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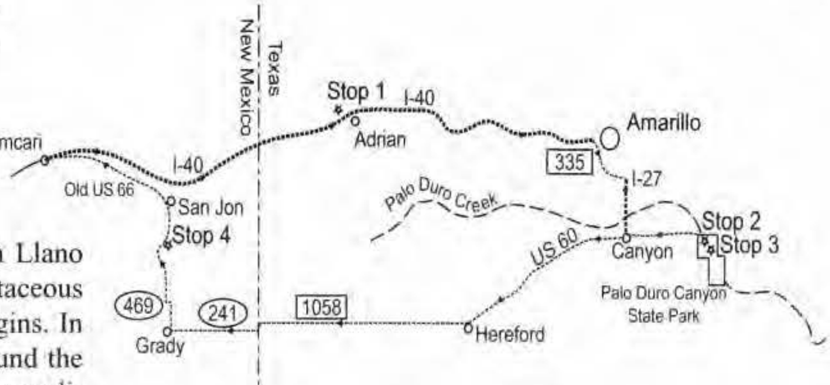
FIRST-DAY ROAD LOG, FROM TUCUMCARI TO THE EDGE OF THE LLANO ESTACADO AT GRUHLKEY, TEXAS, PALO DURO CANYON, TEXAS, AND SAN JON HILL, NEW MEXICO

SPENCER G. LUCAS, ADRIAN P. HUNT, BARRY S. KUES, ANDREW B. HECKERT and VIRGINIA T. MCLEMORE

THURSDAY, SEPTEMBER 27, 2001

Assembly point: Mesalands Dinosaur Museum, 222 East Laughlin, Tucumcari
Departure time: 7:30 AM
Distance: 286.9 miles
Stops: 4



SUMMARY

Today's trip takes us across part of the northern Llano Estacado to examine Permian, Triassic, Jurassic, Cretaceous and Neogene sedimentary rocks exposed at its margins. In so doing, we review the entire section exposed around the staked plains, focusing on problems of stratigraphy, sedimentation, biostratigraphy and magnetostratigraphy.

At STOP 1, just as we ascend the Llano Estacado, we examine the Neogene Ogallala Group and discuss its stratigraphy, sedimentology and geohydrology. We then "scoot" over to Palo Duro Canyon, south of Amarillo, the "Grand Canyon of Texas," on the eastern edge of the Llano Estacado. STOPS 2 and 3 feature the canyon's spectacular scenery due to Neogene erosion into Permian and Triassic red beds. These red beds, and problems regarding their age and correlation, are the focus of the stops.

Palo Duro Canyon is the high point and the endpoint of the Texas portion of this field conference. The trip continues back to New Mexico to STOP 4 at "San Jon Hill," where the eroded northern face of the Llano Estacado exposes a classic Jurassic-Cretaceous section. Here, we collect fossils and discuss regional Jurassic and Cretaceous sedimentation.

Mileage

0.0 Assemble at the Mesalands Dinosaur Museum, 222 East Laughlin, Tucumcari. Mesalands Dinosaur Museum opened in May 2000 and is a part of Mesa Technical College, a state-funded community college. The Museum includes extensive exhibits on the paleontology and geology of eastern New Mexico in a 10,000 ft^2 exhibit hall. The exhibits are designed as a trek through time and reflect the geological sequence exposed in this area—Triassic, Jurassic, Cretaceous and Neogene—that we will be examining on the field conference. Distinctive emphases of the museum include: (1) Triassic paleontology; (2) bronze replicas of paleontological and zoological specimens, including complete skeletons; (3) individual exhibits on the main vertebrate trace fossil groups including coprolites, footprints, skin impressions and eggs; and (4) hands-on exhibits that include dinosaur bones, eggs and even coprolites. **Turn left out of museum parking lot onto S. Adams and immediately turn left (west) onto East Laughlin. 0.1**

0.1 Stop sign. **Turn left** (south) on First Street and proceed south. **0.1**

0.2 Continue straight through traffic light with Tucumcari Boulevard (Old Highway 66) and continue south out of town. Settlement in the Tucumcari area began with the small Hispanic community of Tierra Blanca, about 3 mi to the north. This community became Liberty in the 1860s, after Fort Bascom was established in 1863. Liberty was beyond the five-mile limit within which soldiers could not consume alcohol—needless to say, Liberty became a boisterous community. In 1901, it became widely known that the Rock Island Railroad would pass through the valley just north of Tucumcari Mountain. Land speculators quickly surveyed a town site before the railroad arrived. Half the population of Liberty moved north, and a community was estab-

FIGURE 1.1. Main street, Tucumcari, date unknown (but certainly prior to the arrival of I-40!). Courtesy Museum of New Mexico (negative 11596).

lished, initially and unofficially as Ragtown and then Six Shooter Siding. From 1901-1902, the post office was named Douglas, but this was changed to the current Tucumcari in 1902 (Julyan, 1996; Geyler, 1998).

Tucumcari (Fig. 1.1) is named for the prominent butte of Tucumcari Mountain. As early as 1840 this landmark was associated with the name Tucumcari in its modern spelling (Kues, 1985), and perhaps the earliest version is a 1777 burial record of a Comanche woman captured at Cuchuncari (Julyan, 1996). The name is obviously Native American, but there are disagreements as to its etymology (Pearce, 1965; Julyan, 1998). The most elegant explanation is that is a variant of *tukamukaru,* a Comanche word meaning "to lie in wait for someone or something to approach" (Pearce, 1965). This is consistent with Comanche occupation of the area and with the obvious utility of Tucumcari Mountain as a lookout post. **1.4**

1.6 Pass under bridge of Interstate 40. **Move into left lane to turn left and enter eastbound Interstate 40. 0.5**

2.1 Bridge over canal. Tucumcari Mountain at 2:30. The stratigraphic section exposed at Tucumcari Mountain is (in ascending order): Upper Triassic Bull Canyon and Redonda formations, Middle Jurassic Entrada Sandstone and Summerville Formation, Upper Jurassic Morrison Formation, and Lower Cretaceous Tucumcari Formation and Mesa Rica Sandstone (Fig. 1.2). The Tucumcari area receives water via a canal from Conchas Lake reservoir. The roots of this irrigation project have a long history dating back to 1925 when the "Canadian River Development Association" was formed by H. B. Jones, James L. Briscoe and Arch Hurley. These gentlemen spent an enormous effort, including tens of trips to Washington, to further their goal of providing abundant irrigation water to the area. Finally, in 1936, Congress passed the Flood Control Act that appropriated funding for Conchas Dam. The dam was finished in 1939, and the Arch Hurley Conservancy District (AHCD) was completed in 1954. AHCD utilizes 40 mi of canals and 350 mi of laterals and ditches to provide approximately 1.33 acre feet to over 42,000 acres of land (Geyler, 1998). **0.6**

2.7 Exit 333. **1.3**

4.0 Roadcut developed in the Upper Triassic Bull Canyon Formation immediately before exit 335. The Bull Canyon Formation is a relatively soft, mudstone-rich formation that overlies the sandstone- and conglomerate-dominated Trujillo Formation. As we drive east, I-40 is essentially lying on the contact between the Trujillo and the Bull Canyon formations. Thus, the Trujillo underlies the flat plain between the Canadian River to the north and I-40. South of I-40, badlands of the Bull Canyon

FIGURE 1.2. Tucumcari Mountain, with stratigraphic units numbered: 1 = Bull Canyon Formation, 2 = Redonda Formation, 3 = Entrada Sandstone, 4 = Summerville and Morrison formations, 5 = Tucumcari Formation, 6 = Mesa Rica Sandstone, 7 = Ogallala Group.

Formation will be intermittently visible. **2.0**

6.0 Mesa Redonda at 3:00; in the distance the edge of the Llano Estacado is between 1:00-2:00. **1.7**

7.7 Exit 339. **2.6**

10.3 Pass under overpass. Extensive badlands to the southeast are developed in the Upper Triassic Bull Canyon Formation. These badlands yield numerous Triassic vertebrate fossils, and an inset Pleistocene fluvial deposit also contains bones of sloth (*Paramylodon*), horse (*Equus*), camel (*Camelops*), bison (*Bison*) and mammoth (*Mammuthus*). This is the Rancholabrean (mid-late Pleistocene) Badlands Ranch local fauna of Morgan et al. (2000). **1.0**

11.3 Substation on right. **0.7**

12.0 Low roadcuts in tributary of Barranca Creek are developed in the Upper Triassic Trujillo Formation (Cuervo Sandstone of Kelley, 1972). Indeterminate phytosaurs and the aetosaur *Typothorax coccinarum* have been found in this area (see accompanying minipaper). *Typothorax coccinarum* is an index taxon of the Revueltian land-vertebrate faunachron and indicates an early-mid Norian (Late Triassic: 210-218 Ma) age (Lucas, 1998). **0.6**

PALEONTOLOGY AND AGE OF THE UPPER TRIASSIC TRUJILLO FORMATION, EAST-CENTRAL NEW MEXICO AND WEST TEXAS

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The Trujillo Formation of the Chinle Group (Upper Triassic) is as much as 70 m of sandstone and conglomerate with minor mudrock that crops out widely in West Texas and northeastern New Mexico. This unit is unfossiliferous except for two areas, Randall County, Texas and Quay County, New Mexico. MDM refers to the Mesalands Dinosaur Museum.

The putative angiosperm *Sanmiguelia* and other fossil plants have been recovered from the Trujillo Formation in Sunday Canyon, Randall County (Ash, 1976, 1980; Cornet, 1986). Dunay (1972), Dunay and Fisher (1979) and Cornet (1986) described pollen from the Trujillo in Sunday Canyon. The only vertebrate fossils reported from the Trujillo in this area are coelacanth and *Semionotus*-like scales (Olsen, 1984).

Hunt (1991) described fossils from the Trujillo Formation in Revuelto and Barranca Creeks in Quay County, New Mexico. The Revuelto Creek specimens include the bivalve *Unio* sp., an indeterminate phytosaur, the aetosaur *Typothorax coccinarum*, an indeterminate rauisuchian and vertebrate coprolites. The Barranca Creek assemblage includes an indeterminate phytosaur and *Typothorax coccinarum*.

During the last five years, the Mesalands Dinosaur Museum has been collecting specimens from the Trujillo Formation from a variety of localities in central Quay County. Generally, the exposures of the Trujillo Formation in east-central New Mexico are not ideal for fossil collecting. In Quay County, the Trujillo underlies the plain that extends from approximately I-40 north to the Canadian River and is thus poorly exposed. Northwest of Mesa Rica in San Miguel County, the Trujillo forms the steep edges of the escarpments. However, some drainages in east-central New Mexico provide low outcrops of the Trujillo Formation that are ideal for fossil prospecting. Several of these outcrops are associated with the Quay anticline.

Large mass mortality beds of unionid bivalves have been found at two localities. These contain thousands of specimens, most of which are articulated. These specimens are found in pale reddish orange (10 R 5/4) to moderate reddish orange (10 R 4/6), matrix-supported, intraformational conglomerates (e.g., MDM 212). The majority of clasts in these beds are rounded calcrete pebbles up to 6 cm in diameter. Taxa include *Unio arizonensis*, *Unio* sp. and *Antediplodon dockumensis*. The amphibian *Apachesaurus gregorii* is represented by a single vertebra (MDM 213).

By far the most common fossils pertain to phytosaurs. The most important specimens are one side of a partial crested rostrum that extends from just anterior to the external nares to near the tip (MDM 214), the tip of a rostrum (MDM 215) and a posterior fragment of a squamosal (MDM 216). The squamosal indicates the presence of a phytosaur with rod-like squamosal processes such as *Pseudopalatus* or *Nicrosaurus*.

The stagonolepidid *Typothorax coccinarum* is represented in the fauna by a large fragment of a paramedian osteoderm (MDM 217) and by small fragments (e.g., MDM 218). These specimens have the diagnostic features of an ornament of rounded pits, an anterior bar and also a ventral bar. One specimen is a portion of a skeleton of an aetosaur with articulated osteoderms and vertebrae (MDM 219), but it is too poorly preserved to be identified.

Other reptile specimens include caudal vertebrae of a rauisuchian (e.g., MDM 220) and half a centrum that is similar to the herrerasaurid *Chindesaurus* (MDM 221). Vertebrate coprolites are also common (e.g., MDM 222, 223). Fragments of fossil wood are abundant, and a few specimens of the tree fungus *Polyporites* have been collected (e.g., MDM 224).

The presence of *Typothorax coccinarum* indicates that the Trujillo Formation belongs to the Revueltian land-vertebrate faunachron, which is of early-mid Norian age (Lucas and Hunt, 1993; Lucas, 1998). This is consistent with the presence in the Trujillo Formation of Texas of *Sanmiguelia* of Ash's (1980) *Sanmiguelia* floral zone, which is also Norian in age (Lucas, 1993). Further support for this age is the presence of *Pseudopalatus/Nicrosaurus*-grade phytosaurs, which are only known from Norian strata (Hunt, 1994). Pollen data from Sunday Canyon have been interpreted to indicate a late Carnian age for the Trujillo (Dunay, 1972; Dunay and Fisher, 1979; Cornet, 1986), but the preponderance of the data indicates that the Trujillo Formation is Norian in age.

12.6 Badlands of Barranca Creek exposed at 2:00-3:00. Llano Estacado in the distance. *Barranca* means gorge or ravine in Spanish (Julyan, 1996). The former community of Barranca was several miles to the south of here.

Drake (1892) was the first to apply formal stratigraphic nomenclature to the Triassic rocks in east-central New Mexico. He measured a series of stratigraphic sections in eastern New Mexico and brought Cummins' (1890) name Dockum beds into Quay County. One of his measured sections is at the head of east Fossil Creek. Marcou (1858) showed a Fossil Creek as a north-south flowing stream northeast of Mesa Redonda (Big Tucumcari Mountain of Marcou). The geographic location of Fossil Creek identifies it as Barranca Creek (cf. Kues, 1985, fig. 11), even though Marcou shows the location of the headwaters incorrectly. By inference, East Fossil Creek must be Revuelto Creek, which joins Barranca Creek near I-40. Note that there are no other areas east of Fossil Creek (Barranca Creek) where Drake (1892, pl. 5) could have measured his thick section of "Dockum beds" (approximately 181 ft estimated from his plate) in Quay County. Drake (1892, plate 5) indicated he measured 81 ft of lower beds (Garita Creek Formation), 25 ft of central beds (Trujillo Formation) and 75 ft of upper beds (Bull Canyon Formation), but these thicknesses are much too thin, and the entire section was probably measured in the Bull Canyon and upper? Trujillo formations. **0.4**

13.0 Exit 343. **3.2**

16.2 Cross bridge over Revuelto Creek. On the right the Upper Triassic Trujillo Formation is overlain by Pleistocene sediments that include fragmentary mammoth teeth and bones. Tributaries of Revuelto Creek, Barranca Creek and Plaza Larga contain Pleistocene terraces that have yielded several vertebrate specimens, including at least two partial mammoth tusks and horse teeth (see Morgan et al., this guidebook). **1.0**

17.2 Upper Triassic badlands of Revuelto Creek at 3:00. This creek is named for Monte Revuelto, a topographic feature that is not on modern maps, but it is the point of the Llano Estacado that extends farthest north between Tucumcari and the state line. The headwaters of what are now called San Jon and Revuelto Creeks are in this area. The ornithischian dinosaur *Revueltosaurus callenderi* Hunt, 1989 and the Revueltian land-vertebrate faunachron are named for this drainage. This name is doubly appropriate because: (1) the holotype of *Revueltosaurus* was found near the creek; and (2) *revuelta* means revolution in Spanish, and the Late Triassic, including the Revueltian (early-mid Norian), saw a great evolutionary turnover of life on land, when the sprawling reptiles and amphibians characteristic of the Paleozoic were replaced by "modern" groups with upright gaits, such as dinosaurs, pterosaurs and mammals. **2.8**

20.0 Note blowouts developed in the Bull Canyon Formation along the road for next few tenths of a mile. **2.2**

22.2 Pass under overpass. Little Rattler mine (sec. 11, T11N, R33E) is located a few miles north of here. The mine produced 59 tons of ore containing 41 lbs U_3O_8 and 44 lbs V_2O_5 and was hosted by Chinle Group strata (McLemore and North, 1985). Numerous small, sedimentary copper-uranium (redbed copper) deposits are present north and south of I-40 in the San Jon area. **2.9**

25.1 San Jon exit (exit 356). **1.7**

26.8 Weigh station. **3.3**

30.1 Exit 361 to Bard, a tiny village that was never more than a trading point along the railroad. Bard dates from the time of the railroad (1908), although it is several miles to the north of the Chicago, Rock Island and Pacific line. Julyan (1996) gives two versions of the origin of the name--it was either named after a place in Texas or it was derived from the Bar-D Ranch. Given its proximity to Endee, which is named after the ND Ranch, the latter explanation seems more likely. Currently, Bard and Endee share a volunteer fire department. **2.6**

32.7 Pass under overpass. **2.4**

35.1 Mile marker 366. Note Triassic roadcuts are crossbedded, channelized Trujillo Formation sandstones and conglomerates for next 1.5 mi. **3.6**

38.7 Exit 369 to Endee, essentially a vanished settlement that was named for the brand of the ND Ranch. Endee was originally founded in about 1885 by John and George Day. The settlement of Endee has had three main iterations. It started several miles south of here, had a second and more prosperous existence on US-66 and is finally represented by the abandoned tourist facilities on I-40. The original settlement consisted of picket houses with sod roofs (Julyan, 1998). **3.0**

41.7 Cross Trujillo Creek; exposures are Triassic redbeds and Quaternary alluvium and dune sands. **0.4**

42.1 Port of entry on left. **0.4**

42.5 Texas-New Mexico state line. **0.2**

42.7 Exit 0 to Glenrio. Glenrio represents one of many small towns that were killed off by I-40. An attempt to move one of the gas stations to the I-40 exit ended in failure. Glenrio started as the settlement of Rock Island when the Chicago, Rock Island and Pacific railroad came through this area in 1909. The name was changed in 1915 to avoid confusion in delivering mail to the town and to the CRI & P depot here. The name derives from the Celtic *glen* and the Spanish *rio*. Julyan (1996) states that both names are inappropriate, but views of the Llano Estacado off to the east and south leave you no doubt that you are in a valley, and the perennial streams nearby were important to early settlers. The town prospered until World War II, and, indeed, some scenes in the 1940 movie "The Grapes of Wrath" were filmed here. After the construction of I-40, however, all that remains are a post office and two residences. **0.3**

43.0 Pass under overpass. Low bluffs on the right are developed in the lower part of the Upper Triassic Bull Canyon Formation. **1.6**

44.6 We have been in Deaf ("DEEF" to you native English speakers!) Smith County; Oldham County line. Deaf Smith County was named for Erastus "Deaf" Smith, a famous scout of the Texas Revolution. Oldham County derives its name from William Simpson Oldham, pioneer Texas lawyer and Confederate Senator. **1.0**

45.6 Redbeds of Bull Canyon Formation sediments immediately to the right of the road. The Bull Canyon Formation is the youngest Upper Triassic unit in West Texas. The overlying Mesozoic section has been truncated to the east. South of San Jon, the Jurassic and Cretaceous overlie Upper Triassic strata. Farther east in the escarpment south of Endee, the Redonda Formation is the highest Mesozoic unit, but by the Texas line Cenozoic erosion has removed the Redonda Formation. **0.7**

46.3 Old railroad bed of the Chicago, Rock Island, and Burlington Pacific on right. Ermine Cowles Case of the University of Michigan followed this route when he was searching for Upper Triassic fossils here in 1912 (Case, 1914). **1.2**

47.5 Mile marker 5. Low bluff to the right and low hills in distance to left are lower Bull Canyon Formation. Note that Triassic stratigraphy here can be read from the topography. Thus, the sandstone-dominated Trujillo Formation underlies the nearly flat surface we are driving on, and slopes and low hills immediately above it are developed in the mudstone-dominated Bull Canyon Formation.

Gould (1907) published one of the earliest and still one of the most accurate geologic maps of this part of Texas (Fig. 1.3). You can trace the Texas portion of our route on it, which begins just south of the Chicago, Rock Island and Pacific railway going east nearly to Amarillo, then south to Canyon, east to Palo Duro Canyon, then returning west through Hereford, south of Garcia Lake and into New Mexico. **2.1**

49.6 Cross a tributary of Mujares (probably should be Mujeres, "women") Creek. Lower Bull Canyon Formation crops out to right in creek. Note the beveling down of the Ogallala surface toward the east. **3.2**

52.8 Crest low ridge. Edge of Llano Estacado that we will cross is visible ahead. Roadcuts, such as they are, are developed in the Bull Canyon Formation. **1.1**

53.9 Cross creek; note Bull Canyon Formation exposures in creek to right. **1.0**

54.9 Picnic area on right. **1.6**

56.5 Mile marker 14. Roadcuts on the left and right side of the road for the next 0.8 mi are in the Bull Canyon Formation. We are now climbing the escarpment of the Llano Estacado. **0.8**

57.3 Exit 15, Ivy Road. **0.9**

58.2 Ogallala Group roadcuts left and right. The Ogallala in usually tripartite in this area with a basal conglomerate, a medial sandy interval and an upper massive calcrete. Formation of the calcrete ceased about 2.5-3 million years ago. Vertebrate fossils date the Ogallala Group (or Formation) as primarily of Miocene age (Wood et al., 1941). **0.4**

58.6 Crest hill; we are now on the Llano Estacado. Our first stop is the abandoned pit on the left. The Llano Estacado extends from the Pecos River on the west to Palo Duro Canyon in Texas on the east and southward to Hobbs, New Mexico. Also known as the Staked or Stockaded Plains, it covers an area of about 32,000 mi^2 (Reeves, 1972; Hawley, 1993; Holliday, 1995). The origin of this name is disputed by New Mexican and Texan historians and geologists (e.g., Rathjen, 1974; Spearing, 1991; Metz, 1994; Julyan, 1996). There are two possible translations of the Spanish and three possible explanations. The term could be translated "staked plains" from *estaca* or stake/picket and this could denote: (1) stakes were used to mark routes across the featureless plains or to tie up horses; or (2) the frequent yucca plants looked like stakes. *Estacada* literally means stockade or palisade and could refer to the fortress-like aspect of the edge of the caprock. **0.6**

59.2 Sign for exit 18, Gruhlkey. W. H. Gruhlkey was a roadmaster of the Rock Island Railway and owned the land here where a small railroad station was built. Prepare to take exit. **1.0**

60.2 **Exit Interstate 40 at exit 18**, Gruhlkey. **0.1**

60.3 **Turn left** to go east on frontage road. **0.1**

60.4 **Turn left** to cross bridge over Interstate 40. **0.2**

60.6 Stop sign. **Turn left** to go west on frontage road. **Do not get back on Interstate 40. 1.1**

61.7 **STOP 1. Pull off on small road to left** to parking area for the City of Adrian type 3 dump site. Permit #352. Cross road to north and pass through fence. Note, no dumping allowed!

The Neogene Ogallala Formation (Group) contains the Ogallala (High Plains) aquifer, the major water source for domestic and agricultural use on the southern High Plains of New Mexico-Texas. The Ogallala Formation (or Group) is present east of the Rocky Mountains over an area that extends from South Dakota to West Texas (Fig. 1.4). It consists of alluvial sediments that partly fill paleovalleys and widespread eolian sediments that cap paleouplands, deposited under mostly semiarid to subhumid climatic conditions (Gustavson, 1996). Fossil mammals from the Texas Panhandle indicate a Clarendonian-Hemphillian (middle Miocene-early Pliocene) age (see accompanying minipaper).

Here, at Gruhlkey, we can see typical fluvial valley fill sands and gravels and eolian sands below the Caprock calcrete (Fig. 1.5). This calcrete (caliche) is a distinctive, approximately 6-ft thick bed of erosion-resistant, calcium-carbonate rich rock that supports the rim of the Caprock Escarpment. Early workers thought the calcrete represented deposition by a vast lake on the High Plains (e.g., Elias, 1931). However, its pedogenic origin was demonstrated in the 1940s (e.g., Smith, 1940; Bretz and Horberg, 1949a, b). Gustavson (1996) has most recently argued that the Ogallala Caprock calcrete is time transgressive, representing pedogenic carbonate that locally accumulated at various times during the Miocene-Pleistocene interval. Indeed, the Caprock calcrete represents a long period of landscape stability, rather than a particular period of increased aridity (Gustavson, 1996).

After stop retrace route to Interstate 40. 1.0

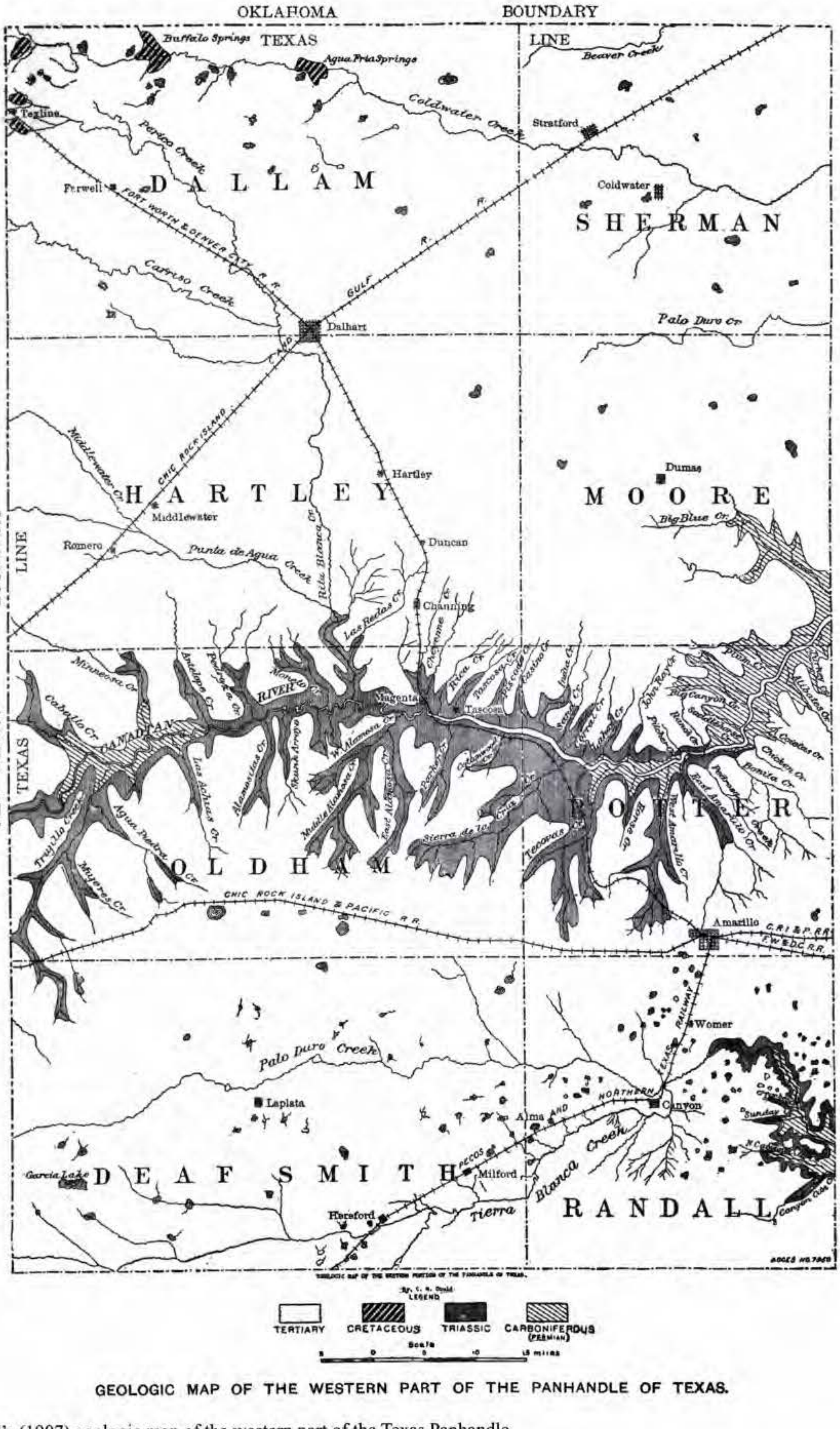

FIGURE 1.3. Gould's (1907) geologic map of the western part of the Texas Panhandle.

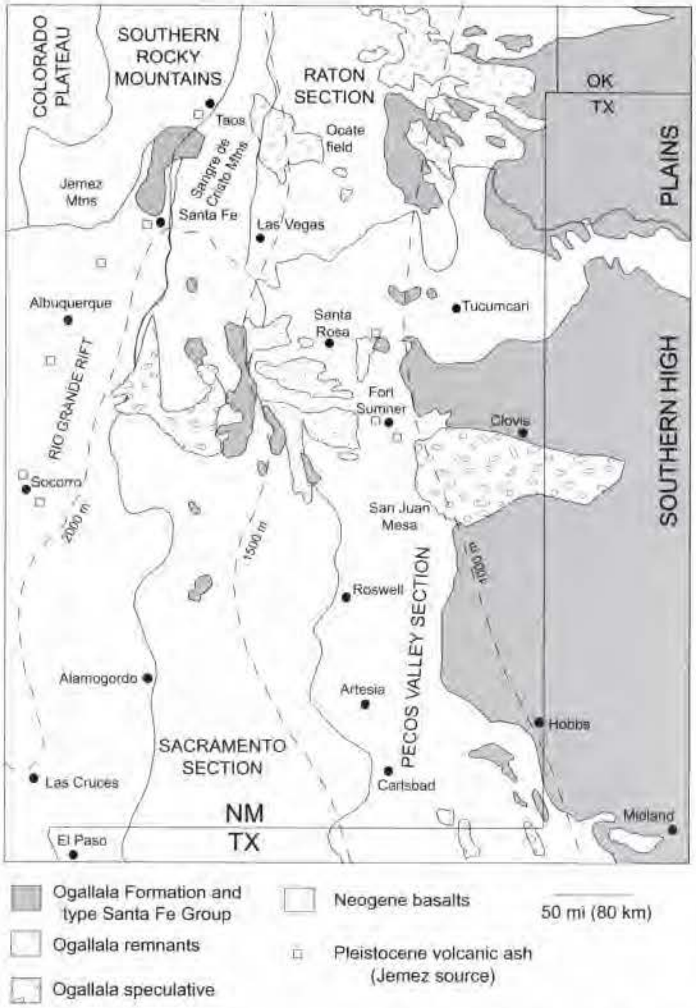

FIGURE 1.4. Map of northeastern New Mexico and adjacent areas showing distribution of Ogallala deposits, Neogene basaltic volcanics, Pleistocene volcanic ashes, major physiographic elements and structural features. The heavy dashed lines indicate magnitude of vertical crustal movement during the past 10 million years (after Hawley, 1984).

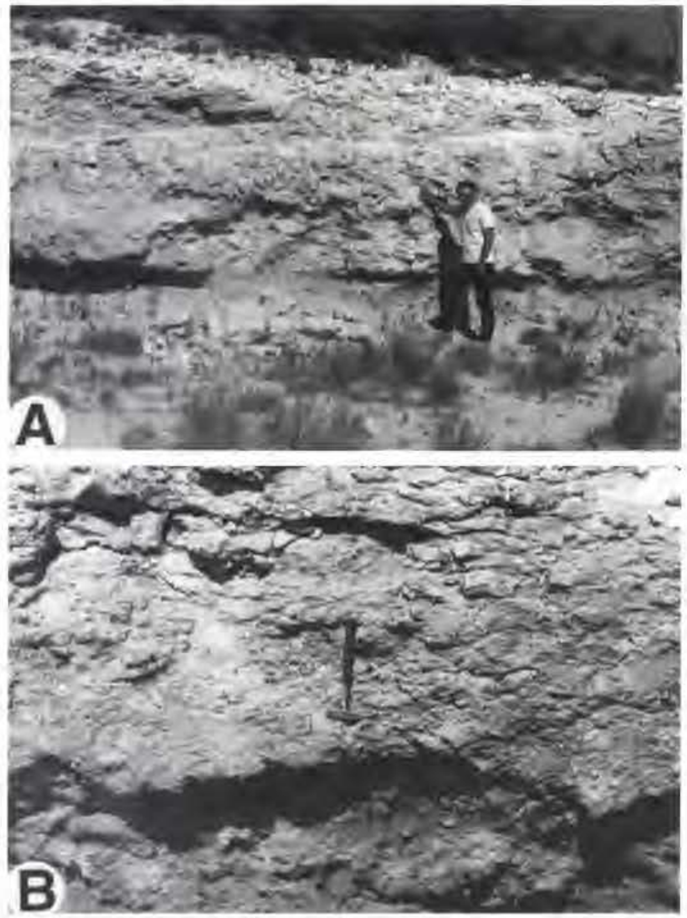

FIGURE 1.5. The Ogallala Caprock calcrete at Stop 1. A, World-famous dinosaur paleontologist Adrian Hunt in front of the calcrete. B, Close-up of the calcrete.

NEOGENE LAND-MAMMAL "AGES" IN THE TEXAS PANHANDLE

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Perhaps the most important contribution vertebrate paleontologists have made to the subdivision of geologic time is the succession of land-mammal "ages" (lmas) Wood et al. (1941) proposed for Cenozoic time in North America. Three of the North America lmas were originally based on fossil mammal assemblages found in the Texas Panhandle – Clarendonian, Hemphillian and Blancan (Fig. 1.6). The first two were coined for fossil mammal assemblages from the Ogallala Formation, whereas the Blancan type assemblage comes from a localized lacustrine deposit termed the Blanco Formation.

An aggregation of mammalian fossils with a stratigraphic distribution in a body of sedimentary rock is an assemblage zone. Vertebrate paleontologists have long referred to such an assemblage zone as a fauna or local fauna. The geologic time equivalent to such a fauna is a lma. This means that lmas are biochronological units—intervals of geologic time recognized by distinctive fossils (Tedford, 1970). Lmas are not the ages of formal stratigraphic terminology. Such ages are intervals of geologic time equivalent to stages, which are bodies of strata. Each age is thus based directly on strata in a specific area; these strata are the stratotype of the stage/age. Lmas lack such stratotypes, so to call them ages is to use that term in a different sense than is usual, which is why the term "age" should be placed in quotation marks. Nevertheless, each lma is based on a type assemblage of mammal fossils, and the lma name is taken from a geographic feature near (or at) that type assemblage (Fig. 1.6).

Wood et al. (1941, p. 12) based the Clarendonian on "the Clarendon local fauna (and member?) near Clarendon, Donley County, Panhandle of Texas." Cope (1893) first reported fossil mammals from this area. The Clarendonian lma as currently understood spans part of late Miocene time, ~ 9-11.5 Ma (Woodburne and Swisher, 1995). The first appearance of the cat-like nimravid *Barbourofelis* marks the beginning of the lma, and the dispersal of

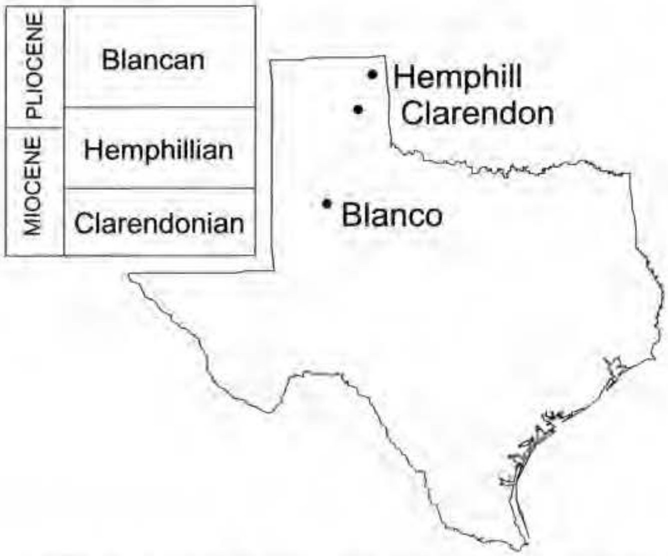

FIGURE 1.6. Location of type fossil assemblages of Texas Neogene land-mammal "ages."

hipparionine horses from North America to Eurasia (the famous "*Hipparion* datum") took place close to the beginning of the Clarendonian. The North American Clarendonian fauna includes an ochotonid, leporids, diverse rodents, chiropterans, erinaceoid and soricoid insectivorans, diverse carnivorans, artiodactyls (especially camels and pronghorn antelopes), horses (especially hipparionines), rhinoceroses (especially aceratheres) and gomphotheres. Mammal assemblages of Clarendonian age are distributed across a broad area in the western United States, and are especially abundant in Nebraska and South Dakota. In New Mexico, the upper part of the Tesuque Formation in the Española basin contains mammals of Clarendonian age (Tedford, 1981).

Wood et al. (1941, p. 12) based the Hemphillian lma on "the Hemphill Member of the Ogallala, which includes both the Hemphill local fauna from the Coffee Ranch quarry and the Higgins local fauna, Hemphill County, Panhandle of Texas." However, there is no recognized "Hemphill Member," and the "Higgins local fauna" is actually from Lipscomb County, Texas (Gustavson et al., 1990). The first discoveries of Hemphillian mammals in the Texas Panhandle were in the 1920s (e.g., Matthew and Stirton, 1930). As now construed, the Hemphillian lma encompasses part of late Miocene-early Pliocene time, ~ 4.5-9 Ma (Woodburne and Swisher, 1995). The immigration of some cricetid rodents from Eurasia to North America and an immigration of ground sloths from South America mark the beginning of the Hemphillian. Hemphillian mammal assemblages are widely distributed in the United States, from Washington and California to Florida and North Carolina. In New Mexico, the best documented Hemphillian mammal assemblage is from the Chamita Formation in the Española basin (MacFadden, 1977; Tedford, 1981). The North American Hemphillian fauna includes sloths, lagomorphs, diverse rodents, soricid and talpid insectivores, diverse carnivores, diverse artiodactyls (especially camels and pronghorn antelopes), horses (especially *Dinohippus* and hipparionines), gomphotheres and the last North American rhinocerotids.

W. F. Cummins first collected fossil mammals in the Blanco Canyon area of Texas in 1890 (Cope, 1893). Wood et al. (1941, p. 12) defined the Blancan lma "based on the local fauna at 'Mt. Blanco' and the adjoining draws, near the 'old rock house,' north of Crawfish Draw, Crosby County, Panhandle of Texas." The type assemblage comes from the Blanco Formation, a localized basin accumulation about 60 m thick of predominantly lacustrine origin (Evans and Meade, 1945). The Blancan lma is now construed to represent much of Pliocene time, about 1.8-4.5 Ma (Woodburne and Swisher, 1995). Blancan mammal faunas are found over a broad region, from Washington/California to Florida. In New Mexico, several Blancan assemblages are found in the upper part of the Santa Fe Group of the Rio Grande rift basins (Morgan and Lucas, 2001). The Blancan begins with the first appearances of several immigrant taxa of rodents, carnivores and true cervids from Eurasia to North America. The North American Blancan fauna includes a few sloths, diverse lagomorphs and rodents (especially sciurids and cricetids), chiropterans, soricid and talpid insectivorans, diverse carnivorans, camels, horses (especially the last hipparionines and first "true" *Equus*) and most of the last gomphotheres.

62.7 Yield sign. Continue straight for 100 ft then **turn right** to cross bridge over Interstate 40. **0.3**

63.0 Stop sign. **Turn left to enter Interstate 40** eastbound. **0.2**

63.2 **Sharp left onto Interstate 40** (leave Old Highway 66). **Do not go straight**. Welcome back to the Llano Estacado. You are now driving across a landscape that is almost unchanged for the past 2 million years! **2.3**

65.5 Large sink on right reflects dissolution at depth. **1.3**

66.8 **Exit 22 to Adrian.** Named for Adrian Cullen, an early farmer in the area, Adrian was founded in 1900 when the Rock Island Railway picked the site as a station. The population in 1990 was 220, including one "E. Presley." **1.0**

67.8 Exit 23. **3.9**

71.7 Large playa on right. **1.6**

73.3 Exit 28 to Landergin; grain elevator to left. Brothers Pat and John Landergin established ranch headquarters here in 1906 that later grew into a small community. **3.0**

76.3 Picnic area on right. **3.4**

79.7 Exit 35 to Vega, the seat of Oldham County. The name is Spanish for "plain" or "meadow." A town since 1903, the 1990 population was 840. Vega is located within the boundaries of the enormous XIT Ranch that extended 200 mi north to south. **1.3**

81.0 Exit 36, town of Vega to left. **1.7**

82.7 Exit 37 (last exit to Vega). **2.7**

85.4 Note trees to left, good indicators of which way the wind blows. **1.5**

86.9 Exit 42 to Everett Road. **6.7**

93.6 Exit 49 to Wildorado. Named for nearby Wildorado Creek, a community was established here in 1900 as a shipping point on the Chicago, Rock Island and Pacific Railway. 1990 population was 180. **2.7**

96.3 Potter County Line. Amarillo is the seat of Potter County, which was named after Robert Potter, a signatory of the Texas Declaration of Independence. **1.9**

98.2 Parking area to right. **0.8**

99.0 Exit 54 to Adkisson Road. **1.8**

100.8 Windmills on right are part of USDA experimental station. **1.1**

101.9 Exit 57 to Bushland. Bushland was established in 1908 as a station on the Chicago, Rock Island and Pacific Railway. It was named for William Henry Bush of Chicago, who donated the land for a townsite. 1990 population was 130. **3.1**

105.0 Exit 60 to Arnot Road. **1.5**

106.5 Cadillac Ranch to right. **0.5**

107.0 Exit 62A to Hope Road and Helium Road. **0.5**

107.5 Exit 62B to Business 40 Amarillo Boulevard. **1.7**

109.2 **Take exit 64, Texas loop highway 335 south to Palo Duro**, leave Interstate 40 here at Amarillo city limit. Amarillo is the metropolis of the Texas Panhandle (1998 population = 171,000) and the largest city on I-40 between Albuquerque and Oklahoma City. When the Fort Worth and Denver City Railway began building across the Texas Panhandle in 1887, a group of merchants chose a site to build stores that became Amarillo. By 1890, the fledgling town was one of the world's busiest cattle-shipping points. Today, its principal income derives from petroleum and cattle. **0.3**

109.5 **Turn right** on Soncy Road, Texas Loop Highway 335. **0.1**

109.6 Proceed through traffic light at Westgate. **0.1**

109.7 Enter Randall County. The county takes its name from Horace Randal, a Confederate general who was killed at the battle of Jenkins' Ferry, Arkansas, in 1864. In 1876, a clerical error doubled the l's in the name! **0.5**

110.2 Proceed through traffic light at West 34th Street. **1.0**

111.2 Leave Amarillo after crossing through traffic light at West 45th Street. **2.6**

113.8 Road curves sharply to left—stay on main highway. **1.3**

115.1 Cross traffic light at Coulter Road. **0.5**

115.6 Interstate 27 bridge. **Just before bridge, turn right at Amarillo city limit to get on Interstate 27 south. 0.2**

115.8 Get into left lane onto Interstate 27 south. **0.7**

116.5 Exit 115. **1.8**

118.3 Exit 113, McCormick Road. **1.2**

119.5 Exit 112, Texas Farm Road 2219. **1.0**

120.5 Exit 111, Rockwell Road. **1.4**

121.9 Exit 110. **Leave I-27 on South US-87, to Canyon, Texas. 0.9**

122.8 Pass under overpass. Entering greater Canyon, Texas. Note deep incision in Ogallala Formation here. **1.0**

123.8 Cross Palo Duro Creek. **0.1**

123.9 Canyon city limit. Canyon, originally Canyon City, was founded in 1878 and named for Palo Duro Canyon to the east. The site was originally the headquarters of the T Anchor Ranch. The Pecos & Northern Railroad made Canyon a shipping point in 1898 (Metz, 1994). Canyon is home to West Texas A & M University and the Panhandle Plains Historical Museum. 1990 population was 11,365. **Get into left lane. 0.8**

124.7 Street light at North 3rd Avenue. Continue straight. **0.3**

125.0 **Turn left on Texas 217/4th Avenue to Palo Duro Canyon. 0.1**

125.1 Panhandle Plains Historical Museum on left. This is not only the largest historical museum in Texas, but it also includes impressive paleontological displays as well as a large exhibit on the petroleum industry, part of which is visible outdoors. Continue straight on Texas 217 to Palo Duro Canyon (12 mi). **1.4**

126.5 Cross Tierra Blanca Creek (leaving Canyon). **0.8**

127.3 Junction with Interstate 27 (go under overpass). Continue straight. **1.4**

128.7 Road bends left. **0.5**

129.2 Junction with Texas Farm Road 1541. Stop sign and light. Continue straight ahead. **6.3**

135.5 Crest low ridge. Breaks of Palo Duro Canyon visible ahead. The Spanish words *palo duro* ("hardwood") refer to the hardwood shrubs and trees in the canyon. **0.8**

136.3 Ogallala on right in headcut of Sunday Canyon, a Palo Duro tributary. **0.2**

136.5 Ogallala Group deposits over red beds of Triassic Tecovas Formation on right in canyon. **0.9**

137.4 Enter Palo Duro Canyon State Park. **0.1**

137.5 Stop to enter park and pay here. **0.7**

138.2 **STOP 2.** Scenic overlook on right, **turn right into parking lot of visitor center**.

From this vantage point (Fig. 1.7), it is easy to understand why Palo Duro Canyon is called the "Grand Canyon of Texas." The canyon is devel-

FIGURE 1.7. Overview of part of Palo Duro Canyon from Stop 2. The cliff-forming sandstone in the foreground is part of the Trujillo Formation of the Chinle Group.

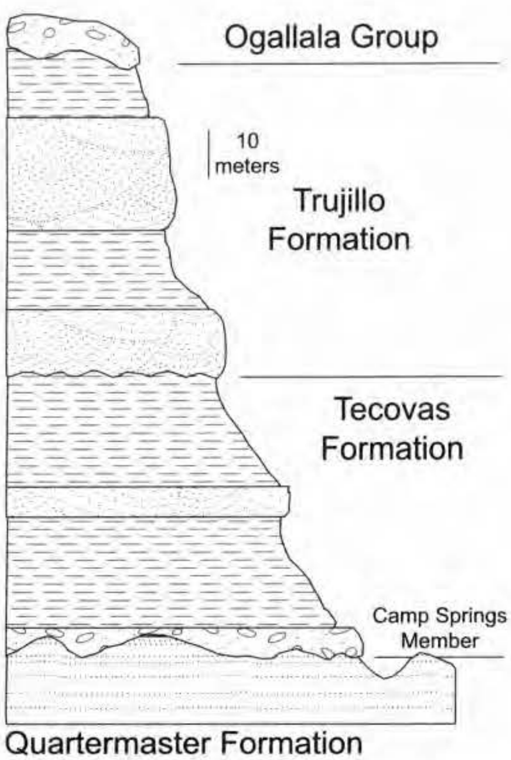

FIGURE 1.8. Summary of the strata exposed at Palo Duro Canyon.

oped around the Prairie Dog Town Fork of the Red River; it is 120 mi long, 1.5-20 mi wide, has a depth of 800-1000 ft and an elevation of 3500 ft at the rim. Palo Duro Canyon State Park opened on 4 July 1934 and encompasses ~16,402 acres of the northernmost portion of the canyon. The Civilian Conservation Corps built most of the park buildings and roads during the 1930s.

Here, we can summarize the stratigraphic section exposed in the park (Fig. 1.8) and examine its uppermost part. That section is (in descending order):

1. Neogene Ogallala Formation (Group), less than 100 ft thick, consisting of a lower interval of reddish brown sandstone and conglomerate overlain by the Caprock calcrete. Note the excellent outcrop here in the lower parking lot next to the visitor center.

2. Upper Triassic Trujillo Formation of Chinle Group (see accompanying minipaper), about 150 ft thick, of cliff-forming sandstone and conglomerate with lesser interbeds of mudstone. These beds are the youngest Triassic strata exposed in the canyon, and form most of the cliffs that rim the canyon (Fig. 1.7).

3. Upper Triassic Tecovas Formation of Chinle Group, up to 200 ft of red-bed mudstone and minor, trough-crossbedded sandstone. A basal, 1-6-ft thick

conglomerate bed, the Camp Springs Member, is locally present.

4. Upper Permian Quartermaster Formation, about 60 ft of which is exposed in the park, consists of red beds of cyclically bedded siltstone, sandstone and gypsum.

After stop return to main road and turn right to continue into park. 0.1

ABANDON THE TERM DOCKUM!

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

The oldest name for an Upper Triassic stratigraphic unit in the American Southwest is the term "Dockum Beds" of Cummins (1890, p. 189-190), introduced as follows:

> A few miles before reaching Dockum, situated in the western edge of Dickens County [Texas], I came upon a bed of conglomerate sandstone and red clay, resting unconformably upon the clays and sandstones of the upper Permian, entirely unlike anything I have heretofore seen in Texas. This formation lies along the foot of the Staked Plains in a narrow belt. Because of its extensive occurrence in the vicinity of Dockum, I gave the formation the name of Dockum Beds, but will not for the present attempt to determine their correlation. I have found everywhere on the beds of the Permian belt pieces of conglomerate and large pebbles of white quartz that did not belong to the Trinity sands of the Cretaceous which were supposed to overlie the Permian to the westward, and it is a matter of interest to know where this drift came from. The fragments of conglomerate increased in size as we traveled westward until we came upon the beds of that material in the vicinity of Dockum, and the question was solved as to the origin of the fragments of conglomerate and the quartz pebbles.
>
> In the conglomerates are many silicified trunks of trees, some of them of great length. In the red clay above the conglomerate are fossil remains of large reptiles, whose species I was unable to determine in the field. In the upper sandstones were many casts of a Unio that I have provisionally called Unio documensis [sic]. In most places that fossil occurs only as casts, and in one place only did I find specimens of both valves, and they were so badly encrusted with carbonate of lime that the peculiar markings of the shell could not be seen. The sandstone was everywhere full of scales of mica, some of the scales being one-sixteenth of an inch square. The whole thickness of this formation in the vicinity is about 150 feet. These beds extend under the Staked Plains. I traced them up Blanco Canyon to the falls of White River, where they pass out of sight under the beds of the overlying strata.

Cummins' (1890) description makes it clear what strata pertain to his "Dockum Beds:" they are the units subsequently named Camp Springs by Beede and Christner (1926) and Tecovas and Trujillo by Gould (1907) (Fig. 1.9). However, few modern (post-World War II) workers seem to have concerned themselves with what strata composed the original Dockum of Cummins (1890). This perhaps explains the wide variety of usages of the term Dockum, many of which included strata in the Dockum that are clearly not equivalent to strata of Cummins' original Dockum.

Dockum as used by most workers is thus an imprecise and confusing stratigraphic term. Examples include:

1. Various workers (e.g., Darton, 1928; Gorman and Robeck, 1946; Lehman, 1994) have used Dockum to refer to all Upper Triassic strata in east-central New Mexico. This greatly expands Cummins' (1890) original concept to include, among other strata, a thick post-Trujillo section (Bull Canyon and Redonda formations) in east-central New Mexico. Furthermore it also raises the question, usually not answered, of what are the western and northern limits of Dockum strata? When the question is answered, it is often to assert that there is a distinct Dockum basin of Upper Triassic deposition in eastern New Mexico-West Texas, a concept that has been refuted.

2. The term Dockum has been applied to Triassic strata in western Kansas and southeastern Colorado (e.g., Parker, 1934; Merriam, 1963) that are much older than the Dockum; indeed these strata are not of Late Triassic age (Lucas, 1993).

3. Most of the Upper Triassic section in the Dry Cimarron Valley of northeastern New Mexico-western Oklahoma is stratigraphically above the type Dockum, but it has been assigned to the Dockum (e.g., Baldwin and Muehlberger, 1959).

4. In central New Mexico (Socorro and Lincoln Counties), the term Dockum has been applied in various ways to the Triassic section (e.g., Bates et al., 1947; Wilpolt and Wanek, 1951; Myers et al., 1986), including strata both older and younger than the type Dockum section.

5. In West Texas, the term Dockum has been used in various ways, to refer to all or part of the Triassic section (e.g., Adams, 1929; Adkins, 1932, Reeside et al., 1957).

Furthermore, in all the above areas, the term Chinle has also been applied to some or all of the Triassic strata.

Previously, I have tried to retain the term Dockum, using it as a formation in the Chinle Group and restricting its use to West Texas (e.g., Lucas, 1993; Lucas et al., 1994). But now I believe it would be much simpler if the term Dockum were abandoned altogether. The NACSN (1983) certainly allows for this by stating (Article 20a) that "widespread misuse in diverse ways which compound confusion" may justify abandonment of a stratigraphic name. Dockum has been so misused, and it should die a merciful death.

All Upper Triassic strata from the Colorado Plateau to West Texas represent one integrated depositional system that produced a single, complex lithosome, so what should these strata be named? On the Colorado Plateau they are the Chinle Formation of most authors. The Chinle had a well-defined type section when Gregory (1916, 1917) named it, one that encompasses almost all of the Upper Triassic lithosome of the American Southwest. Chinle has long been used in a precise and consistent manner in a voluminous literature and a myriad of geologic maps. Further-

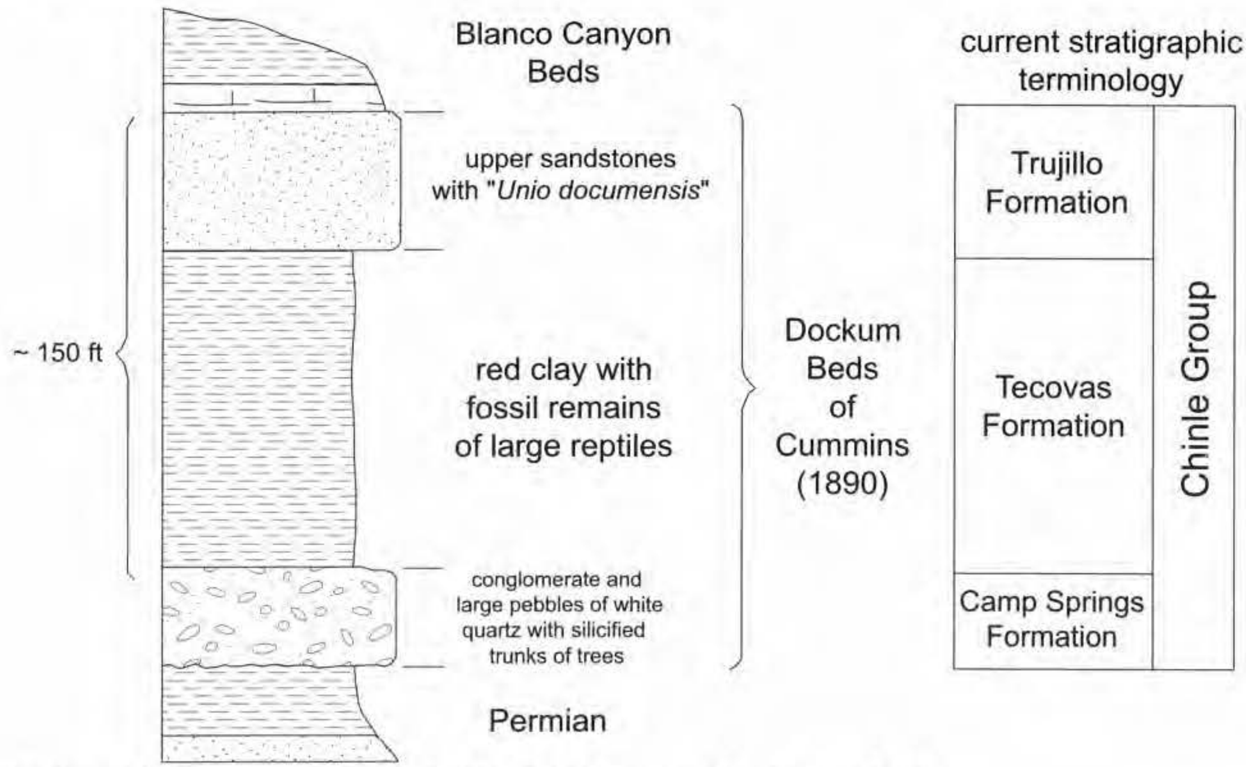

FIGURE 1.9. Stratigraphic interpretation of Cummins' (1890) original description of the "Dockum Beds."

more, the term has been used in eastern New Mexico and West Texas by several workers, dating back to at least the 1930s.

Therefore, I prefer to assign all Upper Triassic nonmarine strata in the American Southwest to the Chinle Group (Lucas, 1993). Dockum admittedly has priority over Chinle (as do the names Dolores and Popo Agie, for Upper Triassic deposits in Colorado and Wyoming, respectively: Lucas, 1993), but Chinle is a much more widely used name with a type section that represents more of the Chinle Group than the original Dockum section of Cummins. I have no doubt that the term Dockum will remain in use in the parochial literature of Texas geology, but for those interested in a precise and consistent nomenclature for the Upper Triassic strata of the American Southwest, all Upper Triassic strata in West Texas can be referred to as Chinle Group divided into formations and members as appropriate (Fig. 1.9).

138.3 Turn right to go down hill. **0.8**

139.1 Begin descent into Palo Duro Canyon. Roadcut to left is in the Ogallala Formation (Group). **0.2**

139.3 Contact between the Ogallala and underlying Triassic Trujillo Formation at green band on left. **0.2**

139.5 Good Trujillo Formation outcrop on right. **0.2**

139.7 Unconformable contact of Upper Triassic Trujillo Formation sandstones and conglomerates over Upper Triassic Tecovas Formation mudstones on right. **0.3**

140.0 Contact of the Upper Triassic Tecovas Formation (redbeds) over the Upper Triassic Camp Springs Conglomerate (white conglomeratic sandstone) at 9:00. **0.2**

140.2 Unconformable contact of the Upper Triassic Camp Springs Conglomerate (white conglomeratic sandstone) over the Upper Permian Quartermaster Formation (orange siltstones and sandstones) on right. **0.1**

140.3 **STOP 3.** Turn right into Pioneer Amphitheater. Here, we can examine an excellent exposure of the Permian-Triassic disconformity (Fig. 1.10) and discuss the following points:

1. The Quartermaster Formation is the stratigraphically highest Permian unit in the Texas Panhandle, and it is the equivalent (senior synonym) of the Dewey Lake Formation of the Midland basin to the south (Lucas and Anderson, 1994). The only biostratigraphically significant fossils from the Quartermaster Formation are three molluscan taxa from Briscoe County, Texas—*Naticopsis transversus* (Beede), *Schizodus oklahomaensis* Beede and *Myalina acutirostratus* Newell and Burma—that suggest a Permian age (Roth et al., 1941). Magnetostratigraphy indicates a Permian age for the Quartermaster Formation—it preserves the mixed polarity characteristic of the Illawara zone of the latest Permian (Molina et al., 1989, 2000). Two ash beds in the Quartermaster Formation at Cap-

FIGURE 1.10. Outcrop of the Permo-Triassic boundary at Stop 3--Permian Quartermaster Formation (Q) beneath Upper Triassic Tecovas Formation (T).

rock Canyon State Park, east of here, have been radioisotopically dated (remember that the Permian-Triassic boundary is well calibrated at ~ 251 Ma: Bowring et al., 1998). K/Ar ages are 261 $\pm$ 9 Ma and 251 $\pm$ 4 Ma (Fracasso and Kolker, 1985; Kolker and Fracasso, 1985). Ar/Ar ages, only published in an abstract (Renne et al., 1996), are 251.2 $\pm$ 0.6 Ma and 249.4 $\pm$ 0.7 Ma, and the latter date was not an ideal plateau age. On face value, these dates suggest that the uppermost Quartermaster Formation may be of earliest Triassic age. Indeed, Schiel (1987, 1988) suggested this based on lithologic similarity of the Quartermaster and Early Triassic portion of the Moenkopi Formation on the Colorado Plateau. We are inclined, nevertheless, to trust the ages given by the bivalves and the magnetostratigraphy, and consider the entire Quartermaster Formation to be Late Permian.

2. There is a substantial unconformity between the Quartermaster Formation and the base of the overlying Chinle Group, representing a hiatus of nearly 25 million years. The age of the Chinle Group base is well constrained biostratigraphically, and Palo Duro Canyon is a critical locality in this constraint. Thus, here, in the basal Camp Springs Member of the Tecovas Formation, a skull of the phytosaur *Paleorhinus* was collected (Fig. 1.11). *Paleorhinus* also is found in the marine Opponitzer Schichten of Austria, strata of late Carnian (Tuvalian) age (Hunt and Lucas, 1991). Other *Paleorhinus*

FIGURE 1.11. Dorsal view of skull of the phytosaur *Paleorhinus* found in the Camp Springs Member of the Tecovas Formation at Palo Duro Canyon.

records are in the lowermost Chinle Group in Texas, Arizona and Wyoming, and in Morocco, India and Germany—all strata of late Carnian (Otischalkian) age based on their vertebrate fossil assemblages, palynoflora and other data (Fig. 1.12) (Hunt and Lucas, 1991; Lucas, 1998). The best estimate of a late Carnian date is about 228 Ma, based largely on an Ar/Ar age from Argentina (Rogers et al., 1993). Therefore, the Quartermaster-Chinle hiatus is a gap from ~251 Ma (or slightly older) to ~228 Ma.

3. McGowen et al. (1979, 1983), Granata (1981) and Johns and Granata (1987) interpreted Tecovas Formation mudstones as lacustrine beds, and Trujillo Formation sandstones/conglomerates as easterly flowing rivers and river deltas that flowed into the lake. Indeed, they reconstructed a Late Triassic lake basin that covered much of West Texas, their "Dockum lacustrine basin." However, this idea has not withstood critical scrutiny.

Tecovas mudstones encase small fluvial channels, contain nodular calcretes and other evidence of pedogenesis and yield fossils of terrestrial plants and animals. These mudstones thus closely resemble Chinle Group mud-

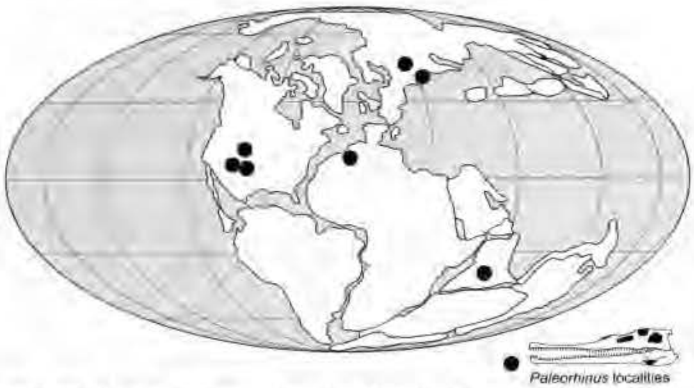

FIGURE 1.12. Late Triassic Pangea showing the distribution of *Paleorhinus* localities.

stones of the Colorado Plateau long interpreted as the deposits of floodplains, stable interfluves and small, isolated ponds (e.g., Dubiel, 1989). Furthermore, paleocurrents measured in Upper Triassic strata on the High Plains of eastern New Mexico and West Texas are generally directed to the northwest (Cazeau, 1960; Kiatta, 1960; Lupe, 1988; May, 1988; DeLuca and Erickson, 1989; May and Lehman, 1989). Riggs et al. (1996) also used age groups of detrital zircons found across the entire Chinle basin to establish paleoflow from the Dockum in the southeast across the Chinle to offshore deposits in Nevada. Yet, McGowen et al. (1979, 1983) combined a few easterly paleocurrent indicators with the generally northwest-southeast orientation of Triassic sand bodies in the subsurface to reconstruct a regional Late Triassic paleoslope down to the east. The orientations of the sand bodies, however, are bidirectional flow indicators consistent with paleoflow to the northwest. Chinle Group sedimentation in West Texas thus was by rivers flowing primarily to the northwest and their associated floodplains (Lucas and Anderson, 1992). No evidence of extensive lakes exists in Chinle Group mudrocks in West Texas.

After stop retrace route to park entrance. 2.9

143.2 Park exit. Retrace route back to Canyon. **8.3**

151.5 Stop sign and light at Texas Farm Road 1541. Continue straight. **1.9**

153.4 Pass under I-27 overpass at eastern edge of Canyon. **2.2**

155.6 **Turn right onto Highway 87** at light at 23rd Street. **0.3**

155.9 **Get into right lane** at 2nd Avenue. Entrance to West Texas State University to right. **0.3**

156.2 Junction with US-60, **go right onto on ramp to Hereford**. **0.3**

156.5 Bear right to Hereford on West US-60 (the Woodie Guthrie Memorial Highway). **2.4**

158.9 Breaks at 2:30 are head of a tributary to Palo Duro Canyon. **7.4**

166.3 Enter Umbarger. Umbarger was founded with a two-room schoolhouse in 1902. It grew in 1915 when the Panhandle and Santa Fe Railroad arrived. During World War Two, about 7000 Italian prisoners of war were housed in Hereford, and they carved a wooden reproduction of Da Vinci's "The Last Supper" in the Umbarger church as well as painting a ten-foot canvas of the Assumption (Metz, 1994). 1990 population = 327. **0.2**

167.5 Road to left leads to Buffalo Lake. **1.4**

168.9 Picnic area on right. **1.9**

170.8 Buffalo Lake at 9:00. **0.8**

171.6 Re-entering Deaf Smith County. **1.8**

173.4 Enter Dawn, Texas. The story goes that in 1887, founder J. T. Parrish referred to the town as either "dawn of a new country" or "dawn of civilization." We invite you to look around and draw your own conclusions! 1990 population = 94. **1.8**

175.2 Large gravel pit on left. **6.3**

181.5 Hereford Municipal airport to right. **2.2**

183.7 Junction with Texas Farm Road 2943 to Dimmitt; entering greater Hereford. Dimmitt was founded in 1890, and is the seat of Castro County; 1990 population = 4408. **1.1**

184.8 Hereford city limits. Hereford, the seat of Deaf Smith County, was named in the 1890s for the large herds of Hereford cattle that were raised in this area. The local groundwater is rich in fluorine and iodine, so Hereford is known as the "town without a toothache." In 1881, one of the first barbed wire fences in Texas was erected here to prevent cattle from the T Anchor Ranch from drifting south (Metz, 1994). Local feedlots process 3 million cattle a year. Hereford is also home to the National Cowgirl Hall of Fame and Western Heritage Center. 1990 population was 14,745. **1.8**

186.6 Junction with Texas Farm Road 1259 (Main Street); continue straight. **0.5**

187.1 **Turn right** on North US-385 (25 Mile Avenue). **Immediately get into left lane**. **0.7**

187.8 **Turn left on Texas Farm Road 1058** toward Grady at its junction with 211. **0.8**

188.6 Leaving Hereford. **5.2**

193.8 Junction with Texas Farm Road 1057. **0.5**

194.3 Pass through playa lake. **1.0**

195.3 Westway. **5.8**

201.1 Pass over small ridge of Ogallala Group. Note playa lake to right. **1.3**

202.4 Aromatic stockyard to left. **2.6**

205.0 Texas Farm Road 2298 to Friona to left. Established as "Frio" in 1898 as a shipping station on the Pecos Valley and North Texas Railway, the town took its name from nearby Frio Draw. 1990 population was 3600. **2.3**

207.3 Note Ogallala Group deposits in trench on right in large playa basin. **2.0**

209.3 Playa lake on right. **1.5**

210.8 Village of Bootleg. Formerly Bootleg Corner, the town dates back to the early 1900s. It was either named for a moonshine still, or more likely for a "bootleg school." Such schools were small buildings built by a land syndicate to convince prospective buyers that there was a school near land they were buying (clever folks, those Texans!). **0.2**

211.0 Junction with Texas 214 to Adrian, continue straight. **6.5**

217.5 Mailbox for Garcia Lake. Low Chinle (Bull Canyon Formation) redbeds in slopes under Ogallala Formation deposits at 3:00. **4.3**

221.8 Playa on left. **0.5**

222.3 Cross through playa. **1.7**

224.0 Enter New Mexico. Note asphalt change—road is now NM Highway 241. **3.7**

227.7 Enter Bellview, a tiny (population 15) community dating from 1905. Several settlements formed in this area around 1905, each with a different post office. Rosedale was on the present site of Bellview and it took its current name in 1918, although the Baptist church still retains the name Rosedale. The village may have received its name from a local school named Liberty Bell (Julyan, 1996) or it may be a variant of *belle vue*, French for a beautiful view, as a humorous allusion to the lack thereof. **6.0**

233.7 Enter Broadview, population 50, founded about 1925. Broadview was first named Boney Curve, for a prominent local family and the fact that it lies on a conspicuous bend in the highway. When the post office was established in 1931, the community settled on the name Broadview. Broadview lies on a slight rise, so it does allow a broad view of the high plains (Julyan, 1996). **0.1**

233.8 NM-241 ends at junction with NM-209. **Bear right on NM-209** after stop sign. **4.4**

238.2 Playa lake on left. **1.0**

239.2 Enter Grady, one of New Mexico's smallest incorporated towns (population 110 in 1990). Grady was founded in 1907 in eager anticipation of the arrival of the AT & SF railroad. It is still waiting! The town was named after a local lady, likely the first postmistress and owner of most of the original town site. Grady still retains a school and is a force in small school high school athletics. It survives as a farming and ranching community. The town has lost more than half of its population since 1940. Be aware of speed traps at speed limit changes. **0.5**

239.7 **Turn right on NM-469** to go north toward San Jon. **3.0**

242.7 Quay County line. **0.9**

243.6 Slow down and stay on main road through hard curve to left. **1.0**

244.6 Playa on right. **1.0**

245.6 Slow through hard curve to right. Roads are on section lines with mile or mile- multiple spacing. **1.0**

246.6 Junction with NM-231; continue straight. **0.9**

247.5 Abandoned schoolhouse on left at Wheatland is made from sandstone from the Upper Triassic Redonda Formation quarried off the caprock ahead (Fig. 1.13). Slabby calcarenites such as these formed on the shorelines of the Redonda lake. They are more commonly used for paving than in wall construction in this area. Wheatland was settled and named in about 1915 as a result of a ballot when three school districts were consolidated. It was named for the main crop that formerly was cultivated in this area (Julyan, 1996). It has been a near ghost town since 1965, when the post office closed. **1.1**

248.6 Junction with NM-275, continue straight. **2.0**

250.6 Sharp bend to left for offset between principal meridians. **0.7**

251.3 Road bends hard right. **0.8**

252.1 Edge of caprock and Ogallala Formation deposits visible at 2:00. **1.2**

253.3 Road bends hard right just before TV translator. View to north of Canadian country. **0.2**

FIGURE 1.13. The abandoned schoolhouse at Wheatland built from slabs of Triassic sandstone.

253.5 Sign reads "Caprock, elevation 4900." San Jon archeological site is east of here (see accompanying minipaper). **0.2**

THE SAN JON SITE, QUAY COUNTY, NEW MEXICO

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The San Jon site is an important archaeological and Quaternary stratigraphic locality on the northwestern edge of the Southern High Plains (Hill et al., 1995; Holliday, 1997). The site was discovered in 1940. The first systematic research was an archaeological excavation in 1941 by Frank H.H. Roberts of the Smithsonian Institution (SI) (Roberts, 1942) with accompanying geological studies by Sheldon Judson, a graduate student at Harvard University working under noted geomorphologist Kirk Bryan (Judson, 1953). Additional stratigraphic work was carried out by Jerry Harbour of the University of Arizona in the 1960s (Harbour, 1975). The authors began continuing archaeological and geoarchaeological work in 1995.

The sediments, soils and artifacts are exposed in an eroded "playa" basin, one of thousands of small depressions that dot the surface of the High Plains (Gustavson et al., 1995; Holliday et al., 1996). The basin fill was dissected in the late Holocene when the prominent High Plains escarpment was breached, and a system of deep arroyos formed as tributaries to the breach (Fig. 1.14). The playa fill containing the archaeological material is preserved in several peninsulas or promontories isolated between arroyos (Fig.1.14).

The San Jon basin has a complex history of filling. The regional surface of the High Plains is underlain by the Blackwater Draw Formation, composed of Pleistocene eolian deposits and buried soils (Reeves, 1976; Holliday 1989, 1990). Below are Neogene eolian and alluvial sediments of the Ogallala Formation. The High Plains escarpment is formed by the famous "Ogallala Caprock Caliche," developed in the upper Ogallala Formation. Bedded pink and buff sands of the Ogallala are exposed low on the arroyo walls in the site. The well-developed, deep reddish brown soils and buried soils of the Blackwater Draw Formation are exposed in the upper arroyo walls below the playa fills.

The archaeological material is associated with late Quaternary sediment that filled a playa cut into Pleistocene deposits that filled an older, larger basin (Fig.1.15). The older Pleistocene basin was inset against the Blackwater Draw Formation (Hill et al., 1995; Holliday et al., 1996). Its fill covered an area that probably was over 700 m in diameter. The younger basin with the archaeological deposits probably was about 360 m in diameter. The late Quaternary sediments, up to 10 m thick, almost completely filled the younger basin before canyon entrenchment. The following geoarchaeological discussion focuses on the late Quaternary sediments in the smaller, younger basin.

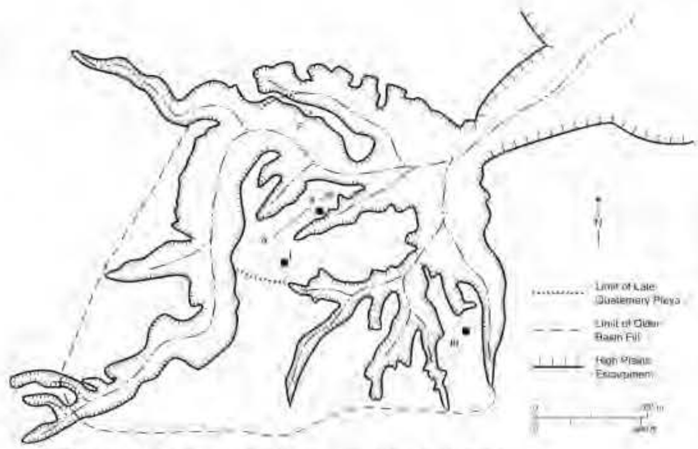

FIGURE 1.14. Map of the San Jon archeological site.

Two basic lithologies were identified in the playa fill. Most of the archaeologically significant sediments are a light gray (sometimes greenish gray) to dark gray, silty loam mud, essentially identical to the Randall Clay soil series (a vertisol) mapped in most playas. Toward the basin margins, especially to the west, southwest and south, there are layers of reddish brown, somewhat sandier loam and silty loam interbedded with the darker muds. Some of these sandier, redder layers are bedded, and other redder deposits are massive, homogeneous and have a higher content of fines. The redder facies of basin fill also exhibits pedogenic modification (Bw and Bt soil horizons), indicative of landscape stability and weathering prior to burial. The fill in the center of the basin essentially is a homogeneous accumulation of the gray muds, but toward the basin margin in the area of most of the archaeological excavations (Area II, Fig.1.14) this deposit splits into four layers (1m-4m: Fig.1.15). There also are four layers of the redder, sandy sediment (1s-4s: Fig.1.15). The gray mud probably is lacustrine and palustrine fill. The coarser, redder deposits include some alluvium from slopewash, and a high content of eolian sediment. The oldest fill in the sequence, stratum 1m, began accumulating >12,000 rcyr BP (radiocarbon years before present), based on dating of the upper 1m. Otherwise the age of the basin or beginning of filling is not known. Filling continued episodically during the late Quaternary. The youngest basin fill is dated to ~1900 rcyr BP. Erosion began sometime after that date.

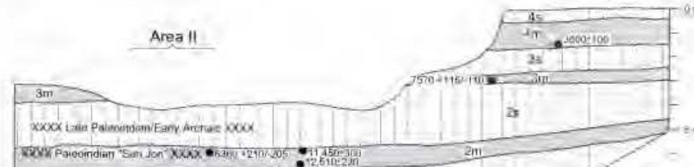

FIGURE 1.15. Stratigraphic cross section of the San Jon archeological site (see location on Figure 1.14).

A number of occupation layers were found at and around the San Jon basin. The best known is near the top of stratum 2m in Area II (Fig.1.15). The SI crew tested a bone bed in 1941 where at least five *Bison antiquus* were represented (Hill et al., 1995). A notable characteristic of some of the bone is that lower limb units were recovered articulated and in an upright position in the mud (Roberts 1942, pl. 3.1; Hill et al., 1995, fig. 7). This situation suggested that animals were mired in mud, died and subsequently were butchered. Data are not available to indicate whether the animals died naturally and then were scavenged or were purposely killed by hunters. A single projectile point was recovered from this feature: an unfluted lanceolate projectile point named "San Jon" by Roberts (1942, p. 8), subsequently identified as a reworked Firstview point (Hill et al., 1995; Knudson, 1995). The bone bed dates to ~8400 rcyr BP.

Above the bone bed, in the sandy sediment of stratum 2s, is an occupation surface discovered by the senior author in 1993. The zone has been the object of intense archaeological investigation by the junior author. The occupation zone consists of considerable debris from stone tool manufacture, as well as broken or discarded stone tools, charcoal and burned rock. The artifacts include several side-notched projectile points similar in morphology to varieties from the central and eastern United States considered to be very Late Paleoindian or Early Archaic. This occupation is dated at ~8000 rcyr BP.

Roberts and the SI crew also discovered and tested a bone bed at the southeastern edge of the basin, in Area III. The bone probably was in stratum 4m (≤3600 rcyr BP), though direct stratigraphic correlations with other areas of the site are impossible because of the intervening arroyos. Portions of seven *Bison bison* were recovered (Hill et al., 1995).

Beginning in 1996, archaeological crews from Texas Tech University have conducted extensive archaeological surveys throughout the large San Jon basin. A number of occupation areas, both buried and at the surface, were found.

The San Jon site has proven to be significant for several reasons. Playa basins undoubtedly were attractive to Native American groups since they first arrived in the region >11,000 rcyr BP. San Jon, however, is one of the few playas where an intact archaeological record has been found (probably because it is one of the rare playas where the fill is exposed). More broadly, it is one of the few sites in the region in any setting with a documented record of multiple, *in situ* occupations spanning the Paleoindian, Archaic and Late Prehistoric traditions. The exposures and the well-stratified and well-dated fill also provide an opportunity to study late Quaternary environmental changes. Samples were collected and are being analyzed (as of the winter of 2000-2001) for stable-carbon isotopes and phytoliths.

253.7 Road to Caprock Amphitheater to right. Begin descent from Llano Estacado. **0.2**

253.9 Ogallala Group roadcuts on left. **0.1**

254.0 Roadcuts of the Cretaceous Pajarito and Mesa Rica formations on left. **0.2**

254.2 Roadcuts of Lower Cretaceous Tucumcari Formation on left. **Prepare to turn into pull out on right. 0.1**

254.3 **STOP 4** at well exposed section of Tucumcari Formation on both sides of highway (Fig. 1.16). The Tucumcari Formation is a marine unit containing a moderately diverse late Albian (late Early Cretaceous) invertebrate fauna (see Kues and Lucas, this volume) that is widely exposed in Quay and eastern Guadalupe Counties. It consists mainly of dark gray shale and mudstone, with thin siltstone, sandstone and shell conglomerate horizons, representing open bay to middle shoreface environments (Scott, 1974).

The Tucumcari Formation was deposited along the western shoreline of the late Albian seaway that extended north across Texas, Oklahoma, Kansas, and eastern New Mexico, linking up briefly with a northern seaway in Colorado. Regression following Tucumcari deposition, resulting in the deposition of the largely nonmarine overlying Mesa Rica Sandstone, severed this link, which was subsequently reestablished, for a longer time, with onset of the Cenomanian Greenhorn transgression (Fig. 1.17). The Tucumcari fauna, together with a similar but less diverse fauna from the Glencairn Formation of northeastern New Mexico, western Oklahoma and southeastern Colorado (see Kues and Lucas, 1987), constitutes the "western endemic center" of the Southern Western Interior biogeographic province of Scott (1986). The Tucumcari fauna is thus distinct from that of the "eastern endemic center" (Kiowa Formation of south-central Kansas), and

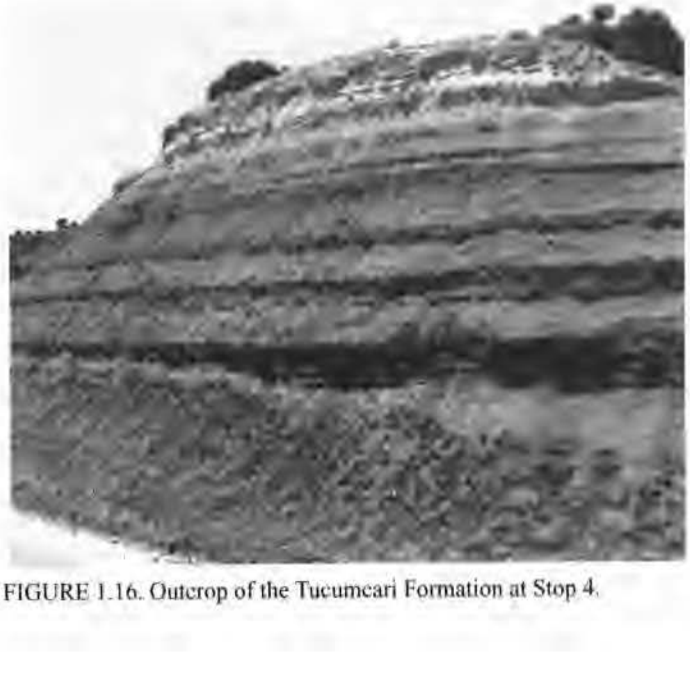

FIGURE 1.16. Outcrop of the Tucumcari Formation at Stop 4.

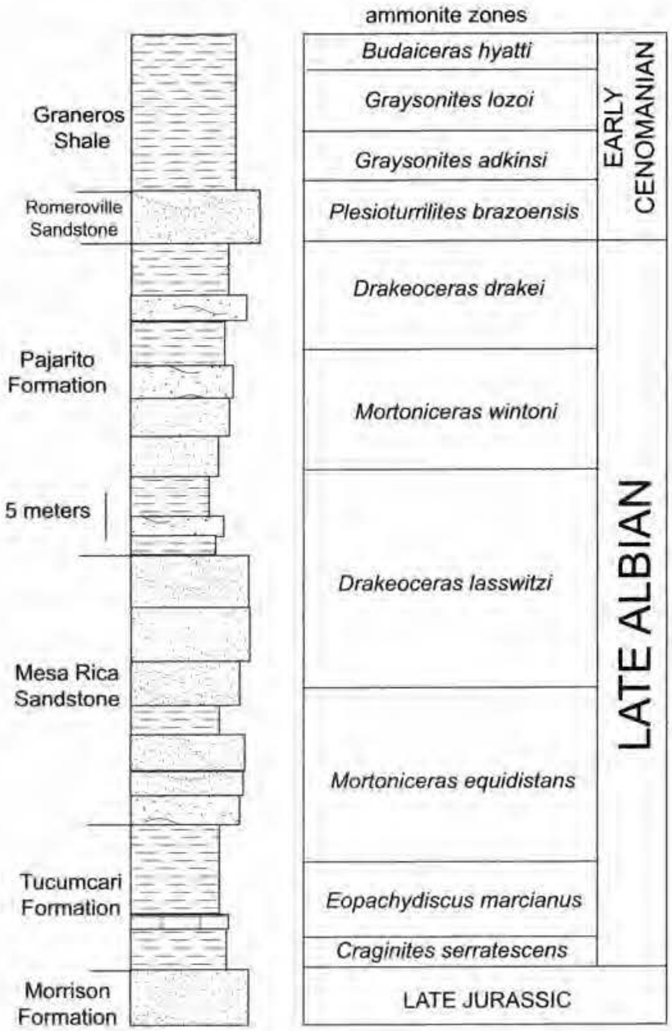

FIGURE 1.17. Summary of the Lower Cretaceous section in east-central New Mexico.

the subtropical Caribbean Province (extreme southern New Mexico, extending into northern Mexico and eastward across Texas).

Here, at San Jon hill, the Tucumcari disconformably overlies the Brushy Basin Member of the Upper Jurassic Morrison Formation, and is about 25 m thick. Only the lower few meters are exposed on the south side of the highway, but the entire Tucumcari Formation is exposed in the tall roadcut on the north side (Fig. 1.16), where it underlies 5-6 m of massive, orange-brown sandstone with late Albian marine fossils representing the basal Mesa Rica Sandstone. The San Jon hill section is probably the most intensively studied exposure of the Tucumcari Formation. Brand and Maddox (1972), Scott (1974) and Lucas and Kisucky (1988) described the stratigraphy of the section, the latter authors establishing it as a primary reference section for the Tucumcari Formation. Scott (1974) studied its sedimentology and faunal associations, and Kues (1997) reported on a distinctive fauna in the basal part of the formation.

Many benthic marine invertebrate fossils typical of the Tucumcari Formation can be observed at this locality. On the low southern roadcut, the lowest 1.5 m contain faunal elements that predate the earliest Tucumcari strata at most other localities in the region, especially the exogyrid oyster *Ceratostreon texanum*. This species is common and characteristic of older Albian strata across Texas and southern Oklahoma, and its presence here is an unusually late occurrence. Two other recently described species, the small ribbed bivalve *Plicatula quayensis* and a small round oyster, *Gyrostrea hinchada*, occur with *Ceratostreon texanum* in the basal Tucumcari Formation. A little higher on the south road cut, beginning about 3 m above the base of the Tucumcari, a more typical fauna appears, including the large oyster *Texigryphaea pitcheri* (formerly known as *T. tucumcarii*, but found to be a synonym of *T. pitcheri*, originally described from Oklahoma: Kues, 1989), abundant specimens of the small, curved, costate oyster *Peilinia levicostata* (identified as *Lopha quadriplicata* in earlier work on the Tucumcari fauna), *Plicatula incongrua*, and the pectinid bivalve *Neithea occidentalis*.

Across the road, in sandier horizons along the western end of the northern road cut, large numbers of *T. pitcheri* have weathered free on the slopes, together with a variety of other bivalves (especially *Peilinia* and *Neithea*) and the high-spired gastropod *Turritella seriatimgranulata*.

Farther upsection, the Tucumcari grades into the basal, massive, orange-brown sandstone of the Mesa Rica Sandstone. These beds contain a nearshore, bivalve-dominated fauna that includes many of the taxa found below in the Tucumcari Formation (see accompanying minipaper). This lower marine facies of the Mesa Rica is absent in most exposures of the formation, including at the type section on Mesa Rica, to the north (Lucas and Kisucky, 1988). Above the basal marine unit, the overlying 15-20 m of the Mesa Rica is regionally a cliff forming, mainly orange-to-brown sandstone deposited in a south- to southeasterly- prograding fluvio-deltaic complex (e.g., Holbrook and Wright, 1992), and lacks marine fossils.

After stop continue north on highway. 0.1

LATE ALBIAN MARINE INVERTEBRATE FAUNA FROM THE BASAL MESA RICA SANDSTONE AT SAN JON HILL, NEW MEXICO

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The basal Mesa Rica Sandstone at San Jon hill is a light brown to orange-brown, 3+ m-thick, cliff-forming, fine- to medium-grained quartz sandstone unit, locally containing small to occasionally large (30 mm) chert pebbles. This massive unit is overlain by about 2 m of softer, slope-forming, brown-to-gray, mottled sandstone. The lower massive unit is locally highly bioturbated, with sparse body fossils, but near the top is a thin horizon that is abundantly fossiliferous, consisting mainly of bivalve steinkerns and some shell material, which continue into the overlying, less well indurated sandstone. These fossils are largely the same taxa as occur in the underlying Tucumcari Formation, and, following Scott (1974), this fauna lived in a mid- to upper shoreface environment, above wave base and close to the shoreline, in shallow marine conditions marked by an unstable sandy substrate. The environment and fauna reflect a shallowing of the Tucumcari sea, and therefore these sandstones were included in the Tucumcari Formation by Scott (1970a, 1974), whereas Griggs and Read (1959), Brand and Maddox (1972) and Lucas and Kisucky (1988) considered them to be better placed within the Mesa Rica Sandstone on lithological grounds. The ammonite *Mortoniceras equidistans* occurs in the basal Mesa Rica at other localities (Kues et al., 1985: Cobban, 1985: Lucas and Hunt, 2000), and the *M. equidistans* range zone extends down into the upper part of the Tucumcari Formation, indicating that there is little or no time missing at the contact of the Tucumcari and Mesa Rica formations. The upper Tucumcari-basal Mesa Rica strata are approximately correlative with the upper Duck Creek Formation of the classic eastern Texas Albian sequence (Kues, 1997).

The fauna of the basal Mesa Rica is generally poorly preserved, consisting of steinkerns of many mollusc taxa, together with shell fragments to occasional complete valves of some bivalves, especially ostreid and gryphaeid taxa. Bivalves dominate this fauna, comprising both the great majority of identifiable taxa, and most of the specimens collected. *Scabrotrigonia emoryi, Protocardia texana, Peilinia levicostata*, and *Pleuriocardia kansasense* are the most abundant bivalves in the basal Mesa Rica collections; *Flaventia belviderensis, Homomya* sp., *Neithea* sp., *Plicatula incongrua, Ludbrookia* sp. and *Phelopteria* sp. are uncommon to rare. Gastropods, including *Turritella seriatimgranulata*, are uncommon and typically too poorly preserved to allow accurate identification. Moderate amounts of ostreid shell debris are present, but few specimens of *Texigryphaea* were observed, in contrast to their great abundance in some horizons of the underlying Tucumcari Formation. *Serpula* tubes are sparsely present as epizoans on bivalve shells. Discussion and illustrations of most of these taxa may be found in Kues and Lucas (this volume). In general, this fauna resembles that of the mid-shoreface *Scabrotrigonia-Turritella* association described by Scott (1974), but with few specimens of *Turritella* and considerable numbers of *Peilinia levicostata* (formally *Lopha quadriplicata*), which Scott found to be most abundant in slightly deeper water, together with *Texigryphaea*, in biostromal communities. In the basal Mesa Rica Sandstone, *P. levicostata* is far more abundant than *Texigryphaea*.

Two bivalve genera occur in the basal Mesa Rica Sandstone that have not been reported previously from New Mexico Albian sequences. The first is a small species of exogyrine oyster, with height and length about equal at 28 mm and an articulated width of 15 mm (Fig. 1.18A-B). The left valve is inflated, subcircular to vaguely subtriangular in marginal outline, with a narrow, closely coiled beak; the right valve is flat to slightly concave, and bears a strongly-coiled, depressed beak. Wide, moderately lamellate growth increments characterize the valves; radial ornamentation is lacking. On the best preserved specimen, a very large, shallowly depressed attachment scar some 18 mm in maximum diameter occupies the entire posterodorsal area of the left valve, nearly obliterating the beak. This species is quite different from *Ceratostreon texanum* from the lower Tucumcari Formation, and is unlike any other oyster reported from the Tucumcari Formation, from the Albian sequence at Cerro de Cristo Rey (Böse, 1910), or from the Albian sequences in Texas and Kansas (Stanton 1947; Scott 1970b).

The morphology of the left and right valves of these Mesa Rica specimens closely resembles that of the Cenomanian species *Rhynchostreon levis* (Stephenson), which is known from

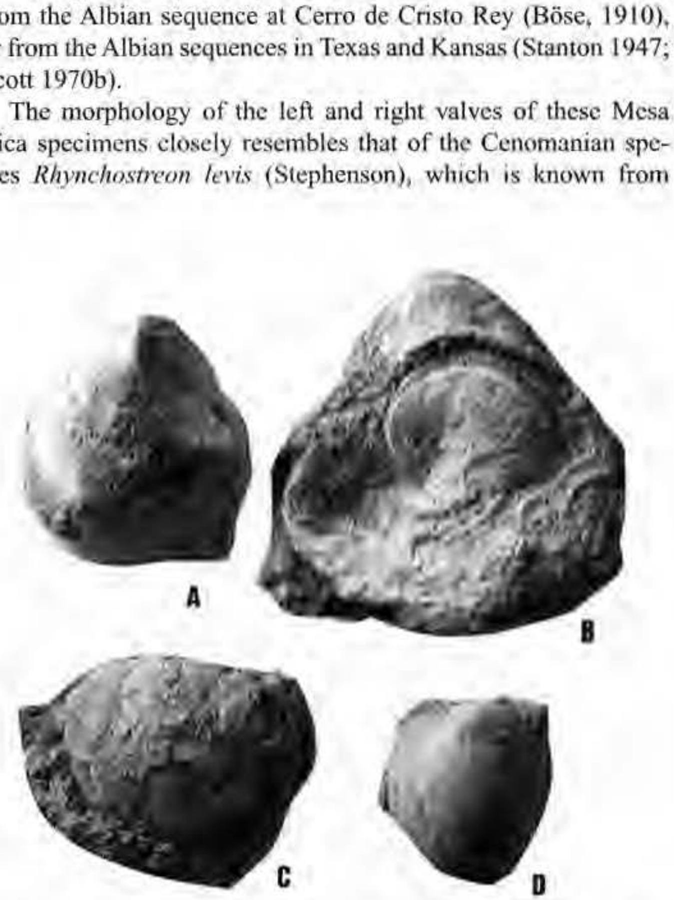

FIGURE 1.18. The bivalves *Rhynchostreon* and *Anomia* in the basal Mesa Rica Sandstone at San Jon hill. A, B, *Rhynchostreon* aff. *R. levis* Stephenson: A, left valve showing large attachment pit near beak, UNM 13,129, x 1.25; B, right valve view, same specimen, x 2. C, D, *Anomia* sp.: C, left valve, UNM 13,130, x 2; D, left valve of a small, relatively inflated specimen, UNM 13,132, x 2.

middle to upper Cenomanian strata in Texas (Woodbine Formation: Stephenson, 1952), New Mexico (intertongued Dakota-Mancos sequence: Cobban, 1977), the Black Mesa region of Arizona (upper Dakota Sandstone: Kirkland, 1996), and equivalent strata in Utah and Montana (Cobban, 1977). The Mesa Rica specimens differ from Cenomanian specimens of *R. levis* in having a pronounced attachment scar (Cenomanian specimens lack significant attachment scars), and in possessing a more strongly coiled right valve. It is doubtful that the Mesa Rica specimens are conspecific with the Cenomanian species *R. levis*, but they appear to be a closely related predecessor of that species, and are here referred to *R.* aff. *R. levis*.

Small specimens of the thin-shelled pterioid bivalve *Anomia* also occur in the basal Mesa Rica Sandstone at San Jon hill, and are reported here for the first time from the Albian of New Mexico. Only left valves are preserved, rarely completely and are generally associated with their underlying steinkern. These valves are subcircular in shape, moderately inflated and possess a slightly convex umbo that ends in a small beak that does not extend to the hingeline. The valves lack radial striae and comarginal wrinkles such as characterize some species of Cretaceous *Anomia*; ornamentation is limited to fine growth lamellae. A typical left valve is about 14 mm long, 12.5 mm high, and 3 mm wide (Fig. 1.18C). Some smaller specimens (e.g., Fig. 1.18D) are more inflated, but this may represent ecological variability (correlated with shape of substrate) rather than having taxonomic significance.

Several Cenomanian to Turonian species of *Anomia* have been described from the Texas-Southern Western Interior region (e.g., Stephenson, 1952; Hasenmueller and Hattin, 1990; Kirkland, 1996), but Albian reports of *Anomia* are rare. Hill (1893) described *A. texana* from the Trinity Group of Texas, and Scott (1970b) described an unnamed species from the Kiowa Formation of Kansas. Species of *Anomia* tend to display high intraspecific variability and are separated on the basis of rather subtle morphological features (Hasenmueller and Hattin, 1990). Preservation of the Mesa Rica specimens is not sufficient to allow identification to species, but these specimens do not differ significantly from the Kiowa specimens.

Anomia lived attached by its right valve to hard substrates, including the shells of other organisms. Turonian species described by Hasenmueller and Hattin (1990) were inferred to have been attached to the shells of the ammonoid *Baculites*, but there is no indication what the host substrate of the Mesa Rica specimens might have been. The survival of thin *Anomia* valves in the relatively high energy conditions in which the basal Mesa Rica Sandstone was deposited is somewhat surprising; most other elements of the Mesa Rica bivalve fauna have strong, thick shells, and even these were typically abraded and broken.

254.4 Upper Jurassic Morrison Formation/Middle Jurassic Entrada Sandstone contact. **0.1**

254.5 Approximate position of Entrada Sandstone/Upper Triassic Redonda Formation contact. **0.4**

254.9 Prior to a highway widening project an outstanding cross-section of a Gilbert delta in the Upper Triassic Redonda Formation was exposed in the roadcut to the left (Hester, 1988). The quarry that produced the sandstone for the Wheatland School was in this vicinity. **0.3**

255.2 At 9:00, the Redonda Formation dips north in the Bonita fault zone, which means we are passing over the northwestern edge of the buried Frio uplift (see accompanying minipaper). **7.4**

THE FRIO UPLIFT: A PALEOZOIC-MESOZOIC CONTROL ON SEDIMENTATION PATTERNS IN EAST-CENTRAL NEW MEXICO

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The Frio uplift is a structural positive element in eastern New Mexico that affected sedimentation patterns from the late Paleozoic until at least the middle Mesozoic. Here, we briefly review its influence from the Desmoinesian (Pennsylvanian) through the Kimmeridgian (Jurassic).

The Frio uplift is a northeast-trending structure that is located approximately along the southeastern Quay County line in east-central New Mexico (Broadhead and King, 1988, fig. 1). It separates the Tucumcari basin to the west from the Palo Duro basin to the east. During the Atokan and Desmoinesian (Pennsylvanian), a north/northeast-trending strip of coarse sandstone delimited the western edge of the emergent Frio uplift and separated it from marine limestones to the west (Broadhead and King, 1988, figs. 14a, b). Marine limestones of the overlying Missourian strata onlapped the Frio uplift and are absent over it (Broadhead and King, 1988, figs. 18a, b, 22a, b).

Early Permian (Wolfcampian) deposition began with the Hueco Formation. Throughout Hueco deposition, stratigraphic units thinned over the emergent Frio uplift (Broadhead and King, 1988, figs. 24a, 26a). There are also facies changes across the uplift during this time. In the lower unit of the Hueco, marine limestones grade into dolostones over the uplift, and in the upper Hueco, coarse sandstones change to marine limestones from northwest to southeast (Broadhead and King, 1988, figs. 24b, 26b). The local fine-grained nature of the Yeso Formation and the absence of thick clastic wedges indicates that the Frio uplift was tectonically inactive by the Leonardian (Early Permian). Similarly, isopachs of the Guadalupian Artesia Group show no influence of a Frio uplift (Broadhead, 1984, fig. 7)

During the Triassic, the Frio uplift was resurgent again. Isopachs of the Middle Triassic Anton Chico Member of the Moenkopi Formation and Upper Triassic Tecolotito Member of the Santa Rosa Formation by Broadhead (1984, fig. 8)--his lower sandstone unit of the Santa Rosa Sandstone--clearly demonstrate thinning over the Frio uplift. The uppermost, Tres Lagunas Member of the Santa Rosa Formation--Broadhead's (1984) upper sandstone member of the Santa Rosa Sandstone--actually pinches out over the Frio uplift (Broadhead, 1984, fig. 9). This explains the absence of the Tres Lagunas Member or any homotaxial equivalent in the Chinle Group in West Texas (Lucas et al., 1994). Between the deposition of the Tecolotito and Tres Lagunas Members in the late Carnian, ispoachs indicate that the geographic expression of the uplift was expanded.

In Norian time, there is a marked thinning of the Trujillo Formation--Broadhead's (1984) Cuervo Sandstone Member of the Chinle Formation--over the Frio uplift (Broadhead, 1984, fig. 10). The isopachs of the Trujillo Formation are more complex, but suggest that the Frio uplift had expanded in size in the early Norian, with two large areas of zero thickness in northern Curry County and southeastern Quay County (Broadhead, 1984, fig. 10). The uppermost unit of the Chinle Group in this area is the late Norian-Rhaetian Redonda Formation, which represents a large lacustrine basin (Hester, 1988). The only subaerial shoreline, deltaic and fluvial facies of the Redonda are in southeastern Quay County, indicating that the Frio uplift was still influencing sedimentation.

The Upper Jurassic sequence exposed in southeastern Quay County (Apache Canyon and San Jon Hill) exhibits a very thin Upper Jurassic Morrison Formation (< 10 m) and the absence of the Middle Jurassic Summerville Formation. This indicates onlap of these units on the Frio uplift during the Callovian-Kimmeridgian. Thinning isopachs of the Cretaceous Mesa Rica Sandstone (Mateer, 1985, fig. 3) could also be interpreted to suggest that the Frio uplift was a positive element as late as the Albian. In conclusion, it is clear that the Frio uplift had a significant impact on sedimentation patterns during the Pennsylvanian (Desmoinesian) to Permian (Wolfcampian), and the Triassic (Anisian) to Jurassic (Kimmeridgian), with a period of quiescence between the two.

262.6 Enter San Jon. Like Tucumcari, San Jon owes its origins to the railroad. The town was named in 1906 by the first postmaster, although there had been dwellings in the area since 1902. "San Jon" is meaningless in Spanish, and Julyan (1996) cited the conventional explanation that the word is a corruption of the Spanish *zanjon* or deep gully. However, elsewhere San Jon is a corruption of San Juan, so the origin of the name is problematic. The town incorporated in 1946; its 1990 population of 277 was down 33% from its height in 1960. Be aware of speed traps at speed limit changes. **0.4**

263.0 **Turn left at stop sign and continue west on old U.S. 66**. Tucumcari Mountain ahead in distance. **3.2**

266.2 Road crosses below overpass. **1.2**

267.4 Cross tributary to Revuelto Creek with exposures of Bull Canyon Formation in badlands to left and right. **0.7**

268.1 Reddish, Triassic-derived alluvium in low roadcut to left. **2.0**

270.1 Crest low ridge. Mesa Redonda at 9:00-9:30, Bulldog Mesa at 10:00, Tucumcari Mountain at 10:30. Note extensive badlands of Bull Canyon Formation in the Revuelto Creek drainage exposed in front of Mesa Redonda. **0.3**

270.4 Note outcrops of Upper Triassic Trujillo Formation in bottom of Revuelto Creek to left. **0.5**

270.9 Roadcut on right is red mudstone under uppermost Trujillo Formation sandstone. Note paleoflow indicators (trough crossbeds) are to west-northwest in these Triassic sandstones (see accompanying minipaper). **0.3**

PALEOCURRENTS IN THE TRUJILLO FORMATION (CHINLE GROUP; UPPER TRIASSIC), EAST-CENTRAL NEW MEXICO, AND THE MYTH OF THE DOCKUM LAKE

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During the late 1970s and 1980s, geologists from the Bureau of Economic Geology in Austin, Texas published a series of studies that suggested the Upper Triassic strata of the Chinle Group in eastern New Mexico and West Texas were deposited in large lakes fed by extensive river deltas (McGowan, 1979, 1980; McGowan et al., 1979, 1983; Granata, 1981; Johns and Granata, 1987; Johns, 1989). These studies were based primarily on subsurface data, but they also included limited outcrop studies. Virtually all strata of the lower Chinle (Trujillo Formation and below) were interpreted as part of a vast lake system. Mudrocks were interpreted as lacustrine, and sandstones as deltaic.

As a local test of this model, we measured 62 paleocurrents from crossbeds in the Trujillo Formation in Quay County, New Mexico, near the confluence of Revuelto and Plaza Larga Creeks (secs. 28-29 T11N, R33E). These measurements indicate a dominantly northwesterly paleoflow (Fig. 1.19), which is inconsistent with the model of McGowen and others. Similar paleocurrents were obtained from a smaller sample by Deluca and Eriksson (1989) from the Trujillo Formation in northeastern New Mexico. Clearly, Trujillo rivers in east-central and northeastern New Mexico were not flowing into lakes in West Texas.

Lower in the Upper Triassic section, Riggs et al. (1996) used age groups of detrital zircons to demonstrate through-flow of a fluvial system from highlands south and east of the Dockum across the Colorado Plateau and into an ocean in the vicinity of modern-day Nevada. Furthermore, several authors have reported paleoflow directions in West Texas from near the posited depocenter of the lacustrine basin, and these too indicate that rivers were flowing to the north and northwest (e.g., Cazeau, 1960;

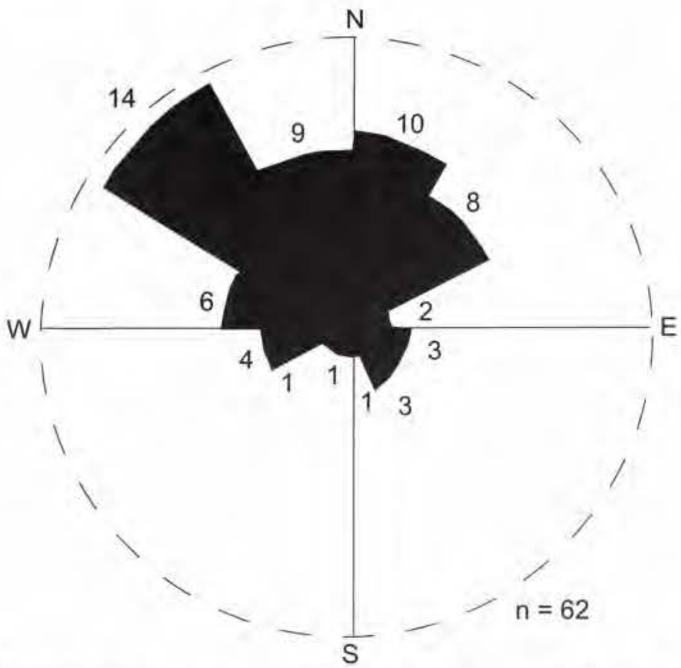


FIGURE 1.19. Rose diagram of Trujillo Formation crossbed azimuths near the confluence of Revuelto and Plaza Larga Creeks, Quay County.

Kiatta, 1960; Asquith and Cramer, 1975; Frelier, 1987; Lupe, 1988; May, 1988). Much of the case for the "Dockum Lake" was based on analysis of the orientation of sandstone bodies in the subsurface of West Texas. Newell (1993, fig. 9) was able to demonstrate that if these are plotted on a rose diagram they are consistent with a northwest flow direction.

Johns (1989) argued that east-west sections of subsurface lithofacies fence diagrams demonstrated that interbedded sandstone-mudrock "deltaic facies" could be seen to laterally grade into "lacustrine" mudstone. Newell (1993) noted that these could just as easily be interpreted as levee deposits grading into floodplain mudrocks associated with northward flowing streams. Indeed, detailed outcrop study of the Tecovas and Trujillo formations in West Texas has demonstrated that they are dominantly fluvial in origin (Asquith and Cramer, 1975; Frelier, 1987; May, 1988). Thus, the Dockum lake model is clearly contradicted by all paleocurrent data and by recent sedimentological studies.

271.2 Old Highway 66 gasoline station. **0.2**

271.4 Excellent Trujillo Formation sandstones in roadcut on right. **0.3**

271.7 Cross Revuelto Creek bridge; more Trujillo sandstones to left. **0.6**

272.3 Bridge over Plaza Larga Creek. **1.4**

273.7 Trees on left mark an abandoned picnic area along Old Highway 66. **2.3**

276.0 Cross creek with Trujillo Formation outcrops here. These outcrops are locally fossiliferous. The Trujillo Formation in this part of Quay County yields vertebrate fossils as well as a large concentration of unionid bivalves. **2.2**

278.2 Pass beneath overpass. **2.0**

280.2 Junction with NM 278. Continue straight. **0.3**

280.5 Junction with NM 286. Continue straight. **3.2**

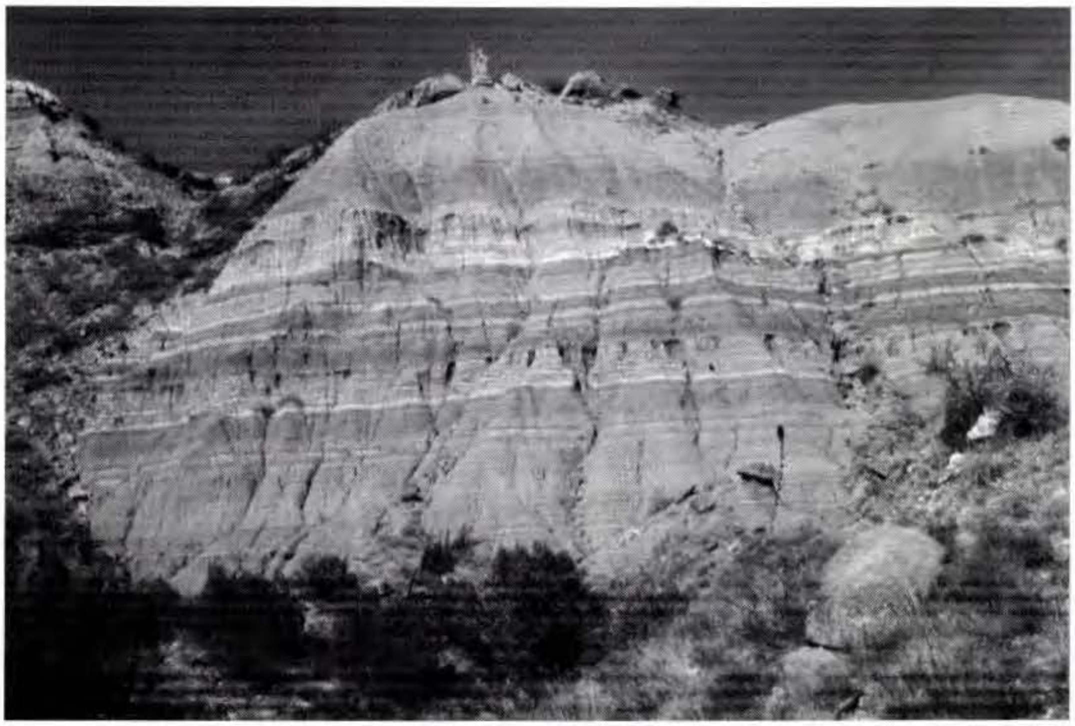
283.7 Junction with Tucumcari Boulevard. Excellent view of Tucumcari Mountain, just to south. **At yield sign turn right to go under Interstate 40** and enter Tucumcari. **1.4**

285.1 Tucumcari Lake and Tucumcari historical marker on right. The origin and age of Tucumcari Lake are the subject of some debate (Dobrovolny and Townsend, 1946; Trauger and Bushman, 1964; Love, 1985). The lake probably formed as a result of dissolution of Permian evaporites and it is at least Quaternary in age. **1.7**

286.8 **Turn right** at light at First Street (NM-104). **0.1**

286.9 **Turn right** at Laughlin and stop at Mesalands Dinosaur Museum.

End of First-Day Road log.



At Palo Duro Canyon in West Texas, Upper Triassic strata of the Chinle Group rest with profound disconformity on Upper Permian strata of the Quartermaster Formation. A white bed of pebbly sandstone marks this hiatus of approximately 25 million years.