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First-day road log, Alamogordo to Tularosa, Mockingbird Gap, Trinity Site, Oscuro, and Three Rivers

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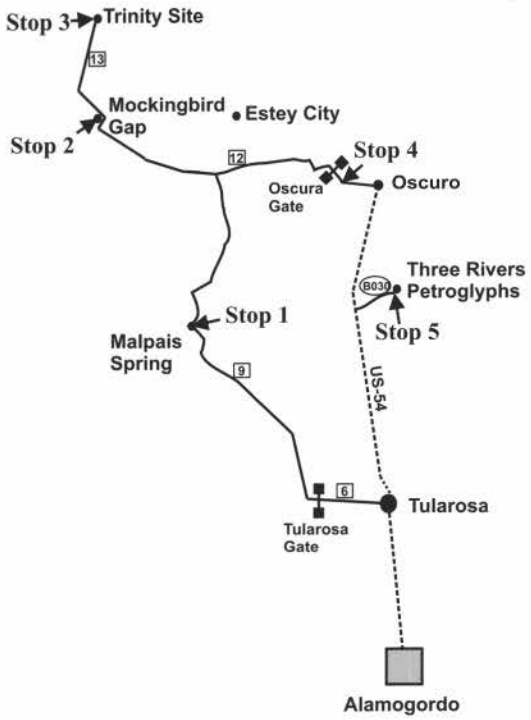
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FIRST-DAY ROAD LOG, ALAMOGORDO TO TULAROSA, MOCKINGBIRD GAP, TRINITY SITE, OSCURO, AND THREE RIVERS

SPENCER G. LUCAS, VIRGIL W. LUETH, BARRY S. KUES, ROBERT G. MYERS AND KATHERINE A. GILES



Assembly Point: Holiday Inn Express, Alamogordo
Departure time: 7:45 AM
Distance: 164.4 miles
Stops: 5

SUMMARY

Today's trip examines the geology of the northern part of the White Sands Missile Range and the region just east of the northern range, in the northern Tularosa basin and along the western front of the Sierra Blanca. We thus begin by proceeding north to Tularosa then west into the Missile Range. Stop 1 is at the southern end of the Carrizozo lava flow to discuss the nature of very long lava flows and the techniques for dating young basalts. From there, we continue northwest to Mockingbird Gap. Here, at Stop 2 we examine an example of Rio Grande rift-type fluorite mineralization. We also discuss the truncation of the lower Paleozoic section in the Oscura Mountains. The trip then continues north into the Jornada del Muerto basin to the western flank of the Oscura Mountains. Here, at the Trinity site, we discuss uplift rates of the Oscura Mountains, mineralization in the Hansonburg Hills, and Lake Trinity.

After the stop, we retrace our route to Mockingbird Gap then continue due east back into the Tularosa basin. Stop 4 is at Bull Gap, just east of the Missile Range. Here, we examine Permian, Triassic and Cretaceous strata and discuss the Laramide Sierra Blanca basin and coal deposits. From there, we proceed south to today's final stop (and barbecue) at the mid-Cenozoic volcanics of the Three Rivers Petroglyph Site.

0.0/164.4 Holiday Inn Express, Alamogordo. **Turn right** on White Sands Blvd, US-70/54 to proceed N. **(0.8)**

0.8/163.6 Light at First St. Note Sacramento Mountain escarpment to right; **continue straight**. The Sacramento Mountain escarpment (Fig. 1.1) abruptly rises nearly a vertical mile above the floor of the Tularosa basin. The mountain range is a fault block uplifted during the late Cenozoic that exposes about 8000 ft of sedimentary rocks, mostly of late Paleozoic age (Pray, 1961). It also coincides with part of the late Paleozoic Pedernal uplift, and thus marks the eastern margin of the late Paleozoic



FIGURE 1.1. Photograph of the Sacramento escarpment immediately south of Alamogordo.

Orogrande basin (Pray, 1959). **(0.3)**

1.1/163.3 New Mexico State Commission for the Blind on right. **(0.4)**

1.5/162.9 Light intersection at 10th St.; **continue straight**. Alameda Zoo and park on left. **(0.3)**

1.8/162.6 Note the "*alamos gordos*" on the left. Alamogordo (population, 37,000 by the 2000 census) was established in 1898, when the initial 960-acre townsite was purchased from Oliver Lee and platted by railroad promoter C. R. Eddy and his brother Charles. The name ("big cottonwood" in Spanish) is derived from huge cottonwood trees that grew around a small spring just southeast of the present city. Proximity to the spring, providing water for the El Paso and Northeastern Railroad, building north from El Paso, influenced the selection of this location for the town. The tracks reached the townsite in June, 1898, and Alamogordo grew rapidly, to 1200 people within its first year. It served as headquarters for the railroad, with offices, shops, and a company hospital, and became the county seat of Otero County when it was created in 1899. The town also served as terminus for a branch line that supported lumbering and recreational excursions in the Sacramento Mountains (Jentgen, 1991), and served as the major trading center for the region. Much of the lumber transported to Alamogordo was utilized in a railroad tie plant that served the entire state. Still, the town had only 4000 residents when World War II began. Construction of the Alamogordo Army Air Field (now Holloman Air Force Base) in 1942, and the proximity of the town to White Sands Missile Range and White Sands National Monument, greatly enhanced its post-war growth. **(0.4)**

2.2/162.2 New Mexico School for the Visually Handicapped on right. **(0.3)**

2.5/161.9 Light at Indian Wells Road intersection; Space Museum and New Mexico State University – Alamogordo to right. **(0.8)**

3.3/161.1 Traffic light at Fairground Road intersection; Horse Ridge, Beeman Canyon to right. **(0.7)**

4.0/160.4 Scenic Drive traffic light/intersection. **(0.5)**

4.5/159.9 Junction with Highway 82 to Cloudcroft, which drives up Fresnal Canyon and is detailed in the Day 1 road log of the 1991 NMGS Guidebook; **continue straight** (north) to Tularosa. Fresnal Canyon is the type locality of Thompson's (1942) Pennsylvanian Fresnal Group. Highway 82 drives through this section, which is 530 ft of interbedded limestone, shale, sandstone and conglomerate. Thompson's Fresnal Group strata are now referred to the Holder and Laborcita formations (Otté, 1959). **(1.5)**

6.0/158.4 Mile marker 71, type Laborcita section at 2:30 (Fig. 1.2). White Sands to the west in floor of the Tularosa Basin and the San Andres Mountains are in background. The Laborcita Formation of Otté (1959) is the Sacramento Mountains equivalent of the Bursum Formation to the north and west. Up to 480 ft thick, the Laborcita consists of interbedded marine and nonmarine strata and yields Wolfcampian fusulinacean assemblages. **(0.8)**

6.8/157.6 Traffic light at NM-545 intersection to La Luz; **continue straight** (north). **(1.1)**

7.9/156.5 Eagle Ranch on left; Sierra Blanca Peak at 2:00 on skyline. Eagle Ranch is one of the



FIGURE 1.2. Photograph of Laborcita Formation at the mouth of Fresnal Canyon, near La Luz.

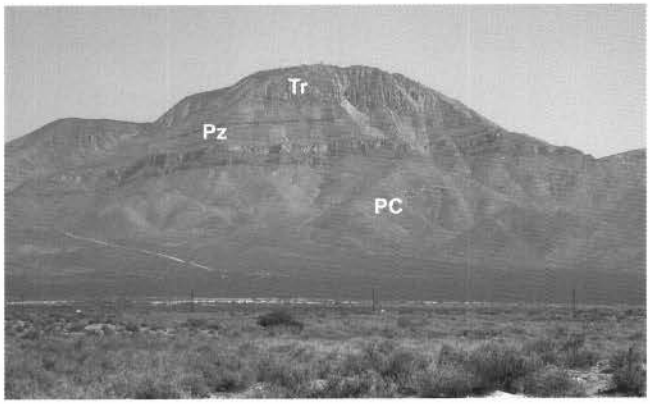


FIGURE 1.3. Photograph of Salinas Peak.

first "Pistachio Ranches" in New Mexico. Planted in 1972, the groves at Eagle Ranch now contain more than 12,000 pistachio trees that are harvested and processed on the premises. **(2.1)**

10.0/154.4 Mile marker 75; note Mockingbird Gap at 11:00 between dark Oscura Mountains at 11:30; San Andres Mountains to west; Salinas Peak, the tallest peak in the San Andres range (elev. 9040 ft) at 9:30 (Fig. 1.3). Like much of the range, Salinas Peak is a tilted fault block dipping 15 to 30 degrees to the west. Proterozoic schist forms the base of the peak. A Paleozoic section consisting of Bliss Sandstone (Cambrian) through Lead Camp Limestone (Pennsylvanian) can be seen in the middle of the mountain. A thick rhyolite sill, as mapped by Bachman and Harbour (1970), caps the mountain and controls its geomorphic expression , resulting in the broad profile. Capitol Peak at 10:00 represents a fault block mountain but with very shallow dip angles (Fig. 1.4), essentially horizontal on the peak. Proterozoic granite forms the base, capped by a Paleozoic section from Bliss Sandstone to a pointed peak of Panther Seep Formation. **(2.9)**

12.9/151.5 Tularosa Historical Marker on right. Tularosa (population 2900 according to the 2000 census) is a quiet, tree-shaded town (Spanish, tule, reed or rush, and rosa, rose) founded in the early 1860s by about 100 Spanish and Mexican immigrants from the Mesilla Valley, after flooding by the Rio Grande had wiped out their small farms. At this location, where the Rio Tularosa comes down from the Sacramento Mountains, they planted orchards and built homes and, aside from occasional problems with the Apaches, the new settlement thrived. As early as 1874, however, cattlemen became aware of the area, and began arriving with their herds and families, followed by merchants, promoters, and former Union soldiers. Cattle wars, especially one in 1888 between the Lee and Good families, political factions, and feuds shattered the tranquility of the town, and the rich grass of the Tularosa Valley disappeared in the drought of 1889-1892. Tularosa survived, and with a population of about 600 in the mid-1890s, was the largest town in the area, although quickly overshadowed a few years later by the growth of Alamogordo. The history of Tularosa has been chronicled by C. L. Sonnichsen (1963), author of "Tularosa: Last of the Frontier West."

Note Sierra Blanca to the right, which is, physiographically speaking, a northward continuation of the Sacramento Mountains. However, the range is fundamentally different from the Sacramentos to the south, as it is primarily composed of mid-Ceno-

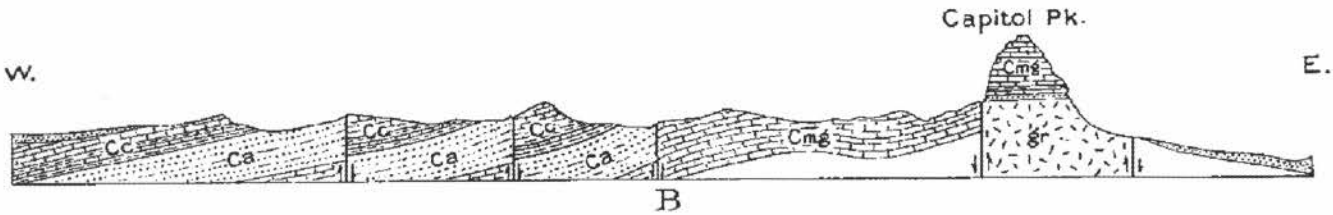


FIGURE 1.4 Cross-section of the San Andres Mountains near Capital Peak as presented by Darton (1928).



FIGURE 1.5. West to east panorama of the San Andres Mountains, Mockingbird Gap, and Oscura Mountains from the vicinity of the Tularosa Gate at the eastern boundary of White Sands Missile Range.

zoic Sierra Blanca volcanics (e.g., Thompson, 1972), not Paleozoic strata. **(0.3)**

13.2/151.2 Tularosa village limit, **get into left lane (0.6)**

13.8/150.6 **Turn left** on Higuera at Tastee Freez. **(0.2)**

14.0/150.4 Road curves left **(0.4)**

14.4/150.0 Stop sign, continue straight. **(0.6)**

15.0/149.4 Stop sign/railroad tracks; **cross tracks and turn right** on Railroad Ave. to proceed north (stay on pavement). **(0.5)**

15.5/148.9 Make **sharp left turn** here at Tularosa Gate Road (Otero County B-6) and proceed west. **(1.0)**

16.5/147.9 Intersection with Pecan Road on left, which, as if by magic, is transformed into River Road on right, **continue straight**. San Andres Mountains from 9:30–2:00 on skyline; Mockingbird Gap and Oscura Mountains at 2:30. **(0.5)**

17.0/147.4 Pecos Road to left. **(1.0)**

18.0/146.4 Note roadcuts in young alluvial fill of Tularosa basin for next 0.5 miles **(1.0)**

19.0/145.4 Enter Tularosa Gate to WSMR Range Road 6 West. **(0.5)**

19.5/144.9 Road crests hill. Good view ahead across Tularosa Basin of San Andres Mountains at 9:30-2:00, Mockingbird Gap at 2:30 and Oscura Mountains at 2:45 (Fig. 1.5).

20.4/144.0 Giant volleyball on stand to left. The conical mountain at 9:30 in the distance is Tularosa Peak, a small hill of Permian Yeso Formation strata. **(0.7)**

21.1/143.3 Cattleguard. (0.8)

21.9/142.5 **Stop sign and checkpoint**; road intersection; **turn right** onto Range Road 9 and proceed north. **(0.8)**

22.7/141.7 Cross Tularosa River. On day 2, we will pass by the termination of Tularosa Creek, Brazel Lake. **(0.2)**

22.9/141.5 Crest hill; San Andres Mountains at 7;00–11:00; Mockingbird Gap with Burro Hills at 11:30; Oscuras at 12:00; beautiful Sierra Blanca at 2:00. In the northern portion of the Tularosa Basin, the main basin structure becomes synclinal, rather than consisting of two half grabens, as is seen farther south (Fig. 1.6). **(0.3)**

23.2/141.2 Road to Dust launch site to right. **(0.7)**

25.9/138.5 Cross Temporal Creek. **(0.7)**

26.6/137.8 Burro Hills at 11:00 sit just east of Mockingbird Gap. These hills are faulted Proterozoic and Paleozoic rocks in the structural accommodation zone (Fig. 1.7) between the east-dipping San Andres and the west dipping Oscura Mountains (Bachman, 1968). **(0.8)**

27.4/137.0 Road to Rita site to right; **continue straight (0.6)**

28.0/136.4 Cross Bitter Creek **(1.2)**

29.2/135.2 Road to Phil launch site to left. **(1.0)**

30.2/134.2 The road is now traversing a stabilized dune field. **(0.6)**

30.8/133.6 Cross Three Rivers. **(0.4)**

31.2/133.2 Road curves left to cross Black Lake. **(0.6)**

31.8/132.6 Road curves right. **(0.2)**

32.0/132.4 Note well exposed Paleozoic strata dead ahead on flank of San Andres Mountains. This section will be featured tomorrow, on the second-day road log, at nearby Rhodes

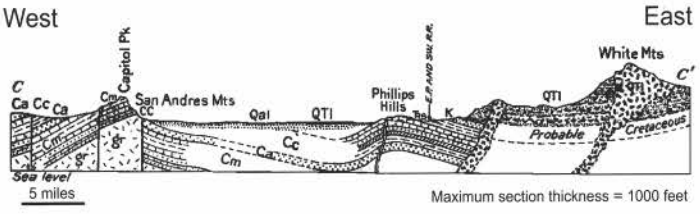


FIGURE 1.6. Geologic cross-section of the northern Tularosa Basin by Darton (1928).

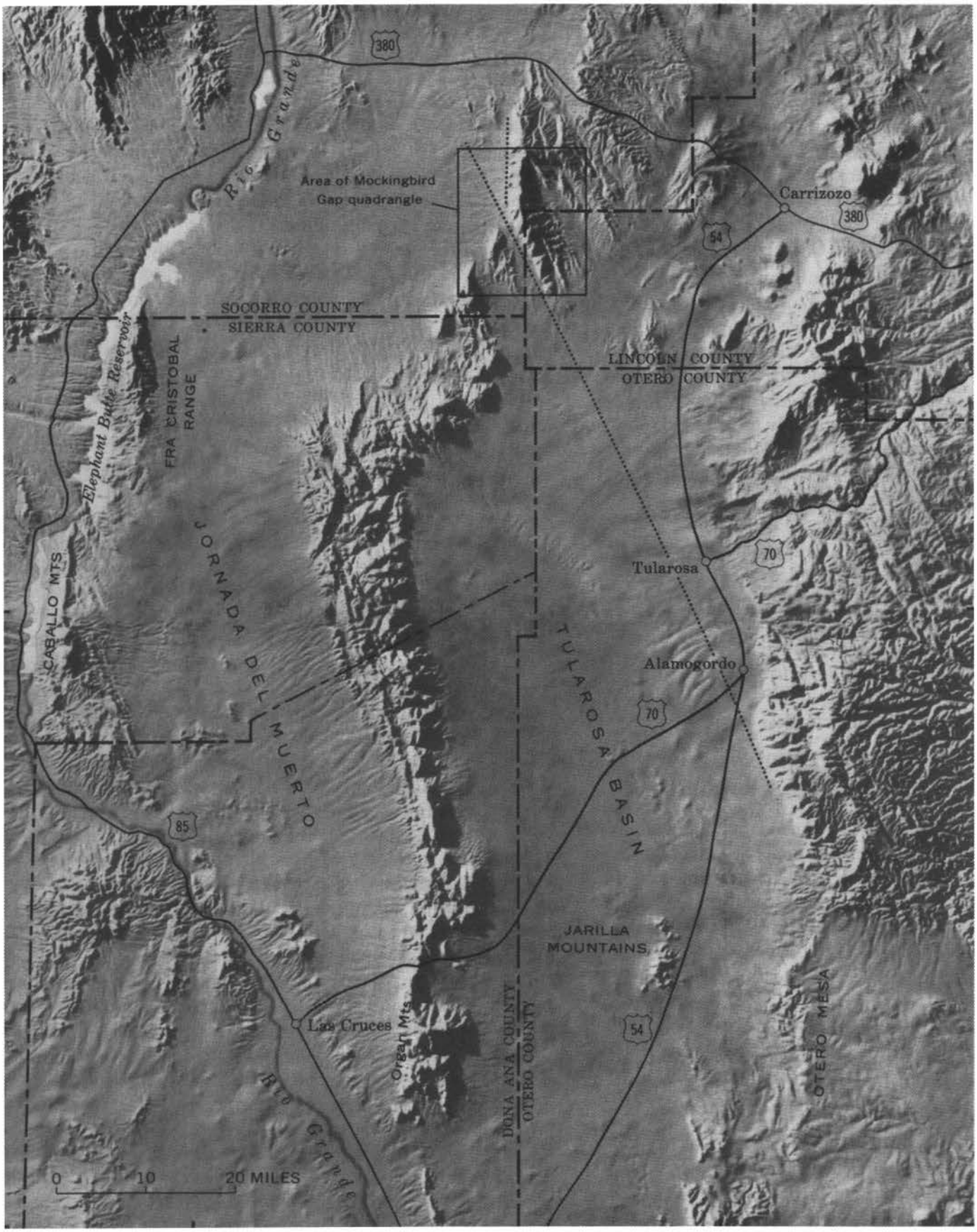


FIGURE 1.7. Physiographic map of south-central New Mexico as presented by Bachman (1968).

Canyon at 10:00. Goodfortune Canyon at 10:30, Salinas Peak at 11:00, Sly Gap and Silver Top Mountain at 11:30 and Sheep Mountain and Thurgood Canyon at 12:00 **(2.2)**

34.2/130.2 Paved road on left, **continue straight**. **(1.7)**

35.9/130.2 A small building and Dead Horse launch site road on right. The prominent, thick limestone cliffs on the upper slopes of Sheep Mountain, dead ahead, are Middle Pennsylvanian (Desmoinesian) strata of the Lead Camp Limestone (Fig. 1.8) **(1.1)**

37.0/127.4 Note low, dark strip, the Carrizozo lava flow ahead and to the right. **(1.2)**

38.2/126.2 Paved road to left to Denver impact area. **(0.3)**

38.5/125.9 Road curves right. Lava field next to road on right. This is literally the southernmost tip of the Carrizozo lava flow, which extends about 44 miles from here to Carrizozo (Fig. 1.9). Highway circumvents the flow for next 2 miles. **(1.9)**

40.4/124.0 Road curves right and crosses flow. **(0.2)**

40.6/123.8 **STOP 1** to look at the terminus of the Carrizozo lava flow and Malpais Spring. Springs issuing from the base of the flows represent the water coursing down the original streambed that was filled by the flow. Rare and endangered pup fish are the most important residents of the springs.

The Carrizozo lava flows occupy a large area on the surface of the northern Tularosa basin, covering about 80 mi^2 (Fig. 1.10). The flows are about 44 mi long, more than 5 mi. wide at their widest point and as much as 150 feet thick (Weber, 1979). The flows are some of the youngest and best preserved lava flows in the United States, and apparently, are about 5,000 years old (see minipaper by Dunbar, this guidebook). Zimbelman and Johnson (this guidebook) discuss the nature of very long lava flows, like this one. After stop, continue NW on highway as it wraps around edge of lava field. **(4.5)**

HISTORY OF THE GEOCHRONOLOGY OF THE CARRIZOZO LAVA FLOWS

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New Mexico Bureau of Geology and Mineral Resources, 801 Leroy Place, Socorro, NM, 87801

The Carrizozo lava flows, located in south-central New Mexico, are one of the youngest-appearing volcanic features in the southwestern U.S. These basaltic lava flows exhibit well-preserved features typical of Hawaiian-style eruptions, such as ropey pahoehoe textures, fissures, tumuli and collapsed lava tubes and are not extensively vegetated. However, due to the basaltic composition of these rocks, determining the age of the flows has been difficult. A number of different approaches to determining the eruptive age of the lava flows have been attempted, and only recently has there been significant agreement between ages for the Carrizozo lava flows determined by different techniques, as well as consistency between ages determinations of these flows and other young basaltic lavas in New Mexico.

The Carrizozo lava consist of two flows, a lower flow that is 75 km long, and an upper flow that is 25 km long. The total erupted volume of the two flows is between 2.8 and 4.3 km^3 (Allen, 1952). The upper flow is wider, and typically thicker, than the lower flow (Weber, 1964). Where the contact between the two flows can be seen, no sediment deposition appears to have taken place (Farris, 1980), suggesting that the two flows were erupted at close to the same time. The Carrizozo lava flows consist of alkaline basalt, and contain phenocrysts of plagioclase, olivine and pyroxene (Farris, 1980).

Based on geomorphology, particularly the preservation of primary flow features and lack of sediment on many parts of the flow, the Carrizozo lava flows appear to be one of the youngest volcanic features in New Mexico. Allen (1952) estimated, based on visual observation alone, that the age of the Carrizozo flows was less than 1000 years. Weber (1964) estimated that the age was around 1500 years. This estimate was influenced by comparison to another young volcanic feature in New Mexico, the McCartys lava flow, in the Zuni-Bandera volcanic field. The McCartys flow appears to be slightly better preserved than the Carrizozo lava flows, still retaining some glass on the ropey pahoehoe surfaces as well as showing even less sediment accumulation. The age of the McCartys flow was originally estimated to be around 1000 years, based on an apparent stratigraphic relationship to a surface containing Pueblo I artifacts (700-900 years) (Nichols, 1946), and the Carrizozo lava flows were inferred to be slightly older. Little progress towards quantitative dating of these flows was made for a number of years.

The first attempt to date the Carrizozo Malpais lava flow quantitatively was made by Salyards (1991). This study involved investigation of the secular variation magnetostratigraphy of the basaltic Carrizozo lava, and the author suggested that the best age interpretation yielded an age of 5100 years old. However, Salyards (1991) noted that there were potential problems with the age, and that an independent age determination would be required for confirmation.

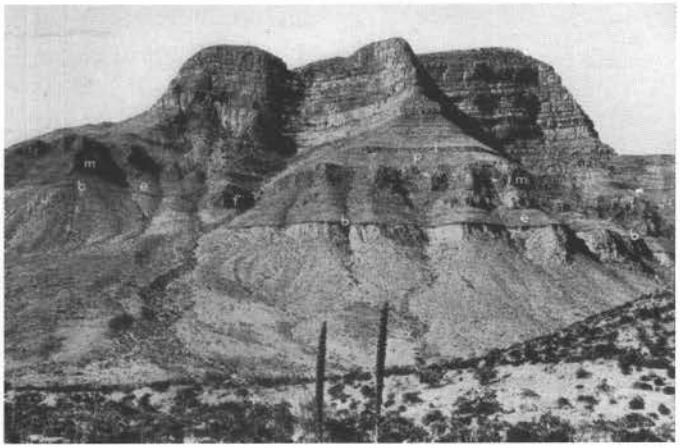


FIGURE 1.8. Photograph of Sheep Mountain at Lava Gap, looking south, as presented by Darton (1928). Abbreviations: b, Bliss Sandstone on Proterozoic granite; e. El Paso Limestone; m. Montoya Limestone; p. Percha Shale, l., Lake Valley Limestone overlain by limestone of the Magdalena group; f. fault.

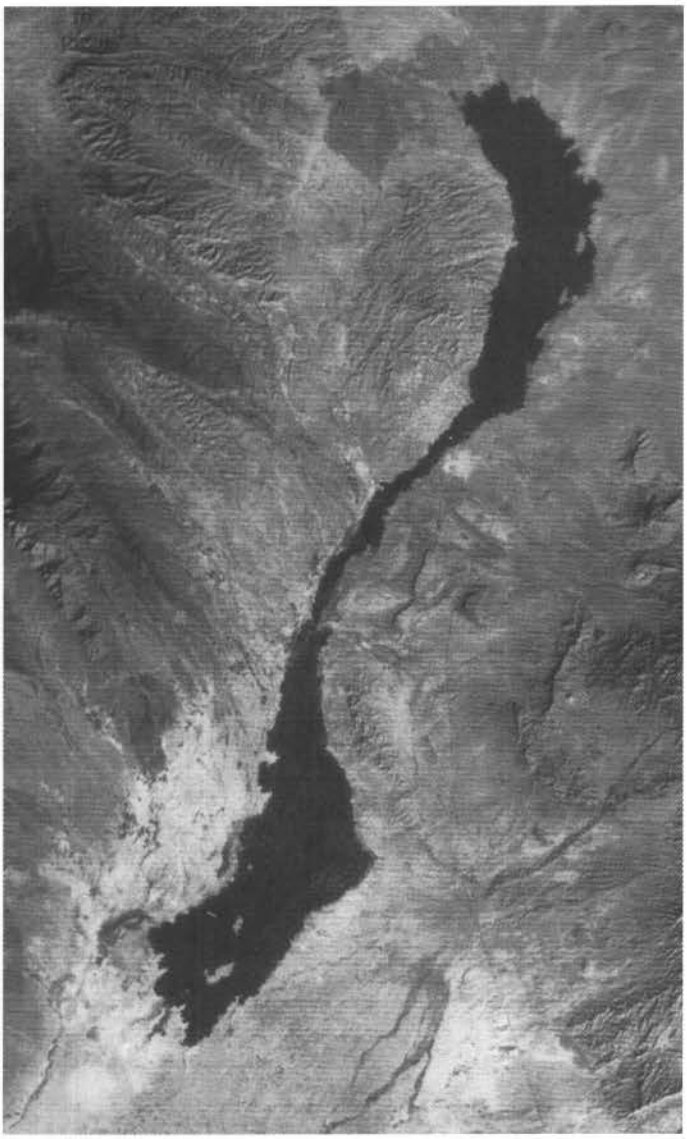


FIGURE 1.9. Satellite photograph of the Carrizozo lava flow.

Although the Carrizozo lavas were deemed unsuitable for $^{40}Ar/^{39}Ar$ analysis due to the low K content and apparently young age of the lava, and for ^{14}C due to the absence of any suitable carbon found under the flow, they appear well-suited for cosmogenic isotope dating due to the exceptionally well-preserved surface flow features. Cosmogenic dating techniques, such as ^{36}Cl and ^{3}He, rely on the measurement of cosmogenic isotopes that begin to build up in the rock as soon as it is exposed at the surface of the earth. Therefore, cosmogenic techniques can be applied to the dating of any surface that is composed of material that was not exposed to cosmic rays before formation of the surface and has been exposed continuously since. In the case of an extrusive volcanic rock, buildup of cosmogenic nuclides begins when the rock is erupted, so measurement of the ratio of a cosmogenic to

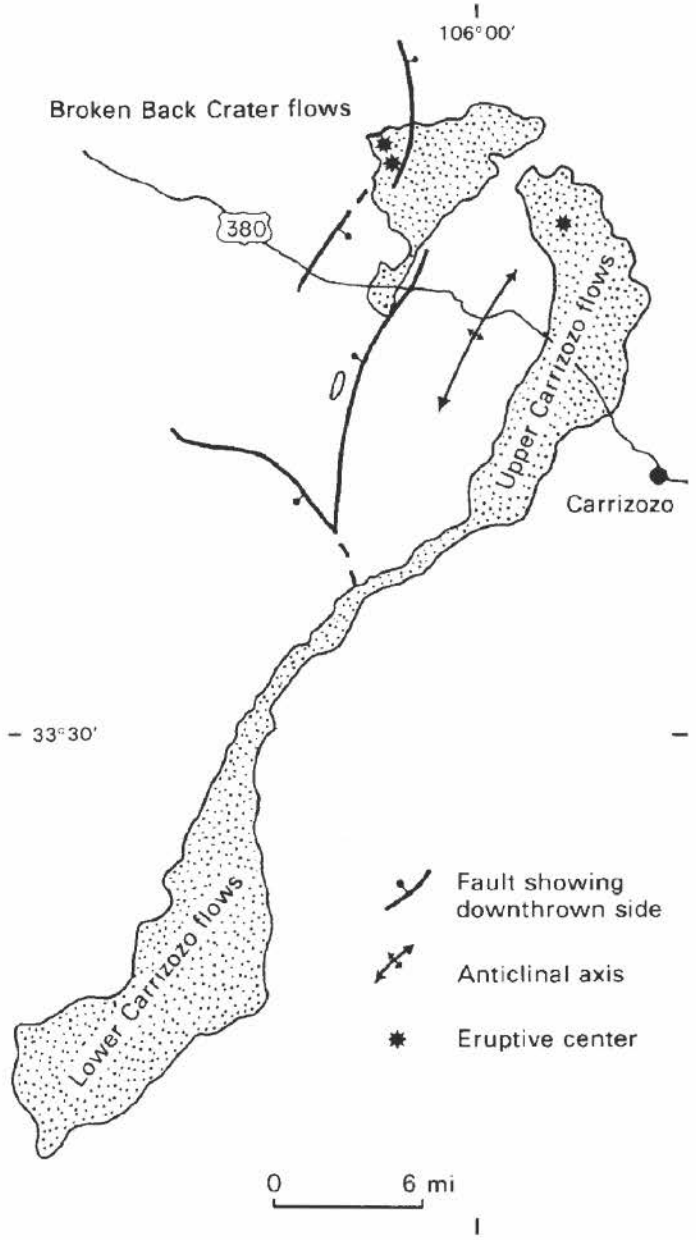


FIGURE 1.10. Map of the Carrizozo volcanic field (from Renault, 1970).

non-cosmogenic isotope can provide an estimate of eruption age (Phillips et al., 1986). Chlorine-36 and ^{3}He dating have been successfully applied to dating of many young basaltic lava flows (Laughlin et al., 1994; Phillips et al., 1996; Zreda et al., 1993).

Two cosmogenic techniques have been successfully applied to dating the Carrizozo lava flows; ^{36}Cl (Dunbar, 1999) and ^{3}He (Anthony et al., 1998). Chlorine-36 ages were determined for three samples, two from the upper flow and one from the lower (Dunbar, 1999). The ages, using a 5 mm/k.y. erosion rate, were 4.9 ± 0.5 and 5.6 ± 0.9 ka for the upper flow, and 5.4 ± 1 ka for the lower flow. The ages of the upper and lower flows are the same, within analytical error. The weighted average age is 5.2 ± 0.7 ka. A single ^{3}He age of 4.8 ± 1.7 ka was reported by Anthony et al. (1998). The ^{36}Cl and ^{3}He ages agree within analytical error.

The ages of the Carrizozo lava flows determined by cosmogenic techniques are considerably older than the earlier geomorphic estimates of the age of the flows of between 1000 and 1500 years (Allen, 1952; Weber, 1964). However, the ages are in good agreement with the secular variation magnetostratigraphy age determined by Salyards (1991). Although the cosmogenic ages are older than earlier estimates of the flows based on geomorphic observations of the lava flow surface, they appear to be consistent with recently-determined ages of other young lava flows in New Mexico. The ages of the McCartys and Bandera Crater lava flows, both in the Zuni-Bandera volcanic field, have been determined using ^{14}C, ^{3}He and ^{36}Cl techniques (Laughlin et al., 1994; Dunbar and Phillips, 1994). The ages of the McCartys and Bandera flows are between 3-4 ka, and 10-11 ka, respectively, based on these three techniques. The Carrizozo lava flows appear distinctly geomorphically younger than the Bandera Crater flow, which is more heavily weathered, vegetated, and infilled with windblown sediment. However, the Carrizozo flows appear geomorphically somewhat older than the McCartys lava flow, based on a lower degree of pahoehoe rope preservation and a smaller amount of preserved glass on the outer skin of the lava surface. This places the eruption of the Carrizozo flow between 3-4 ka and 10-11 ka, consistent with cosmogenic ages of Dunbar (1999) and Anthony et al. (1998). Therefore, the early-determined geomorphic ages, which placed the age of the Carrizozo lava as slightly older than the McCartys lava, although not accurate in an absolute sense, were internally consistent.

45.1/119.3 Road straightens and leaves the edge of the lava field. **(0.9)**

46.0/118.4 Note gypsiferous lake sediments on both sides of road. These are deposits of Pleistocene Lake Otero, which covered a large part (estimated 700 mi^2) of the floor of the Tularosa basin. **(1.6)**

47.6/116.8 Isolated powerline pole on right, left as a nesting site for birds of prey. Northern end of the San Andres Mountains (the "Mockingbird Mountains") at 9:30, and Mockingbird Gap at 10:00. Great view at 10:30–12:00 of granitic basement core of Oscura Mountains overlain by east-dipping Paleozoic section with low, dark red Permian Abo strata dead ahead; in distance behind them are lighter colored, gypsiferous strata of the Permian Yeso and San Andres formations.

The Oscura Mountains are a fault block uplifted during the late Cenozoic that has about 3000 ft of vertical relief along its precipitous, west-facing scarp. This face of the range exposes Precambrian granite overlain by a Paleozoic sedimentary section that generally dips eastward, to form the rugged eastern dip slope of the range (Fig 1.11). South Oscura Peak, at 8640 ft, is the highest point of the range. **(3.2)**

50.8/113.6 Road curves left; note Mound Springs to left. About here, we enter Lincoln County. **(0.6)**

51.4/113.0 Mound Springs to left. **(0.7)**

52.1/112.3 Cross low swale, which is tributary of Salt Creek **(0.8)**

52.9/111.5 Road intersection; go **straight** to Stallion Range Camp. **(0.7)**

53.6/110.8 S-curve, as road curves left, then right. **(1.2)**



FIGURE 1.11. Photograph of the south end of the Sierra Oscura. Geologic cross-section as presented by Darton (1928).

54.8/109.6 Road on Bursum Formation strata, which here are a mixture of clastic red beds and marine limestones. Nodular limestones next to the road contain some large, thick-walled *Triticites*, a fusulinacean characteristic of Bursum strata and of early Wolfcampian time. Red Hill to the right exposes overlying Abo Formation red beds. **(0.7)**

COPPER GLANCE – ESTEY CITY'S BRIEF MOMENT IN THE SUN

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Estey City, New Mexico, now located entirely within the boundaries of the White Sands Missile Range (see day one route map, this guidebook) was the sight of an interesting, if ill-fated, early experiment to mine and process the elusive copper deposits hosted by the Permian-age "red-beds" surrounding the southern Oscura Mountains in eastern Socorro and western Lincoln Counties. American prospectors recognized the deposits at least as early as 1881 (Fritzgaertner, 1882; Jones, 1904), but little serious development was directed their way until David M. Estey of Owosso, Michigan, focused his substantial energies on the area in about 1900. The story of the Estey Mining & Milling Company, and to some degree its successor, the Dividend Mining & Milling Company, is reflective of the "nothing is impossible" attitude of many late nineteenth-century entrepreneurs.

David M. Estey represented the third-generation of a very successful family of manufacturing pioneers. Patriarch Jacob Estey established the business in 1846 when he bought out an earlier manufacturing firm in Brattleboro, Vermont and began to produce the famous, high-quality, and now very collectible Estey Reed Organ. The younger Estey soon desired to branch out on his own and with family assistance established a factory in West Haven, CT in 1865 and began to manufacture an equally high quality line of Estey furniture. Ten years later he again moved the operation, this time to Owosso, Michigan, where he achieved his greatest success, and by the mid-1890s he was owner or part owner of several corporations, some 12,000 acres of prime timberlands in Michigan, and served as mayor of Owosso. However, wealth can interfere with sound judgement and induce one to venture forth into enterprises for which one has no expertise. David M. Estey turned his attention to the field of mining – with ruinous results.

What drew Mr. Estey's attention to the low grade copper deposits of the Sierra Oscura is not known at this time, but by 1900 he was deeply involved both with the acquisition of mining property, eventually totaling some three hundred lode mining claims, (Jones, 1904) and the investigation of copper leaching technology as it then existed. His investigation led him to Chicago metallurgist E. L. Sharpneck, who allegedly developed a proprietary leaching process capable of handling low-grade "rebellious" ore. The Imperial Ore and Reduction Company, organized by fellow capitalists of Boston, Connecticut, and New York, bought Mr. Sharpneck's patents and proceeded to tackle "low grade siliceous copper propositions whenever and wherever opportunity and conditions justify it…" such as those in Lincoln County, New Mexico (Int'l Ind. Record, 1901). Estey would focus his energies on the red-bed copper deposits at the base of the east facing flanks of the Sierra Oscura Range at a point some 16 miles west-northwest of Oscura station on the El Paso & Northeastern Railroad. The name of this soon-to-be Shangri-La would be Estey City.

The rapidity with which the new townsite took shape is nothing short of remarkable (Fig. 1.12). Estey showed up with his workmen and construction materials about the first of April 1901, and within two months "the reduction works, boiler and engine rooms, ore bins, two-story store and office building, commodious boardinghouse and dormitories, blacksmith shop, laboratory, magazine, stables, carpenter shop and dwellings for employees and their families" were completed. The reduction works included a massive stone wall varying in thickness from 20 to 42 inches, and the frame superstructure required a quarter-million board feet of lumber. Additional improvements planned for the immediate future included an electric light plant, electric tramways, and several miles of improved roads (Int'l Ind. Record, 1901). To the casual observer, the whole enterprise was a model of meticulous planning, attention to detail, and high-quality construction. Only two minor details were overlooked by the principals: neither sufficient water nor ore were available to run the plant! Moreover, this was an electrolytic plant, and copious amounts of electricity would have to be produced by burning either coal or wood – neither of which was available locally in any abundance. The engineer's eye immediately perceives other problems. Foremost was the very manner in which the plant was laid out. No flowsheet of the plant seems to have survived the ravages of time, but half-tones in the Dividend Company's prospectus suggest that every pound of rock had to be moved by hand — from feeding the crusher to introducing the pulp into the leaching tanks and removal of the spent pulp from the latter after the copper solutions were decanted off. Metallurgical problems were doubtless present as well. The tendency for copper "glance"



FIGURE 1.12. Photograph of Estey City, ca 1905, from the Dividend Mining & Milling Company prospectus.

(chalcocite) and carbonate ores to "slime" (break down into super-fine particles) during crushing would have presented serious difficulties (Turner, 1902).

The Estey Mining and Milling Company, not surprisingly, went completely bankrupt in May 1902 without producing a pound of copper (Zimmerle, 1963). The failure of David Estey's dream, as well as his other mining ventures in Colorado and elsewhere, doubtless led to his untimely death in September 1903 (Jones, 1904). For a time, Estey City languished in the desert until Estey's son-in-law, John M. Bryson, came to the rescue. Bryson foresaw the crash, gathered his Boston financial friends around him, organized the Dividend Mining & Milling Company, and purchased the assets of Estey's company (The Mining World, 1903). The corporate philosophies couldn't have been more different: where David M. Estey firmly believed in what he was doing, even if he lacked the technical expertise to make it a success, Bryson and his entourage – based upon statements made to the press and in his prospectus — appear to have been a stock-jobbing company from the start. Fayette A. Jones, the well-known engineer, spoke favorably at first: "The Dividend Mining & Milling Company, a new organization, has recently been effected and is now rehabilitating the wreckage and mistakes of its predecessor." However, he also warned, "If success is made in working these low grade ores, it will require the greatest metallurgical skill and strictest economy" (Jones, 1904, p 105). A detailed examination of the prospectus (Dividend, 1905) is instructive. The new company drilled 660 feet to find water and then continued on for an additional 100 feet "to reach a stratum where the supply of water would be unfailing and abundant." The water proved to be neither. The company "has been peculiarly fortunate…by having able men with a special knowledge of matters pertaining to this… line of business." The Dividend Company in fact was comprised of grocers, shoe and paint manufacturers, lumber dealers, real estate agents and bankers (Dividend, 1905). Able men they may have been in their chosen professions, but only Bryson could claim to have any mining experience – and that doubtless limited to his association with his father-in-law's failures.

The "actual photographs" are equally revealing: a half-tone of the "*crusher in operation*" shows two men posed with shovels above a crusher who's flywheel is at rest, and the dust-free surroundings strongly suggest the crusher has yet to operate. The same two men are shown in several of the company's "mines," with moustaches and or hats sketched in to make them appear to be different individuals. Other "actual" views are altered to the point where entire groups of people have been added by the artist's hand – to convey, one presumes, an air of activity and prosperity.

Outrageous as the above may seem, the written statements are worse. Under the heading "Custom Sampling And Assay Office," is the following: Sample No. 1, Colorado No. 1: 45% copper, value per ton of 2,000 lbs., $126.28; Sample No. 5, Homestake: 22% copper, value per ton of 2,000 lbs., $61.60. Total value per ton is given as the sum of the two instead of the average! Additionally, the values shown represented hand picked high-grade. The average grade would not have exceeded 10 %, and 4% was more accurate (Turner, 1902; Jones 1904). Horace J. Stevens, editor of the Copper Handbook (a highly regarded compendium of the mining industry) was equally outraged. The company when queried declined "to give a statement…claiming that that company's business is its own affair…" Stevens stated "the advertising done by the company is indefensible, and must injure its standing in the eyes of all conservative investors. The company advertised in the Boston newspapers that it has received a shipment of "precious rich, virgin copper ore [*whatever THAT means*], taken from the Mocking Bird mine, in the famous copper strike, which is the biggest ever made in the southwest." A most interesting statement because the Mocking Bird Gap mine, like the Estey plant, never produced so much as a pound of copper! And, finally, the icing on the whole fetid cake: "there has been no such opportunity for investment since the Calumet & Hecla and United Verde were first put on the market." About which Stevens commented, "Verbum sap (Copper Handbook, 1906)!"

If Bryson learned one thing from his father-in-law, it was to think BIG! He finally gave up trying to convince the stockholders that sufficient water could be found at Estey City and proposed to ***move the entire plant*** to Alamogordo (Mining & Scientific Press,1905), a suggestion wisely vetoed. A showdown was imminent: produce copper in paying quantities or shut down. The plant, which was supposed to produce 14½ million pounds of copper annually (Copper Handbook, 1910) was fired up in July 1907 just long enough to demonstrate that it could not produce at all. The Dividend Company DID, however, did make one small shipment of high-grade (ore, not refined metal), which contained just a few thousand pounds of copper (Bureau Archives). By 1907, it was over: Bryson and Associates had squandered $380,000 of the stockholders money and produced zero returns (Engineering & Mining Journal, 1907). Bryson spent the next few years trying to settle with the bondholders by giving them title to the property (Copper Handbook, 1910-11). The stockholders doubtless lost everything

Little remains today at the site beyond the fitted stone walls so carefully erected by David Estey and his craftsmen, a sad monument to the failure of this once very proud and successful businessman. It is a shame that Mr. Estey did not stick to his family's core business: that of manufacturing top-quality reed organs, pianos, and furniture. Had he done so, he would have been remembered here in the southwest more for the dulcet tones of his fine musical instruments than the sour notes registered by his ill-fated mining schemes.

55.5/108.9 Excellent view ahead of thick, easterly-dipping section of Pennsylvanian Panther Seep Formation on dip slope of the Oscura Mountains. **(0.7)**

56.2/108.2 Intersection; **turn left** onto Range Road 12 to Stallion Range Center. **(0.5)**

56.7/107.7 Unpaved road to left. You are looking down the axis of the Tularosa basin as you look south; section to right is Panther Seep Formation. **(2.0)**

58.7/105.7 Unpaved road to right, Mockingbird Mountains ahead. **(1.2)**

59.9/104.5 Road curves right, Sheep Mountain ahead

at 10:00. Look right at Abo red beds on the eastern flank of the Little Burro Mountains; outcrops of Permian Yeso Formation limestones immediately on right. **(0.4)**

60.3/104.1 Road curves. **(0.7)**

61.0/103.4 Enter Little Burro Mountains. Red beds on right are Permian Abo Formation. **(0.9)**

61.9/102.5 Road curves. **(0.7)**

62.6/101.8 Excellent Abo roadcut on right is red-bed mudstone and thin sandstones, strata of fluvial origin. **(0.5)**

63.1/101.3 Note upper Panther Seep and Bursum formations (gray strata) faulted in to right. **(1.4)**

64.5/99.9 Intersection with main Range Road 7 to left; **continue straight** on Range Road 7. Abo-Yeso outcrops to right form the ridge above the old ranch. **(0.9)**

65.4/99.0 Note easterly-dipping Panther Seep strata to right. **(0.9)**

66.3/98.1 Limestone outcrops to right in roadcuts are part of a fault block of upper part of Yeso Formation (Bachman, 1968). **(1.0)**

67.3/97.1 As the road gently curves left, we get our first look at the Jornada del Muerto basin of the Rio Grande rift. **(1.2)**

68.5/95.9 **STOP 2. Pull off to the left into the driveway for the two buildings at this installation and park**. This is the northern terminus of the San Andres Mountains and an area known as Mockingbird Gap. The geology of the quadrangle was published by George Bachman (1968) in U.S. Geological Survey Professional Paper 594-J.

A mining camp known as the Independence Group in the Mockingbird Gap mining district once existed here. The deposits here are very similar to those at Hansonburg, farther north and the one of the subjects of Stop 3. Two different workings, known as the Independence Claims, access mineral deposits here. The main working consists of a two-compartment shaft located just over the ridge to the west (Fig. 1.13). The ore, consisting of both sulfide and oxide mineralogies, is hosted by brecciated and silicified limestone. Galena and sphalerite comprise the sulfide ore hosted in a gangue of calcite, barite and quartz. The sphalerite is light colored (iron poor) similar to that at Hansonburg to the north but significantly different from typical Mississippi Valley Type ores. Oxide assemblages contain the zinc and lead carbonates smithsonite and cerussite, respectively. The deposit on the east side of the ridge, also known as the Damon claims, is predominantly a replacement deposit of fluorite, barite and galena accompanied by extensive silicification. Although mineralization persists in a fault to the south of the main workings, ore grade diminishes significantly (Laskey, 1932).

The Proterozoic-Paleozoic contact is exposed immediately south of the mine workings. At this locality, the lower Paleo-

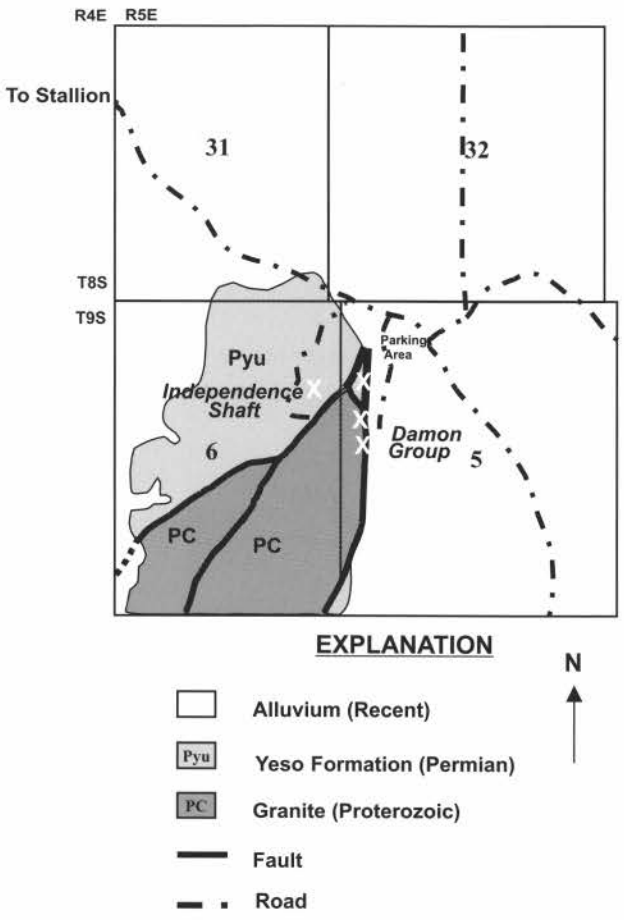


FIGURE 1.13. Geologic map of the Independence Group mining claims at Mockingbird Gap.

zoic section is completely absent. Within about 1.5-2 mi to the south along the west front of the Little Burro Hills, the wedge-edges of the Cambrian-Lower Ordovician Bliss Sandstone and overlying dolomite of the Lower Ordovician El Paso Group pinch out between the Precambrian and overlying Pennsylvanian Sandia Formation. Just 7 mi to the south, in Johnson Park (north end of San Andres range), a much more impressive lower and middle Paleozoic sequence is present (Bachman, 1968), including (in ascending order) the Bliss (15 ft thick), El Paso Group (120 ft), Middle to Upper Ordovician Montoya Group (75 ft), Devonian Oñate and Sly Gap formations (30 ft) and Lower Mississippian Lake Valley Formation (10 ft). The Silurian Fusselman Dolomite, present between the Montoya and Oñate along much of the length of the San Andres range, pinches out farther to the south, about 6 mi south of Rhodes Canyon (Kottlowski et al. 1956).

Along the west-facing southern scarp of the Oscura Mountains (Fig. 1.14), Bachman (1968) documented a similar truncation of early Paleozoic formations, from the southern tip of the Oscuras northward for about 8 mi (i.e., to a point about 4 mi northeast of this stop). Along this distance, the Bliss Sandstone appears as a thin (< 20 ft) black band just above the pink Precambrian granite, and is overlain by gray Ordovician dolomites of the El Paso and Montoya Groups. At the south end of the Oscuras, the Ordovician strata total about 170 ft in thickness, but thin abruptly, to about the thickness of the Bliss, before all these units pinch out between the Precambrian and overlying Pennsylvanian strata. Devonian and Mississippian strata are not present in the Sierra Oscura.

As Kelley and Silver (1952) first observed, these units are not at their northern depositional edges, so their disappearance is not a simple depositional pinchout. Instead, they interpreted the pinchouts to indicate the presence of a southwest-northeast oriented hinge line, running from just north of the Caballo Mountains to the Oscura Mountains. According to Kelley and Silver, the region immediately north of the hingeline was recurrently uplifted during the early Paleozoic, which accounts for the thinning and disappearance of lower Paleozoic strata.

After stop, **continue northwest** on paved highway. **(0.7)**

69.2/95.2 At crest hill, as road curves, look out across the Jornada del Muerto basin to the Fra Cristobal Mountains at 9:00; San Mateo Mountains at 10:00; Magdalena Mountains at 11:00; Cerro Colorado (foreground) and Socorro Mountain at 12:00; Sierra Ladrones at 12:30 and Joyita Hills at 1:00. The long (north-south) and linear Jornada del Muerto basin of the Rio Grande rift extends from eastern Socorro County along the western flank of the Oscura Mountains through

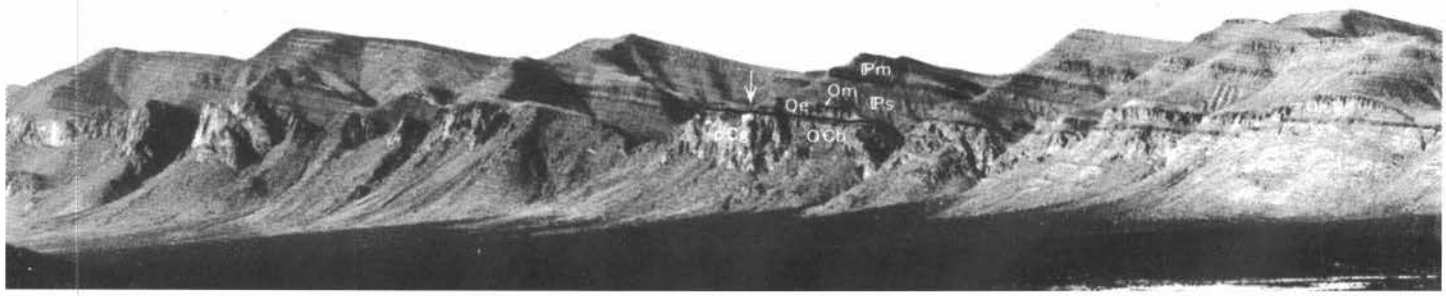


FIGURE 1.14. Southern portion of the Sierra Oscura as viewed to the northeast. The Bliss Sandstone (OCb) rests on Precambrian granite (pCg) and is overlain successively by the El Paso Dolomite (Oe), Sandia Formation (IPs) and Madera Formation (IPm). The arrow approximates the position of the wedge edge of the Montoya Dolomite (from Bachman, 1968).

Sierra and Doña Ana Counties along the western flank of the San Andres Mountains. We are in the central to northern part of the basin now, where Neogene basin fill (Santa Fe Group) is at most about 2000 ft thick and is overlain by gypsiferous lake beds, dune sands and basalt flows (Weir, 1965; Johnson et al., 1989). **(1.0)**

70.2/94.2 Low hills at 1:30 are the Hansonburg Hills. **(1.3)**

71.5/92.9 Intersection with paved road (Zumwalt Track to left); **turn right** on Range Road 13 to Trinity Site. **(0.2)**

71.7/92.7 Road to right; **continue straight** on pavement. **(0.3)**

72.0/92.4 Pass large bunker on right. **(0.5)**

72.5/91.9 Extensive yards of equipment and vehicles on both sides of the road. Much "testing" goes on around here. **(0.6)**

73.1/91.3 Road to left and right; **continue straight. (1.0)**

74.1/90.3 Large bunker on right. **(1.1)**

75.2/89.2 Road to right to McDonald Ranch.; Hansonburg Hills dead ahead. (2.1)

76.6/87.8 **STOP 3. Park in the lot**. The Trinity site is the location of humankind's first atomic explosion, at 5:29 am, July 16, 1945 (Fig. 1.15). The culmination of 3 years of intense, secret effort in Los Alamos and elsewhere (the Manhattan Project) and the expenditure of more than $2 billion (~ $20 billion in today's dollars), this first test of an atomic bomb resulted in the timely end of the war with Japan (after two bombs were dropped on Japanese cities less than a month later), and changed the course of human history forever. This site was chosen after a search committee had considered and rejected several sites from California to Texas (Wheeler, 1983). It provided a very isolated location a considerable distance away from large centers of population, but reasonably close to Los Alamos, flat topography, good weather, and an adequate level of security, being on what was then the Alamogordo bombing and gunnery range.



FIGURE 1.15. Obelisk marking ground zero at the Trinity Site (courtesy of White Sands Missile Range.)

At the site, a 100-ft-tall steel tower was constructed, and components of the bomb were brought by truck from Los Alamos on July 12, assembled, and installed on top of the tower, together with detonators. Seismographs, photographic, and other instruments were set up, and three wooden shelters, one of which was the control center, protected by concrete and earthen barricades, were built 5.7 mi from Ground Zero. Most of the observers and scientists were in an observation point about 20 mi away.

The explosion produced a blinding flash of light visible for a distance of at least 160 mi, and a mushroom-shaped cloud rose some 40,000 ft into the atmosphere (Fig. 1.16). Early risers in Albuquerque and Santa Fe saw the flash to the south and felt the shock waves, and windows rattled in Silver City. A woman on the Arizona border reported that the sun rose twice that day, once very quickly. Animals showed signs of unease. Many wondered if the Japanese were invading, or whether they were witnessing an unusual electri-

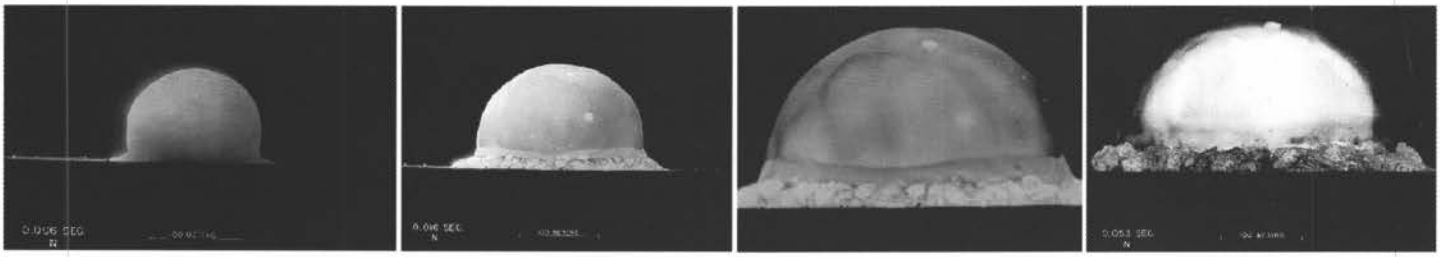


FIGURE 1.16. Series of photographs illustrating the first few seconds of the atomic bomb blast of July 16, 1945 (courtesy White Sands Missile Range).

cal storm, or an earthquake or a meteor impact. Those closer to the scene, eyes protected by dark goggles, were both awestruck and relieved, for it had been uncertain exactly how much energy would be released in the blast; some feared there was a chance that it would consume the planet. Others worried that the bomb would be a very expensive dud.

At Ground Zero, the tower had virtually disappeared, replaced by a shallow crater 1200 ft wide and 8 ft deep. The sand of the crater, and beyond, was fused into a green, glass-like material, up to an inch thick, called "trinitite" or "atomsite". This material was studied by Ross (1948), who reported two distinct types of glass, one from fusion of feldspar and clay minerals, and the other from quartz (Fig. 1.17).

The site was described by Time Magazine (Sept. 17, 1945, p. 68) as follows: "Seen from the air, the crater itself seems like a lake of green jade shaped like a splashy star and set in a sere disc of burnt vegetation half a mile wide. From close up the 'lake' is a glistening incrustation of blue green glass.... The glass takes on strange shapes — lopsided marbles, knobbly sheets a quarter inch thick, broken, thin-walled bubbles, worm-like forms." In late October, Stuart Northrop, then Chairman of the University of New Mexico Department of Geology, was allowed to visit the site (one wonders at the dose of radiation he absorbed, though Stu did live about 50 more years, into his 90s) and collect specimens for a contemplated exhibit in the UNM Geology Museum (Northrop, 1959).

Although the "glass lake" was covered over using bulldozers a few years later, small pieces of trinitite may still be found at the site, although collecting is not permitted. After much of the radioactivity had subsided, Missile Range authorities allowed 600-700 members of the public to visit for the first time in September, 1953, and they now conduct tours twice annually. The level of radioactivity at the site is currently said to be less than that from a radium watch dial (Fugate and Fugate, 1989).

The type section of the Lower Permian Bursum Formation is 5 miles north of here in the Hansonburg Hills. Named by Wilpolt et al. (1946), the term Bursum Formation is widely applied to transitional beds between clearly marine Pennsylvanian strata (Atrasado Formation) and nonmarine red beds of the Lower Permian Abo

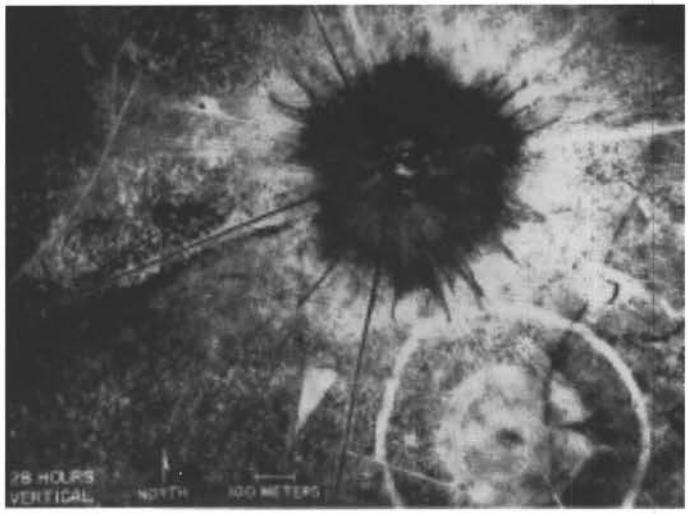


FIGURE 1.17. Areal view of the "glass lake" after the atomic bomb blast. (courtesy White Sands Missile Range).

Formation. Lucas et al. (2000) described the Bursum type section.

M. L. THOMPSON'S PENNSYLVANIAN STRATIGRAPHY IN THE OSCURA MOUNTAINS, NEW MEXICO

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In 1942, Marcus Luther "Luke" Thompson (1906-1985), then working at the New Mexico School of Mines in Socorro, published a monograph on the Pennsylvanian stratigraphy in New Mexico. In it, Thompson presented a comprehensive stratigraphic subdivision of New Mexico's Pennsylvanian strata, arranging them into the Derry, Des Moines, Missouri and Virgil Series and naming eight groups divided into 16 formations. The Upper Pennsylvanian part of this nomenclature was based on detailed lithostratigraphic sections Thompson measured in the northern Oscura Mountains of Socorro County (Fig. 1.18). Here, the section of Missourian and Virgilian strata is about 500 ft thick and consists of a mixture of limestones and clastic rocks. Numerous fusulinid horizons are present, as are a few important macrofaunal localities (Thompson, 1942; Kues and Lucas, 2001). Each formation Thompson named is a distinctive lithostratigraphic unit, though his groups lack a clear lithostratigraphic basis.

Interestingly, Thompson's (1942) Pennsylvanian stratigraphic nomenclature has been little used by subsequent workers. Kottlowski (1960, p. 21) noted that the "formations [Thompson] proposed are recognizable by lithology alone in areas near their type localities, and some of the formations retain their distinctive lithic characteristics for long distances." Nevertheless, the formations Thompson named are relatively thin (most are less than 60 ft thick), and Kottlowski observed that "most field geologists have not had the time nor the paleontologic data to map such detailed units as Thompson's formations" and that some of the formations can only "be correlated by detailed fusulinid studies." Indeed, most workers have simply dismissed Thompson's groups and formations as fusulinid biostratigraphic units, and not recognized them as lithostratigraphic units (e.g., Otté, 1959, p. 15; Bachman, 1968, p. J20).

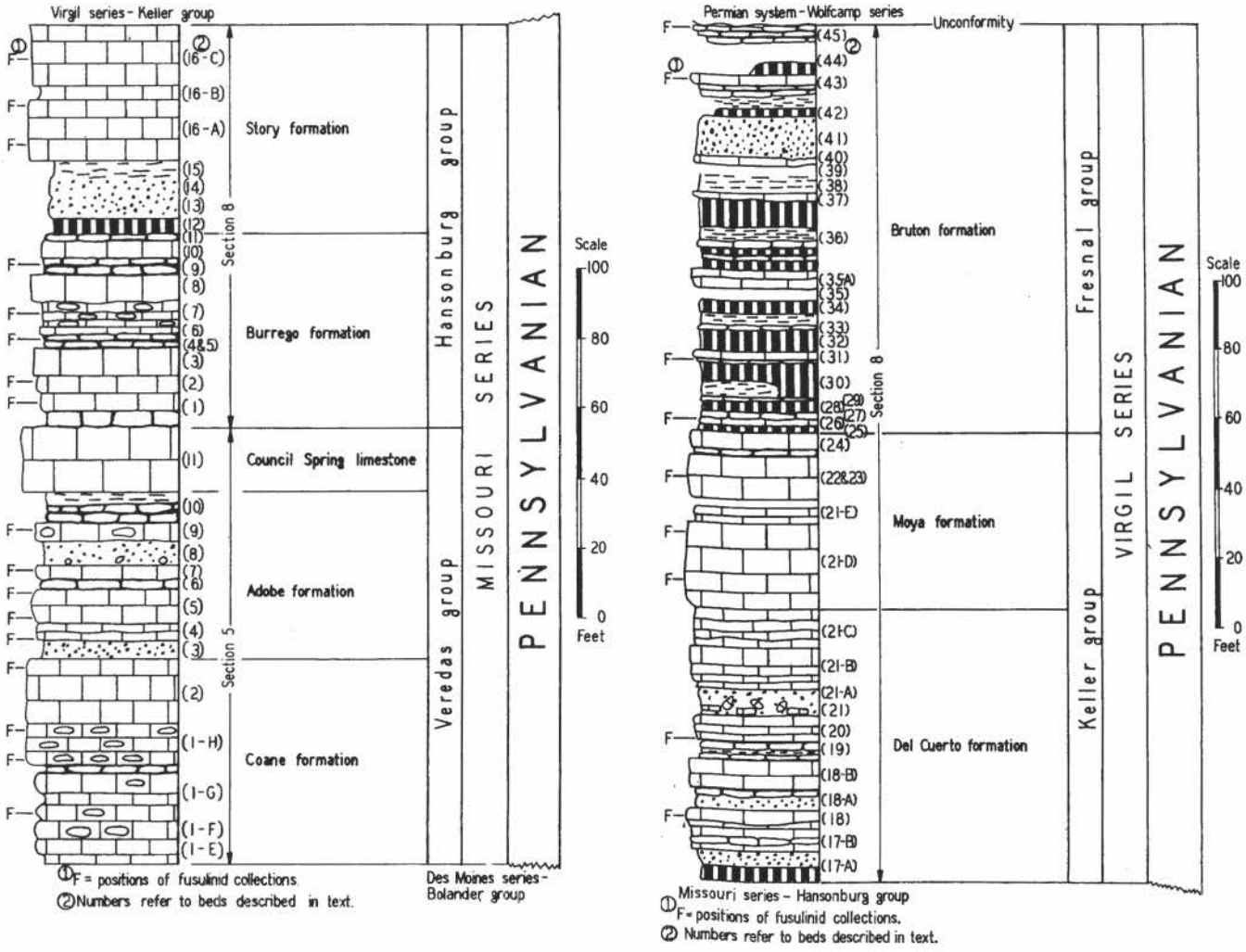


FIGURE 1.18. Measured sections of Upper Pennsylvanian strata in the northern Oscura Mountains (from Thompson, 1942).

One measure of the degree to which Thompson's (1942) lithostratigraphic units were ignored by subsequent workers is the fate of his Bruton Formation. This unit, named for Bruton Canyon in the northern Oscura Mountains, has a 35-m thick type section in the SE1/4 sec. 32, T5S, R6E that is mixed nonmarine and marine strata between Virgilian limestones and Wolfcampian limestone and overlying Abo Formation red beds (Fig. 1.18). Four years later, on a map legend, Wilpolt et al. (1946) renamed essentially the same unit the Bursum Formation, with a type section in the Hansonburg Hills, only 15 km from Thompson's type section of the Bruton Formation (Lucas et al., 2000). Bruton was ignored, subsequently forgotten, and Bursum is the name widely applied to the stratigraphic interval Thompson (1942) named Bruton Formation.

Thompson's formation rank units were properly defined but are generally too thin to be mapped, though some have been mapped in the Cerros de Amado area of Socorro County (Rejas, 1965; Maulsby, 1981; Bauch, 1982). Like Kues (2000, 2001), I refer the Upper Pennsylvanian section in the northern Oscura Mountains to a single, mappable unit, the Atrasado Formation of the Madera Group. However, the Coane, Adobe, Council Spring, Burrego, Story, Del Cuerto and Moya "formations" of Thompson should be recognized as members of the Atrasado Formation, some of which can be identified as far north as the Cerros de Amado. (To maintain nomenclatural stability, the Bruton Formation should continue to be subsumed under the Bursum Formation.) What is needed now is an effort to study and interpret the depositional history of the complex stratigraphic architecture of the Atrasado Formation, first deciphered by M. L. Thompson, in the northern Oscura Mountains.

Also located in the Hansonburg Hills are the Hansonburg copper deposits. The copper deposits were worked as early as 1872, before the more famous lead deposits located 6 miles to the east (Fig. 1.19). Copper mineralization is localized as vein deposits in dolomitized limestones of the arkosic member of the Madera Formation as mapped by Wilpolt and Wanek (1951). The veins trend along, yet are truncated by, the bounding fault on the western margin of the hills. The ore consists predominantly of tennantite (Laskey, 1932), highly unusual for the region and totally lacking in lead values. Another contrasting feature is the lack of silicification and absence of barite and fluorite at the copper deposits compared to the lead mines.

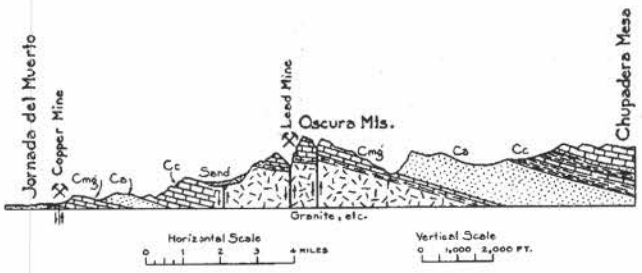


FIGURE 1.19. Geologic cross-section of the Hansonburg Hills to the Sierra Oscura as presented by Laskey (1932).

Six miles to the east are the more famous Hansonburg galena-barite-fluorite deposits on and around what is known as Hansonburg Hill, a fault block on the west side of the Sierra Oscura. These deposits consist predominantly of galena, barite and fluorite with subordinate amounts of sphalerite and even less chalcopyrite. One of the outstanding features of the lead deposits is the vast array of secondary copper and lead secondary minerals that make these deposits a favorite of mineral collectors. Recent radioisotopic dating and stable isotope analysis of jarosite by Lueth et al. (2000) suggest that one stage of fluorite-jarosite mineralization occurred at 7 Ma. Subsequent jarosite mineralization occurred around 4.5 Ma associated with copper secondary mineral formation. They suggest that this age represents a period of juxtaposition between the copper deposits in the Permian red beds and the lead deposits. Later supergene weathering occurred at 1.8 Ma. These age dates allow for the calibration of uplift rates along the Oscura uplift (see Lueth and Kelley, this guidebook).

The broad plain of the northern Jornada del Muerto basin here is about 500 ft above the level of the Rio Grande. The basin here is internally drained, and surface flow is generally southward to a large playa that formerly was inundated by Pleistocene Lake Trinity (Neal et al., 1983). Indeed, we are just northeast of the highest known Pleistocene shoreline of the lake.

LAKE TRINITY

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Although the pluvial lake systems of the Tularosa Valley have received considerable attention in the literature as a result of the public attractions of the White Sands National Monument, the less spectacular features of the Jomada del Muerto remain relatively unknown. Lake Trinity, the youngest of a series of lakes in the Jornada del Muerto, was so designated by Neal (1976) and Neal et al. (1983) in view of its proximity to the atomic bomb test at the Trinity Site. Among the geologic features described in the 1983 report are a high stand at 1,431 in (4,695 ft), indicated by relict strandlines and a thick sequence of lacustrine evaporate deposits of gypsum and hexahydrite revealed by four exploratory bore holes.

Subsequent reconnaissance mapping of the lake basin by Weber (Kirkpatrick and Weber, 1996) provided additional delineation of the 1,431 m shoreline and recognition of a lower, weaker still-stand at 1,426 m (4,685 ft), as shown on Figure 1.20. Still higher lake levels are indicated by lacustrine deposits in dug wells and borrow pits northward of the upper shoreline. The lake level at its maximum is now limited by a sill at approximately 1,443 in (4,735 ft.) at the southern margin of the Jornada basalt flows.

As shown on Figure 1.20, Lake Trinity had a length of 37 km (28 mi.) along its arcuate central axis. Maximum width at the northern end was 9.6 km (6 mi.), and the areal extent was approximately 212 km^2 (80 mi^2). A small, separate basin is shown to the north of the southwestern lobe of the main basin. At least during its late stages, the lake was very shallow, inasmuch as the maximum relief between the lake floor and the upper shoreline is only 6.4 m (21 ft). The prevalence of sulfate evaporates in the stratigraphic record indicate shallow waters throughout most of

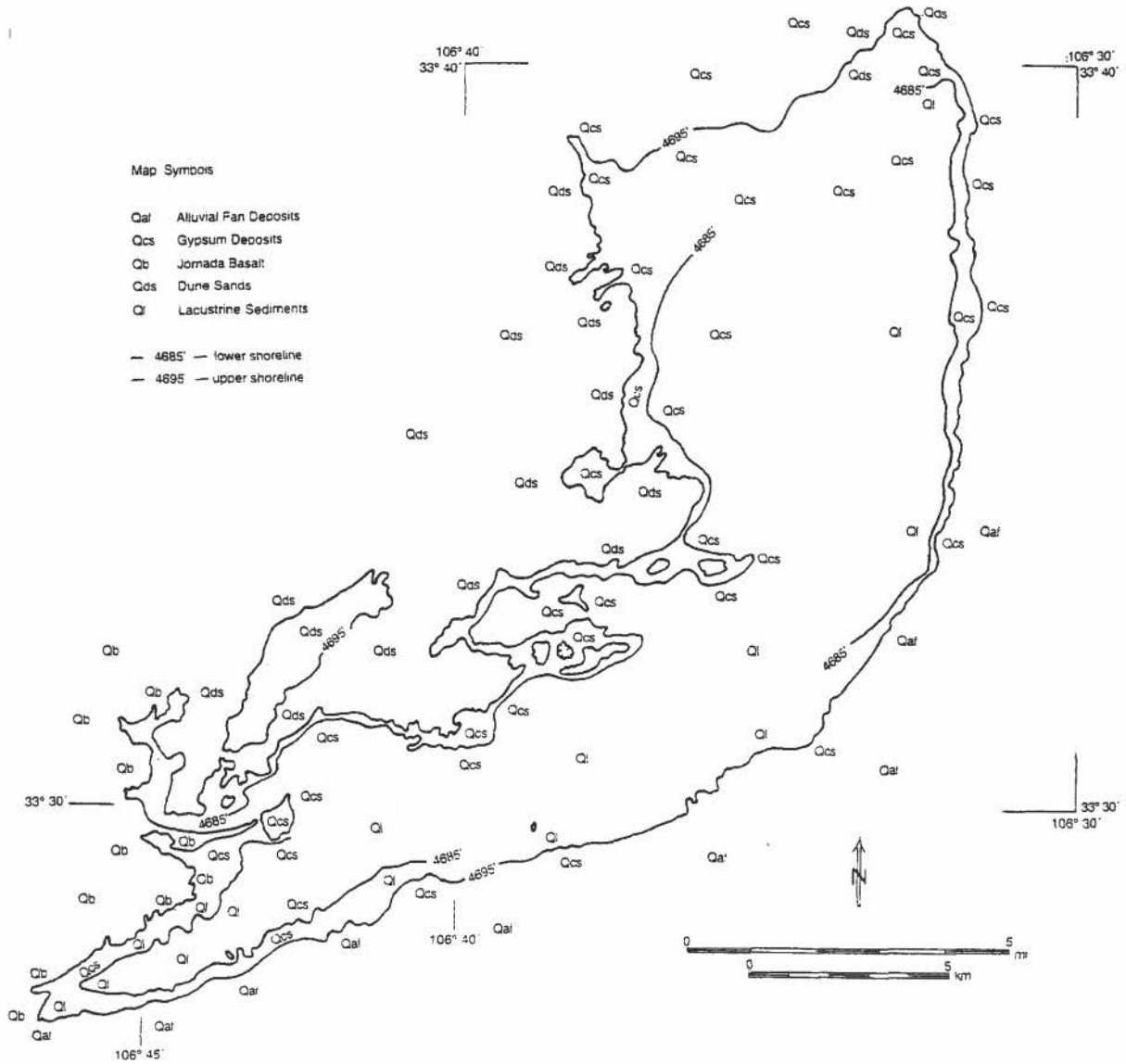


FIGURE 1.20. Synoptic map of the Lake Trinity Basin (after Kirkpatrick and Weber, 1996).

the lake's history (Neal 1976; Neal et al. 1983). Several small modern playas in the southwestern lobe are characterized by barren mud flats with weakly developed shorelines.

Drainage into the lake basin was largely from Chupadera Arroyo, heading to the north on Chupadera Mesa, now a dry, alluviated vestige of its Pleistocene antecedent. Lesser amounts were contributed by drainage of the western slopes of the Sierra Oscura and adjacent piedmont.

No definitive dates for Lake Trinity have been obtained, but the degree of preservation of its features suggest an origin in the pluvial conditions of the late Pleistocene, probably of Wisconsinan age. A much earlier and vastly larger sulfate lake, indicated by sparse exposures in the northern Jornada del Muerto, has not been documented. The earlier lakes possible relationship to an ancestral course of the Rio Grande through the Jornada del Muerto remains a matter for speculation.

The lake shown on the accompanying synoptic map, Figure 1.20, was bordered on the southeast by distal deposits of alluvial fans and arroyos of the bajada of the Sierra Oscura (Qaf); and on the north and northeast by deposits that include both lacustrine gypsum and a pedogenic gypsum caliche that extends regionally across the northern Jornada del Muerto (Weber, 1973; 1997) (Qcs). On the west is a stabilized field of longitudinal dunes (Qds) of northeasterly (commonly N55°E) trend resulting from prevailing southwestern effective winds. Bruier et al. (1992, p. 21) describe these dunes as of transverse type. The northern and western margins of the southwestern lobe of Lake Trinity were determined by the eastern edge of the Jornada Basalt flows (Qb), briefly described by Weber (1963, p. 140-141). K-Ar dating indicates an age of 0.760 ± 0.1 Ma for the basalt (Bachman and Mehnert, 1973, p.286, table 1, no. 27). Surficial deposits on the lake floor (Ql) consist largely of lacustrine clayey slits and silty clays, with gypsiferous silts and fine sands near the northern and western margins. A thin veneer of granite wash occurs near the southeastern margin and minor local accumulations of gravel were noted along the southern beach zone. (It should be noted that the vertical order of the map symbols of Figure 1.20 indicate only the order of treatment in the original text, not relative ages).

Lack of erosional incision of the basin floor severely limits stratigraphic interpretations to the upper 1-3 m (3-10 ft) exposed in a few scattered borrow pits and dug wells. The stratigraphy at depth, however, is shown in some detail by Neal et al. (1983, figs. 4 -5) based on four boreholes across the basin to depths of 40 m. These reveal a sequence of alternating sands, silts, clays, and gravels toward the margins and a thick section of gypsum enclosing a 0.5-m layer of hexahydrite ($MgSO_4 \cdot 6H_2O$) near the center of the basin.

Much remains to be learned concerning the pluvial lake systems of the Jornada del Muerto, particularly the earlier lakes that preceded Lake Trinity. These investigations inevitably will be handicapped by the lack of exposure of the definitive stratigraphic sequences due to the limited depths of erosion in a basin of low relief and closed interior drainage, coupled with restricted access to much of the area.

After stop, **retrace route** to STOP 2. **(0.1)**

76.7/87.7 Excellent view ahead of northern part of the San Andres Mountains (Fig. 1.21). **(5.0)**

81.7/82.7 **Turn left** on Range Road 7 to proceed south, back to Stop 2 **(0.7)**

82.4/82.0 Little Burro Peak at 2:00 is composed of Proterozoic granite. **(1.6)**

84.0/80.4 Road curves through fault blocks of Permian Yeso Formation. **(0.8)**

84.4/80.0 Pass Stop 2 on south side of road. Go southeast on paved road toward Oscura. Note Panther Seep strata on east side of road. **(2.6)**

87.0/77.4 Good view of Sierra Blanca Peak, straight ahead. **(1.6)**

88.6/75.8 Road forks; Range Road 7 curves to right. **Bear left** and travel east to Oscura on Range Road 12. Johnson Park at 2:00. **(1.1)**

89.7/74.7 Road curves; note again the black stripe of Cambrian Bliss Formation on pink granite to the left on the Oscura Mountain front. **(0.7)**

90.4/74.0 Cross creek; note light colored Yeso strata on north side of road, faulted in against Abo red beds. **(0.4)**

90.8/73.6 Crest of hill **(2.5)**

93.3/71.1 Road crests hill through outcrops of Panther Seep Formation. Note Tularosa Mountain at 2:00 in basin. **(3.7)**

97.0/67.4 Road intersection with Range Road 9 South to lava field. **Go straight** to Oscuro gate on Range Road 12. Red Hill at 2:00 is Abo Formation red beds. **(0.8)**

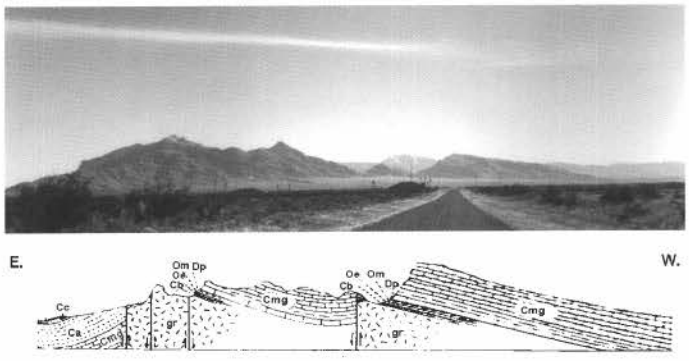


FIGURE 1.21. Photograph of the northern San Andres Mountains. Geologic cross-section of the northern San Andres Mountains as presented by Darton (1928).

97.8/66.6 Curve in road; Sierra Blanca ahead. Road on Yeso valley fill. **(2.6)**

100.4/64.0 Crest hill; gate here for road closure during bombing. **(1.3)**

101.7/62.7 Road to left to Oscura bombing range. **(1.3)**

103.0/61.4 Note Triassic red beds overlain by Cretaceous Dakota Group strata ahead in the low bluff just above the valley floor beyond the lava field - this is Bull Gap, the next stop. **(0.9)**

103.9/60.5 Gate for bombing closure and US Army Oscura Range Center to right. **(0.3)**

104.2/60.2 Road intersection; **continue straight. (0.7)**

104.9/59.5 Road to left. Note lava field ahead. Behind the lava flow are escarpments of Mesozoic and Cenozoic rocks. The lower escarpment of Mesozoic section is at Bull Gap, our next stop (Fig. 1.22). **(0.5)**

105.4/59.0 Enter lava field to cross it at its at narrowest spot. **(0.3)**

105.7/58.7 Leave lava field. **(1.8)**

107.5/56.9 Pass under powerline; note outcrops of Permian San Andres Formation on right in the Phillips Hills. Good view ahead of Triassic red beds overlain by light-colored Cretaceous Dakota Sandstone. **(1.0)**

108.5/55.9 Oscuro gate, leave WSMR heading east. Note Triassic strata under Dakota on left. **(0.1)**

108.6/55.8 Pavement ends. **(1.0)**

109.6/54.8 Pass under powerline at bend in road. Some of the Keen Spring fossil mollusc localities of Ashbaugh and Metcalf (1986) are just to our left. These are in late Pleistocene spring-related deposits and yield both aquatic and terrestrial gastropods that suggest local marshy habitats, and thus cooler and wetter paleoclimates here during the late Pleistocene. **(0.4)**

110.0/54.4 **STOP 4 at cattleguard; pull off and walk north to Bull Gap**: Here, at Bull Gap, we can examine the oldest Mesozoic strata exposed on the western flank of the Laramide Sierra Blanca basin (Fig. 1.23). At the base of the bluff, and out on the flats to the west, is the top of the Permian section, regionally—pale red, orange and yellow gypsiferous sandstones, siltstones and mudstones of the Middle Permian (Guadalupian) Artesia Group. These beds were deposited on the vast shelf that lay landward of the famous Capitan reef system of the Permian basin.

Triassic red beds above the Artesia here are up to 300 ft thick and are grayish red, trough crossbedded sandstone, intraformational conglomerate and mudstone. Long referred to as "Dockum" (Darton, 1928; Kottlowski, 1963; Weber, 1964; Osburn and Arkell, 1986), Lucas (1991) identified these strata as Middle Triassic Moenkopi Formation (Fig. 1.24). Moenkopi strata are fluvial deposits of a vast basin that covered much of western North America when it was part of Pangea. Note here how easy it is to distinguish the texturally and mineralogically mature, gypsiferous Permian red beds from the immature Triassic red beds.



FIGURE 1.22. View to the east looking over the narrowest portion of the Carrizozo lava flow toward Bull Gap. Note the escarpments of Mesozoic and Cenozoic rocks.



FIGURE 1.23. Photograph of the Mesozoic section exposed at Bull Gap.

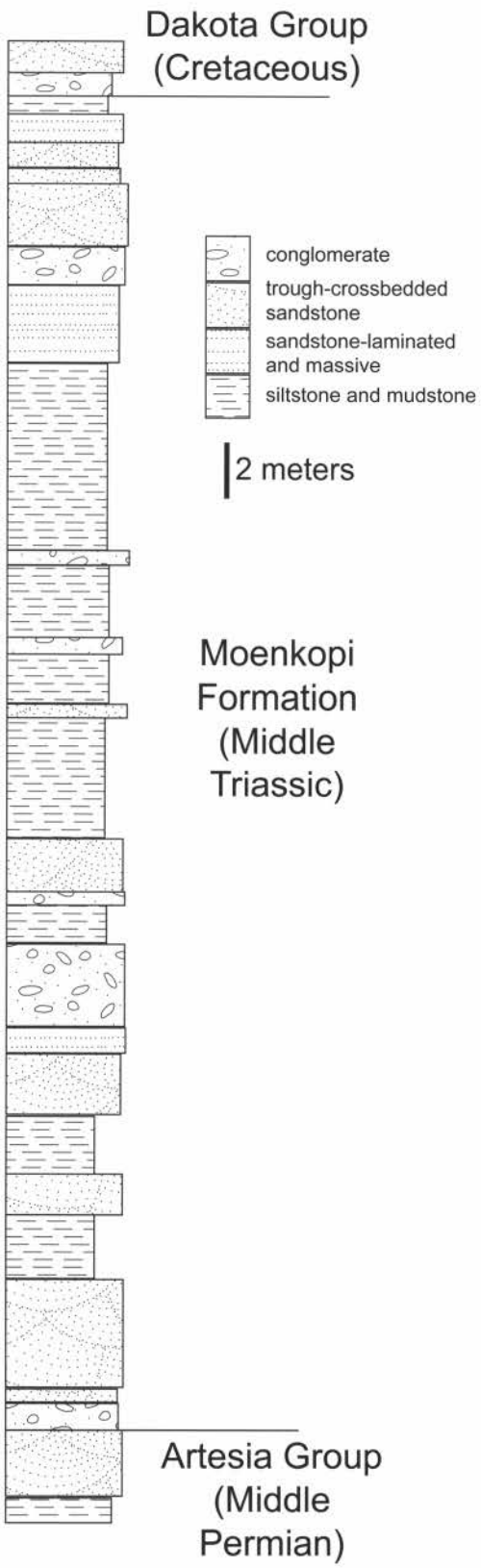


FIGURE 1.24. Measured stratigraphic section of Triassic Moenkopi Formation and base of Cretaceous Dakota Group at Bull Gap (after Lucas, 1991).

Strata above the Moenkopi Formation at Bull Gap belong to the Cretaceous Dakota Group. Note the extensive local color mottling of the lower 3-8 ft of Dakota conglomerate and sandstone. Furthermore, locally Moenkopi strata immediately below the Dakota have been extensively weathered, so as to be colored mottled yellow, white and green. This appears to be deep paleoweathering indicative of the Middle Triassic-Middle Cretaceous unconformity at the Moenkopi-Dakota contact, a hiatus of more than 100 million years.

One of the unresolved problems at this stop is the correlation of the Dakota Sandstone, and therefore interpretation of local depositional history during part of the Cretaceous. In New Mexico, the name "Dakota" is applied to Lower Cretaceous strata in east-central New Mexico that represent a late Albian cycle of transgression and regression, and it is also used for Upper Cretaceous sandstones throughout much of the state that represent the initial flooding the Late Cretaceous Western Interior seaway (base of the Greenhorn cyclothem of Kauffman). In the Sierra Blanca basin, the Dakota Sandstone is about 180 feet thick, and consists of a lower, fluvial portion and an upper portion with marine trace fossils (such as *Ophiomorpha*) (Arkell, 1986). It is tempting to correlate the lower, fluvial portion with the Lower Cretaceous "Dakota" (Mesa Rica Sandstone to the north) and the upper, marine Dakota here to the Upper Cretaceous "Dakota." Note, incidentally, that shale immediately above the Dakota near Bull Gap yields ammonites of the *Acanthoceras amphibolum* zone, which is middle Cenomanian in age and characteristic of the lower part of the intertongued Dakota-Mancos succession in west-central New Mexico (Cobban, 1986). This could be used to argue that the underlying marine Dakota here is equivalent to the Cubero or Oak Canyon members to the north. However, without fossils (age data), correlation

of the Dakota section at Bull Gap remains uncertain.

After the Stop, continue east on the unpaved county road to Oscuro. **(0.4)**

THE SIERRA BLANCA BASIN

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The southeasternmost Laramide basin in New Mexico, the Sierra Blanca basin is an elliptical structural depression in the Carrizozo–Ruidoso area. The basin trends north–northeast and is strongly asymmetrical, with its steep limb on the east and southeast. These steep sides of the basin are bounded by the Mescalero anticlinorium (or arch: Kelley, 1971), a complexly faulted and folded tectonic feature of late Laramide age (Fig 1.25).

The principal units that fill the Sierra Blanca basin are the Cub Mountain and the Sanders Canyon formations. The Cub Mountain Formation (Bodine, 1956; Weber, 1964; redefined by Cather, 1991) consists of a red-bed sequence of siliciclastic sandstone, mudstone, and conglomerate about 760 m thick. It was derived from the southwest, from either the Rio Grande uplift (Seager et al., 1997), or possibly from a Laramide Tularosa uplift, now structurally inverted as the Tularosa Basin. The Cub Mountain Formation contains fossils of Eocene age, probably late Wasatchian–early Bridgerian (Lucas et al., 1989) and disconformably overlies Upper Cretaceous strata of the Crevasse Canyon Formation. The Cub Mountain Formation (upper Eocene) is transitionally overlain by volcaniclastic mudstone and sandstone of the Sanders Canyon Formation (Cather, 1991). The Sanders Canyon Formation may be a distal facies of the Rubio Peak and Palm Park formations of southwestern New Mexico.

The Sanders Canyon Formation is gradationally overlain by locally derived volcaniclastic breccia, sandstone, and conglomerate of the Sierra Blanca Volcanics. The Sierra Blanca Volcanics range in age from about 38 to 26 Ma (Moore et al., 1991) and appear to post-date subsidence within the Sierra Blanca basin (Kelley, 1971).

The tectonic setting of the Sierra Blanca basin is not well understood. It seems likely that reactivated structures related to the western margin of the Pedernal uplift of late Paleozoic age may have influenced late Laramide subsidence in the basin, based simply on the spatial coincidence of the two features. Chapin and Cather (1981) tentatively classified the Sierra Blanca basin as a Denver-type basin, although evidence for the existence of an adjacent uplift to the southwest is weak. Another possibility is that dextral slip acted along the arcuate trend of the Mescalero arch. This would have caused extensional subsidence in a releasing-bend geometry, and would explain the half-graben-like, asymmetrical geometry of the Sierra Blanca basin in a manner similar to that interpreted for the Eocene Galisteo basin to the northwest (Cather, 1992; Abbott et al., 1995).

110.4/54.0 Pass under powerline. Cretaceous outcrops at 10:00 are coal-bearing strata of the Crevasse Canyon Formation. The Oscura coal mine is located on the west side of the hill, behind the hill in the foreground. (Fig. 1.26). **(0.6)**

SIERRA BLANCA COAL FIELD, LINCOLN AND OTERO COUNTIES, NEW MEXICO

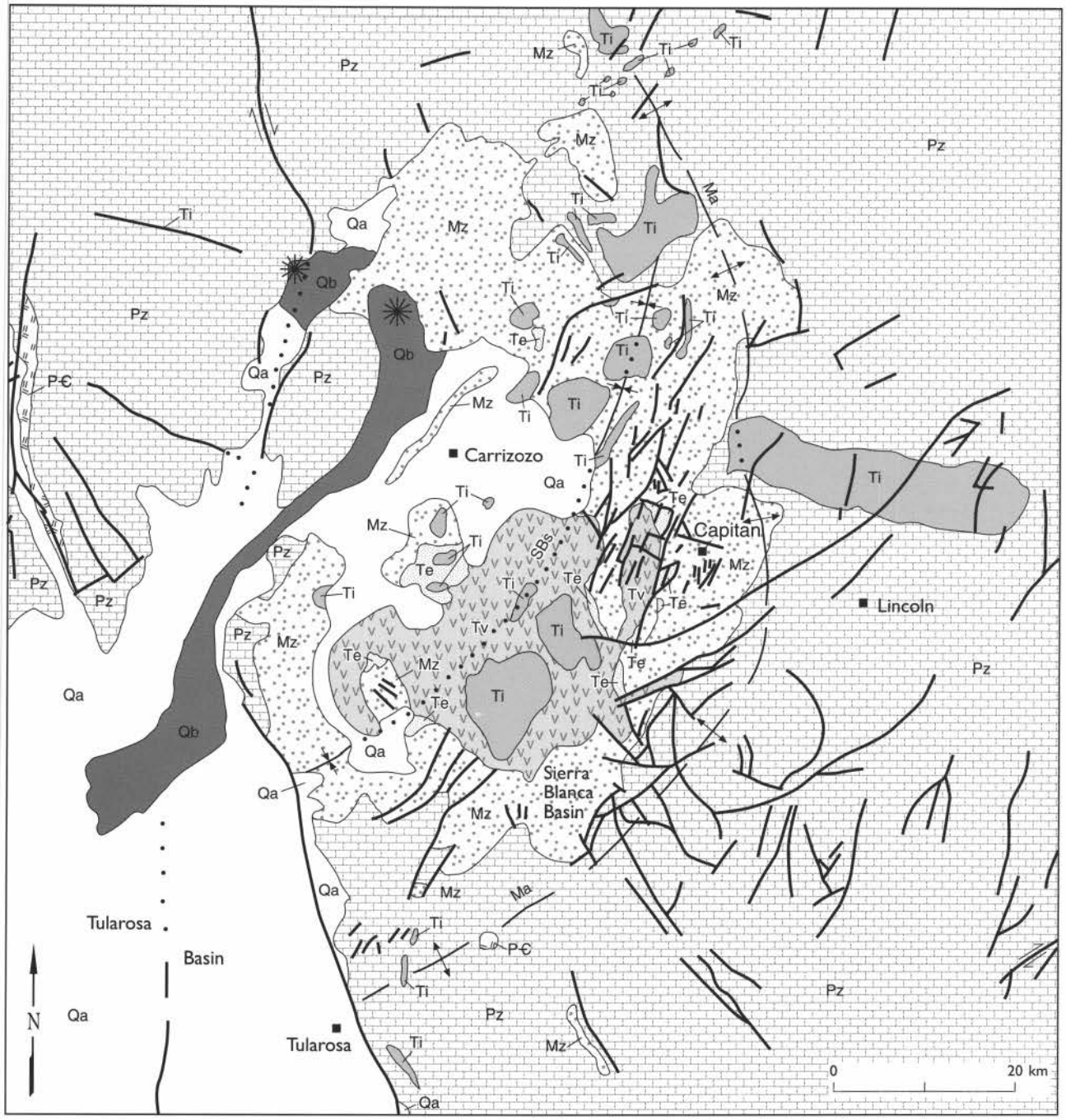
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Coal mining began in the Sierra Blanca coal field in the 1890s to supply coal to nearby Fort Stanton. Aside from supplying coal to the fort, mines in the area supplied home heating fuel and fuel for the nearby railroads. Most mining activity ceased in the area by the 1940s because of the marginal coal thickness and difficult mining conditions. The proximity of a railroad, for easy transport, and the high quality of the coals revived interest during the 1970s and into the 1990s. The latest appeal of the coal in the Sierra Blanca coal field is as a source of coalbed methane.

Located on the northeast margin of the Tularosa basin, the Cretaceous coal–bearing strata that define the Sierra Blanca coal field crop out near White Oaks, Capitan, Three Rivers, Oscuro, Willow Hill and Carrizozo in Lincoln and Otero Counties. These outcrops form a broken semicircle on the west, north, and east sides of Sierra Blanca. The Sierra Blanca coal field is part of a synclinal basin that has been complicated by igneous intrusions and subsequent faulting (Fig. 1.27). Consequently, mining in this area is extremely difficult. Outcrops of the coal-bearing Cretaceous rocks are limited and good exposure of the complete section is lacking, making it difficult to map individual units.

Fisher (1904) was the first worker to mention coal near White Oaks in the geologic literature. He described the coal-bearing unit as consisting of limestone, sandstone, and shale with two coal horizons separated by a considerable thickness. Fisher felt the mining of this coal was unfavorable due to the faulting, the presence of dikes and inaccessibility. Campbell (1907) described the Cretaceous coal-bearing sequence in the Capitan area, near Fort Stanton. He recognized a 1000-ft unit consisting of sandstone, shale and thin coals. Campbell delineated the coal-bearing sequence in the Capitan area as outcrops along a north-south trend that is faulted in several areas (Fig. 1.26).

Wegemann (1912) and Melhase (1927) were the first workers to deal with all the coal areas in the Sierra Blanca field. Wegemann discussed the White Oaks in detail, with reconnaissance work in the Capitan, Three Rivers and Willow Hill areas. The Cretaceous section Wegemann measured at White Oaks is the basis for his discussion of the units. He recognized the Dakota and divided the remaining Cretaceous into three unnamed units; 500 ft of dark gray fossiliferous shale with bentonite beds near



Qa- Quaternary sedimentary deposits

Qb- Quaternary basalt

Ti- late Eocene – early Miocene intrusive rocks

Tv- late Eocene – early Miocene volcanic rocks

fault, locally showing sense of Laramide lateral slip

Ma Mescalero anticlinorium

Te- Laramide (Eocene) deposits of Sierra Blanca basin

Mz- Mesozoic strata of Triassic and Cretaceous age, includes Jurassic Morrison Formation near Capitan

Pz- Paleozoic strata (Cambrian – Permian)

P-€- Precambrian rocks

SBs Sierra Blanca basin

Quaternary cinder cone

FIGURE 1.25. Geologic map of the Sierra Blanca Basin.



FIGURE 1.26. Photograph of the Oscura coal mine. Note the dike adjacent to the mine and its trend into the sill at the crest of the hill.

the base; 440 ft of shale, sandstone and limestone; and a 650-ft coal-bearing sequence with shales, sandstones, and limestone.

Melhase (1927) used the same stratigraphic division of the Cretaceous units in the Sierra Blanca field as Wegemann in discussing the coal-bearing areas. Melhase was the first to apply the term Mancos Shale to the thick, gray shale unit overlying the Dakota Sandstone. He mentioned thin coal beds at the base of the Mancos interbedded with sandstones, which are probably minor

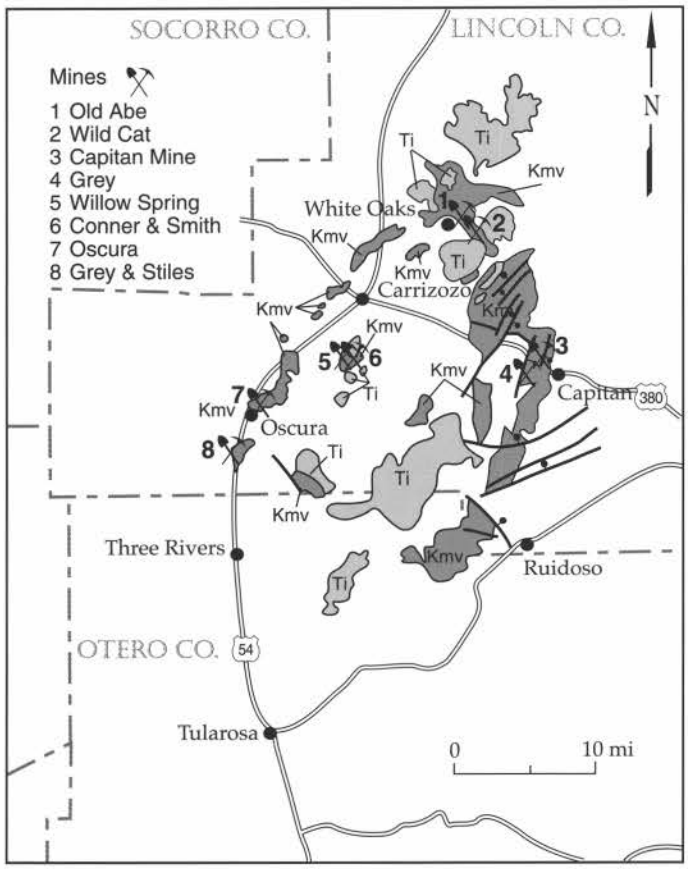


FIGURE 1.27. Map of the distribution of coal deposits in the Sierra Blanca Basin. Map symbols are as follows: Kmv = Cretaceous, Mesa Verde group; Ti = Tertiary intrusive rocks.

coals associated with the Dakota Sandstone that intertongues with the Mancos Shale. Melhase felt Wegemann's section was not representative of the entire sequence in the Sierra Blanca field, particularly in the Willow Hill-Three Rivers area. Melhase's section of what he attributed to being equivalent to the Mesaverde Group includes a lower sandstone, shale, and coal unit below a massive sandstone which is present in the Three Rivers-Oscuro-Willow Hill area but is absent at White Oaks and Capitan.

Wegemann and Melhase's papers discuss the igneous rocks in the Sierra Blanca and their influence on the coal-bearing units. Both workers noted the importance of the structure with respect to the coal-bearing units. Wegemann was the first investigator to note that the overall structure of the area is that of a synclinal basin, but because of intrusives and subsequent faulting, many of the coal-bearing areas are more complex. The White Oaks area was described as being highly faulted, the general dip of the beds to the south, and most of the coal-bearing outcrops are southeast of the village of White Oaks. Both Melhase and Wegemann described the coal-bearing outcrop area south of the Capitan Mountains as being broken by north-south faults, creating a repeated coal section west of the town of Capitan. The Cretaceous units near Capitan dip to the west, towards the center of the Sierra Blanca basin. The Three Rivers area on the west side of Sierra Blanca is described as part of a north-trending syncline with Godfreys Hill, southeast of Oscuro, located in the trough. Both writers agreed that the Willow Hill area is highly faulted.

Bodine (1956) mapped 16 mi^2 west of the town of Capitan, looking at the structural and stratigraphic relationships of the region. Bodine referred to Pike's (1947) work illustrating the transgressive-regressive cycles and subsequent intertonguing of the Upper Cretaceous in the Four Corners area, and used this regional picture to correlate the Cretaceous units in the Capitan area. Bodine divided the Mesaverde Group into three units; lower sandstone, middle shale, and upper sandstone, and mapped these divisions. He felt the coal-bearing upper part was equivalent to the Crevasse Canyon Formation.

Weber (1964) was the first investigator to make a detailed geologic map of the Carrizozo 15' quadrangle, covering the northwest part of the Sierra Blanca coal field. Weber mapped the Dakota Sandstone, Mancos Shale, and Mesaverde Group, but did not subdivide the Mesaverde Group. Mapping subdivisions of the Mesaverde Group near Carrizozo would be difficult because much of the section is covered by alluvium, and the available Cretaceous outcrops do not expose a complete section. Weber agreed with Wegemann and Melhase that faulting downthrown to the west had occurred northwest of Willow Hill, creating an exaggerated thickness of Mancos and Mesaverde. The distance from the Mesaverde Group outcrops at Willow Hill to those to the west-northwest of Carrizozo and the regional dip of 7-25^0 southeast supports the probability of faulting.

Arkell (1983) worked in the Willow Hill-Cub Mountain area, southeast of Carrizozo, investigating the Cretaceous units and their coal potential. Arkell divided the Mesaverde Group into four units; a lower white quartz arenite with minor shale and siltstone; a transitional unit of black fossiliferous shale, subarkosic sandstone and siltstone; a barren member of gray, black

and yellow claystone, siltstone and sandstone; and a coal-bearing unit of sandstone, claystone, and coal. The overlying sandstone, previously included in the Mesaverde Group, was assigned to the Cub Mountain in this study. Cather (1991) feels this sandstone should be in the Mesaverde Group as Weber originally stated.

Cobban (1986) determined through ammonite zonation that the Cretaceous sequence in the Sierra Blanca field is similar to that found in the Carthage area. Starting at the base is the Dakota Sandstone, followed by the lower part of the Mancos Shale with Bridge Creek Limestone beds, the Tres Hermanos Formation, D-Cross Tongue of the Mancos Shale, Gallup Sandstone and the Crevasse Canyon Formation (see stratigraphic column). Coal is found at the base and near the top of the Crevasse Canyon Formation (Arkell, 1986).

Coal beds in the Sierra Blanca field are difficult to mine because the coal-bearing units are broken by many faults and intruded by numerous igneous dikes and sills associated with the Sierra Blanca igneous complex (Fig. 1.27). Outcrops of Cretaceous rocks in this field are limited and highly faulted. Very little of the coal can be surface mined because of dips greater than 5° and excessive overburden. Average coal thickness is 4 ft and estimated resources within 150 to 250 ft of the surface are 42 million st.

Most of the seams in this field are of high-volatile C bituminous apparent rank, and some of the coal near Carrizozo appears to have coking qualities. These coals are low in sulfur, moisture and have a moderate ash content. There are an unusually large number of sandstone "rolls," lenses of sandstone that replace parts of the seams, which make mining expensive and prohibitive. The average of 15 as-received weighted-average analyses for this field is:

	Average	Std. Dev.	No. of Samples
Moisture (%)	5.53	4.51	15
Ash (%)	13.51	5.32	14
Volatile matter (%)	31.46	7.91	14
Fixed carbon (%)	47.24	5.94	14
Sulfur (%)	0.75	0.16	15
Calorific value (Btu/lb)	11174	1787	15
Lbs of Sulfur/MBtu	0.68	0.13	12

Total coal production in the Sierra Blanca field from the 1890s to 1940 was minimal, about 671,000 tons. Early coal mining was centered in the White Oaks and Capitan areas of the Sierra Blanca field, where the majority of coal production for the field occurred. The earliest mines opened in the 1880s, near White Oaks northeast of Carrizozo. The Old Abe coal mine (No. 1, Fig. 1.27), opened in 1898 and continued to operate until 1927, supplied coal to the gold mine of the same name and later to the village of White Oaks. The Wild Cat mine (No. 2, Fig. 1.27), also in the White Oaks area, operated from 1914 until 1958, furnishing coal to the local power plant that served White Oaks, Carrizozo, and Nogal. Coal mining in the Capitan (Nos. 3-4, Fig. 1.27) area started in the 1880s when the army opened a mine to meet the needs of nearby Fort Stanton. In 1899, a rail spur of the El Paso and Northeastern Railroad (EP&NE) was laid from Carrizozo to a site called Salado, later to be known as Coalora, north of the town of Capitan. The New Mexico Fuel Company opened coal mines in this area and shipped coal to smelters in Arizona from 1899 to 1905. During this time, the EP&NE railroad extended its line to Santa Rosa with a spur to Dawson, southwest of the town of Raton where a better and larger source of coal could be mined. The rail spur to Coalora was abandoned in 1905, and many of the company houses in the area were moved to Dawson (Slagle, 1991). Coal in the Capitan area continued to be produced on a small scale for domestic purposes into the 1930s. Small coal mines opened for short periods near Oscuro and Three Rivers, on the west side of Sierra Blanca. Near Willow Hill, south of Carrizozo, the Conner and Smith mine (No. 6, Fig. 1.27) opened in 1910 and mined a 4 ft, 10.5-inch thick coal seam. No production records for this mine are available. The nearby Willow Springs mine (No. 5, Fig. 1.27) operated from 1906-1908 and from 1914-1923 under different ownership. Production from the Willow Springs mine totaled 2282 tons. The Oscura mine (No. 7, Fig. 1.27), about 2 miles north of Oscuro, opened in 1921 by the Consumer Coal Company of El Paso. The coal here was very thin (16-20 in), and only 340 tons were produced from 1924-1926. South of Oscura, the Grey and Stiles mine (No. 8, Fig. 1.27) opened in 1923. For the next four years, 2450 tons were produced from a 3-ft seam. The lease on this property expired in 1927, and there was no activity until 1935. In 1935, the property came under new ownership, and the name was changed to the Three Rivers mine. Another stope was opened at this time because the coal had been faulted out in the original stope. From 1935 to 1940, when the mine closed, only 537 tons of coal was produced.

Exploration in the 1970s-1990s focused on the coal-bearing sequence northwest of Carrizozo. Three coals 3-4 ft thick were identified as a result of drilling projects. The area of interest is on the edge of a southeast plunging syncline with 3-12° dips, therefore mining would have begun as a surface operation and switched to an underground operation as the coal deepened. Up until recently, coal leases northwest of Carrizozo were held by Peabody Holding Co., a subsidiary of Hanson, PLC, but these leases are no longer active.

111.0/53.4 Cross cattleguard. **(1.0)**

112.0/52.4 Oscuro, (Spanish, "dark") began as a pumping station on the El Paso and Northeastern Railroad in 1899, as it built northward to Carrizozo. The townsite was laid out in 1906 by a group from Chicago, and Oscuro reached its height (possibly 200 residents) around 1910. By 1950, only a few people remained, and today it is nearly abandoned. **Cattleguard**; stop sign intersection with paved U.S. Highway 54 **turn right**, south, on US 54 toward Tularosa; Sierra Blanca to east; San Andres Mountains to southwest. **(0.5)**

112.5/51.9 Cross North Mill arroyo. The Godfrey Hills at 10:00 (Jackass Mountain is their

lovely northern peak) are mostly andesite breccias and trachytes of mid-Cenozoic age (Thompson, 1972). **(0.9)**

113.4/51.0 Road curves; Phillips Hills to the west (with towers and radar installations on top) are a cuesta developed on the Permian San Andres Formation. **(0.5)**

113.9/50.5 Cross Jackson Draw. **(0.5)**

114.4/50.0 Crest of hill; igneous rocks on right. **(1.5)**

115.9/48.5 Cretaceous sandstone on right. **(1.1)**

117.0/47.4 Cross tributary of Jackson Draw **(1.6)**

118.6/45.8 Otero County line. **(0.2)**

118.8/45.6 Mile marker 101; note Tularosa Peak, the small, conical hill in the distance at 11:30 **(0.5)**

119.3/45.1 Cretaceous sandstone on right. **(0.2)**

119.5/44.9 Rest stop; Mockingbird Gap at 4:00. **(2.4)**

121.9/42.5 Coming out of curve in road, note the escarpment (fault scarp?) in alluvium to the east. **(1.4)**

123.3/41.1 Three Rivers (Fig. 1.28) and the road to the Three Rivers petroglyph site to left. **Turn left** to proceed east on Otero County Road B-030 to Three Rivers petroglypgh site.

Three Rivers has a long and interesting history. Pat Coghlan, so-called "king of Tularosa," established his Three Rivers Ranch 2 mi east of here in the late 1870s; the post office arrived in 1883, and the railroad in 1899. The following, quoted from Chilton et al. (1984, p. 543-544), provides some of the flavor of the area's history: "Among other profitable ventures here, Coghlan fenced cattle stolen by William Bonney, alias Billy the Kid. After the killing of William McSween during the Lincoln County War, his widow, Susan McSween Barber, acquired part of the valley above Coghlan and became known as "the cattle queen of New Mexico." By 1915, Senator Albert Fall had bought out both Pat Coghlan and Susan Barber. Its name now translated as Tres Ritos, the ranch became a desert paradise under Emma Fall's horticultural care. The Falls enlarged Coghlan's mansion, and this was the scene, in 1921, of the discussions that created the Teapot Dome Scandal. Whether Fall was guilty of accepting a bribe from his business associates Doheny and Sinclair in return for granting them oil drilling contracts in the Elk Hills Reserve in Wyoming, or whether he was a scapegoat who paid for the low public morality of the times, is a still-debated issue. Fall, broken and ailing, spent six months in prison in 1931.

Thomas Fortune Ryan was the next to be captivated by Three Rivers. He acquired the ranch in 1941, tore down all of Fall's mansion except the library, and built a Spanish-style house surrounded by poplar and cottonwood trees. Despite its magnificent setting — the broad Tularosa Valley below, cool creek water underfoot, and Old Baldy towering over all — an aura of sinister mystery hangs over this "magic valley". Murders, suicides, unexplained corpses, hair-raising tales, and ruined millionaires have been a part of the ranch from the 1870s to the present." **(0.2)**



FIGURE 1.28. Photograph of the Three Rivers Trading Post currently known as the "Indigo Lizard."

123.5/40.9 Cross railroad tracks. **(0.4)**

123.9/40.5 Road curves; view ahead of Godfrey Hills. **(0.6)**

124.5/39.9 Cross cattleguard **(0.7)**

125.2/39.2 Crest of hill; note cultivated floodplain of Three Rivers to the south **(0.8)**

126.0/38.4 Road curves. **(0.8)**

126.8/37.6 Cross cattleguard. **(1.1)**

127.9/36.5 Note petroglyph site on north side of road on ridge. Turn left into unpaved picnic ground.**(0.1)**

128.0/36.4 **STOP 5:** park in available spaces at the picnic ground. For our last stop of the day, we will inspect the Walker Andesite Breccia unit that is distributed throughout the Three Rivers area. At this locality, the volcanic breccia rests on sandstones of the Upper Cretaceous Mesa Verde Group. Early residents of New Mexico left their marks (Fig. 1.29) on the weathered fracture surfaces of the andesite and lived along the banks of Three Rivers.

THE THREE RIVERS PETROGLYPH SITE, OTERO COUNTY, NEW MEXICO

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The Three Rivers Petroglyph Site is located approximately 17 mi north of Tularosa, and 28 mi south of Carrizozo, New Mexico in northern Otero and southern Lincoln Counties in the Godfrey Hills along the western slopes of the Black Mountains. The site is managed by the U.S. Bureau of Land Management and is open year round. There are two short hiking trails that begin near the picnic area and go through the petroglyphs (rock carvings) and a partially excavated prehistoric village.

Three Rivers derives its name from the drainage's made by Three Rivers, Indian, and Gollondrinas Creeks. The archaeological site consists of more than 21,000 petroglyphs (rock carvings) made by Jornada Mogollon Indians from about 900 to 1200 A.D. The number and concentration of petroglyphs here, including masks, sunbursts, wildlife, handprints, and geometric designs, makes this one of the largest and most interesting rock art sites in the Southwest.

Paleoindians first inhabited the area about 10,000 yrs ago. The Jornada Mogollon Indians evolved from these nomadic hunters and gathers, and, by 900 A.D., established primitive villages along dependable water sources throughout southern New Mexico, including one near the Three Rivers Site. Their first homes were simple pit houses constructed out of beams covered with branches, mud, and grass. Later, they constructed adobe walled houses. These people relied on agriculture, hunting, and gathering edible desert plants, such as mesquite seeds, prickly pear cactus, and yucca (Sharp, 2001). Water draining from Sierra Blanca allowed these people to grow corn, squash, and beans. Extensive trade routes linked the Jornada Mogollon Indians with other cultures to the north, south, and west. By 1400 A.D., the sites around Three Rivers had been abandoned, possibly as a result of drought, warfare, or disease. The people may have joined the pueblos along the Rio Grande or reverted back to a nomadic lifestyle.



FIGURE 1.29. Photograph of petroglyphs on Walker Andesite Breccia. Note Rose Peak, elevation 7138 in the background.

The petroglyphs were photographed and recorded by the Rock Art Recording Field School of the Archaeological Society of New Mexico and are on file at the Las Cruces Bureau of Land Management Office. Many of the petroglyphs are geometric designs; the circle and dot motif is most common at the Three Rivers site and may represent corn or a population count. Masks also are common and are similar to the Pueblo kachina masks, usually round with almond-shaped eyes and triangular noses. Animals, such as big horn sheep and bear, are found at the site; the legs are often bent to represent motion. Animal tracks are common, especially mountain lion, bear, and turkey. Some of the petroglyphs are positioned on curved rock surfaces that give the petroglyph a three-dimensional view. A covered shelter is at the end of the trail and offers excellent views of the San Andres Mountains to the west with the White Sands at the base and Sierra Blanca to the east. There are only a few petroglyphs past this point and no maintained trails.

The oldest rocks exposed in the Three Rivers area are Cretaceous Mesaverde Group, which are poorly exposed. The best exposures are along the west side of the northwest-trending main ridge. The sequence consists of predominantly yellow-colored sandstone, siltstone, and shale. The sandstone ranges from fine-grained lithic arenite interbedded with conglomerate to medium-grained quartz arenite. Some sandstone outcrops contain abundant marine shell fragments. The shale and siltstone are poorly exposed and typically form the slopes of the ridges.

The main ridge at Three Rivers that contains the petroglyphs consists of dark-green, fine-grained trachybasalt sill that contains hornblende crystals as long as two inches. This igneous rock is part of the Tertiary Walker Andesite Breccia and is found throughout the upper Three Rivers Canyon (Segerstrom et al., 1979). The Godfrey Hills also is made up of the Walker Andesite Breccia, which is overlain by the Godfrey Hills Trachyte (Thompson, 1972). The Walker Andesite Breccia is as much as 2355 ft thick and consists of 36 separate flow units of alternating andesite flows and andesite flow breccias. One of the volcanic sources is a vent in sec. 6, T10S, R10E (Thompson, 1972). The Godfrey Hills Trachyte consists of 600-1800 ft of latite porphyry flows, tuffs, and volcanic breccias, and the age is about 26.1 Ma (Thompson, 1972). The trachybasalt at Three Rivers Petroglyph Site has an $^{40}Ar/^{39}Ar$ age of 36.32 ± 0.35 Ma (Miller et al., 1997; McMillan et al., this guidebook).

A well-developed dark patina (surface coating), called desert varnish, coats most of the exposed surfaces of the trachybasalt out-

crops forming the main ridge. The patina consists of a thin coating of manganese and iron oxides and clays on the surface of sun-baked boulders. Desert varnish is believed by some scientists to be formed by colonies of bacteria that live on the rock surface and absorb trace amounts of manganese and iron from the atmosphere, and precipitate it as a black layer of manganese oxide or reddish iron oxide on the rock surfaces (Dorn and Oberlander, 1981). This thin layer also contains cemented clay particles, which help to shield the bacteria against desiccation, heat, and solar radiation. Several genera of bacteria are known to produce desert varnish, including *Metallogenium* and *Pedomicrobium*. Once formed over thousands of years in an arid climate, the surface coating is easily scratched and removed to produce some of the petroglyphs by the prehistoric Indians. Other petroglyphs were actually created by pecking through the patina with two rocks used as a hammer and chisel. Over time, the exposed surfaces oxidize and return to the dark color, thereby making the older petroglyphs difficult to see today.

Lamprophyre dikes or sills intrude Cretaceous sedimentary rocks west and north of the Three Rivers Petroglyph Site. A lamprophyre south of the Three Rivers Petroglyph Site has an $^{40}Ar/^{39}Ar$ age of 36.11±0.32 Ma (McMillan et al., this guidebook), which is younger than a lamprophyre sill (camptonite) collected from Oliver Lee State Park, south of Alamogordo, that has an age of 44.01 ± 0.01 Ma (McMillan et al., this guidebook).

The Black Mountain stock, forming much of the Black Mountains, consists of hornblende syenite, quartz syenite, and alkali gabbro-syenogabbro (Moore et al., 1988). These intrusive rocks typically contain 1-5% magnetite. Sedimentary rocks of the Cretaceous Mesaverde Group, Cretaceous Dakota Sandstone, Permian San Andres Limestone, and Permian Yeso Formation form the western flanks of the Black Mountains (Moore et al., 1988). Tertiary syenite to diorite, lamprophyre, and trachyte dikes, locally porphyritic, intrude both the sedimentary and volcanic rocks in some areas.

Most of the rock units along the valley at the site consist of surficial deposits. Stream floodplain alluvium fills the active channel of the drainages that drain the west side of Godfrey Hills. Older deposits of stream gravels cap the low terraces adjacent to Three Rivers and represent older stream floodplain deposits. Thick deposits of caliche cap the higher parts of the petroglyph ridge. Talus deposits derived from the igneous rocks that cap the petroglyph ridge cover much of the west side of the escarpment and conceal the underlying Cretaceous rocks. Young alluvial fan deposits surround the petroglyph ridge and overlie older, broader, partially dissected alluvial fans that were derived from Godfrey Hills.

Barbecue Dinner; after stop retrace route to US 54. **Turn right** onto paved road. **(4.6)**

132.6/31.8 Stop sign, turn left onto U.S. Highway 54 and proceed south to Tularosa. **(0.5)**

133.9/30.5 Cross bridge over Three Rivers.

136.3/28.1 Mile marker 93; Sacramento Mountains coming into clear view at 10–11:00. **(4.1)**

140.4/24.0 Snake Tank Road to left. **(2.6)**

143.0/21.4 Cross Temporal Creek **(0.2)**



FIGURE 1.30. Photograph of the Scorpion Mounds northeast of Tularosa.

143.2/21.2 JOBE concrete quarry on right. Note well exposed strata of Permian San Andres Formation to east at southern end of the Sierra Blanca in the Coyote Hills. **(1.5)**

144.7/19.7 Powerline; note Scorpion Mounds to left at 9:30-10:00 above the pecan orchards (Fig. 1.30). The Scorpion Mounds are part of the southern edge of a complex of algal bioherms in the middle part of the Lower Permian Laborcita Formation. An extensive literature has been published on these mounds, and they were visited on stop 2 of day 1 of the 42nd NMGS Fall Field Conference (Colpitts et al., 1991). **(3.4)**

148.1/16.3 Cross bridge over railroad. **(1.2)**

149.3/15.1 Cross bridge over Tularosa Creek; enter Tularosa. **(0.7)**

150.0/14.4 Yield sign at intersection of US 54/70; **continue straight**, south, on U.S. 54-70. **(0.3)**

150.3/14.1 St. Francis de Paula Church on left (Fig. 1.31). **(0.3)**



FIGURE 1.31. St Francis de Paula Franciscan Mission in Tularosa.

150.6/13.8 Tastee Freez/Higuera Road, **continue straight**. Follow morning portion of road log for return to Alamogordo. **(13.8)**

164.4/0 Holiday Inn Express, Alamogordo

End of the Day 1 Roadlog.

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