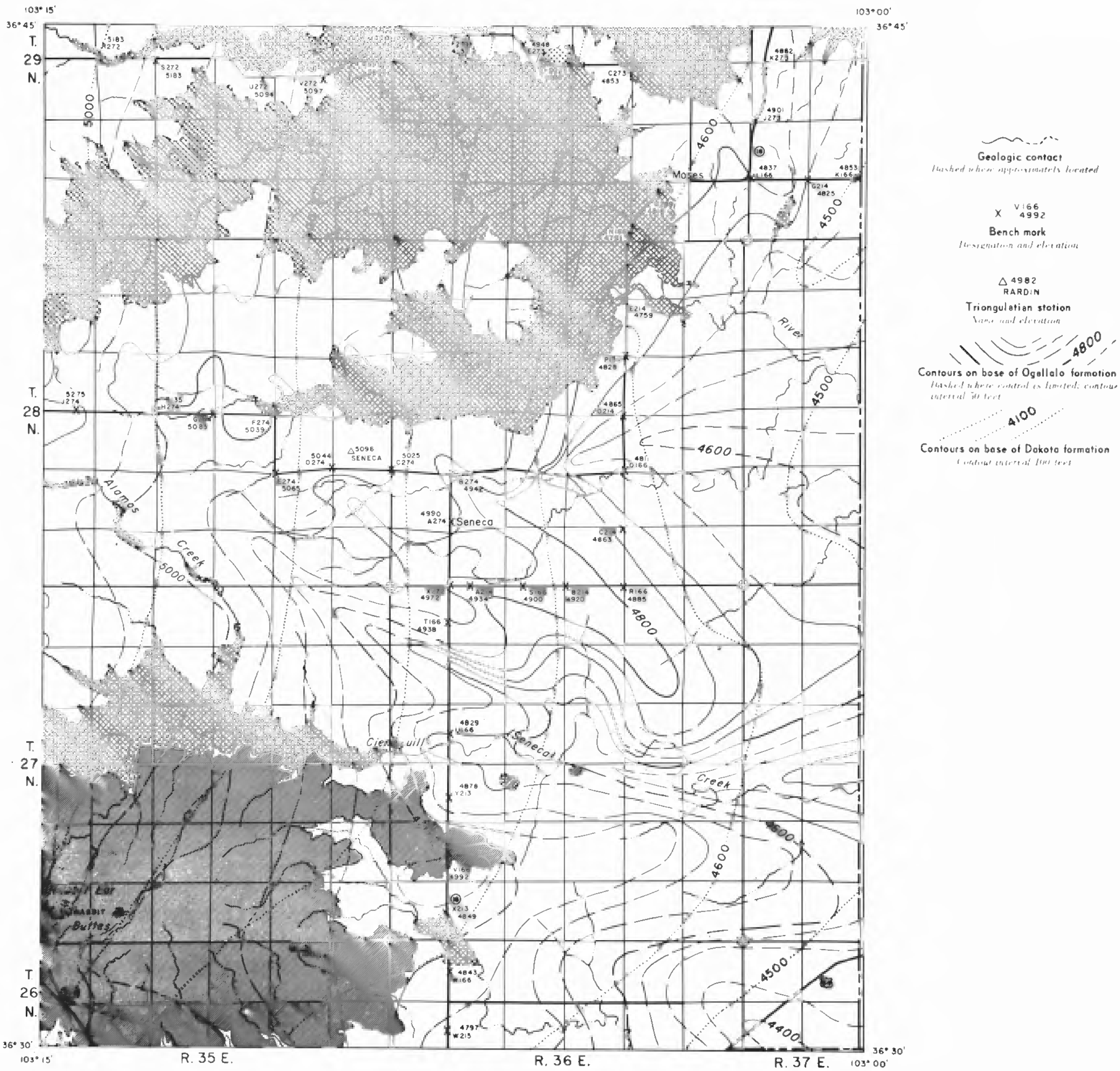

FIGURE 1.3. Geological map of the Seneca quadrangle (from Baldwin and Bushman, 1957). The heavy pattern indicates Clayton basalts; blank area is the Ogallala Formation and overlying alluvium; the cross-hatched pattern is Cretaceous bedrock (Graneros Shale, Dakota Group).

loa amphoralis), two borages (*Biorbia microendocarpica* and *B. papillosa*) and three hackberries (*Celtis hatcheri, C. willistoni* and *C.* cf. *C. reticulata*). According to Leonard and Frye (1978), this flora pertains to the Ash Hollow flora zone of the Ogallala Formation, of late Miocene age. **1.0**

21.1 Good outcrops of Ogallala Formation in roadcuts, next 0.2 mi. **0.8**

21.9 Outcrops at 1:30 in Corrumpa Creek are stream alluvium. An inconspicuous wire gate on the right opens to a ranch road leading 0.5 mi to the windmill visible in the distance, near the creek. This was McNees Crossing, where the Santa Fe Trail crossed Corrumpa Creek. Both upstream and downstream the creekbed is loose sand, but here a rock ledge (Romeroville Sandstone) in the creek provided firm footing for wagons. In 1828 a young trader named McNees and a partner rode ahead of their caravan and stopped to take a nap at this crossing. Indians stole their guns and then shot them dead. A small monument erected in 1921 near the windmill commemorates the first Independence Day celebration in New Mexico which took place here on 4 July 1831. **0.7**

22.6 Roadcut as we descend into Corrumpa Creek reveals bioturbated sandstones and gray-blue siltstones of the Pajarito Formation (Fig. 1.7A). **0.2**

22.8 Bridge over Corrumpa Creek. To left, up the creek, are heavily bioturbated sandstones of the Romeroville Sandstone (Fig. 1.7B). Cretaceous strata in northeastern New

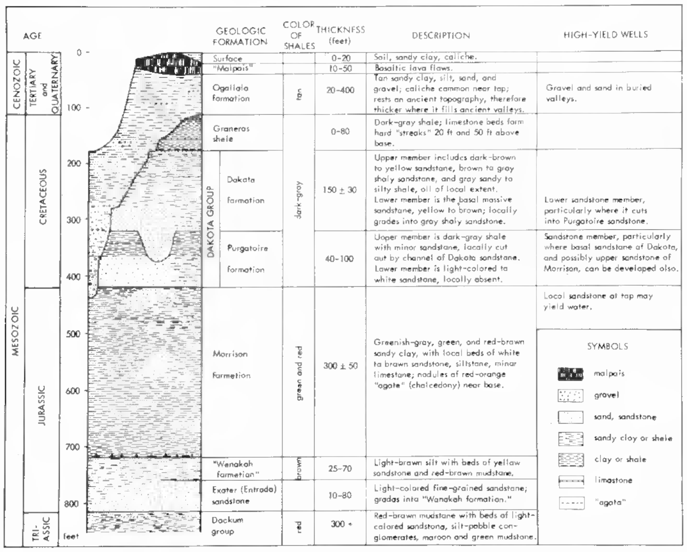

FIGURE 1.4. Stratigraphy and aquifers in the Clayton area (from Baldwin and Bushman, 1957). Note that the "traditional" stratigraphic nomenclature employed here differs somewhat from that advocated in today's road log.

FIGURE 1.5. Abandoned Seneca school.

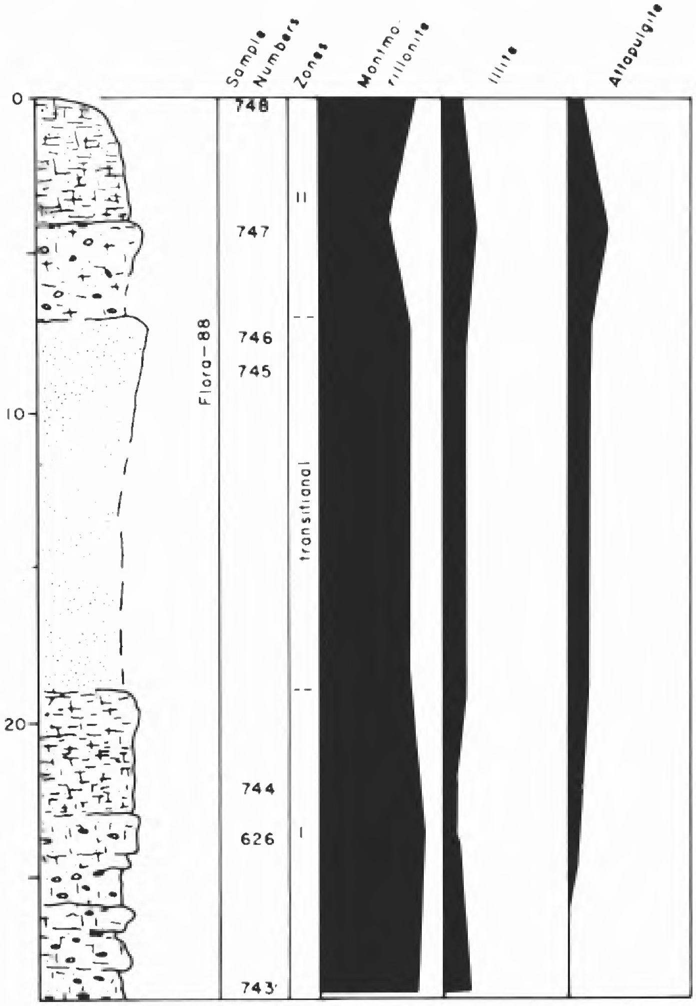

FIGURE 1.6. The Ogallala Formation at the Seneca northeast section (SE1/4 NE1/4, sec. 15, T28N, R36E, Union County) of Leonard and Frye (1978). Numbers on left indicate ft below top of Ogallala exposure.

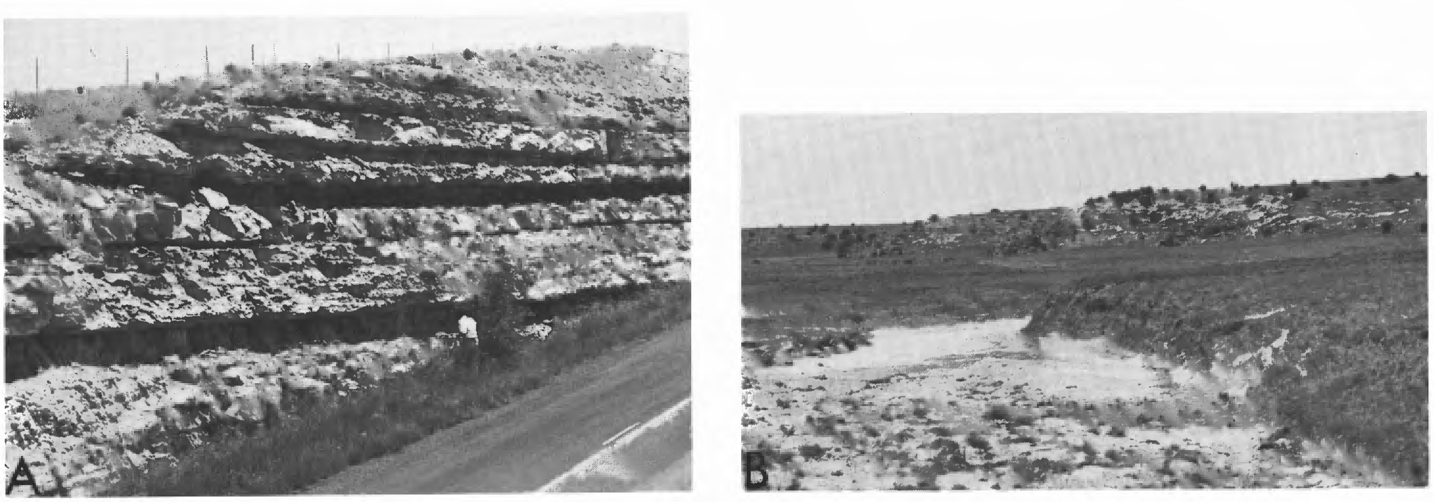

FIGURE 1.7. Cretaceous strata exposed at Corrumpa Creek crossing, miles 22.6–22.8. A, Interbedded sandstones and siltstones of the Pajarito Formation on east side of NM Highway 18. B, View looking W up Corrumpa Creek of Romeroville Sandstone.

Mexico previously referred to as Dakota Formation (Baldwin and Muehlberger, 1959) here are termed Dakota Group consisting of three formations (Lucas et al., 1986; Kues and Lucas, 1987). The lowermost, Mesa Rica Sandstone, is generally grayish orange and dark yellowish orange, well indurated, crossbedded quartzarenite that averages about 30 ft in thickness. The overlying Pajarito Formation is as much as 30(?) ft of interbedded light gray siltstone and laminar-to-bioturbated, yellowish gray/yellowish orange quartzarenite. The Romeroville Sandstone is as much as 20 m of orange-to-brown, bioturbated to crossbedded quartzarenite. The tripartite nature of the Dakota Group (Fig. 1.8) of northeastern New Mexico has been noticed by most previous workers, and extension of the stratigraphic nomenclature used in east-central New Mexico (San Miguel, Guadalupe, Quay and southern Harding Counties) for this interval into Union County is well justified (Kues and Lucas, 1987). **0.5**

23.3 Romeroville Sandstone caps hill to left of highway. **0.2**

23.5 Entering Moses. Sheepranchers and homesteaders settled this area shortly after the turn of the century, and the village of Moses grew up to serve them. A post office was established in 1909 (lasting to 1955) and by 1910 there were about 450 people in the Moses area. Most of them moved away during the 1930's, and Moses returned to rural tranquility. The highway is on soil-covered and vegetated Graneros Shale. **0.2**

23.7 Leave Moses. **1.3**

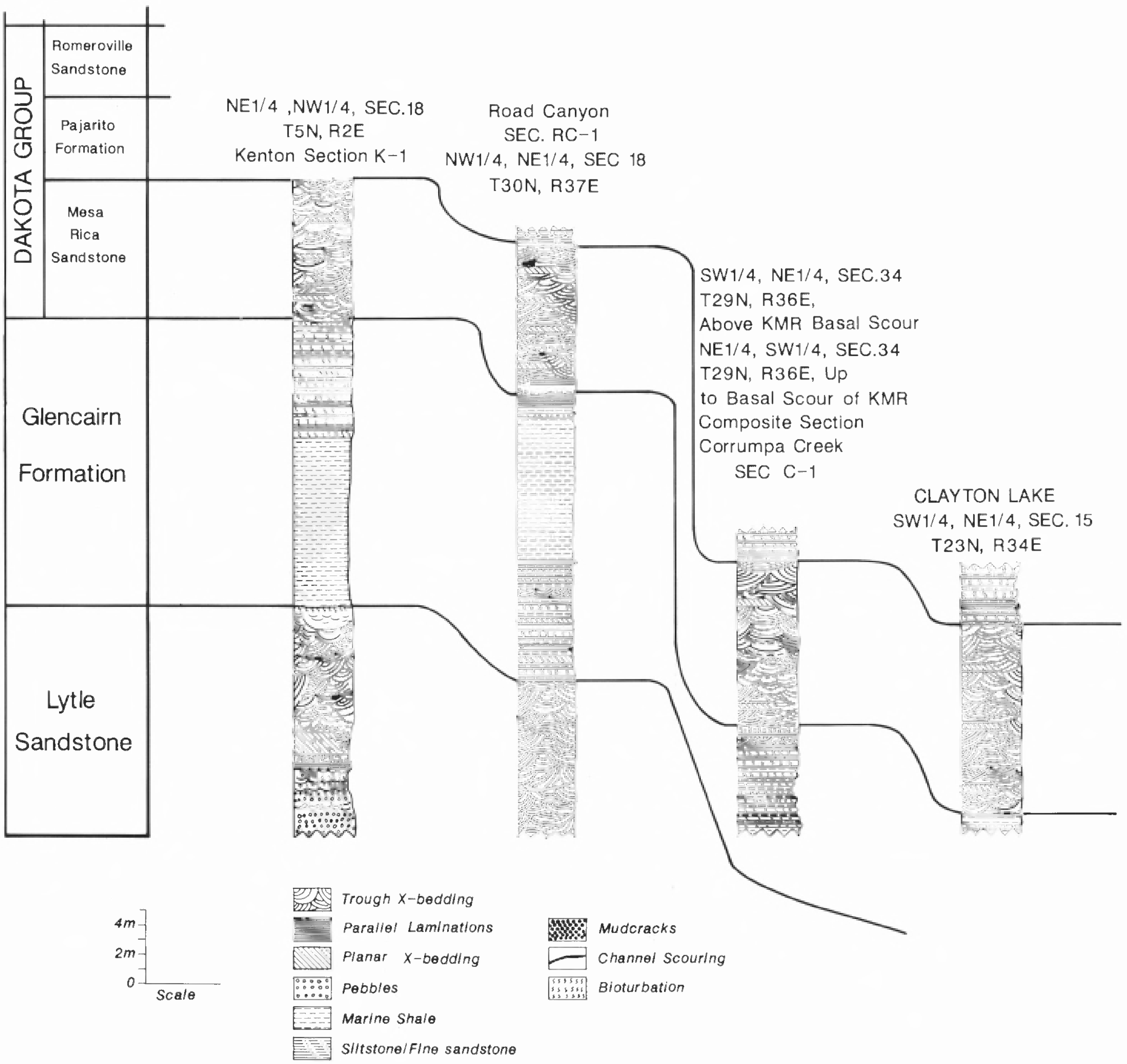

FIGURE 1.8. Cretaceous stratigraphic sections in southern Union County (measured by John Holbrook) and the Dakota Group terminology used in this road log.

A BRIEF HISTORY OF THE SANTA FE TRAIL AND EARLY GEOLOGICAL STUDIES ALONG THE CIMARRON CUTOFF IN NEW MEXICO

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For nearly 60 years the Santa Fe Trail was the main avenue of commerce between the settled midwestern part of the U.S. and New Mexico. Beginning originally in Franklin, Missouri (and later in Independence and Kansas City, and then Fort Leavenworth, Kansas) the trail headed southwest across Kansas and divided into two branches near Cimarron, in western Kansas. The Mountain Branch followed the Arkansas River west to Bent's Fort (near La Junta, Colorado), and then turned south, crossing Raton Pass and passing through Cimarron, Watrous and Las Vegas before entering Santa Fe. The Cimarron Cutoff branch struck southwest through southwestern Kansas, the Oklahoma Panhandle and northeastern New Mexico, joining the Mountain Branch at Watrous. Because the Cimarron Cutoff passed through the heart of the area we are examining on this field conference, and several of the geological features we will see were important landmarks for travelers, a brief historical summary of the Santa Fe Trail is presented here. For more detailed descriptions of trail history and what remains today of the trail, the interested reader is directed to James (1966) and Simmons (1984) and references therein. To understand and appreciate the panorama of life on the trail in the 1830's and 1840's there is no better source than Gregg (1844). The history of Fort Union, which was the prime stimulus to trade on the trail in the 1850's and 1860's, was well documented by Utley (1962).

Trade on what was to become the Santa Fe Trail began in 1821. Captain William Becknell and four companions started westward from Missouri with the intention of trading with Indians, fell in with some Mexican rangers, and eventually sold their small inventory of goods in Santa Fe at a very handsome profit. Mexico had just become independent of Spain; previously New Mexicans were forced to obtain all of their supplies from old Mexico at exhorbitant prices. Now New Mexican authorities encouraged trade with Americans, and word spread quickly after Becknell's successful expedition. New Mexicans could obtain goods more cheaply and in much greater variety from the Americans, while the Americans could make excellent profits (paid in gold from the Ortiz Mountains, silver from Chihuahua, livestock, furs and wool), even with the rigors and dangers of a 40- to 60-day journey and sizeable duties paid to New Mexican customs officials. According to Gregg (1844), the average profit made by traders each trip was between 20 to 40%. Some made even more, while others lost not only their inventories but their lives as well.

Trade on the trail expanded tenfold from 1822 to 1828. Originally only pack mules were used, and early traders crossed the plains in small groups, with each man carrying only about 200 to 300 dollars worth of goods. Wagons were soon introduced, however, and within a few years large caravans transporting tens of thousands of dollars worth of merchandise were the rule. Oxen became the draft animal of choice, as they were found to be hardier and easier to handle than mules, and were not as likely to be stolen by Indians. Sporadic problems with Indians did little to slow the increase in trade, and eventually military escorts were provided to some caravans as far as western Kansas, the limit of American territory. By the 1840's large investors were subsidizing trading expeditions; two hundred or more wagons would make the journey to Santa Fe in a year, carrying upwards of half a million dollars worth of goods. Many traders stopped at Santa Fe and then continued south to Chihuahua.

The first attempt to find a shorter, more direct route to Santa Fe than that taken by the Mountain Branch was made by Becknell. With nearly 30 men and $5,000 worth of goods his party crossed the Arkansas River near the present Cimarron, Kansas, and headed toward the Dry Cimarron in June 1822. They ran out of water and nearly perished of thirst, but managed to shoot a buffalo that had just filled its stomach with water, and survived by drinking its contents. The party then retreated to the Arkansas River and continued west over the known route. Later travelers located several springs, and the route quickly became the first segment of the Cimarron Cutoff trail, but never lost its reputation as a waterless wasteland. Today, this part of Kansas is covered with farms supported by deep-well irrigation.

The Cimarron Cutoff offered less water and greater Indian dangers than the Mountain Branch, but cut more than 100 mi from the total distance of the Santa Fe Trail, and there were no mountains to cross. It quickly became the most popular route for travelers. Upon entering Oklahoma, the Cimarron Cutoff passed near Wolf Mountain, north of Boise City, angled southwest, crossing the present highway between Mexhoma and Wheeless, and hitting Corrumpa Creek in New Mexico just south of Moses, at McNees Crossing. It then progressed to a point about 3 mi north of modern Clayton Lake, coming into sight of Rabbit Ear Mountain, and followed the north side of Seneca Creek to Mt. Clayton (called Round Mound by travelers). From there the Cimarron Cutoff headed west to Point-of-Rocks (near Chico), crossed the Canadian River at Taylor Springs (8 mi east of Springer) and passed Wagon Mound before linking up with the Mountain Branch at Watrous (La Junta) for the remainder of the journey to Santa Fe.

This international phase of the Santa Fe Trail's history ended in 1846, when Stephen W. Kearny and his Army of the West marched the entire length of the Mountain Branch to Santa Fe during the opening of the Mexican War, and added New Mexico to the possessions of the United States. Under American administration, military expeditions, exploring and surveying parties, government officials, gold-seekers en route to California, missionaries and others increased the diversity of traffic on both branches of the trail. Fort Union, near the intersection of the Mountain and Cimarron branches north of Watrous, became an important Army supply center and the base from which Indian campaigns were launched in the 1850's and 1860's. The volume of freight carried on the trail, mostly destined for the Army now, rose far beyond levels attained during the Mexican period. During some years in the 1850's as much as $5 million worth of supplies, amounting to 10,000 tons, were carried to New Mexico in as many as 1,800 wagons.

During this period the first observations on the geology of the Cimarron Cutoff in northeastern New Mexico and western Oklahoma were made. Adolph Wislizenus (1848) described a few features of the geology along the trail, recognizing basalt and Cretaceous sandstones at several places in the Seneca Creek-Mt. Clayton-Wagonmound area (see Kues, 1985, for more detail on Wislizenus' geological observations). In the late 1850's, John Strong Newberry traversed the Cimarron Cutoff from the west, following the disbandment of the Ives Expedition in 1858, and from the east the following year, en route to join the Macomb Expedition forming in Santa Fe. In two reports Newberry (1861, 1876) described in a fair amount of detail the geology of the Santa Fe Trail from the Canadian River crossing northeastward into the Dry Cimarron Valley and beyond.

Newberry observed the volcanic rocks of the Rabbit Ear Mountain and Mt. Clayton areas, attributing these isolated volcanic mountains to minor vents "where a portion of the molten matter contained in some vast subterranean reservoir found exit" (Newberry, 1876, p. 31). He noted that some of the basalts represented portions of an extensive volcanic flood that had become separated by subsequent erosion. Newberry came close to recognizing that the basalt flows in the Raton area marked earlier eruptions than those of the Clayton area, observing that the Raton basalts extensively covered high mesas that had since been subjected to a considerable amount of downcutting. The Raton area, he said (Newberry, 1861, p. 107), seemed to form a "great volcanic focus," and the Raton volcanoes "had innumerable subordinate vents scattered over all the adjacent region, from which the flow of lava was, in part, subsequent to the erosion of the beds of many of the present streams, for . . . the melted lava, obeying the laws that govern the flow of water, has followed the lines of drainage, and dispossessed some of these streams from their beds." Subsequent study, many decades later (Baldwin and Muehlberger, 1959, p. 70), has proven the correctness of these observations for the extensive Clayton basalt flows in Union County.

Newberry also correctly observed that in many places the basaltic lavas had flowed over Cretaceous sandstones, causing local metamorphism. He wrote at length on Tertiary sediments in this region, described as "white, tuffaceous limestone" that he believed once covered a vast area but now were limited to isolated patches over the divides between streams, and attributed these rocks to deposition in freshwater basins. He perceptively noted (Newberry, 1876, p. 25) that these Tertiary units (now known as the Ogallala Formation, of Mio-Pliocene age) were laid down "at some time subsequent to the period of greatest volcanic activity, and yet apparently before the fires of this great furnace were entirely extinguished." We now know that the older Raton basalts have an age of about 7.2 m.y. (Stormer, 1972a, b), and thus preceded deposition of much of the Ogallala, which continued in northeastern New Mexico until about 4 to 5 million years ago (Hawley, 1984). Eruption of the younger Raton, and all of the Clayton basalts, on the other hand, occurred after the cessation of Ogallala deposition. Newberry's brief survey of northeastern New Mexico geology from the Santa Fe Trail had led him to an accurate generalization about the temporal relationships between the Tertiary volcanics and sediments that cover so much of this area.

Newberry did not have the opportunity to examine in detail the Cretaceous stratigraphy and paleontology he encountered along the trail, but he did provide brief stratigraphic sections and made collections of fossils at several points between the crossing of the Canadian River near Springer and the Dry Cimarron Valley in western Oklahoma. At the crossing of the Canadian he made a collection of invertebrates and fish teeth and measured a stratigraphic section. Hook and Cobban (1980) located and restudied this important locality, which includes the uppermost Graneros, Greenhorn, Carlile and basal Niobrara formations, and found Newberry's observations to be accurate. They concluded (p. 45) that "it is obvious that Newberry's pioneering observations are of more than mere historical interest; they form an important and integral part of the biostratigraphic literature on the Cretaceous of the Western Interior."

Farther to the northeast Newberry (1876, p. 32) reported the presence of a large number of fossil-plant leaves in the Cretaceous sandstones (most likely the Dakota Group) near Whetstone Creek. This locality is apparently about 20 mi west of Mt. Clayton, on a tributary of Ute Creek south of Laughlin Peak, but I have not been able to determine its exact position. Here he described the leaf-containing sandstone beds as having been split by a remarkable fissure 4.5 ft wide that was devoid of basalt but had blackened, glazed and blistered sides, indicating that great heat, but no lava had issued from the fissure. To my knowledge this locality has never been subsequently examined. In a posthumous publication, Newberry (1898) described five species of fossil plants from this locality: *Abietites cretacea, Myrica? trifoliata, Salix foliosa, S. flexuosa* and *Sequoia gracillina* (the first three being new species). Newberry had a good eye for fossil plants; he also reported trunks and leaves in the Dakota near Rabbit Ear Mountain and leaves at Enchanted and Cedar Springs, in the Dry Cimarron area. Collection and study of the fossil leaves at these localities would be worthwhile, as little information is presently available about Dakota floras in northeastern New Mexico.

Newberry's observations on the topography of the Dry Cimarron and neighboring areas are best stated in his own words (Newberry, 1876, p. 30):

> The . . . Cretaceous sandstones form a line of bold bluffs, which border the excavated valley of the Cimarron. From this point up to the base of the mountains the surface has nothing of the monotony of the plains below, but is greatly varied, and the scenery is frequently impressive, occasionally grand. With the exception, however, of the volcanic outlayers [*sic*] of the Raton Mountains, there are few evidences of the action of violent disturbing causes, and the variety which the scenery presents is due almost entirely to the erosion of nearby horizontal strata by the drainage from the Rocky Mountains. Here the traveler, journeying to New Mexico, obtains his first view of the peculiar and impressive scenery so characteristic of nearly all portions of the great central plateau of the continent. Here he first hears the word *mesa,* and sees it embodied in the long lines of table-lands which fill the horizon and stretch away in perspective, like the walls of Cyclopean cities. . . . [T]here can be no question [that the mesas and canons] are to be regarded simply as phenomena of surface erosion, of which they are the grandest examples known.

Newberry's geological observations showed an excellent understanding of the large-scale processes that operated across northeastern New Mexico and an accurate, though necessarily general appreciation of their temporal relationships. No further study of this area was accomplished until after the beginning of the 20th century, when U.S. Geological Survey parties began reconnaissance surveys (e.g., Lee, 1902; Stanton, 1905).

The Santa Fe Trail carried the heaviest traffic of its history during the 1860's. New Mexico was the major western theater of the Civil War and experienced a Confederate invasion in 1862 that occupied Albuquerque and Santa Fe before being turned back at Glorieta Pass by soldiers from Fort Union and reinforcements from Colorado. Immediately afterward, campaigns were launched against the Mescalero Apache (1862) and Navajo (1863–1864) tribes. On the plains to the east the Kiowas and Comanches became increasingly troublesome and posed a continuous threat to travelers on the Santa Fe Trail. In 1864 and 1865 detachments of troops from Fort Union established strategic camps on both branches of the trail and for a time provided escort services to supply caravans. A campaign in 1868 finally broke the resistance of the plains Indians.

This activity resulted in Fort Union being almost entirely rebuilt and expanded during the 1860's. It remained the Army supply depot for all of New Mexico, incorporating a sprawling quartermaster depot with large warehouses and elaborate repair and maintenance facilities. The bulk of goods (food, clothing, arms and ammunition, building supplies and tools) used and disbursed at Fort Union came in over the Santa Fe Trail. At Fort Union wagons were unloaded, and the freight was repacked and assigned as needed to other forts across the territory.

The Army did little of its own freighting, but rather contracted with various companies to haul the goods needed from the East. Large companies grew up to supply the Army's needs. Their wagon caravans would leave Fort Leavenworth, Kansas, in the spring, arrive at Fort Union in the summer and return in the fall. A typical caravan consisted of about 25 wagons, each carrying three to three and a half tons of merchandise. The wagons were drawn mainly by oxen, usually four to a wagon but sometimes eight, with the four extra oxen being left at Fort Union to furnish meat for the soldiers.

Large-scale freighting along the Santa Fe Trail began to decline in 1866, when the railroad began building west through Kansas. Each advance of the rails shortened the length of the trail. By 1879 the railroad pushed south from Colorado along the Mountain Branch across Raton Pass to Las Vegas, leaving only 65 mi of the original route. In February 1880, the rails reached Lamy, and newspapers in Santa Fe announced in headlines that "The Santa Fe Trail passes into oblivion." Rail lines were later built along the Cimarron branch of the trail into Cimarron County, Oklahoma. With freight into New Mexico now carried by trains along the Mountain Branch, wagon traffic on the Cimarron Cutoff ceased. This great highway of commerce gradually faded into the landscape and today is almost gone. Faint traces of wagon tracks are still visible in a few places, reminding us of a part of New Mexican and American history that vanished more than a century ago.

25.0 **Intersection** with paved highway. **Turn right** to proceed E to Mexhoma and Wheeless, Oklahoma. To the north (left) of the road the Santa Fe Trail is represented by a wide swale in the fenced pasture. In late summer, because the trail collects extra moisture, it is marked by a profuse growth of bright green rabbit weed (Simmons, 1984). NM-18 N to its junction with NM-325 in the Dry Cimarron Valley is logged in Supplemental Road Log 1. **0.8**

25.8 Road crosses Plunket Draw; Ogallala Formation exposed on both sides of highway. **1.1**

26.9 Highway bends sharply to left; house on right; sign says

"Wheeless 7 miles." Enter **Cimarron County, Oklahoma.** **0.4**

27.3 Highway bends sharply to right; at 12:00, Black Mesa is visible on the skyline. **2.0**

29.3 Enter **Mexhoma,** populated now by two families; church and road to cemetery on left. This area is irrigated farm and ranch land. **0.5**

29.8 Leave greater Mexhoma. **1.3**

31.1 Small playa on right. **2.1**

33.2 **Wheeless,** center of town with a defunct white-brick store, service station, church and cemetery. **4.9**

38.1 **Intersection** with unpaved road. House on right ("Kenneth L. Evans" on mailbox); telephone lines to E parallel N-S unpaved road. **Turn left** and proceed N on unpaved road. **1.0**

39.1 Yield sign on right at intersection; continue N. **0.3**

39.4 **Stop sign** at intersection with pavement; **bear left** onto paved highway and proceed N. **1.7**

41.1 Cattleguard; enter area of open range. **0.6**

41.7 Cross bridge over Cold Springs Creek. Ogallala Formation on both sides of highway. **0.7**

42.4 Cross bridge over north fork of Cold Springs Creek. **0.4**

42.8 Marker for Santa Fe Trail on left and Fort Nichols (Fig. 1.9). The Santa Fe Trail crossed the road here, heading southwest to Fort Nichols and to McNees Crossing in New Mexico. Fort Nichols, 7 mi to the SW, was founded by Kit Carson in May 1865 to guard this section of the trail from hostile Indians. The fort was about 200 ft^2 and built of stone, but was abandoned late in 1865, a few months after construction had begun. **0.3**

43.1 Cattleguard. **0.2**

43.3 Crest of hill. Signs to left mark road to Lake Carl Etling (Black Mesa State Park) (see Supplemental Road Log 2). Continue ahead to the N. **0.2**

43.5 From 10:00–11:30, the Dry Cimarron Valley is visible in the distance. This valley was carved by the Cimarron River, but the prefix "Dry" is usually used to differentiate it from the Cimarron River Valley near Cimarron, Colfax County, New Mexico. Also, the sinking and later rising of the Cimarron River in this area lead some early residents to believe the Cimarron is a "disappearing river" (Pearce, 1965). **0.6**

44.1 Highway begins descent through Ogallala Formation. **0.6**

44.7 Cross tributary of Cottonwood Canyon. **0.3**

45.0 Cattleguard. **0.8**

45.8 Cross tributary of Cottonwood Canyon. **0.4**

46.2 Note Mesa Rica Sandstone at 10:00 on W flank of Cottonwood Canyon. **2.4**

48.6 Cattleguard. **0.4**

49.0 Crest of hill; Black Mesa in distance at 11:00–12:00. Bluffs in foreground are Mesa Rica Sandstone exposures in Cottonwood Canyon. **0.3**

49.3 Good view of Mesa Rica Sandstone on both sides of road. **0.3**

49.6 **STOP 1.** Heavily crossbedded sandstones to right are Mesa Rica Sandstone. Below them, the slope is Glencairn Formation which contains a *Texigryphaea* horizon about halfway up the hill (Fig. 1.10). The oldest Cretaceous strata exposed in the Dry Cimarron Valley pertain to the Lytle Sandstone (also called Lytle Sandstone Member of the Purgatoire Formation, but see Kues and Lucas, 1987). This unit represents fluvial deposition during the late Albian by a river system that flowed dominantly E-NE (Long, 1966). Application of the Kansas name Cheyenne Sandstone to this unit in Cimarron County, Oklahoma by Stovall (1943) is demonstrably incorrect. The Cheyenne, a unit remarkably similar in lithology to the Lytle, is only present in south-central Kansas and pinches out to the west (Latta, 1946, 1948; Franks, 1975; Ward, 1986).

Above the Lytle, the Glencairn Formation (also called Glencairn Shale Member of the Purgatoire Formation, but see Kues and Lucas, 1987) represents late Albian marine deposition during the Skull Creek-Kiowa cyclothem. The base of the Glencairn generally is a thin (as much as 10 ft), bioturbated, fossiliferous sandstone (Long Canyon Sandstone Bed of Kues and Lucas, 1987) that represents the transgression of the Early Cretaceous seaway. Above this sandstone are interbedded marine shale, sandstone and siltstone that contain one or more fossiliferous horizons dominated by shells of the gryphaeid bivalve *Texigryphaea* (Fig. 1.11). At some localities the uppermost Glencairn is estuarine siltstones and sandstones that contain terrestrial plant fossils and apparently represent the initial regressive phase of the Glencairn seaway. The fluvio-deltaic Mesa Rica Sandstone overlies the Glencairn. As Scott (1970) noted, the

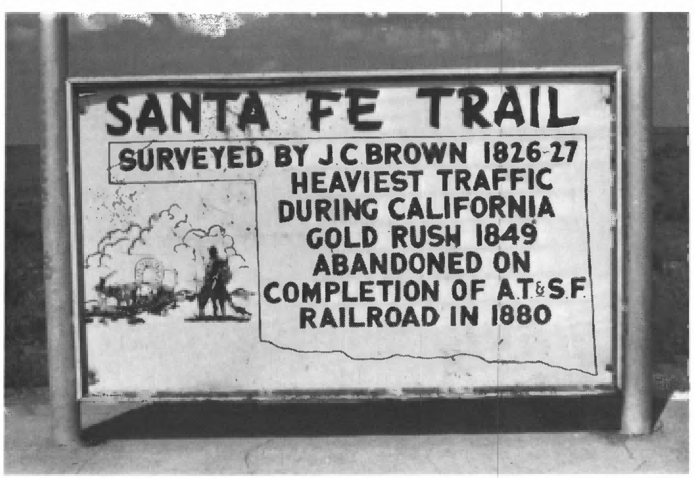

FIGURE 1.9. Marker for Santa Fe Trail at mile 42.8.

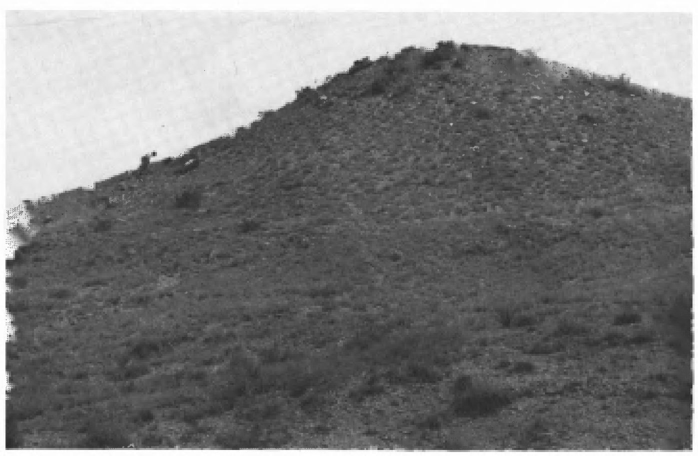

FIGURE 1.10. The Glencairn Formation at Stop 1. The man is standing at the level of *Texigryphaea* concentration.

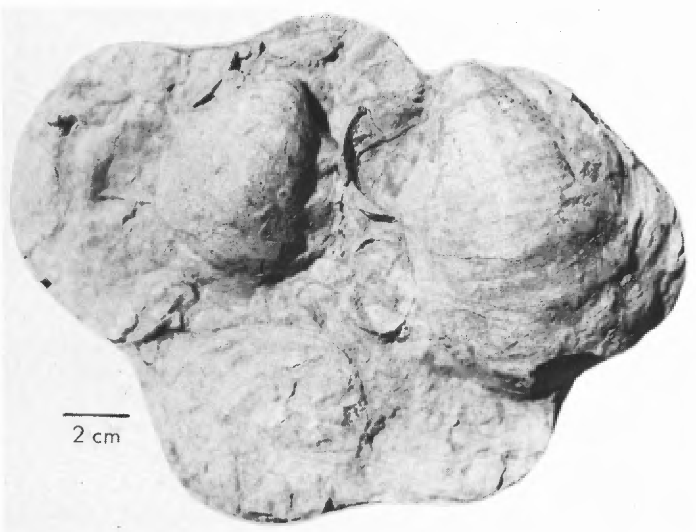

FIGURE 1.11. *Texigryphaea* shells from the Glencairn Formation in the Dry Cimarron Valley.

term Glencairn is best used in Cimarron County, Oklahoma to distinguish these relatively sandy strata from the lithologically distinct Kiowa Shale of Kansas (Stovall [1943] used the term Kiowa Shale here). **After the stop, continue N. 0.1**

49.7 Sandstone to right is Lytle Sandstone. **1.0**

50.7 **Road forks** and an unpaved road heads NE; **stay on pavement to the left. 0.1**

50.8 To the right is Stovall's (1938) dinosaur-bone quarry 1 in the Morrison Formation marked with a plaster cast of a sauropod femur (Fig. 1.12). This quarry is one of several excavated during the 1930's and 1940's with funding from the Federal Works Projects Administration. The dinosaurs collected from these quarries include the typical Late Jurassic taxa *Stegosaurus, Allosaurus, Camarasaurus* and *Diplodocus* (see Hunt and Lucas, 1987). Cross cattleguard a little beyond the quarry. **0.1**

50.9 Cross bridge over Cottonwood Canyon. Bluffs that surround the canyon are capped by Mesa Rica Sandstone overlying vegetated slopes of the Glencairn Formation. **0.4**

51.3 Mesa ahead is capped with Mesa Rica Sandstone above covered Glencairn slope; basal sandstone is Lytle. **0.2**

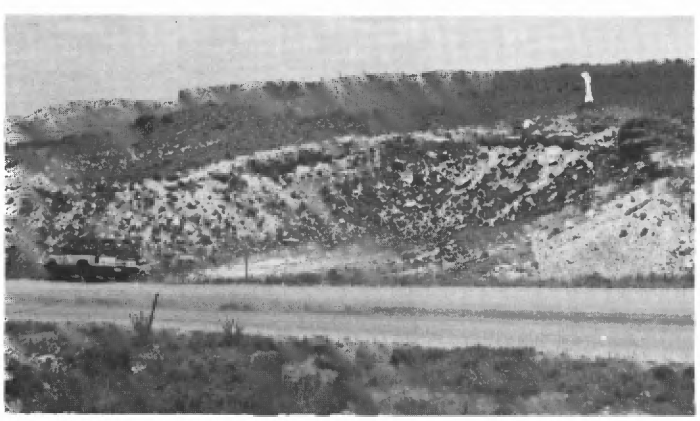

FIGURE 1.12. Stovall's (1938) dinosaur-bone quarry 1 in the Morrison Formation marked by a plaster cast of a sauropod femur.

51.5 Cattleguard. **0.1**

51.6 White sandstone to right for next 0.1 mi is the Lytle Sandstone. Above that, is a partly covered slope of the Glencairn Formation beneath the bluff-forming Mesa Rica Sandstone. Just above the barbed-wire fence is a major *Texigryphaea* horizon in the Glencairn Formation at the same stratigraphic level as the horizon we examined at Stop 1. For the next 2.5 mi the highway winds through exposures of the Glencairn and Mesa Rica. The earliest comprehensive study of the geology of this part of Cimarron County, Oklahoma was Rothrock (1925). Rothrock, however, made a grave stratigraphic error that was soon corrected by DeFord (1927). Thus, below Rothrock's (1925) Dakota (Mesa Rica Sandstone), he termed the strata Purgatoire until reaching variegated "shales" that were identified as Morrison (Fig. 1.13). As DeFord (1927) noted, these "shales" are Upper Triassic strata (Sloan Canyon Formation of Parker, 1933),

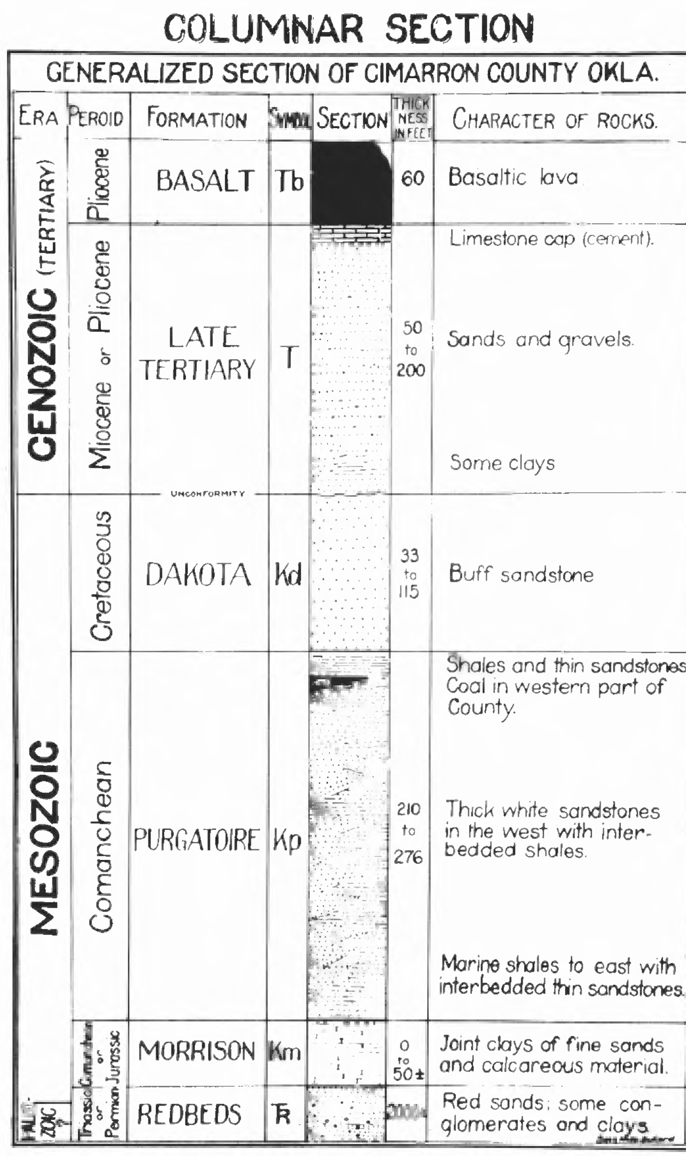

FIGURE 1.13. Columnar section of rocks exposed in Cimarron County, Oklahoma (from Rothrock, 1925). Note that strata identified as "Morrison" actually are Upper Triassic Sloan Canyon Formation, and that the "Purgatoire" includes the Entrada, Morrison, Lytle and Glencairn formations.

and thus Rothrock's (1925) "Purgatoire" includes strata now assigned to the Entrada, Morrison, Lytle and Glencairn formations. **0.3**

51.9 Note natural window in Mesa Rica Sandstone at 3:00 (Fig. 1.14). This feature is known locally as the "old maid" or "old woman's head." **0.1**

52.0 The Mesa Rica Sandstone is now just above road level. **0.1**

52.1 Gray siltstones and sandstones at crest of hill to left for next 0.2 mi are Pajarito Formation. **0.5**

52.6 Note Mesa Rica Sandstone capping ridges at 3:00. **0.2**

52.8 Pajarito Formation on left of highway, eroded into small isolated pinnacles locally. **1.1**

53.9 Unpaved road to left goes to Black Mesa State Park (this is the endpoint of Supplemental Road Log 2). Proceed straight (W) across the cattleguard and begin descent of 101 Hill. Sandstone from 10:00–4:00 capping the hill is heavily crossbedded Mesa Rica Sandstone. **0.1**

54.0 Highway passes through fossiliferous shale and sandstone of Glencairn Formation. Shells of *Texigryphaea tucumcarii* are abundant in the roadcuts. Note sandy, upper part of Glencairn and overlying cliff-forming Mesa Rica Sandstone to right, high above road level. **0.1**

54.1 White sandstone with intercalated gray and green siltstone on right is Lytle Sandstone. This is one of the best places in this area to examine the lithology and stratigraphy of the Lytle, Glencairn and Mesa Rica formations. In fact, Kues and Lucas (1987) designated this outcrop a reference section for the Lytle and Glencairn formations in the Dry Cimarron Valley. **0.7**

54.8 Bridge over Tesesquite Creek (a bastardization of "tequesquite," a Mexicanism for "alkali?"). **0.4**

55.2 Gray and white sandstone on right is Morrison Formation. The Dry Cimarron Valley here is floored by Morrison sandstone and claystone. **0.3**

55.5 Morrison sandstone on left of highway. **0.5**

56.0 Another Morrison sandstone on right of highway. **0.1**

56.1 At 10:00, green claystone of the Morrison underlies a white sandstone bluff of Lytle. Above the Lytle, mostly covered Glencairn Formation leads up to the Mesa Rica Sandstone which caps the ridge. **0.6**

56.7 Unpaved road to right bears sign for "Easter Pageant." The Kenton Easter pageants began in 1952. Each Easter weekend, local residents act out the crucifixion and resurrection of Jesus, based on scripts written by local church people (Young, 1986). Continue W on paved highway. **0.1**

FIGURE 1.14. Natural window in Mesa Rica Sandstone at mile 51.9. This feature is known locally at the "old maid" or "old woman's head."

56.8 Green claystones of the Morrison are overlain by Lytle Sandstone to right. **0.1**

56.9 Highway intersects base of Glencairn Formation. On the hill to left are good exposures of the Glencairn. **1.0**

57.9 Paved highway to right goes to Labrier Butte (see Supplemental Road Log 3). Caves in this area have produced Pleistocene vertebrate and invertebrate fossils, especially of mammoths, and younger archaeological material (Fig. 1.15). Some of these fossils are on display at the Kenton store just ahead. **0.4**

58.3 Enter **Kenton,** Oklahoma (population 50). The Kenton area was settled by ranchers in the 1870's; before that the only inhabitants were outlaws operating from "Robber's Roost" (near Black Mesa, to the north), who preyed upon freight caravans traveling the Santa Fe Trail. The town of Kenton was established in 1890, and grew with the arrival of homesteaders and a brief attempt to mine copper nearby (Fay, 1983). After Cimarron County was formed in 1907, Kenton served briefly as the county seat before it was moved to Boise City. By 1910 Kenton numbered about 250 inhabitants and had a bank, newspaper and numerous commercial establishments, but has declined since then to the quiet village we see today. As we now drive up the Dry Cimarron Valley from Kenton to Wedding Cake Butte in Union County, New Mexico,

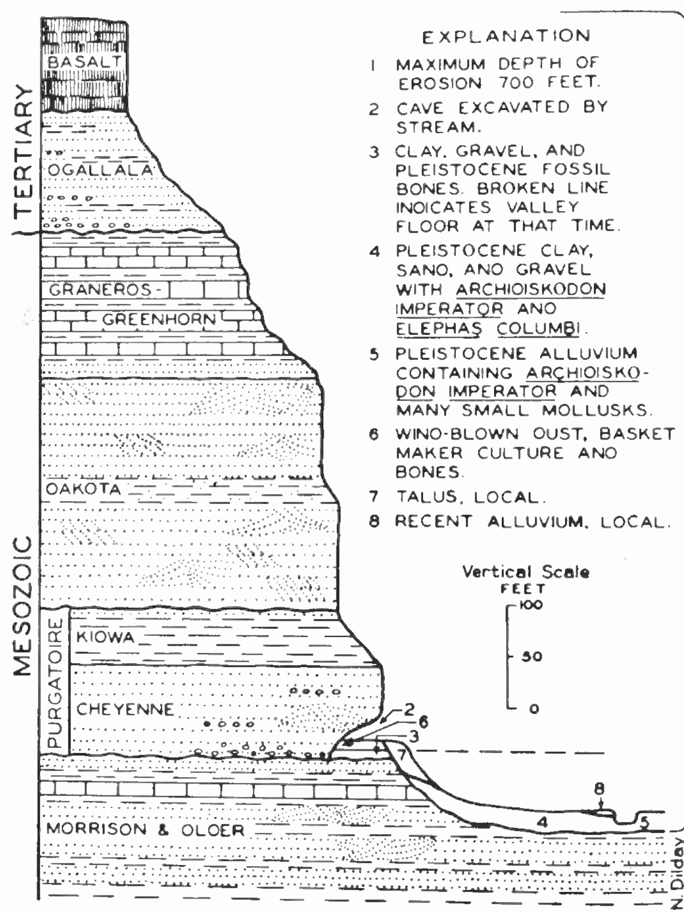

FIGURE 1.15. Sketch indicating the presumed amount of erosion in the Dry Cimarron Valley prior to Pleistocene time (from Stovall and Schoff, 1943). Note the occurrences of mammoth fossils (*"Archidiskodon"* and *"Elephas"*) in caves.

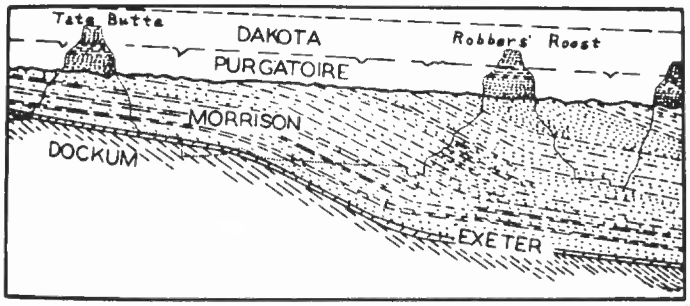

FIGURE 1.16. Restored cross section from Labrier (Tate) Butte southeastward through Robber's Roost, about 3–4 mi N of Kenton (from Stovall, 1938). Prelate Albian (before "Purgatoire" time), but post-Jurassic warping of the strata suggests a little-studied, local episode of Early Cretaceous tectonism.

we actually drive up elevation slightly (about 100 ft) but descend stratigraphically from a valley floored near Kenton by the Upper Jurassic Morrison Formation to a valley floored near Wedding Cake Butte by the Upper Triassic Travesser Formation. This occurs because of a regional dip of the strata toward the east as well as local structural features (e.g., Fig. 1.16), in particular the pre-Entrada anticline evident at Wedding Cake Butte which has at least 200 ft of structural relief (see discussion at Stop 3). **0.2**

58.5 Kenton post office on left. **0.2**

58.7 Bridge over creek. **0.1**

58.8 Road to Kenton cemetery on left. Leave Kenton. Black Mesa visible from 1:00–4:00. Black Mesa is capped by an early Raton basalt (late Miocene) that has small (1.0 mm) euhedral olivine phenocrysts (5%) (Baldwin and Muehlberger, 1959). The white sandstone at its base is the Entrada Sandstone. **0.8**

THE EXETER (ENTRADA) SANDSTONE OF CIMARRON COUNTY, OKLAHOMA AND ADJACENT PARTS OF UNION COUNTY, NEW MEXICO

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Four lithologic units differentiated by distinct assemblages of sedimentary structures characterize the Late Jurassic Exeter (Entrada) Sandstone in the Black Mesa area of northwestern Oklahoma and northeastern New Mexico (Snoparsky, 1986; Fig. 1.17, Table 1.1). All four are composed primarily of fine-grained quartzarenite (Snoparksy, 1986). Three of the units are considered lithofacies because of the complex vertical and lateral relationships among them at the outcrop. They are designated as facies 1, facies 2 and facies 3 (Fig. 1.18). Facies 1 ranges from 0 to 65 ft (0–20 m). It consists of sets of large-scale (set width or length greater than or equal to 18 ft [5.5 m]), low-angle, trough and wedge-planar cross-strata and is interpreted as an inland dune deposit. Facies 2 ranges from 0 to 29 ft (0–8.8 m) thick and consists primarily of laminated to homogeneous sandstone containing scattered, green shale-laminae. It is interpreted as a fluvial deposit. Facies 3 ranges from 0 to 20 ft (0–6.1 m) thick and consists primarily of medium-scale and large-scale high angle trough cross-stratification and is interpreted as a high-gradient, low sinuosity stream (Snoparsky, 1986). A fourth unique assemblage, unit A, truncates the cross-strata of facies 1 and 3 and consists of sandstone that shows mottled bedding and symmetrical ripples. The unit is interpreted as a shallow pond deposit (Snoparsky, 1986).

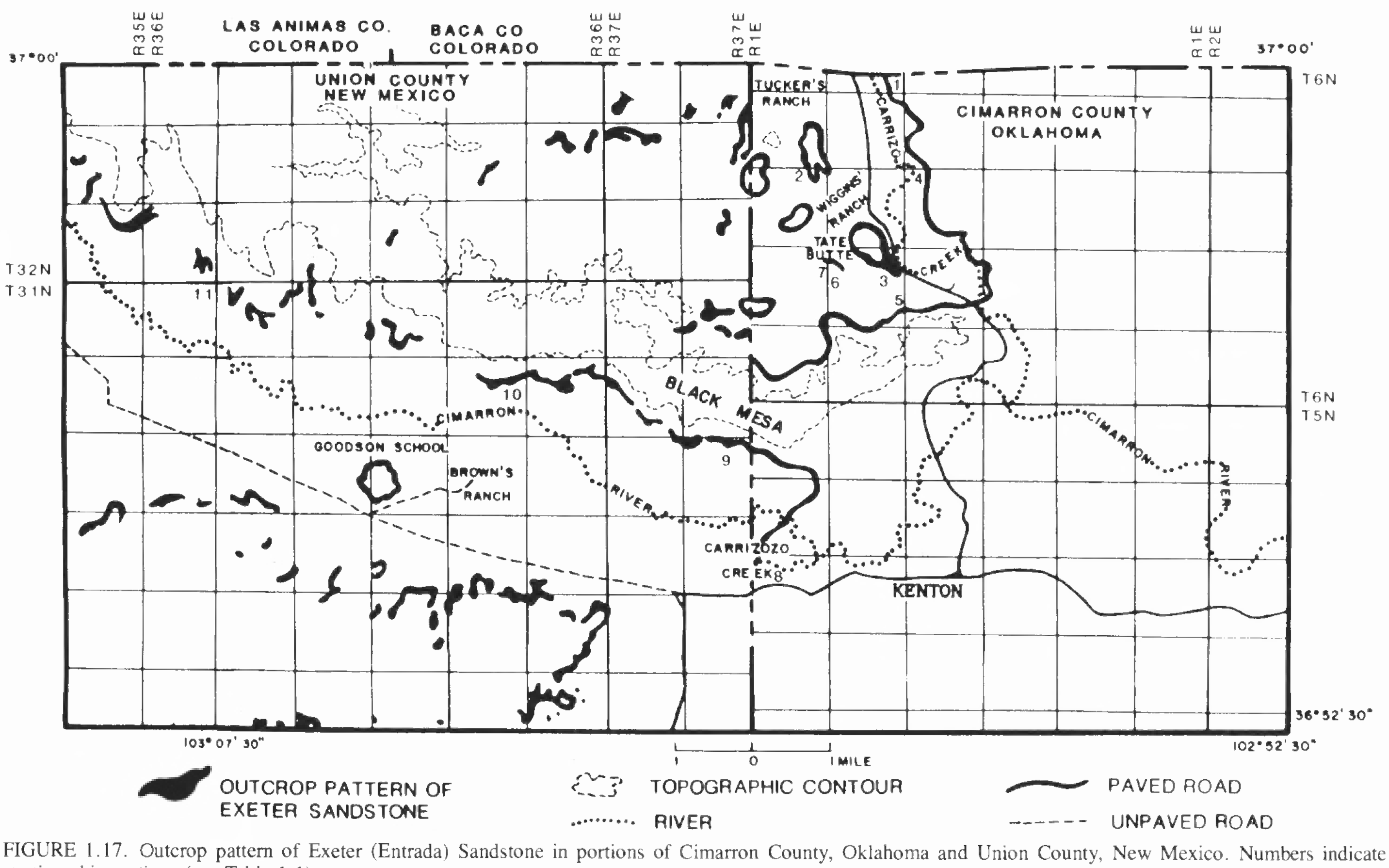

FIGURE 1.17. Outcrop pattern of Exeter (Entrada) Sandstone in portions of Cimarron County, Oklahoma and Union County, New Mexico. Numbers indicate stratigraphic sections (see Table 1.1).

The areal association of the units of the Exeter suggests an extensive inland dune system and associated extradune deposits consisting of peripheral fluvial systems with ponds (Snoparsky, 1986). This interpreted paleogeography is similar to Lupe and Ahlbrandt's (1979) eolian depositional model. Similarities in composition between all three lithofacies suggest that some of facies 1 dune-sand was reworked into the extradune deposits of facies 2 and 3, and unit A (Snoparsky, 1986). Possibilities include the underlying Dockum Group, the Pennsylvanian to Permian and Triassic sandstones of the Colorado Plateau and the ancestral Rocky Mountains (Snoparsky, 1986).

TABLE 1.1. Location of stratigraphic sections indicated in Figure 1.17 and their included facies.

Stratigraphic section	Location	Exeter unit exposed
1	Across from Tuckers, Ranch, intersection of secs. 8,9,16 & 17, T6N, R1E Cimarron County, Oklahoma	facies 1
2	Wiggins Ranch, intersection of NE 1/4, sec. 20 & NW 1/4, sec. 19, T6N, R1E, Cimarron County, Oklahoma	unit A
3	Tate Butte, NE 1/4, sec. 29 T6N, R1E, Cimarron County, Oklahoma	unit A facies 1
4	Rice's Ranch, NE 1/4, sec. 21, T6N, R1E, Cimarron County, Oklahoma	unit A facies 1
5	SE 1/4, sec. 29, T6N, R1E, Cimarron County, Oklahoma	facies 1
6	NW 1/4, sec. 29, T6N, R1E, Cimarron County, Oklahoma	facies 1
7	NE 1/4, sec. 30, T6N, R1E, Cimarron County, Oklahoma	facies 1
8	Under bridge on Carrizozo Creek at OK-NM state line, sec. 18, T5N, R1E, Cimarron County, Oklahoma	facies 3
9	NW 1/4, sec. 17, T31N, R37E, Union County, New Mexico	facies 1,2, & 3 unit A
10	NE 1/2, sec. 11, T31N, R36 E, Union County, New Mexico	facies 1 & 2
11	SE 1/4, sec. 31, T32N, R36E, Union County, New Mexico	facies 2 & 3

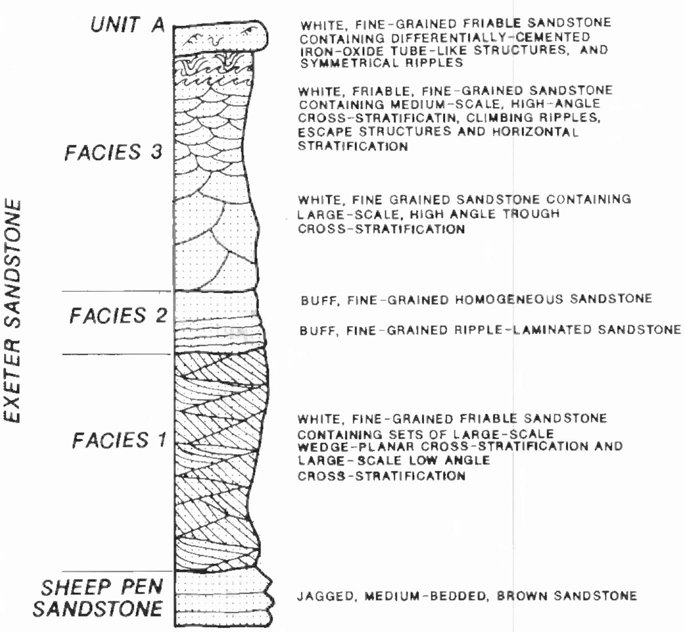

FIGURE 1.18. Schematic diagram of the Exeter (Entrada) Sandstone in Cimarron County, Oklahoma and Union County, New Mexico.

59.6 Cross creek. **0.4**

60.0 The hill at 10:00 is capped by the Mesa Rica Sandstone. Underneath, a covered slope of Glencairn Formation overlies the Lytle Sandstone which, in turn, overlies Morrison claystone (visible in the roadcuts ahead). **0.3**

60.3 Note cottonwood bosque to N of highway along the Dry Cimarron River. **0.3**

60.6 Bridge over Dry Cimarron River. **Leave Oklahoma.** The white sandstone at 8:00 in the riverbank is Entrada Sandstone overlying dark red and green siltstones of the Sloan Canyon Formation. **0.1**

60.7 **New Mexico state line. 0.9**

61.6 **Intersection** of NM-325 and NM-18. Quonset hut to right is for fire engine of local volunteer fire department. **Continue W** on NM-325. The sandstone pillar at 10:00 is a clastic plug in the Upper Triassic Sheep Pen Sandstone. Triassic strata in the Dry Cimarron Valley are discussed at length by Lucas et al. (1987) in this guidebook. In brief, the Triassic section consists of: (1) Baldy Hill Formation, at least 113 ft of yellowish orange and reddish brown, bioturbated, quartzose sandstone and siltstone capped by as much as 9 ft of lithic- and limestone-cobble conglomerate termed the Cobert Canyon Sandstone Bed; (2) Travesser Formation, as much as 512 ft of reddish brown, laminar and ripple-laminar, quartzose sandstone, siltstone and minor lithic conglomerate; (3) Sloan Canyon Formation, as much as 137 ft of yellowish green and greenish gray siltstone, sandstone and limestone; and (4) Sheep Pen Sandstone, as much as 100 ft of yellowish orange, laminar quartzose sandstone (Fig. 1.19). The clastic plugs developed in the Sheep Pen will be discussed at Stop 2. **0.1**

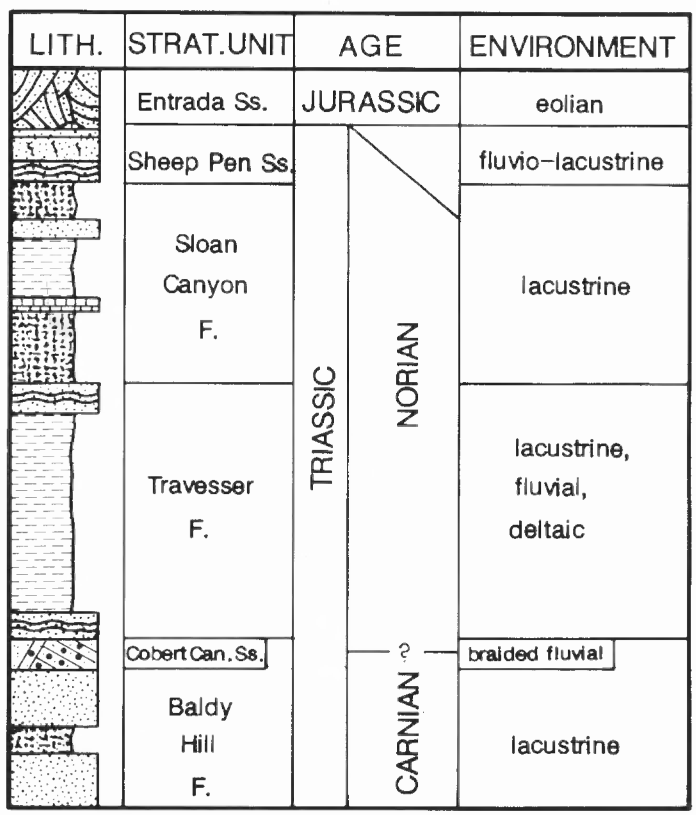

FIGURE 1.19. Triassic strata exposed in the Dry Cimarron Valley.

FIGURE 1.20. Clastic plug in Sheep Pen Sandstone at mile 62.5.

61.7 Paved highway ends. The unpaved road ahead is on the Upper Triassic Sloan Canyon Formation. **0.8**

62.5 Clastic plug on right (Fig. 1.20). **0.1**

62.6 At 9:00, red and green siltstone of the Sloan Canyon Formation is exposed under sandstone bluff of the Sheep Pen Sandstone. **0.4**

63.0 The sandstone capping the ridge ahead is the Mesa Rica Sandstone above a short, covered slope of Glencairn Formation. A thin, white sandstone of the Lytle Sandstone (note especially the knob to the west) underlies the Glencairn and overlies a covered slope of Jurassic Morrison Formation. The Morrison overlies the Entrada Sandstone just above the valley floor. **0.3**

63.3 Roadcuts at crest of hill are in green and red mottled siltstones and thin bioturbated sandstones of the Sloan Canyon Formation. **0.3**

63.6 Clastic plug on right. **0.2**

63.8 Cattleguard; enter open range. **0.7**

64.5 Road crosses Potter Arroyo. **0.8**

65.3 Cattleguard. **0.2**

65.5 Bridge over Bontz Arroyo. **0.3**

65.8 Stone building at 3:00 is old Goodson School. At 10:00, note sandstone ledges in the Morrison Formation. **0.7**

66.5 White sandstone capping low mesa on right is the Entrada Sandstone. **0.6**

67.1 Good view of Entrada Sandstone on left at base of cliffs capped by Mesa Rica Sandstone. **0.5**

67.6 Clastic plug on right. **0.2**

67.8 Cross Smiley Arroyo. **0.9**

68.7 Clastic plugs on right and left. **0.3**

69.0 Mile marker 60. **STOP 2.** The clastic plug we will examine here (Fig. 1.21) is discussed in the accompanying mini-paper.

FIGURE 1.21. Clastic plug at Stop 2.

BLACK MESA MINING DISTRICT

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INTRODUCTION

Copper minerals were mined in the Dry Cimarron Valley and adjacent areas of northeastern New Mexico (Union County), northwestern Oklahoma (Cimarron County) and southeastern Colorado (Baca County) from about 1889 to 1956 (Gould, 1908, 1910; Rothrock, 1925; Henderson, 1926; Parker, 1930, 1933; Harley, 1940; Everett, 1953; Soulé, 1956; Baldwin and Muehlberger, 1959; Fay, 1983). More than 210 prospects are known, all in the Upper Triassic Sheep Pen Sandstone. Rothrock (1925) and Soulé (1956) erroneously attributed the prospects to a sandstone in the Lower Cretaceous Purgatoire Formation. Most of these prospects are adits or steeply inclined shafts less than 30 m deep developed in clastic plugs or mineralized sandstone pods no more than one m in diameter. In places, fossilized plant debris (leaf and stem impressions and petrified wood) is mineralized. Major copper minerals are chalcocite, malachite and azurite occurring in sandstone either as cement or along bedding planes and veins. Although the Black Mesa District was active sporadically for more than half a century, its small, low to moderate grade copper deposits were not, and probably never will be, viable commercially.

MINING HISTORY

The earliest mine in the Black Mesa District apparently was the Independence Mine in Baca County, Colorado opened in 1889. Mining had commenced in the New Mexico and Oklahoma portions of the district by 1899.

In Union County, New Mexico, the Old Hickory Mining Company was formed in 1899 but was absorbed by the Copper Chief Mining Company in 1901. The Copper Chief Company, with a reported ten claims and a capital value of $500,000 was taken over in 1903 by the Sater Copper Company, which had 20 claims, a five-acre smelter site and a reported 2,500,000 shares with a par value of one dollar per share. In 1907, the Fort Pitt Copper Company absorbed the Sater and ostensibly represented the largest capital venture in copper mining in the Black Mesa District. Thus, the Fort Pitt Company boasted of $2,500,000 capital value, held 27 claims, constructed five buildings and a 190-horsepower steam plant and owned two hoists. However, despite its reported value and size, the Fort Pitt Company was discontinued in 1913. As Stevens (1911, pp. 818–819) put it:

> The prospectus of the company, written by a cheerful liar, states that not one of the great mines of the United States has as great a percentage of copper as the Fort Pitt, and that there is a greater value back of this stock than any stock on the market, and that it is as safe as real estate, with ten times the earning power, all of which statements are unmitigated prevarications. By reason of its bad antecedents and willful lies, the company is considered a swindle.

No records of mining activity apparently exist after this time until 1956–1957 when the Cimarron Copper Company shipped several truckloads of hand-picked ore from its San Miguel Mine with a total market value of $307 (see below).

It is difficult to estimate the total production of the Black Mesa Mining District, but some idea of the limited value of the enterprise can be gained from figures available for the Baca County, Colorado portion of the district. Henderson (1926) reported a total production from mines in Baca County for the years 1900, 1901, 1902, 1915, 1916 and 1917 of 21,511 lbs of copper, 356 oz of silver and $292 worth of lode gold, total value of $4,959.

SAN MIGUEL MINE

The prospect examined at Stop 2 of the First-Day Road Log is the San Miguel Mine. A large strip pit of the Cimarron Copper Company, it is located in the NE1/4 SE1/4 SE1/4, sec. 12, T31N, R35E. The mine was developed in a clastic plug that stands about 10 m above a sandstone bench that is the base of the Sheep Pen Sandstone (Fig. 1.22). The plug consists of fine- to medium-grained sandstone, generally laminar

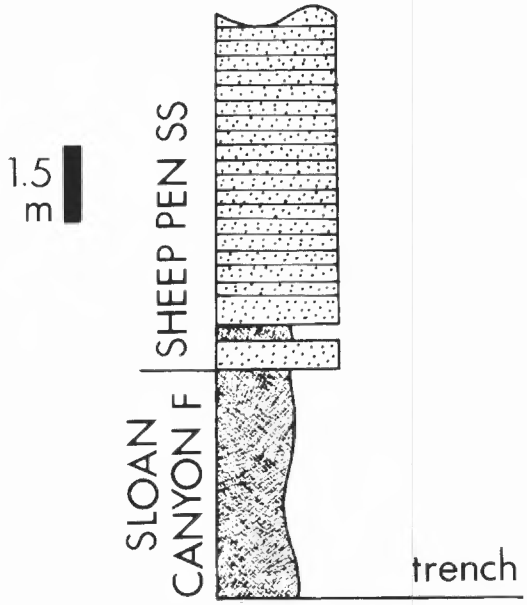

FIGURE 1.22. Stratigraphic section of clastic plug at Stop 2 (after Baldwin and Muehlberger, 1959).

but locally brecciated. Hematite staining and chalcocite veins and seams as much as 15 cm wide mark the outer margins of the plug. Malachite is present just above the Sloan Canyon-Sheep Pen contact. Fluting and slickensides around the plug suggest vertical movement occurred after consolidation. Two samples from the mineralized sandstone, analyzed by Fay (1983), yielded 2.82% and 24.3% Cu, respectively.

ORIGIN OF COPPER DEPOSITS

The likely mode of formation of the nearly 200 clastic plugs in the Black Mesa Mining District was the intrusion of mobile sand along fracture intersections prior to deposition of the Middle Jurassic Entrada Sandstone (for a different point of view on the origin of the plugs see McLemore and North [1987] in this guidebook). The mobile sand was derived from sandstone of the Upper Triassic Baldy Hill Formation 127 to 300 m below the stratigraphic level of the plugs (Parker, 1933). Mobilization of this sand probably reflects earthquake activity associated with Early Jurassic tectonism in the Sierra Grande arch. This tectonism produced the angular unconformity separating Upper Triassic strata from the Middle Jurassic Entrada Sandstone that can best be observed 5 km northwest of the San Miguel Mine on the flanks of Wedding Cake and Steamboat Buttes. Evidently the mobilized Upper Triassic sand contained copper ions in solution that were derived from weathered Permian or Triassic red beds. Since the major copper minerals in the clastic plugs are those formed under reducing conditions, copper ions must have precipitated below the ground-water level. Brecciated areas proved to be the major loci of this precipitation.

After the stop, continue W on NM-325. **0.4**

69.4 Bridge over Sloan Creek. The type section of the Sloan Canyon Formation is to the south (left) (Lucas et al., 1987). The Sheep Pen Sandstone caps the low cuestas W of the creek. **0.4**

69.8 The buttes at 2:00 are capped by the Sheep Pen Sandstone at its type section (Fig. 1.23). **0.3**

70.1 Road to Carl Schaeffer ranch on right. **0.2**

70.3 Road crosses culvert. **0.2**

70.5 Excellent view of Jurassic-Cretaceous units on side of mesa, ahead to right (Fig. 1.24). **0.6**

71.1 Sign for NM Highway 325. **0.5**

71.6 Cattleguard. **0.3**

71.9 Wedding Cake Butte at 2:00 (Fig. 1.25); Steamboat

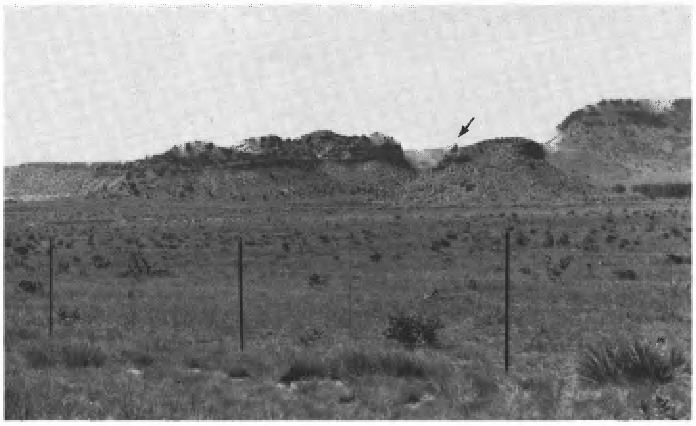

FIGURE 1.23. Buttes capped by Sheep Pen Sandstone at mile 69.8. The arrow indicates the location of the Sheep Pen type section (see Lucas et al., 1987).

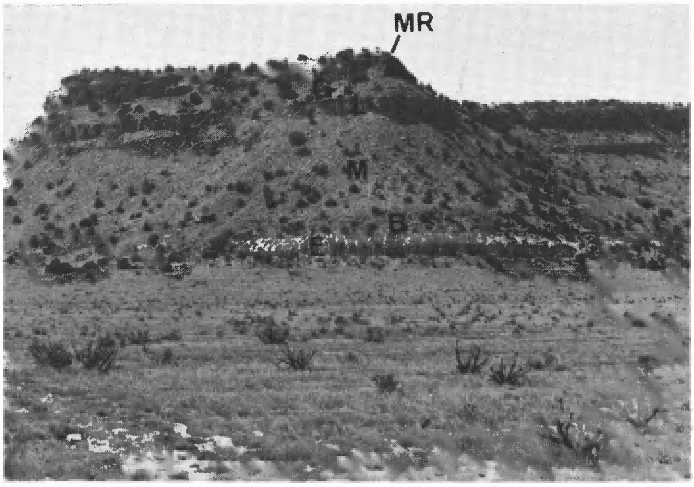

FIGURE 1.24. Mesa at mile 70.5 displays Entrada Sandstone (E), Bell Ranch Formation (B), Morrison Formation (M), Lytle Sandstone (L), Glencairn Formation (G) and Mesa Rica Sandstone (MR).

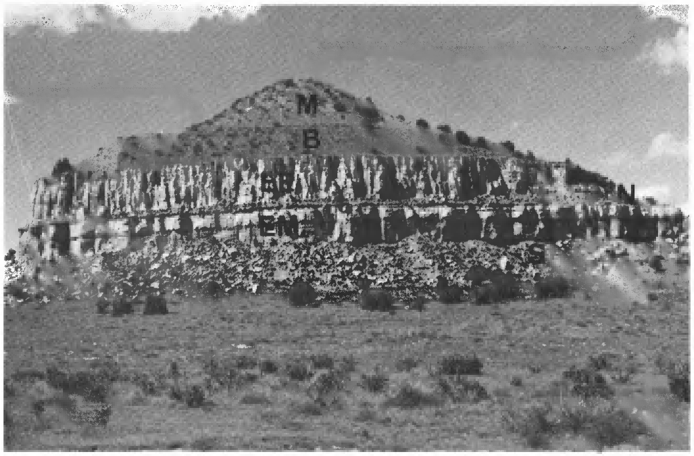

FIGURE 1.25. Wedding Cake Butte at mile 71.9. Note Sloan Canyon Formation (S), main body of Entrada Sandstone (EM), "Todilto Notch" (N), Exeter Member of Entrada Sandstone (EE), Bell Ranch Formation (B) and Morrison Formation (M).

Butte behind and to left of Wedding Cake Butte; Shiprock, a long projection of the large mesa S of the road, is at 12:00–1:00. **0.3**

72.2 Road crosses arroyo. **0.3**

72.5 Road to Harold Davis ranch on right. **0.3**

72.8 Road crosses arroyo, then passes Wedding Cake Butte on right and Shiprock on left. **0.6**

73.4 Crest of hill. **STOP 3.** Steamboat Butte on right, Shiprock on left. Two major points of geological interest are evident at this stop: (1) the spectacular angular unconformity between Upper Triassic and Middle Jurassic strata most evident on the flanks of Steamboat Butte (Fig. 1.26); and (2) the stratigraphy of the Entrada Sandstone (see accompanying mini-paper). This angular unconformity was misinterpreted by Darton (1928), who assigned the variegated "shales" immediately below it to the Morrison Formation (Fig. 1.27). Thus, Darton (1928) considered Lee's (1902) Exeter Sandstone to be a member of the Morrison. Instead, the strata immediately beneath the unconformity are Upper Triassic Sloan Canyon Formation (at Wedding Cake Butte) and Travesser Formation (at Steamboat Butte). Lee's (1902) Exeter Sandstone is the same unit at the Entrada Sandstone (Heaton, 1939).

The angular unconformity here is at the eastern edge of a pre-Entrada anticline (Fig. 1.28) that has more than 200 ft of structural relief. Triassic strata here were folded and eroded before deposition of the Entrada. Folding of these strata can be recognized as far west as T31N, R32E, in the Travesser Park-Baldy Hill area about 14 mi W of here, but has been little studied.

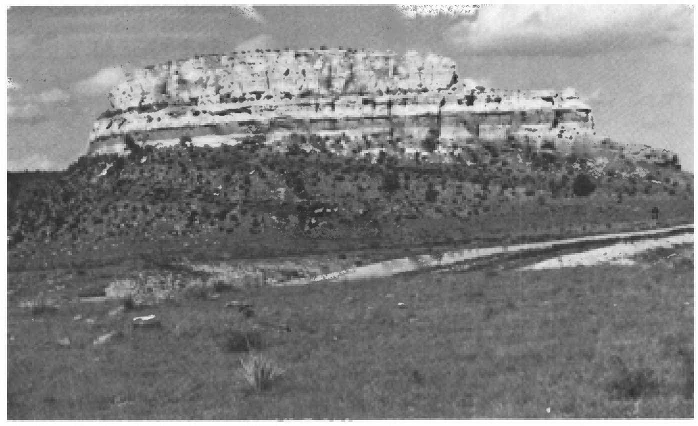

FIGURE 1.26. The angular unconformity between Upper Triassic strata (Travesser Formation) and overlying Middle Jurassic strata (Entrada Sandstone) on the western face of Steamboat Butte.

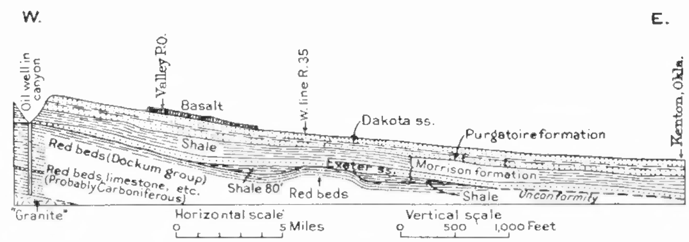

FIGURE 1.27. Restored cross section along the south side of the Dry Cimarron River (from Darton, 1928). Stop 3 is located near the point marked "W. line R. 35" in the middle of the cross section.

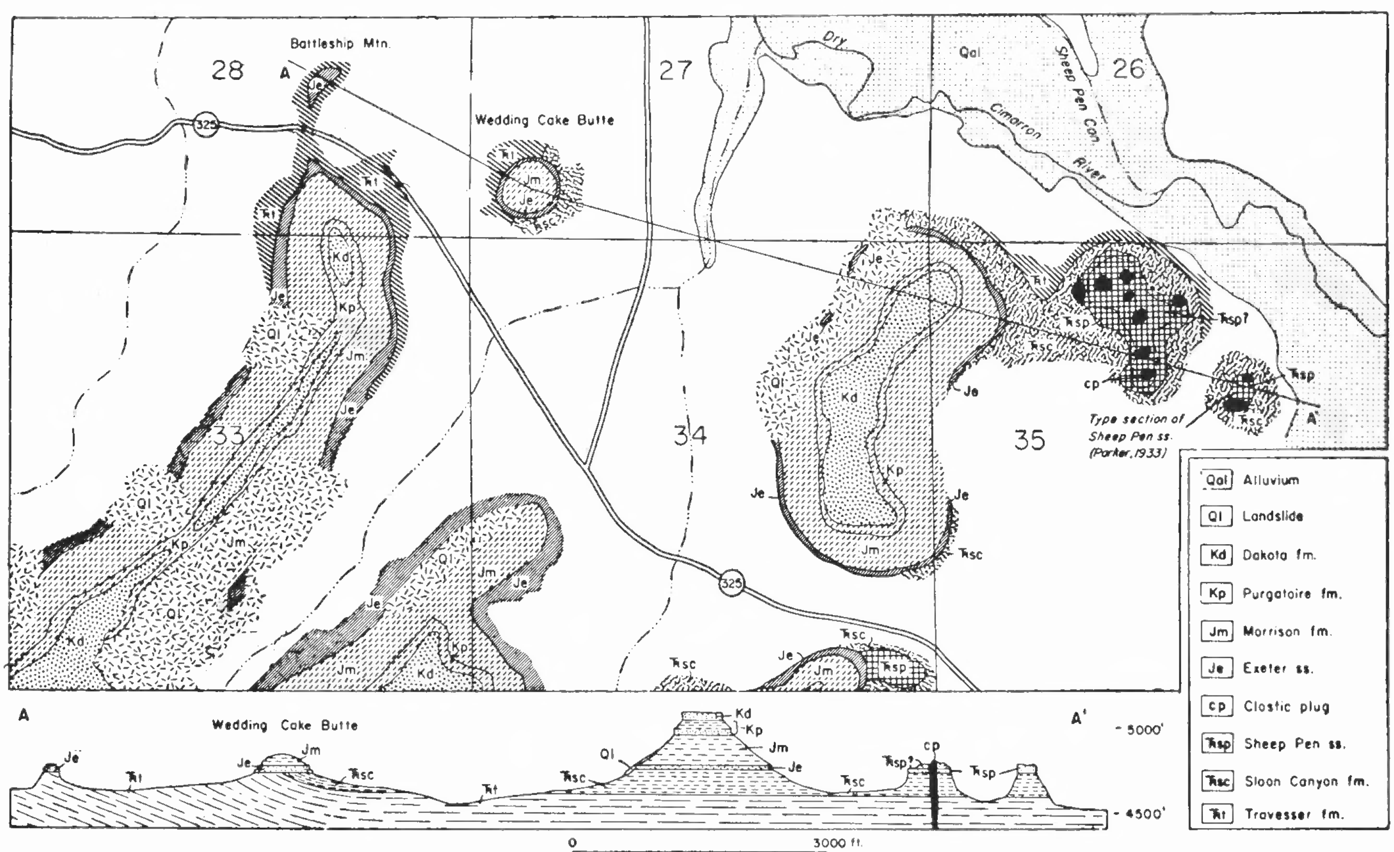

FIGURE 1.28. Geologic map of the vicinity of Wedding Cake Butte (from Baldwin and Muehlberger, 1959).

TYPE SECTION OF EXETER MEMBER OF ENTRADA SANDSTONE, JURASSIC OF NORTHEASTERN NEW MEXICO

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INTRODUCTION

Lee (1902, p. 45) coined the name Exeter Sandstone for "a firm, hard and rather coarse but evenly laminated sandstone, pink to white in color" exposed in the Dry Cimarron Valley of Union County, northeastern New Mexico. The type section of the Exeter Sandstone (Lee, 1902, fig. 5; also see Baldwin and Muehlberger, 1959, p. 46 and Lucas et al., 1985, pp. 213 and 241) is in the SW1/4 SW1/4 SE1/4, sec. 28, T32N, R35E on the western face of Shiprock (Fig. 1.29). Use of the term Exeter in southeastern Colorado, northwestern Oklahoma, northeastern New Mexico (Colfax and Union Counties) and east-central New Mexico (San Miguel, Harding, Guadalupe and Quay Counties) has been extensive (e.g., Stanton, 1905; Duce, 1924; Rothrock, 1925; DeFord, 1927; Darton, 1928; Parker, 1930, 1933, 1934; Sanders, 1934; Stovall, 1943; Mankin, 1972; Sapik and Goemaat, 1973; Staatz, 1986; Scott, 1987). However, the work of Heaton (1939), Cooley (1955) and Baldwin and Muehlberger (1959) demonstrated the equivalence of Lee's Exeter Sandstone with the Middle Jurassic Entrada Sandstone of Gilluly and Reeside (1928).

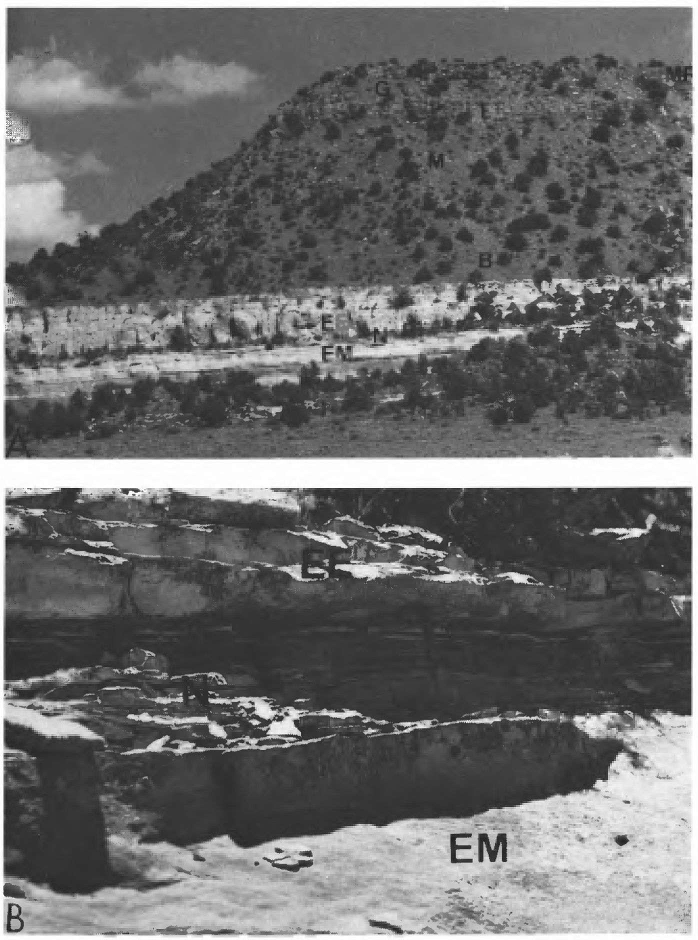


FIGURE 1.29. The type section of the Exeter Member of the Entrada Sandstone. A, View of the western face of Shiprock, showing the Travesser Formation (T), main body of the Entrada Sandstone (EM), "Todilto Notch" (N), Exeter Member of the Entrada Sandstone (EE; type section indicated by black bar), Bell Ranch Formation (B), Morrison Formation (M), Lytle Sandstone (L), Glencairn Formation (G) and Mesa Rica Sandstone (MR). B, The "Todilto Notch" (N), laminar sandstone between the main body of the Entrada Sandstone (EM) and the Exeter Member of the Entrada (EE).

Thus, Lucas et al. (1985) argued for rejection of the name Exeter and its replacement by the more widely used name Entrada, even though Exeter antedates Entrada by 26 years. This decision best serves the goal of stability of stratigraphic nomenclature and also emphasizes that the Entrada lithosome extends from the Colorado Plateau eastward into the Great Plains (cf. Kocurek and Dott, 1983). However, although Lucas et al. (1985) applied the name Entrada to the strata Lee (1902) originally termed Exeter, they redefined the Exeter as an upper member (tongue) of the Entrada Sandstone in east-central and northeastern New Mexico. Here, we describe in detail the type section of the redefined Exeter Member of the Entrada and briefly discuss its stratigraphic relationships to other Jurassic units.

TYPE SECTION

The type section of the Exeter (Fig. 1.30) we measured is the same section described by Lee (1902, fig. 5). At this section, the basal "main

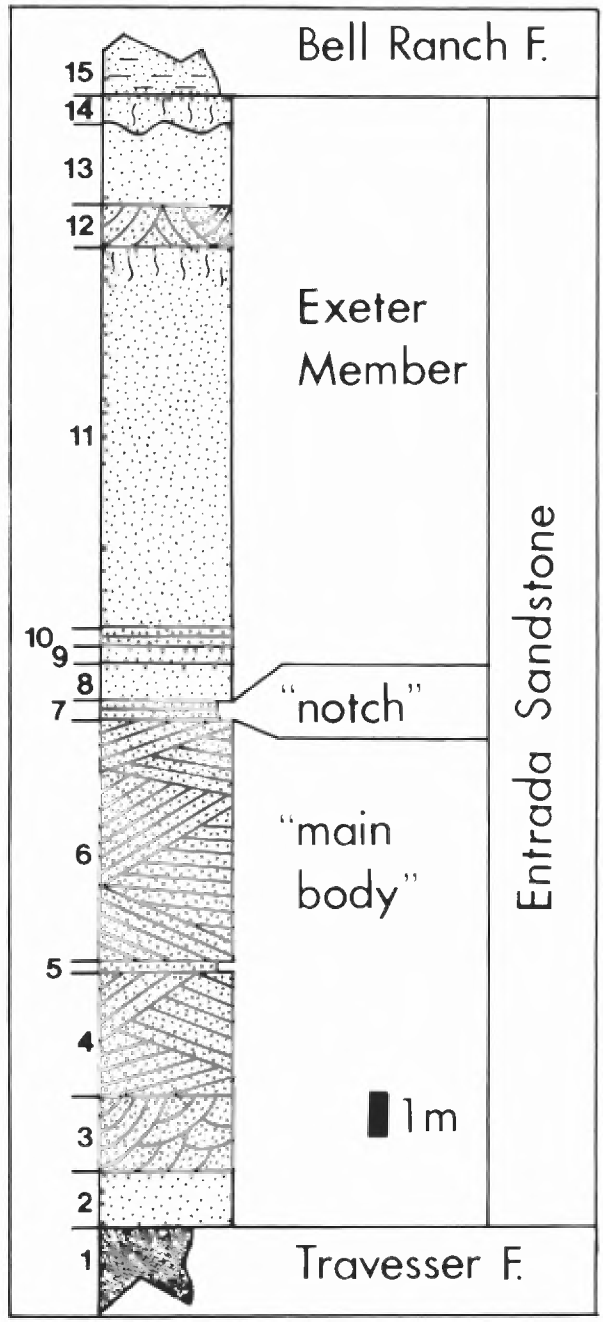


FIGURE 1.30. Section of Entrada Sandstone on the western face of Shiprock. See text for description of lithologies.

body" of the Entrada Sandstone is separated from the underlying reddish brown siltstones of the Upper Triassic Travesser Formation by an angular unconformity. The Travesser dips 20° to S15°E, whereas the Entrada is essentially flat-lying. The Entrada main body (units 2–6 of Fig. 1.30) is 11.2 m (34.1 ft) of dominantly pale orange to reddish brown, fine- to medium-grained quartzarenite. A distinct scour surface 5.6 m above its base (unit 5 of Fig. 1.30) probably represents a disconformity analogous to (but not clearly correlative with) the surface that separates the basal Iyanbito Member from the overlying medial silty member of the Entrada in west-central New Mexico.

Above the main body of the Entrada at Shiprock a 0.4-m-thick interval of soft, very fine-grained, laminar quartzarenite (Fig. 1.29B; unit 7 of Fig. 1.30) creates a distinct topographic notch that separates the Entrada main body from the overlying Exeter Member. Lucas et al. (1985) suggested that this notch represents the landward equivalent of the Todilto salina basin during the Middle Jurassic.

Above the notch, the Exeter Member of the Entrada is 13.2 m of dominantly pale orange to gray, very fine- to medium-grained quartzarenite. The Exeter is overlain by clayey sandstone that we assign to the Bell Ranch Formation of Griggs and Read (1959), although Cooley (1955) identified these strata as Wanakah Formation and Baldwin and Muehlberger (1959) termed these strata the siltstone member of the Morrison Formation. The type section of the Exeter (Fig. 1.30) is as follows:

unit	lithology	thickness (m)
	Bell Ranch Formation (Upper Jurassic):	
15	Clayey sandstone; yellowish gray (5 Y 7/2); quartzose; very fine grained; subrounded; very poorly sorted; slightly calcareous; exposed on a slope much covered by colluvium.	not measured
	Disconformity	
	Exeter Member, Entrada Sandstone (Middle Jurassic?):	
14	Sandstone; grayish orange (10 YR 7/4) to very pale orange (10 YR 8/2); quartzose; medium grained; well rounded; well sorted; slightly calcareous; friable; intensively bioturbated; base of unit is a scour surface with as much as 0.3 m of relief.	0.6
13	Sandstone; very pale orange (10 YR 8/2) with limonitic specks of dark yellowish orange (10 YR 6/6); quartzose; medium grained; well rounded; well sorted; moderately calcareous; friable; massive.	1.8
12	Sandstone; very pale orange (10 YR 8/2) to white (N 9); quartzose; medium grained; well rounded; well sorted; very calcareous (calcite cement); friable; faintly trough cross-stratified; base of unit is a scour surface with as much as 0.1 m of relief.	0.8
11	Sandstone; very pale orange (10 YR 8/2) to white (N 9); quartzose; medium-grained; well rounded; well sorted; slightly calcareous; friable; massive; joint fractures with calcium carbonate; upper 1.5 m has faint traces of burrows.	8.5
10	Sandstone; very pale orange (10 YR 8/2), weathers to grayish orange (10 YR 7/4); quartzose; very fine grained; well rounded; very poorly sorted; indurated; laminar bedding; much iron staining.	0.4
9	Limy sandstone; yellowish gray (5 Y 8/1) to light greenish gray (5 GY 8/1); quartzose; fine grained; well sorted; well rounded; indurated; massive; forms a ledge.	0.3
8	Sandstone; white (N 9) to very pale orange (10 YR 8/2); quartzose; very fine grained; well sorted; well rounded; very calcareous; massive; ledge former.	0.8
	Notch (equivalent of Todilto Formation?), Middle Jurassic:	
7	Sandstone (laminar beds of less and more resistant sand); more resistant sand is white (N 9) to bluish white (5 B 9/1); quartzose, very fine grained, well rounded, well sorted and calcareous; less resistant sand is yellowish gray (5 Y 8/1), quartzose, very fine grained, well rounded, poorly sorted and calcareous.	0.4
	Entrada Sandstone (main body), Middle Jurassic:	
6	Sandstone, pale yellowish orange (10 YR 8/6) with limonitic splotches that are very pale orange (10 YR 8/2) and a weathering rind that is olive black (5 Y 2/1); quartzose; medium grained; well rounded; well sorted; moderately friable; very calcareous; low angle planar crossbeds that are slightly arcuate in 0.6-m-thick sets.	5.4
5	Sandstone; pale reddish brown (10 R 5/4) to very pale orange (10 YR 8/2); quartzose; fine grained; well rounded; poorly sorted; well indurated; very slightly calcareous; forms a recessed notch that appears to represent a disconformity.	0.2
4	Sandstone; moderately reddish brown (10 R 4/6) to pale reddish brown (10 R 5/4); quartzose; medium grained; very poorly sorted; well rounded; friable; moderately calcareous; limonitic staining; large scale planar crossbedding.	2.7
3	Sandstone; very pale orange (10 YR 8/2) to yellowish gray (5 Y 7/2); quartzose; medium grained; well rounded; very poorly sorted; friable; calcareous; low angle arcuate crossbeds in 0.07 m sets; sets are bounded by gravelly beds of coarse- to very coarse-grained sandstone that is 80% quartz and 20% black/yellowish orange chert.	1.7
2	Sandstone; very pale orange (10 YR 8/2) to yellowish gray (5 Y 8/1) with a weathering rind that is olive black (5 Y 2/1); quartzose; fine grained; well rounded; poorly sorted; friable; moderately calcareous; massive; base of unit is a scour surface with as much as 0.15 m of relief.	1.2
	Angular unconformity	
	Travesser Formation (Upper Triassic):	
1	Siltstone; moderate reddish brown (10 R 4/6); very slightly calcareous.	not measured

STRATIGRAPHIC RELATIONSHIPS AND AGE

The Entrada Sandstone in the Dry Cimarron Valley of northeastern New Mexico was deposited near the eastern edge of the Entrada erg, a sand sea that covered most of the southern Western Interior during the Middle Jurassic (Imlay, 1980; Kocurek and Dott, 1983). In west-central and northeastern New Mexico, the Entrada basin margin is represented by homotaxial sequences composed of two eolian sandstones and a thin, intermediate interval deposited by water (Condon and Huffman, 1984; Lucas et al., 1985). The lower eolian sequence of sandstone is the main body of the Entrada Sandstone, a continuous lithosome throughout the basin. The intermediate interval encompasses the Todilto Formation which represents a large salina that developed within the Entrada erg. The upper eolian sandstones are upper tongues of the Entrada that prograded basinward with the evaporation of the Todilto salina. These tongues—Cow Springs and Bluff Sandstones of west-central New Mexico and Exeter Member of east-central and northeastern New Mexico—grade basinward into a clastic lacustrine sequence—Wanakah and Bell Ranch formations—or the upper, gypsum member of the Todilto Formation (Vicellette and Chittum, 1981; Lucas et al., 1985). Thus, the Exeter Member occupies a stratigraphic position homotaxial with the unit termed Cow Springs and Buff Sandstone (most properly regarded as a single, upper tongue of the Entrada) in west-central New Mexico (Condon and Huffman, 1984, figs. 5–6).

Regional stratigraphic relationships suggest that the unfossiliferous Entrada Sandstone is of late Bathonian to late Callovian age (Imlay, 1980). Furthermore, fossil fishes from the Todilto Formation indicate a latest Bathonian-middle Callovian age (Schaeffer and Patterson, 1984). The oldest age of the Morrison may be Oxfordian (Imlay, 1980), and the Bell Ranch Formation arguably is Oxfordian in age (Lucas et al., 1985). Thus, a middle or late Callovian age for the Exeter Member of the Entrada Sandstone is consistent with available evidence.

After this stop, **continue W** on NM-325. **0.4**

73.8 Mile marker 55. **1.3**

75.1 Note slight angular unconformity between the Triassic Travesser Formation and the Jurassic Entrada Sandstone on left. **0.2**

75.3 Cattleguard. **0.3**

75.6 Road crosses irrigation canal. **0.8**

FIGURE 1.31. Stromatolites from the lower part of the Morrison Formation at Stop 4 (photograph by K. Neuhauser).

76.4 At 9:00, note the Sloan Canyon Formation above the Travesser and underneath the Entrada Sandstone. **0.6**

77.0 Road crosses irrigation canal and then the Dry Cimarron River. **0.1**

77.1 Road crosses irrigation canal. **0.7**

77.8 Road crosses arroyo. **0.2**

78.0 Cattleguard. **0.7**

78.7 At 2:00 note the stratigraphic section from the Sloan Canyon Formation through the Mesa Rica Sandstone. **0.6**

79.3 Carl Taylor Ranch on left. The road to the left leads to Peacock Canyon (see Supplemental Road Log 4) where abundant reptile footprints, first noted by Parker (1933), and subsequently described by Baird (1964) and Conrad et al. (1987), are present in the upper part of the Sloan Canyon Formation. **2.2**

81.5 Sandstones of Travesser Formation on right. **0.6**

82.1 The road is now passing through the Travesser Formation. **1.2**

83.3 This is the approximate location of the long defunct town of Valley (~1879–1930's), formerly called Exter. Lee (1902), in naming the Exeter Sandstone, misspelled the name, and the misspelling was adopted by the U.S. Geological Survey (Wilmarth, 1938). **0.9**

84.2 Bridge over Dry Cimarron River. **0.6**

84.8 Cattleguard. Note that the canyon walls here are capped by the Mesa Rica Sandstone. **1.0**

85.8 Cattleguard. **2.4**

88.2 Cattleguard. **0.8**

89.0 **Junction** with NM Highway 370. **Turn left** and proceed S on NM-370. See Supplemental Road Log 5 for the continuation of NM-325 W to Folsom. Baldy Hill, at 3:00, is capped by the Travesser Formation above gray-colored strata of the Upper Triassic Baldy Hill Formation, the oldest bedrock exposed in the Dry Cimarron Valley. In Union County, the Baldy Hill Formation is only exposed in this area, over about 8 mi^2 along the northwestern, higher part of the post-Cretaceous(?) Guy monocline. The Guy monocline is one of the three major structural axes of Union County (the other two are the Sierra Grande arch and the Clapham anticline). To the east, the Guy monocline, which has a generally northward trend, steps the Dakota Group down as much as 400 ft, and locally strata dip about 10° (Baldwin and Muehlberger, 1959). **1.0**

90.0 At 2:00 the type section of the Travesser Formation (cf. Lucas et al., 1987) is exposed at the base of the bluff. **1.2**

91.2 Cattleguard. **STOP 4.** Up hill to right (W) are stromatolites in the Jurassic Morrison Formation. These stromatolites (Fig. 1.31) are an unusual occurrence in the lower part of the Morrison Formation, and were formed in an extensive lake during the Late Jurassic. Neuhauser et al. (1987), in this guidebook, provide a preliminary analysis of these stromatolites.

The Jurassic section exposed here, and better exposed to the north across the valley (Fig. 1.32), is representative of the Jurassic strata in the Dry Cimarron Valley. At the base of the Jurassic section is the Entrada Sandstone, already discussed at the last stop. Above the Entrada is a troublesome stratigraphic interval previously termed Wanakah Formation (Cooley, 1955) or brown-silt member of the Morrison Formation (Baldwin and Muehlberger, 1959). Here, the name Bell Ranch Formation, coined by Griggs and Read (1959) for strata near Tucumcari, is used for this interval (Lucas et al., 1985).

The Bell Ranch Formation in the Dry Cimarron Valley is as much as 70 ft of interbedded siltstone and very fine-grained, typically gypsiferous sandstone. Cooley's (1955) studies of this unit (Fig. 1.33) demonstrated that it intertongues with the upper part of the Entrada Sandstone. Furthermore, the base of the Morrison Formation is a disconformity with as much as 30 ft of stratigraphic relief (Cooley, 1955; Neuhauser et al., 1987).

The Morrison Formation above the Bell Ranch contains a thin (as much as 1 ft) bed of nodular, red-brown chalcedony usually referred to as the "agate bed." Whether this bed represents a volcanic ash (Ogden, 1954) or a pedogenic silcrete (Lucas et al., 1985) still is unclear. Above the agate bed the Morrison is interbedded channel sandstones and variegated claystones/siltstones. The late Albian Lytle Sandstone disconformably overlies the Morrison Formation throughout the Dry Cimarron Valley. After this stop, **continue S** on NM-370. **1.6**

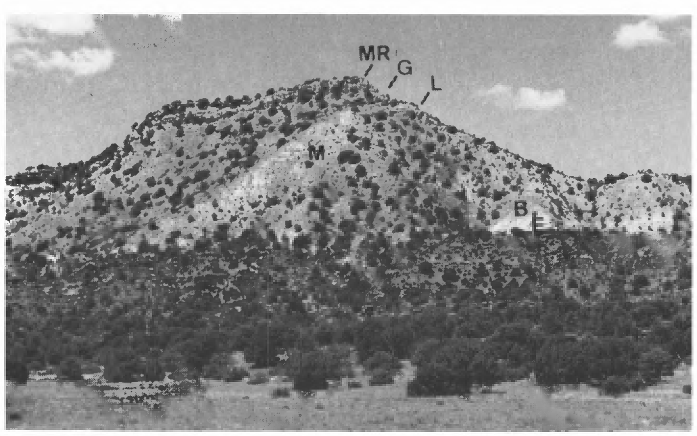


FIGURE 1.32. The well-exposed Jurassic section to the north of Stop 4. Stratigraphic units are: Travesser Formation (T), Entrada Sandstone (E), Bell Ranch Formation (B), Morrison Formation (M), Lytle Sandstone (L), Glencairn Formation (G) and Mesa Rica Sandstone (MR).

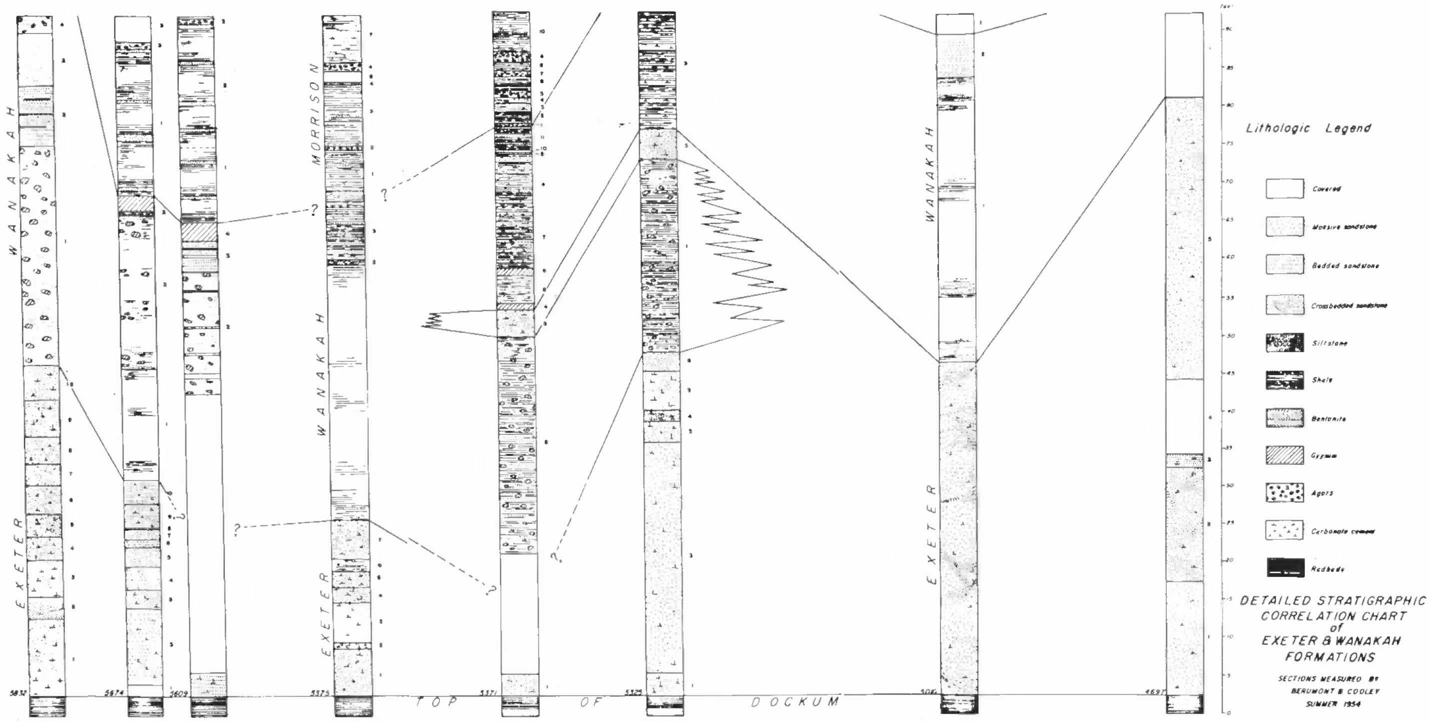


FIGURE 1.33. Stratigraphic relationships of the Wanakah (Bell Ranch) Formation in the Dry Cimarron Valley (from Cooley, 1955). Sections extend from W (sec. 30, T31N, R30E) to E (sec. 32, T32N, R35E).

92.8 Cattleguard. House on right. **0.2**
93.0 Bridge over Travesser Creek. **0.3**
93.3 Cattleguard. **0.1**
93.4 Begin ascent out of Dry Cimarron drainage. **0.3**
93.7 Paved highway begins. **0.2**
93.9 Highway crosses Middle Jurassic Entrada Sandstone. **0.4**
94.3 Highway crosses Bell Ranch Formation (Lucas et al., 1985). **0.1**
94.4 Base of Upper Jurassic Morrison Formation. The Morrison is exposed to the right of the highway for the next 0.2 mi. **0.3**
94.7 Highway now crosses Morrison-Lytle contact. **0.1**
94.8 End of paved highway. **0.5**
95.3 Cattleguard. Highway Department facility to left; escarpment edge beyond exposes Cretaceous section. **0.7**
96.0 Cross arroyo. **1.0**
97.0 Highway reaches upland surface of High Plains; some outcrops of Pajarito Formation on left. **0.2**
97.2 Cattleguard. **1.0**
98.2 Intersection. Continue straight. **0.5**
98.7 Road makes sharp turn to left. **1.1**
99.8 Road makes sharp turn to right. **0.1**
99.9 The Romeroville Sandstone caps a low ridge on the left. **0.3**
100.2 Enter and leave **Guy,** a former small settlement (post office, 1910–1945) that served as the headquarters for the Colorado-Arizona Sheep Company. **1.4**
101.6 Rabbit Ear Mountain at 10:00. **0.5**
102.1 Road bears left. **3.7**
105.8 Mile marker 31. Note Ogallala Formation at 10:00. **1.1**
106.9 Roadcut in Ogallala at 10:00. **0.9**
107.8 Rabbit Ear Mountain at 12:00; road bends left. **1.0**
108.8 The roadbed is Ogallala calcrete. **0.9**
109.7 Road curves right and its bed is dirt again. Just N of the highway is the upper part of Frye et al.'s (1978) Guy southeast composite section of the Ogallala Formation; the lower part of their section was along the highway 3 mi back (Fig. 1.34). This section conforms to a statewide pattern of clay-mineral zonation of the Ogallala, although sepiolite and clay-mineral zone III are conspicuously absent. **1.5**
111.2 At 3:00, the conical mountain is Capulin Mountain; to its south is Sierra Grande. **0.6**
111.8 Intersection; continue straight. **2.9**
114.7 McLaughlin Bridge over Corrumpa Creek. To left the

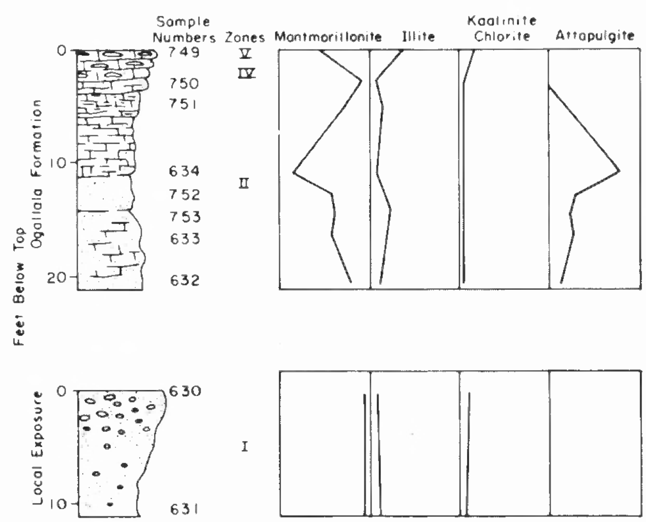


FIGURE 1.34. The Guy southeast composite section of the Ogallala Formation (from Frye et al., 1978).

Romeroville Sandstone overlies the Pajarito Formation. **1.0**

115.7 Alamosita Creek bridge. Romeroville Sandstone to left and right. **0.5**

116.2 Graneros Shale in roadcuts for next 0.3 mi. **1.8**

118.0 Intersection, continue straight. **1.0**

119.0 Cross creek. Note Romeroville Sandstone exposures, especially to the left. **1.1**

120.1 Cross creek. Note exposures of Ogallala Formation on left and right. **1.9**

122.0 Road makes sharp turn to left. **1.0**

123.0 Romeroville Sandstone exposed to left and right in small gullies for next 0.3 mi. **0.7**

123.7 Road forks, bear right. **0.7**

124.4 Abandoned house on left. **0.1**

124.5 Paved highway. **0.1**

124.6 Roadcuts to left and right for next 0.1 mi are in Pajarito Formation. **0.2**

124.8 Bridge over Seneca (Cieneguilla) Creek. **0.5**

125.3 Clayton basalt overlies Ogallala Formation on right. **0.9**

126.2 Turnoff to Clayton Lake State Park. **Turn right.** Rabbit Ear Mountain at 10:00. **0.7**

126.9 Highway makes **sharp turn to right.** Bible Top Butte at 9:00 and Mount Dora at 11:00 are capped by the Clayton basalts. **0.2**

127.1 Sierra Grande at 10:00 in distance. **0.3**

127.4 **Highway turns sharply to right.** Clayton Lake visible below. **0.1**

127.5 Sign and entrance to Clayton Lake State Park (Fig. 1.35). Road now descends to lake. Clayton Lake was created by the State Game and Fish Commission in 1955 with the damming of Cieneguilla (Seneca) Creek. The dam is a 92-ft-high structure, constructed of 400,000 yd^3 of earth, with a blanket of riprap on the upstream fall and an open spillway 150 ft wide. Unlike other New Mexico lakes, which were originally designed for flood control and irrigation, the purpose of Clayton Lake from the beginning was recreation. The lake covers about 170 acres, contains a billion gallons of water when it is full and serves as a winter refuge for waterfowl. Clayton Lake State Park was established in 1967, with the addition of camping grounds, a boat dock and launching ramp (Foster, 1983; Young, 1984). **0.1**

127.6 **Turn sharply to right** and proceed to boat launching area at end of blacktop. **0.2**

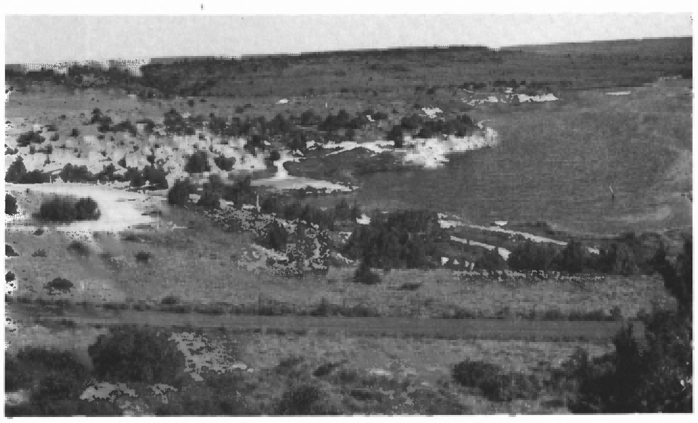
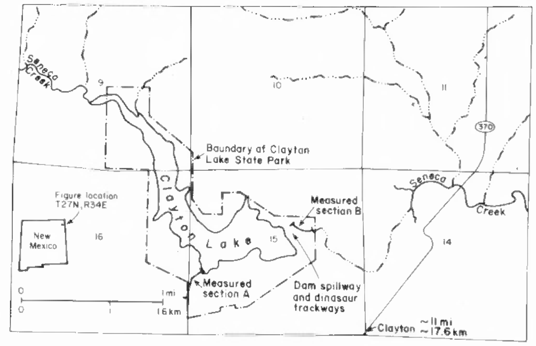


FIGURE 1.35. View of part of Clayton Lake at mile 127.5. The lake is fringed by the Pajarito Formation, overlain by Romeroville Sandstone. Clayton basalts cap uplands in distance.

127.8 **STOP 5** at boat launching area. Here we will examine Cretaceous stratigraphy and dinosaur footprints in the dam spillway. Lucas et al. (1986) described the stratigraphic section at Clayton Lake (Fig. 1.36) and determined that the dinosaur footprints in the dam spillway



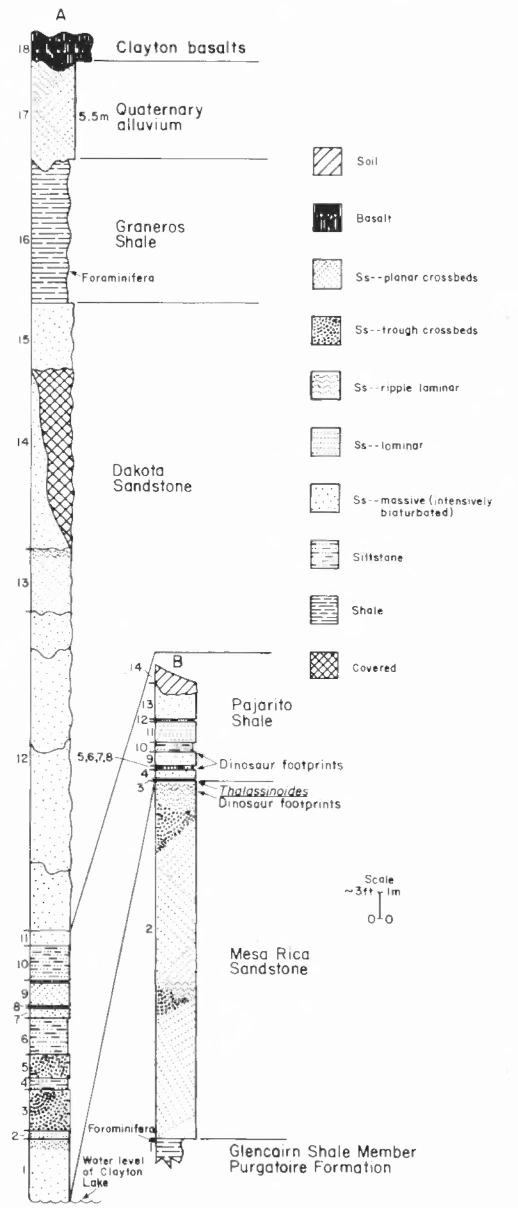


FIGURE 1.36. Cretaceous stratigraphy at Clayton Lake State Park (from Lucas et al., 1986).

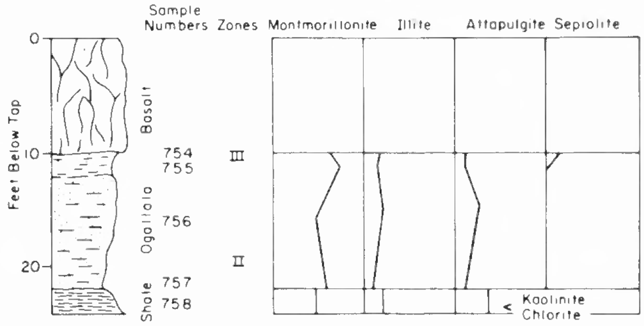


FIGURE 1.37. The Clayton Lake State Park section of the Ogallala Formation (from Frye et al., 1978).

are in the uppermost Mesa Rica Sandstone and lower Pajarito Formation. Calichified sands termed Quaternary alluvium by Lucas et al. (1986), and believed to be post-Ogallala (Fig. 1.36), were assigned to the Ogallala Formation by Frye et al. (1978), who identified clay-mineral zones II and III in these strata (Fig. 1.37). The dinosaur footprints in the dam spillway (Fig. 1.38) were described by Gillette and Thomas (1985). Most of them pertain to ornithopod dinosaurs (ichnogenus *Amblydactylus*), and theropods. After the stop, **retrace route to NM-370** (1.6 mi). **1.6**

129.4 **Intersection** with NM-370. **Turn right** to proceed south toward Clayton. **1.9**

131.3 Crest of hill. The highway is passing through the Clayton basalts at the base of Rabbit Ear Mountain, which is at 12:00. Bible Top Butte at 4:00. **1.9**

133.2 Crest of hill. Clayton is visible across the valley at 12:00–1:00. At 1:00–2:00, the Clayton basalts form the south rim of Apache Canyon. **2.4**

135.6 Road makes sharp turn to left and descends into Apache Canyon. **0.2**

FIGURE 1.38. Footprint of a theropod dinosaur at Clayton Lake State Park.

135.8 Calichified sandstones on left (Ogallala Formation?) under Clayton basalts. **1.2**

137.0 Road curves left. Apache Creek to left. Note calichified sands under basalts that form ridges in this area. **1.2**

138.2 Road ascends to Clayton Upland. Basalt on right above calichified sands. **0.2**

138.4 Top of Clayton Upland. **1.0**

139.4 Enter greater Clayton. **0.4**

139.8 **Intersection** with US-64/87. **Stop sign. Turn left and proceed S** on First Street. **0.4**

140.2 **Stop light** at intersection of Main and First Streets; **continue straight. 0.4**

140.6 Sunset Motel on right. Turn left and stop on Locust Street.

End of road log for First Day.