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First-day road log: From Inn of the Mountain Gods to Bent Dome, Tularosa, Alamogordo, Cloudcroft and return to Inn of the Mountain Gods

Colpitts, Robert M., Jr., George S. Austin, James M. Barker, Paul W. Bauer, W. Richard Hahman, John W. Hawley, and Richard P. Lozinsky

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This is one of many related papers that were included in the 1991 NMGS Fall Field Conference Guidebook.

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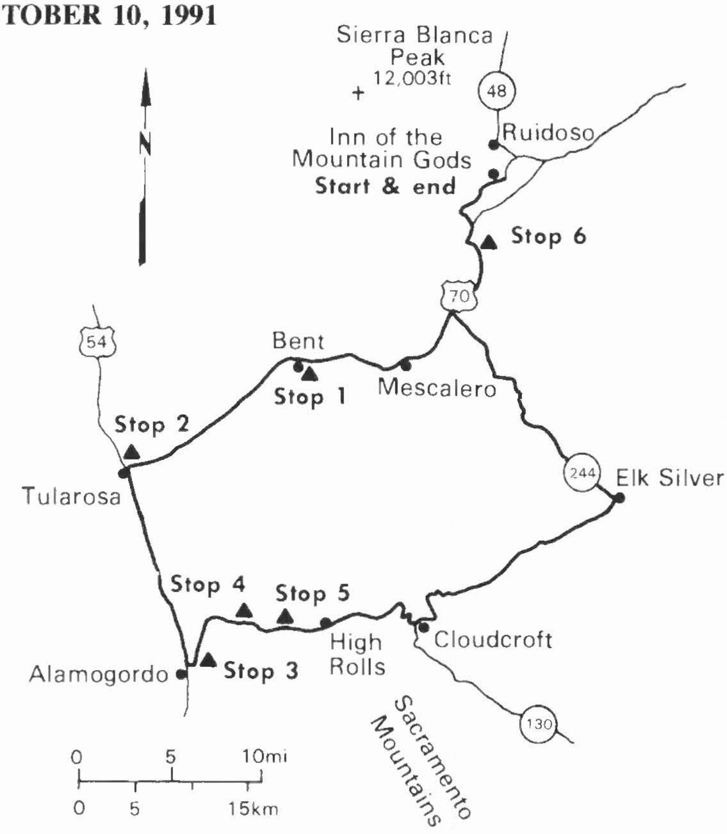
FIRST-DAY ROAD LOG, FROM INN OF THE MOUNTAIN GODS TO BENT DOME, TULAROSA, ALAMOGORDO, CLOUDCROFT AND RETURN TO INN OF THE MOUNTAIN GODS

ROBERT M. COLPITTS, GEORGE S. AUSTIN, JAMES M. BARKER, PAUL W. BAUER,
W. RICHARD HAHMAN, JOHN W. HAWLEY and RICHARD P. LOZINSKY

THURSDAY, OCTOBER 10, 1991

Assembly point:	Inn of the Mountain Gods, near Ruidoso, New Mexico.
Departure time:	7:45 a.m.
Distance:	108.9 mi
Stops:	6



SUMMARY

On Day 1, the trip departs from the front of the Inn of the Mountain Gods and travels west across the crest of the northern Sacramento Mountains. Passing across Apache Summit we will see evidence of solution collapse and complex karst geology. Stop 1 will be at Bent to examine ore deposits at the Virginia mine and discuss the geology of the Bent dome, a structure with a core of Proterozoic(?) rock flanked by Cambro-Ordovician and Permian strata.

As we descend into the Tularosa Valley we will see east-dipping Permian strata of the San Andres, Yeso and Laborcita Formations. Stop 2 will be at Scorpion Mound, northeast of Tularosa, to examine the connection between Permian sedimentation and tectonics. We then proceed to Alamogordo, home of the Space Museum Hall of Fame, which is the location of Stop 3. There will be an opportunity to visit the museum, the show in the nearby Clyde W. Tombaugh Theater, or investigate Pennsylvanian-age strata along the west side of the Sacramento Mountains. We will also discuss the modern reactivation of the Alamogordo fault zone, which we cross several times during this trip.

After lunch, we proceed up US-82 and Dry Canyon to Cloudcroft. At Stop 4, we examine Pennsylvanian algal bioherms and associated facies in the Holder Formation. We then proceed east toward the only highway tunnel in New Mexico. We will cross the Fresnal fault, a Pennsylvanian-Permian structure that was reactivated during late Cenozoic uplift of the Sacramento Mountains. At Stop 5, in the Tunnel Vista parking lot, we will discuss Paleozoic tectonic activity and the archeology of caves in Fresnal Canyon. We then proceed to Cloudcroft and traverse the crest of the Sacramento Mountains through the beautifully forested Mescalero Apache Reservation. After re-crossing Apache Summit, we will examine a roadcut quarry in a debris-filled sinkhole at Stop 6. The First-Day Road Log ends at our point of origin, the Inn of the Mountain Gods.

Mileage

0.0 Inn of the Mountain Gods entrance. **Proceed ahead and bear left. 0.1**

0.1 **Turn right** and proceed through underpass. **0.1**

0.2 Stop sign. **Turn left** onto Reservation Highway #4 and proceed west. Roadcuts ahead and to the left are outcrops of Grayburg Formation (Permian) overlain by Dakota Formation (Cretaceous) at top of hill (Moore et al., 1988). Valley to right is underlain by Mancos Shale, and Dakota and Grayburg Formations. **0.2**

0.4 Side road to right leads to Convention Center at Inn of the Mountain Gods and golf course. **0.2**

0.6 Outcrops on left are Dakota Formation. **0.2**

0.8 Outcrops on right are Dakota Formation, underlain by Permian Grayburg Formation. **0.2**

1.0 Cattle guard. **0.4**

1.4 Trap and Archery Range ahead at 2:00. Bingo parlor in distance. Bear left on Tribal Highway #4. **0.8**

2.2 Outcrop on left in Dakota Formation. Approaching downgrade. **0.2**

2.4 Interbedded Dakota Formation and Mancos Shale at top of grade on left. Crossing under powerline. **0.3**

2.7 Base of Dakota Formation exposed in outcrop at 9:00. Dakota is underlain by reddish siltstone and sandstone of Permian Grayburg Formation. Triassic Santa Rosa Sandstone and Chinle Formation are missing because of tilting and beveling prior to deposition of Dakota Formation sands during Late Cretaceous time. **0.4**

3.1 Cattle guard. Intersection with US-70. **Turn right** toward Alamogordo and Apache Summit. **0.1**

CLIMATE OF CLOUDCROFT-RUIDOSO COUNTRY

Jerry E. Mueller

Department of Earth Sciences, New Mexico State University, Las Cruces, New Mexico 88003

Twelve long-term weather stations are operating in the field conference area. These stations and the years of record used in this discussion are Alamogordo (1931–1983) (Table 1.1), Capitan (1931–1983), Carrizozo (1931–1983) (Table 1.2), Cloudcroft (1931–1983) (Table 1.3), Elk (1931–1983), Fort Stanton (1931–1974), Mayhill (1931–1976), Mescalero (1931–1978), Mountain Park (1931–1983), Picacho (1951–1978), Ruidoso (1942–1983) (Table 1.4) and Tularosa (1908–1983). All data are from the Office of State Climatologist; temperatures indicated are in °F.

Among the twelve stations, Alamogordo has the lowest elevation (4350 ft) and the highest mean annual temperature (61.4°). Cloudcroft has the highest elevation (8801 ft) and the lowest mean annual temperature (45.4°). The remaining ten stations have elevations between 4430 ft and 6838 ft, with mean annual temperatures in the range 48.2° to 60.9°. The average vertical temperature gradient in the field confer-

TABLE 1.1. Temperature and precipitation averages, Alamogordo, New Mexico, 1931–1983.

	Temperature (°F)			Precipitation (inches)		
	Max	Min	Mean	Mean	High--Yr	Low--Yr
January	56.1	28.0	42.1	0.72	2.61 49	0.00* 67
February	61.3	31.8	46.5	0.53	2.14 31	0.00* 55
March	67.9	37.3	52.8	0.42	3.02 58	0.00* 82
April	76.9	44.6	60.8	0.29	2.13 42	0.00* 82
May	86.1	53.1	69.6	0.43	3.03 41	0.00* 74
June	94.9	62.0	78.5	0.77	3.04 33	0.00* 64
July	94.7	65.4	80.1	1.92	6.36 76	0.25 34
August	92.5	63.8	78.3	1.90	6.67 59	0.08 56
September	87.3	58.0	72.7	1.74	6.94 41	0.00* 51
October	77.6	46.9	62.3	1.00	5.66 74	0.00* 82
November	65.0	34.4	49.7	0.51	2.91 78	0.00* 79
December	57.6	28.6	43.1	0.64	2.36 82	0.00* 76
Annual	76.5	46.2	61.4	10.86	21.87 41	2.93 56
Winter	58.3	29.5	43.9	1.89	4.54 83	0.00 34
Spring	77.0	45.0	61.0	1.14	5.66 41	0.00* 72
Summer	94.0	63.7	79.0	4.59	8.74 72	0.66 34
Fall	76.6	46.4	61.5	3.24	9.71 41	0.31 73

Source: State Climatologist 1988 * Also earlier years

TABLE 1.2 Temperature and precipitation averages, Carrizozo, New Mexico, 1931–1983.

	Temperature (°F)			Precipitation (inches)		
	Max	Min	Mean	Mean	High--Yr	Low--Yr
January	50.6	22.6	36.6	0.72	2.90 36	0.00* 76
February	55.7	25.5	40.6	0.62	3.51 31	0.00 43
March	62.3	31.1	46.7	0.66	2.75 58	0.00* 71
April	71.3	38.4	54.8	0.51	4.87 31	0.00* 82
May	80.0	46.9	63.4	0.77	2.83 36	0.00* 75
June	87.7	55.9	72.7	0.97	4.08 33	0.01 45
July	88.9	60.6	75.6	2.20	5.37 62	0.40 78
August	86.3	58.7	73.4	2.45	7.93 35	0.00 78
September	82.3	52.5	67.4	1.92	9.69 41	0.04 56
October	72.6	41.0	56.8	1.01	4.16 74	0.00* 75
November	60.2	28.7	44.4	0.63	3.08 78	0.00* 56
December	52.4	23.1	37.8	0.75	3.05 31	0.00* 76
Annual	70.9	40.4	55.9	13.21	35.60 31	5.00 45
Winter	52.9	23.7	38.3	2.09	5.85 32	0.61 64
Spring	71.2	38.8	55.0	1.95	7.89 31	0.17 66
Summer	87.6	58.4	73.9	5.62	14.60 35	0.82 78
Fall	71.7	40.7	56.2	3.55	13.45 41	0.54 73

Source: State Climatologist 1988 * Also earlier years

TABLE 1.3. Temperature and precipitation averages, Cloudcroft, New Mexico, 1931–1983.

	Temperature (°F)			Precipitation (inches)		
	Max	Min	Mean	Mean	High--Yr	Low--Yr
January	41.6	19.1	30.4	1.84	5.24 46	0.00 67
February	43.3	20.5	31.9	1.63	4.75 31	0.09 43
March	48.2	24.0	36.1	1.64	7.31 58	0.00* 72
April	56.8	30.5	43.6	0.76	3.49 42	0.00* 72
May	64.9	37.3	51.1	0.96	5.20 41	0.00* 66
June	73.3	45.2	59.2	1.86	6.17 43	0.15 51
July	73.0	47.7	60.3	5.51	10.75 50	1.88 35
August	71.2	46.8	59.0	4.81	9.69 31	1.19 50
September	67.5	42.6	55.1	2.85	11.62 41	0.02* 56
October	59.6	34.4	47.1	1.55	5.68 72	0.00* 66
November	50.3	25.3	37.8	0.98	3.95 31	0.00* 56
December	44.1	21.1	32.6	1.78	5.73 65	0.00* 50
Annual	57.8	32.9	45.4	26.16	48.10 41	15.33 70
Winter	43.0	20.2	31.6	5.25	9.14 62	0.85 34
Spring	56.6	30.6	43.6	3.35	10.30 41	0.38 67
Summer	72.5	46.5	59.5	12.18	17.58 49	6.27 83
Fall	59.1	34.1	46.6	5.38	16.34 41	0.75 59

Source: State Climatologist 1988 * Also earlier years

TABLE 1.4. Temperature and precipitation averages, Ruidoso, New Mexico, 1931–1983.

	Temperature (°F)			Precipitation (inches)		
	Max	Min	Mean	Mean	High--Yr	Low--Yr
January	49.0	17.2	33.1	1.23	3.44 82	0.00 67
February	51.9	18.5	35.2	1.09	2.32 65	0.00 43
March	57.1	22.4	39.8	1.19	4.58 58	0.00* 72
April	65.1	27.5	46.3	0.74	3.49 42	0.00* 74
May	73.4	33.3	53.4	0.82	2.42 54	0.00* 72
June	82.1	41.3	61.7	1.86	6.39 65	0.00 64
July	81.5	47.7	64.6	4.17	10.86 50	1.16 66
August	79.4	46.8	63.2	4.02	8.24 63	1.12 48
September	75.4	40.5	58.0	2.53	5.80 64	0.06 59
October	67.4	30.7	49.1	1.30	6.49 74	0.00 52
November	57.5	21.7	39.6	0.81	2.48 78	0.00* 77
December	50.8	17.7	34.2	1.59	8.88 78	0.00* 81
Annual	65.9	30.4	48.2	21.36	34.81 65	12.27 70
Winter	50.5	17.8	34.2	3.91	12.54 79	1.99 67
Spring	65.2	27.8	46.5	2.75	7.02 58	0.00 72
Summer	81.0	45.3	63.2	10.05	16.74 65	4.26 83
Fall	66.7	30.9	48.9	4.64	11.69 74	0.71 59

Source: State Climatologist 1988 * Also earlier years ence area is approximately 5.0°/1000 ft, though summer gradients are 40–50% greater than winter gradients. Intense solar heating at the lower elevations probably accounts for the enhanced summer gradient across the region. Cold-air drainage from the mountains to the lowlands of the eastern Tularosa Basin is responsible for the more equitable temperatures and reduced gradient found in the winter season. Tularosa, which is both north of and at a slightly higher elevation than Alamogordo, actually has slightly warmer winter mornings because of less access to cold-air drainage. Record high and low temperatures, respectively, are Alamogordo, 110° and –14°; Capitan, 98° and –15°; Carrizozo, 105° and –18°; Cloudcroft, 89° and –21°; Elk, 99° and –24°; Fort Stanton, 101° and –28°; Mayhill, 98° and –16°; Mescalero, 100° and –19°; Mountain Park, 101° and –10°; Picacho, 104° and –17°; Ruidoso, 97° and –26°; Tularosa, 111° and –3°. The number of days per year with temperatures below 32° ranges from a low of 78 at Tularosa to a high of 199 at Ruidoso.

Based on annual precipitation, the climate of the region is classified as arid at the eastern edge of the Tularosa Basin, semiarid at intermediate elevations along the flanks and valleys of the mountains, and humid alpine at both Cloudcroft and Ruidoso. Annual precipitation averages are 9.59 in. (Tularosa), 10.86 in. (Alamogordo), 12.86 in. (Picacho), 13.21 in. (Carrizozo), 13.85 in. (Fort Stanton), 15.77 in. (Capitan), 15.98 in. (Elk), 18.48 in. (Mountain Park), 18.91 in. (Mayhill), 19.39 in. (Mescalero), 21.36 in. (Ruidoso) and 26.16 in. (Cloudcroft). The driest year on record is 2.93 in. at Alamogordo in 1956. The wettest year on record for the ten stations in operation at the time was 1941. Cloudcroft received a total of 48.10 in., of which 11.62 in. fell in the month of September. Whitetail (7800 ft), at the eastern edge of the Mescalero Reservation, holds the state record for annual precipitation at 62.45 in., also in 1941 (Tuan, 1969). Mueller et al. (1973) estimated that the maximum precipitation from a 100-year, 24-hour storm is 3.5 in. at the lowlands of the eastern Tularosa Basin and 5.0 in. in the Sacramento Mountains near Cloudcroft, the east flank of Sierra Blanca near Ruidoso, and the Capitan Mountains.

July to September is the wettest period at all twelve stations and coincides with the season of maximum thunderstorm development in the region. A secondary maximum of precipitation occurs in middle to late winter and is associated with moisture advected from the eastern Pacific. Much of the winter precipitation falls in the form of snow, especially at the higher elevations. Ruidoso averages 43.2 in. of snowfall annually and Cloudcroft 84.5 in.; in 1958, the two communities received record snowfalls of 75.9 in. and 178.0 in., respectively.

3.2 Hills to left consist of limestone and dolomite of the San Andres Formation. **0.1**

3.3 Outcrop ahead and to the right is San Andres Formation. **0.3**

3.6 Outcrops of San Andres Formation are obscured by dense growths of pine. **0.3**

3.9 "Dangerous Crosswinds" sign on right. **0.2**

4.1 Outcrops on right are San Andres Formation. Greenish-colored outcrop represents copper staining. Source of copper is probably from fluids accompanying intrusions in this region; they may or may not be associated with dike emplacement. **0.2**

4.3 Terraced roadcut ahead at 10:30 to 11:30 is the east end of the quarry highwall used by a construction company for road metal for recent regrading and widening of US-70. This quarry was cut in part of a collapse feature that occurs at the confluence of Dark, Cherokee Bill and Pete Gaines Canyons. Karst features are common in roadcuts from this point westward to Apache Summit, but are also common from the Pecos River area west to Mescalero and from Fort Stanton to south of Cloudcroft. These features are characterized by boulders, cobbles and pebbles of limestone, dolomite and sandstone, cemented by travertine, dripstone and reddish to pinkish friable cave-filling silt, sand and conglomerate. Cobbles and large boulders are derived from overlying San Andres strata (Fig. 1.1). **0.1**

4.4 Side road on right leads back to Inn of the Mountain Gods. **0.3**

4.7 Milepost 254. Outcrops on right and ahead on left are San Andres Formation. Valleys between these outcrops frequently display travertine and dissolution features that surrounded leached mafic and intermediate dikes and sills. **0.4**

5.1 Outcrop on left displays contorted and fractured San Andres Formation. Yellowish-colored rocks are leached dikes and sills. Apparently, dissolution came right up to the dike/limestone contact, leaving a vug or cave on one side and little or no dissolution on the other side. Many dikes become sills up-section (Fig. 1.2). **0.4**

5.5 Outcrops on right and ahead display more leached San Andres Formation. **0.2**

5.7 Roadcut on right displays extensive leaching and karst. **0.8**

6.5 Crossing Apache Summit, elevation 7591 ft (2314 m). Outcrop on right is Permian Grayburg Formation. **0.1**

6.6 Begin descent into North Fork of Tularosa Canyon. Outcrop ahead and to left is Cretaceous Dakota Formation. **0.1**

6.7 Milepost 252. **0.2**

6.9 Grayburg Formation in roadcut to right. **0.6**

7.5 State-owned green storage shed and well house on left. Crossing a series of high-angle, down-to-the-east normal faults that raise the San Andres Formation on the west, exposing Yeso Formation strata in side canyons and roadcuts from here to Mescalero. Amount of throw on faults is uncertain because of poor exposures. Faulting is most likely late Tertiary in age. **0.7**

8.2 Surrounding hills are forest-covered San Andres Formation. **0.5**

8.7 Milepost 250. **0.1**

8.8 Roadcut to right in uppermost part of the Yeso Formation. This interpretation is supported by color, grain size, sorting and the presence of an oolite grainstone bed just above eye-level in the cut. No oolite grainstones have

FIGURE 1.1. Roadcut displaying collapsed cavern roof in San Andres Formation (Rio Bonito Member) at mile 4.2.

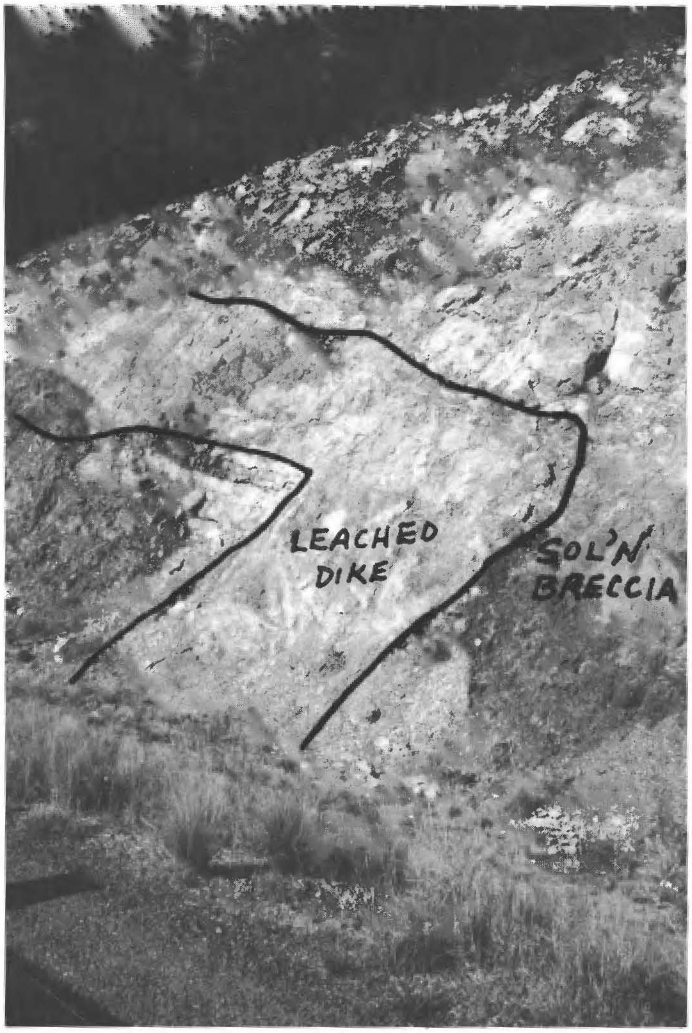


FIGURE 1.2. Dike becoming a sill intruding San Andres Formation at mile 5.1. Note solution breccias ending at the dike boundary at right side of photograph.

been reported from the Grayburg Formation in this area, so this outcrop is Yeso Formation. **0.5**

9.3 Intersection with NM-244 on left. This road leads south to US-82 and Cloudcroft. We will be returning over this road later this afternoon. **0.4**

9.7 Outcrop on right is in upper part of Yeso Formation. Forested hills surrounding highway are capped by San Andres Formation. **0.3**

10.0 Roadcut to right displays rubbly blocks of gray limestone and dolomite derived from the overlying San Andres Formation. These blocks are either part of a landslide or are associated with a sinkhole in the upper Yeso Formation. **0.4**

10.4 Big Hunter Drive to right. **0.3**

10.7 Milepost 248. Outcrop in valley to left in brecciated and rubbly San Andres Formation. This is either part of a slump block or karst with Yeso Formation evaporites dissolved away, allowing San Andres Formation to collapse and fill resultant sinkhole. **0.5**

11.2 Roadcut to right is either a slump of San Andres Formation or is derived from one of the Yeso Formation carbonates. **0.8**

12.0 Leached Yeso Formation exposed in hillslope to right. Jumbled appearance and lack of distinct bedding may be caused by dissolution of evaporites down-section. **0.7**

12.7 Milepost 246. Side road to right (with cattle guard) leads to quarry in a large block of San Andres Formation. This block is either the downthrown side of a normal fault or a toreva block of San Andres Formation that slid down across soft, weathered Yeso Formation sandstone and siltstone. **0.3**

13.0 Side road to right. **0.5**

13.5 Mescalero village limit, population approximately 900. Mescalero is presently the location of Tribal government offices, school and medical facilities. **0.1**

13.6 **Continue west** on US-70. Off ramp to right leads to Indian hospital and elementary school. Cathedral built of sandstone visible at 8:30. **0.5**

14.1 Mescalero tribal store to left. **0.2**

14.3 Mescalero Tribal Offices at 9:00. **0.3**

14.6 Scorched building at 9:00 is all that remains of Mescalero Elementary School, firebombed in 1989 by conservative members of the Mescalero Tribe who felt that education should emphasize traditional Indian values rather than those of other ethnic groups. **0.2**

14.8 Old adobe buildings at right and left are remnants of an old flour mill, Blazer's Mill, scene of one of the first gunfights of the Lincoln County War. The historic marker (Fig. 1.3) for this confrontation is located 3 mi farther west beside the eastbound lane. See minipaper in Part Two of Second-Day Road Log for more on the Lincoln County War. **0.3**

15.1 Gas station on right. Slopes in distance underlain by Yeso Formation. **0.3**

15.4 Hills surrounding valley floor are made up of Yeso Formation capped by San Andres Formation. Reddish sandstone and silty sandstone are part of the lower Yeso Formation. **0.3**

15.7 Milepost 243. **0.3**

16.0 Tribal housing development at 2:30 and 3:00. **0.3**

16.3 Roadcuts ahead and on right are in talus and alluvium derived from Yeso Formation. **0.6**

16.9 Side road to right leads to Mescalero Forest Products office and sawmill. **0.6**

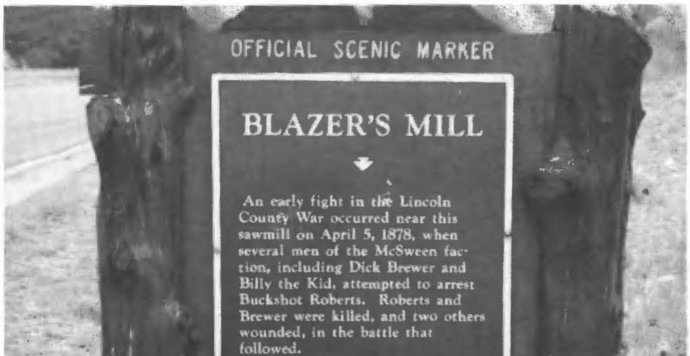


FIGURE 1.3. New Mexico historic marker for Blazer's Mill, near Milepost 241 on the south side of US-70.

17.5 Eddie's Bar on left. **0.2**

17.7 Milepost 241. Outcrops on left are in alluvial gravels. **0.1**

17.8 Leaving Reservation. About 0.5 mi up the major drainage at 9:00 are exposures of red mudstone, white sandstone and dark red granite that Bauer and Lozinsky (1991, this guidebook) concluded are Abo Formation, Bliss Sandstone and Proterozoic granite. They determined that Bliss unconformably overlies the granite and Abo unconformably overlies Bliss. This area, known as the Bent dome (Bachman, 1960), is a structural high on which Paleozoic rocks between Bliss Sandstone and Abo Formation are missing. Bachman (1960) thought that this area is a southern prong of the ancestral Rocky Mountain Pedernal uplift. (See Bauer and Lozinsky, 1991; Foord and Moore, 1991; Bowsher, 1991; all in this guidebook, for more information on Bent dome.) **0.2**

18.0 Light-gray and brown sandstones in roadcut on right were mapped by Bachman (1960, 1964) as Pennsylvanian strata. The brown sandstone consists of fine-grained quartz sand and silt with scattered, rounded, coarse quartz and glauconite grains cemented by dolomite. This unit also contains scattered brachiopods and straight-shelled cephalopods. Some thin bedding planes are apparent, but the outcrop is fairly massive with locally intense bioturbation. The light-gray sandstone is fine to medium grained and consists of well-sorted, subangular-to-rounded, quartz grains. The lowest beds have indistinct laminations and are somewhat bioturbated. Above this, bedding is better developed and dips 10° north. The brown sandstone is separated from the overlying light-gray sandstone by a disconformity with approximately 6 m of relief. Thin shale laminae separate the two units and display compaction drapes in several places. Scattered sandstone pipes and dikes below the contact contain sand derived from the overlying light-gray sandstone. Bauer and Lozinsky (1991, this guidebook) interpreted this as Cambro-Ordovician Bliss Sandstone, based on lithologic similarity to sandstone units to the south. Foord and Moore (1991, this guidebook) mapped this unit as Yeso Formation. **0.1**

18.1 Side road to right. At 4:00 (Fig. 1.4) a red conglomerate bed overlies the sandstone described at mileage 18.0. This conglomerate bed appears to be overlain by red-brown mudstone and channel sandstone that are characteristic of the Abo Formation farther to the west. Bauer and Lozinsky (1991, this guidebook) interpret the conglomerate as being Quaternary in age, based on the presence of Tertiary(?) quartz-eye rhyolite clasts, and similar exposures to the south, where a red piedmont-slope deposit overlies the Bliss Sandstone. **0.3**

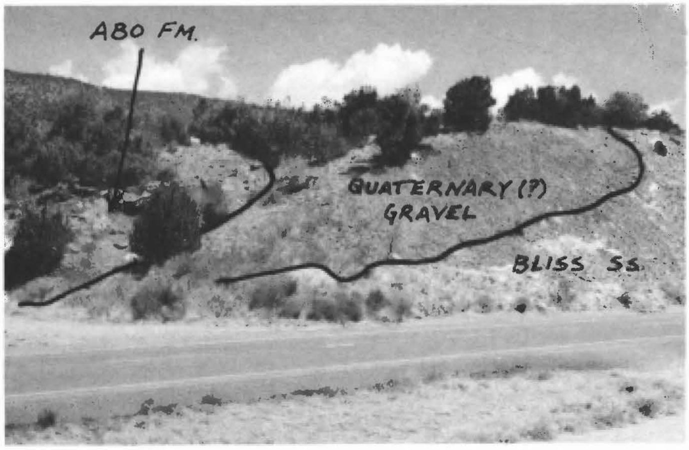


FIGURE 1.4. Contact relationship between the Bliss Formation (Cambro-Ordovician), Abo Formation (Permian) and Tertiary(?) or Quaternary(?) gravels north of US-70 at mile 18.0.

18.4 Red sandstones of the lower part of Yeso Formation are overlain by alluvial gravels on right. Sandstones are leached. **Slow and move into left lane. 0.1**

18.5 **Turn left** onto Nogal Canyon Road (old US-70). Foundations of old 100-ton-per-day mill visible on hillside at 3:00. Copper ore from the Virginia mine was processed here for several years beginning in 1909. **0.3**

18.8 Entering Bent. This is a farming and ranching community that was originally settled around 1904 upon development of the Virginia copper mine just to the southeast. George Bent operated the mine and mill for a number of years. Production was minor, and the mine has been inactive since the mid-1920s. **0.2**

19.0 Intersection with Nogal Canyon Road (Otero Co. B17). Bent Post Office is to right. **Turn left (south)** toward Tularosa Creek. **0.2**

19.2 Crossing Tularosa Creek. **0.1**

19.3 Intersection. **Turn left (east)** onto gravel road. **0.2**

19.5 Hills at 3:00 underlain by thinly covered Yeso Formation and possibly some thin Abo Formation (Bachman, 1960, 1964). **0.2**

19.7 Yeso Formation exposed in roadcut on right and ahead is intruded by Tertiary hornblende andesite dikes and sills. **0.1**

19.8 Crossing arroyo. Side road to right. Road forks immediately ahead. **Bear left on well-traveled road. 0.1**

19.9 Side road to left. **Continue straight. 0.1**

20.9 **STOP 1.** Small cemetery on left (Fig. 1.5), old road to the Virginia mine on right. **Pull off to right side of road and park as directed by flaggers. Cross fence and walk east along old dirt road.** We are walking on a piedmont-slope deposit that contains rounded clasts of reddish quartzite, limestone and various igneous rocks. The quartzite clasts are probably Bliss Sandstone (Cambro-Ordovician), similar to rocks that crop out 1 mi to the east. The limestone clasts are eroded from the Yeso and/or San Andres Formations exposed to the east and south. The igneous clasts are most likely derived from Tertiary rhyolite found to the north and Precambrian granite that crops out 1 mi east. The piedmont-slope deposit rests on an erosional surface on bedrock that once extended over most of this area. Its red color suggests the source is the Yeso and/or Abo Formation.

Follow the overhead electric line to the left. We descend through 2 to 3 m of piedmont-slope alluvium to an incised terrace. This terrace is the former floor of the tributary drainage. The present drainage is 8 to 11 m below this terrace level.

Follow eroded road to left to arroyo crossing. Note valley fill in arroyo walls. Fill consists of interbedded clay and silt (overbank deposits), poorly sorted silty sand and gravel (debris-flows), and coarse-grained channel gravels of reworked Permian rocks. The arroyo is widened by caving and slumping of sidewalls.

FIGURE 1.5. Grave at Bent cemetery where one of Billy the Kid's pals was laid to rest. (Photograph by Paul Bauer)

Note concrete culverts in channel floor; these were probably used beneath an old bridge that crossed nearby. Similar culverts are found 60 m downstream. These are good indicators of stream competence during high-flow events. Collapsed remains of an old US-70 highway bridge can be seen 60 m downstream (Fig. 1.6). An old-timer who lives nearby recalls that the old road, abandoned around 1936, actually crossed this arroyo over a spillover, and the channel was not incised headward past the road. If so, the channel has incised 8 to 9 m in the past 55 years!

Cross arroyo and continue east on old road. Ahead and to the right is a prospect pit exposing dark-red muddy sandstone. Near the pit are float blocks of coarse arkosic conglomerate with rounded clasts of various rock types. The conglomerate and sandstone were mapped as Abo Formation by Bachman (1960). However, mapping by Bauer and Lozinksy (1991, this guidebook) suggests this unit is actually the basal, cemented horizon of a Quaternary piedmont deposit, which contains reworked Abo Formation clasts. This deposit caps hills to the east.

Continue to the left on the old dirt road for about 45 m. Mine dumps ahead are from the Virginia mine.

FIGURE 1.6. East abutment, old US-70 highway bridge in 1991, at Bent. This part of the road was abandoned about 1936 and the erosion visible here has occurred since that time. (Photograph by Paul Bauer)

Bear right onto dumps toward the mine. There are two materials composing the mine dumps. The alluvial material underfoot is Quaternary fill that was removed from the southern part of the open pit mine. The rock removed from the underground mine forms the mine dumps to the north. Placement of the alluvial material has blocked the arroyo drainage and creates a closed basin in the open pit mine, which floods during heavy rainstorms.

The primary ore mineral here is chalcocite, Cu_2S, although Foord and Moore (1991, this guidebook) reported that much of the copper is actually in djurleite, $Cu_{31}S_{16}$. In 1905, the workings consisted of underground levels at 35 and 70 ft. The highest grade ore was found on the 35-ft level, which corresponds to the floor of the open pit and large stope to the north. The open pit was developed sometime around 1912. Many of the rocks here are highly altered but two general rock types can be easily distinguished. Most of the quarry face consists of extremely altered Proterozoic(?) diorite. The central wedge above the main portal is sandstone with minor carbonate beds that Bauer and Lozinsky (1991, this guidebook) correlate with the Cambro-Ordovician Bliss Sandstone. They found that it contains scales of a Cambrian-Devonian, jawless marine vertebrate and is identical to Bliss Sandstone exposed in the Sacramento escarpment to the south. Most previous workers thought that it was Pennsylvanian (Ball, 1913; Bachman, 1960, 1965; Foster, 1959). Foord and Moore (1991, this guidebook) concluded that it is Cambro-Ordovician Bliss Sandstone. The unit commonly contains cross-laminations and bioturbated horizons. Not all of the green color in the basal sandstone is due to copper mineralization; much of the deep green color is from glauconite, a mineral characteristic of the Bliss Sandstone and many marine sandstones.

The north face of the quarry displays a good example of structural control of mineralization. The sedimentary rocks have been down-dropped graben-like along two north-striking normal faults. Mineralization and alteration are concentrated along the intersection of faults and at the diorite-sandstone contact. The mineralized fault zones probably represent a later (Tertiary?) remobilization of older copper mineralization that is concentrated at the top of the diorite and along the diorite-sandstone contact. Smaller workings and prospects are scattered to the north and south along the same trend. The pervasive, gently west-dipping planar feature in the diorite is probably a joint set; it is parallel to bedding in the overlying sedimentary rocks. The foundations of the old 100-ton-per-day mill and affiliated buildings are just north of here (Fig. 1.7). **Retrace route to vehicles. 0.2**

A SHORT HISTORY OF THE OLD VIRGINIA MINE

Paul W. Bauer

New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico 87801

A chalcocite deposit was discovered near the present town of Bent by Andrew Wilson in 1870, and a small furnace was erected on the site. In 1904, George Bent obtained an option on the property and the Tularosa Mining and Milling Company was formed. In March 1905 the company reorganized as the Tularosa Copper Company, and by May 1905 the company was building a water-powered concentrator while development of the low-grade copper deposit continued. The property consisted of 15 claims (300 ac), a 10-ac millsite, and 300 ac of miscellaneous lands. The mine was developed by two 70-ft shafts, with levels at 35 ft and 70 ft. The richest ore, said to grade between 25–45% copper, from diorite porphyry laced with chalcocite, was extracted from a large stope at the 35-ft level. The ore also contained 3–4 oz/ton silver. Returns of $93/ton were reportedly received from ore shipped to the smelter in El Paso. Between 1906 and 1910, the company milled 7000 tons of ore yielding 221,230 lbs of copper (with some silver), a net return of 1.5% copper.

By 1909, 50 miners worked at Bent, and in 1912 the company entirely remodeled the mill and enlarged the operation to handle 100+ tons/day of ore. A hydroelectric plant was installed to provide power to mine and mill. Reports from around this time state the property now consisted of 307 ac of patented mining claims, 15 unpatented claims, along with a farm, ranch, and water rights capable of developing 200 hp. (The presence of patented claims on this property is not supported by any records available today.) The mine now consisted of a glory hole that measured 120 × 60 ft and 35 ft deep, and workings which exposed over 85,000 tons of ore. It was reported that 12 diamond-drill holes, from 88–400 ft deep, had blocked out an additional 800,000 tons of ore with an average grade of 2.5% copper. The drill records are not available. Stock sold as high as $10/share, and promoters and consultants were comparing the Virginia mine to such copper porphyry deposits as Chino, Ray and Miami. The future looked bright for Mr. George Bent and associates. However, the Mines and Copper Handbook (1913, p. 898) prophetically stated, "Compared with other deposits of similar character, this one is extremely small and the ore bed very thin, averaging perhaps 35′, while the ore reserves cannot be considered large enough to be even compared with those of any of the copper porphyries. This, of course, means that the property does not warrant a large mill, and the handling of the great tonnages which alone make it possible to produce copper at a low cost." Production ceased in 1918, probably due to the low price of copper ($0.08/lb), poor extraction, inexperienced management and insufficient operating capital. In 1926, the Tularosa Copper Company properties were sold at sheriff's sale.

Sources for this text include Lindgren et al. (1910), Ball (1913), The Mines Handbook and Copper Handbook (v. 8, 11, 15, 16, 17, 18) and Wilson (1921).

20.2 Dead-end sign ahead. **Turn left** onto side road. **0.1**

20.3 **Caution, road bends sharply to left. 0.1**

20.4 Intersection. **Turn right** toward Nogal Canyon Road. **0.6**

21.0 Intersection. **Turn right** on Nogal Canyon Road (Otero Co. B17) toward Bent. **0.2**

21.2 Intersection with old US-70. Bent Post Office at 12:00. **Turn left** toward Tularosa. **0.1**

21.3 Intersection. **Turn left** on new US-70 toward Tularosa. **1.0**

22.3 Gas station on left. Mountain range on skyline is the San Andres Mountains, location of type section of San Andres Formation (Lee and Girty, 1909; Needham and Bates, 1943; Kottlowski et al., 1956). **0.1**

22.4 White gypsum dunes of White Sands are visible in distance at 11:00 in the Tularosa Basin, one of the major basins of the Rio Grande rift. Round Mountain, with cross (Fig. 1.8), is at 10:30 next to highway. This was the scene of a battle in 1868 between Apaches and settlers from Tularosa augmented by a troop of U.S. Cavalry. Attacking Apaches were beaten back several times before finally giving up the fight. Battle is commemorated each year by local residents and Mescalero Apaches. **0.8**

STRUCTURE AND BASIN-FILL UNITS OF THE TULAROSA BASIN

Richard P. Lozinsky and Paul W. Bauer

New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico 87801

The north-elongate Tularosa Basin of south-central New Mexico is one of the major basins of the Rio Grande rift (Seager and Morgan,

FIGURE 1.7. Foundations of the 100-ton-per-day mill just north of the Virginia mine. Production ceased in 1919.

FIGURE 1.8. Round Mountain at mile 22.4.

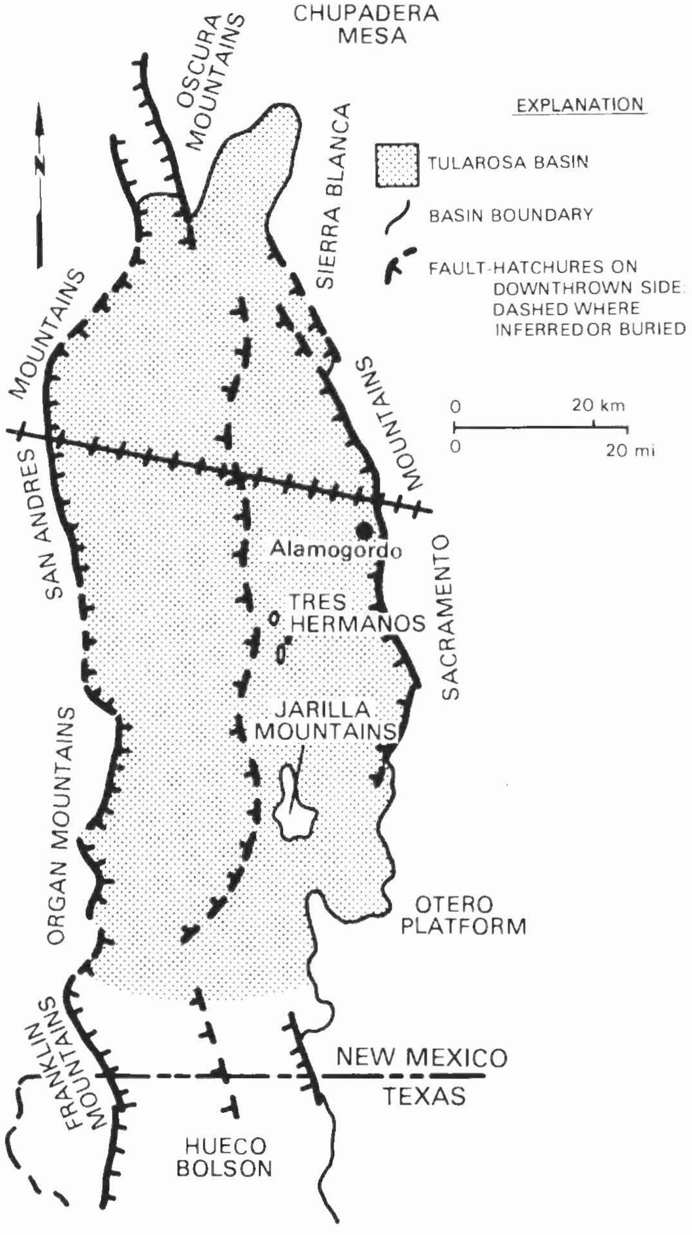


FIGURE 1.9. Generalized map of Tularosa Basin. Barbed line shows approximate location of cross section (Fig. 1.10). Modified from Woodward et al. (1978) and Seager et al. (1987).

1979). It covers an area of about 6500 mi^2 (16,800 km^2) and is one of the few Rio Grande rift basins with internal drainage (Fig. 1.9). The basin is bordered by Sierra Blanca, the Sacramento Mountains and the Otero Platform to the east, and the San Andres–Organ–Franklin Mountains to the west. Phanerozoic strata in these uplifts generally dip away from the basin. The Oscura Mountains and Chupadera Mesa border the basin to the north and a low topographic divide separates the basin from the Hueco Bolson to the south.

Major faults with several thousand feet of stratigraphic throw separate the basin from the east- and west-flanking uplifts. Studies of fault-scarp morphology by Machette (1987) show that activity along many of these faults continued into the late Quaternary and a few segments have been active in the Holocene (Gile, 1987).

The Tularosa Basin is structurally complex. It consists of two north-trending half-grabens that are separated by the buried Jarilla fault zone (Fig. 1.10). This interpretation is supported by gravity surveys and limited water and oil-test well data (Healy et al., 1978; King and Harder, 1985; Seager et al., 1987). As shown on Fig. 1.10, the eastern half-graben tilts eastward with the thickest basin fill (at least 4000 ft) adjacent to the Sacramento Mountains (Healy et al., 1978; Orr and Myers, 1986, p. 33). Isolated, intrabasinal bedrock highs that protrude above the basin fill (i.e., Tres Hermanos, Jarilla Mountains) mark the western edge of the eastern half-graben.

The thickest section of basin fill in the Tularosa Basin occurs along the western margin. Basin-fill thickness in the western half-graben is at least 6000 ft, based on water well T-14 that reportedly bottomed in the Santa Fe Group at a depth of 6015 ft and on gravity surveys (Healy et al., 1978; Orr and Myers, 1986; Seager et al., 1987). However, the structure of the western basin is poorly known because wells drilled in this area have not penetrated bedrock. Seager (1980) and Seager et al. (1987) have interpreted this part of the basin to be a westward-tilted half-graben.

The latest Oligocene to middle Pleistocene Santa Fe Group is the major basin-fill deposit within the Tularosa Basin. It is not known if lower Tertiary deposits underlie the Santa Fe Group. The only wells penetrating the Santa Fe Group are along the eastern margin of the basin. Analysis of water-well cuttings and electric logs indicate that the Santa Fe Group consists mainly of interbedded sand, silt, clay and evaporites in the central part of the basin (Meinzer and Hare, 1915; Orr and Myers, 1986; Seager et al., 1987). These deposits generally coarsen toward the bordering uplifts. Most of the evaporite deposits consist of gypsum derived from Yeso Formation outcrops in the San Andres and Sacramento Mountains (Weber and Kottlowski, 1959). Overall, the basin-fill deposits are typical for closed-basin deposition. During the late Pliocene to early Pleistocene, however, the ancestral Rio Grande flowed into the southern part of the basin via Fillmore Pass, creating a large alluvial-fan delta that extended southward outside of the basin into northern Chihuahua, Mexico (Seager, 1981; Seager et al., 1984, 1987).

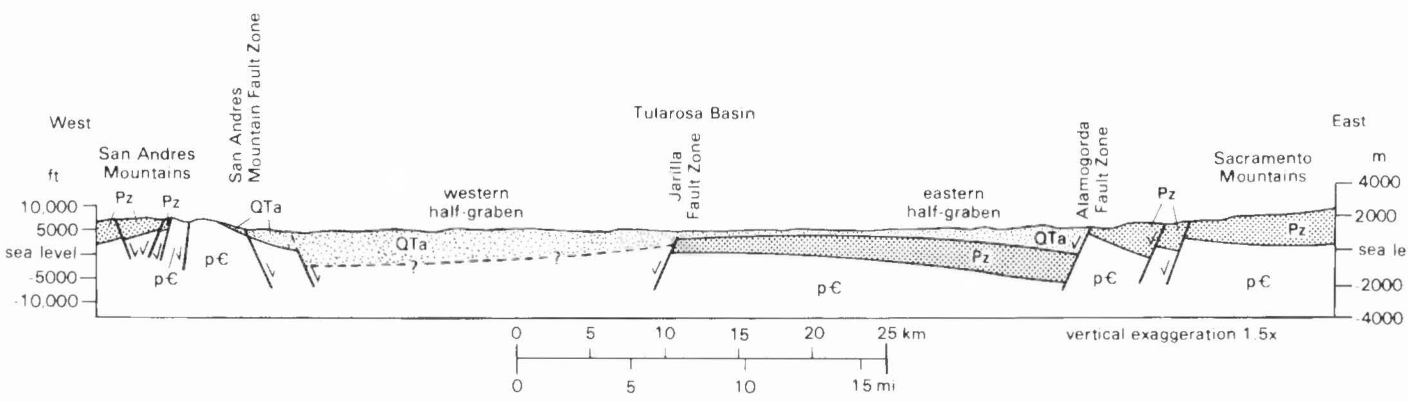


FIGURE 1.10. Tularosa Basin cross section showing half-graben morphology. Cross section extends from Hospital Canyon in the San Andres Mountains to La Luz Canyon in the Sacramento Mountains. QTa—Late Tertiary to Quaternary alluvium (basin fill); Pz—Undifferentiated Paleozoic rocks; pC—Undifferentiated Precambrian rocks. Modified from Seager et al. (1987) and Johnson et al. (1989).

A large, shallow, intermittent lake occupied most of the western half-graben north of the Jarilla Mountains from late Pleistocene into the Holocene. It was first recognized by Herrick (1904) who named it Lake Otero. Shoreline features of this lake are still visible around portions of the western half-graben.

Other important surficial deposits within the basin include alluvial-fan deposits and abundant eolian dunes and sheets (Blair et al., 1990). Many of these fans display classical apron-shapes along the major mountain fronts. Among the eolian deposits are gypsum sand dunes that comprise the famous White Sands National Monument (McKee and Moiola, 1975). This is the largest gypsum dune field in the world. The gypsum sand is derived mainly from evaporite deposits associated with Lake Otero (Weber and Kottlowski, 1959; McKee and Moiola, 1975; Blair et al., 1990). Present-day Lake Lucero and Alkali Flat playas, remnants of Lake Otero, also contribute gypsum sand to the dune fields.

23.2 Hills at 9:00 capped by Yeso Formation carbonates. Lowest part of slope in Abo Formation. At 3:00 note prominent ledge-forming carbonate in Yeso Formation. This is an excellent mapping horizon in this area, but apparently does not extend north or west across the Tularosa Basin. **1.0**

24.2 Ridge at 3:00 in distance capped by massive San Andres Formation carbonates. Underlying reddish to pinkish outcrops are Yeso Formation sandstones and limestones with some poorly exposed gypsum beds. **0.9**

25.1 Roadcuts ahead on left are Abo Formation. These mudstones and sandstones grade westward into the Paleozoic Orogrande basin. Two miles south, Cibola Energy drilled its Ysletano Canyon #1 Federal well in SE1/4 SE1/4 sec. 7, T14S, R11E. Petroleum Information shows the projected T.D. for this well as 1160 m in Devonian strata (Sly Gap and Onate Formations). A potential target in this area is the Silurian Fusselman Formation. A second well, the Cibola Virden 1, was drilled in NW1/4 NW1/4 sec. 20, T14S, R11E. Petroleum Information shows the projected T.D. for this well as 1460 m in the Ellenburger Formation (Bliss or El Paso Formations). Both wells are 5 mi southwest of Bent dome. Presence of a complete (for this region) section of Paleozoic rocks at this location suggests there is either a fault or series of faults on the west flank of Bent dome or a thickening wedge of Lower Permian through Cambrian strata between Bent dome and the wells listed above. **1.0**

26.1 Low hills surrounding highway consist of Abo Formation mudstones with small, thin, channel sandstones. **0.8**

26.9 Outcrops flanking highway are Abo Formation mudstones. Pediment gravels cap higher ridges north and south of highway. These middle Pleistocene gravels range in thickness from about 6 to 15 m and consist mainly of limestone clasts derived from the San Andres Formation (Otte, 1959). The gravels, and the erosional surface they rest on, once extended from the steep escarpment formed by the Yeso Formation westward into the Tularosa Basin. The pediment rests on the Abo Formation and probably formed as the mountain front eroded eastward during periods of quiescence along the frontal fault system (Alamogordo fault zone). Otte (1959) and Pray (1961) first recognized at least two levels of this west-dipping surface. Pray (1961) named the upper, more extensive level, the Ranchario pediment.

In this area, the pediment surface elevation is generally 15 to 45 m above the present stream level. Farther south near La Luz Canyon, the elevation is as much as 90 m above the present stream level (Otte, 1959; Pray, 1961). Renewed uplift along the Alamogordo fault zone resulted in dissection of the pediment. **0.5**

27.4 Adobes on right. **0.2**

27.6 Roadcut at 9:00 is in Abo Formation. **0.3**

27.9 Milepost 233. **0.5**

28.4 Outcrops in hills at 2:00 are east-dipping Abo Formation. **0.9**

29.3 View at 9:00 is of high Sacramento Mountains. **0.1**

29.4 Side road to right. **0.5**

29.9 Laborcita Formation exposed at 3:00 in hills. **0.5**

30.4 City of Tularosa in distance at 12:00. **0.5**

30.9 Milepost 230. **0.1**

31.0 Outcrops of fluvial deposits of Laborcita Formation on left contain accretionary crossbedding. White tanks on right store Tularosa's water supply. We are crossing the Alamogordo fault zone (just west of the Laborcita outcrops) and are entering the Tularosa Basin. This structure is the major basin-bounding fault zone of the eastern Tularosa Basin. It has several thousand feet of normal displacement (down-to-the-west) and can be traced about 64 km along the Sacramento escarpment. Numerous scarps which offset alluvial-fan deposits indicate that this fault was active into late Quaternary time (Machette, 1987). See Bauer and Lozinsky (1991, this guidebook) for a discussion of recent faulting and the Tularosa Basin. **0.2**

31.2 Entering "suburbs" of Tularosa. **0.4**

31.6 Tularosa city limits, elevation 4520 ft. Tularosa is Spanish for reddish reeds or willows. First established as an agricultural community in the early 1860s, the town had a rough early history due to frequent attacks by Apache Indians living in the nearby Sacramento Mountains. The town is still a major farming and ranching center. **0.6**

32.2 Senior Citizen Center and museum on left. **0.1**

32.3 IGA Farmers Market ahead at 11:30. **Turn right** onto Bookout Road. **0.2**

32.5 Crossing Tularosa Creek. **0.5**

33.0 **Intersection** with Bookout NE (Otero Co. B18). **Turn right (east)** where pavement ends. **0.3**

33.3 Cattle guard. Knobs at 12:00 are the Laborcita mounds. Sierra Blanca Peak is visible at 10:00. **0.2**

33.5 Culvert. **0.4**

33.9 **STOP 2.** Eroded scarp of Alamogordo fault immediately ahead at foot of slope. **Pull off to right side of road and park.** The purpose of this stop is to examine early Permian sedimentation processes along the eastern shelf and shoreline of the Paleozoic Orogrande basin. The mounds at 12:00 are part of the southern edge of a complex of algal bioherms in the middle Laborcita Formation (Fig. 1.11). These bioherms were first described by Otte (1959). Otte and Parks (1963), Parks (1962, 1977), Cys and Mazzullo (1977), Mazzullo and Cys (1979), Halley (1980), Cross and Klosterman (1981), Shinn et al. (1983) and Bowsher (1986) described the details of the mounds, including the types of cement and algae that characterize these features. The depositional environments of the Laborcita Formation are summarized by Carr (1983), Bowsher (1986) and Fly (1986).

The Laborcita Formation represents a mixed carbonate-siliciclastic package deposited in shoreline, lagoonal

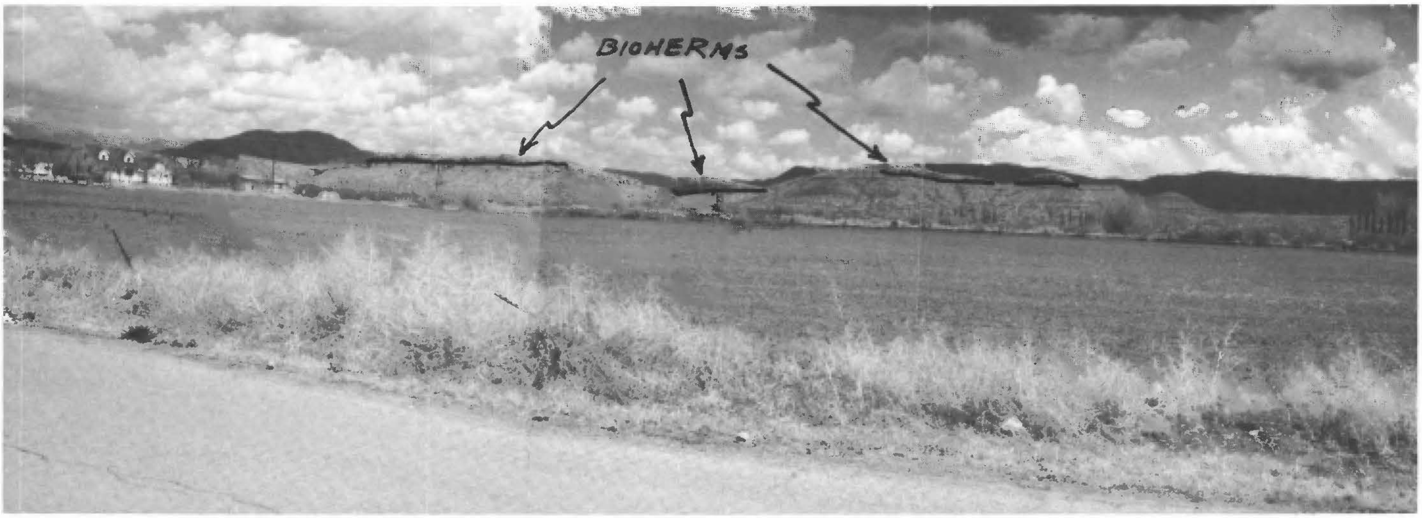


FIGURE 1.11. Panorama of Laborcita mounds (Scorpion Mounds) looking east near Stop 2. Bioherms are outlined.

and shelf-edge environments (Fly, 1986). Otte (1959) thought the middle and upper part of the sequence was early Wolfcampian (Permian) in age whereas the lower part was Virgilian (Pennsylvanian) in age based on fusulinid studies. Subsequent fusulinid studies by Steiner and Williams (1968) showed the Laborcita is entirely lower Wolfcampian.

Otte (1959) mapped and described the Laborcita Formation using a series of continuous marker beds. Beds with good continuity indicate periods of lower water level and, possibly subaerial exposure of the sediment (Fly, 1986). The bioherm horizon occurs between marker beds 52 and 53. Bed 52 at the base of the bioherm consists of a dolomitic limestone that grades southward into gray shale then red-brown mudstone. Northward, bed 52 grades into a 2-m-thick medium-gray skeletal limestone with algal fragments (phylloid algae?). Marker 53 is a greenish-gray feldspathic sandstone with faint crossbedding that grades southward into a quartzite-pebble conglomerate south of Tularosa Creek and US-70. It ranges from 2 to 5 m in thickness at this location and occurs approximately 5 m above the bioherms.

The sequence of depositional events recorded in the sediments at Stop 2 are summarized by Fly (1986, p. 94 and 95): (1) Transgression produced by an apparent sea level rise across a low-relief distal alluvial fan; (2) Progradation of alluvial fans and fan deltas produce a regression; (3) Transgression produced by reduced influx of clastics and/or a sea level rise. Algal bioherms that produce Scorpion Mound develop at this time; (4) Fan deltas prograde again into basin, producing an apparent regression but not disturbing bioherm development to any great degree; (5) Another transgression drowns the fan-delta platforms (sea level rise + decrease in clastic influx); (6) Fan-delta progradation over the bioherms ends carbonate deposition; (7) Sequence 1 through 6 repeats; (8) Entire shoreline complex is finally covered by prograding fan deltas (upper Laborcita Formation) and fluvial channel sands and overbank muds (lower Abo Formation). This event marks the final regression recorded here before return to shoreline/sabkha conditions during Yeso time. Occasional storm events are also recorded by current structures and local limestone-pebble conglomerates made up of algal-limestone fragments.

The distribution of bioherms at this locality suggests an embayment in the shoreline during Early Permian time, affected by rises in sea level and changes in rates of siliciclastic sedimentation.

At completion of discussion, return to buses and retrace route toward US-70. 0.9

34.8 **Turn left (south)** onto Bookout Road (paved). **0.5**

35.3 Crossing Tularosa Creek. **0.2**

35.5 Intersection. **Turn right (west)** on US-70 toward center of town and intersection with US-54. **0.6**

36.1 Intersection with US-54. **Follow US-70 to left** and proceed south on US-54 and US-70 toward Alamogordo. **0.5**

36.6 World-famous Tulie Cafe on left. **0.3**

36.9 Leaving Tularosa. Water for irrigation of fields along highway is derived from wells and surface runoff from the mountains (Orr and Myers, 1986). **0.6**

37.5 Milepost 78. Hills at 10:00 consist of Pennsylvanian Holder Formation capped by Permian Laborcita Formation. Deep notch at 11:00 is Laborcita Canyon; type section of the Laborcita Formation (Otte, 1959). Western margin of hills is bounded by the Alamogordo fault zone and forms a succession of stair-step blocks dropping younger Permian strata down to the west. Sacramento Mountains in distance at 9:00 are capped by San Andres Formation and underlain by Yeso Formation sandstone and carbonate. **1.0**

38.5 Milepost 77. At 4:00 on the skyline of the San Andres Mountains is Rhodes Canyon, named for the famous cowboy writer Eugene Manlove Rhodes. NM-52 once crossed the San Andres Mountains through Rhodes Pass. Rhodes is buried near a small ranch he owned in the canyon. His epitaph reads: "Pasó Por Aquí" ("He passed by here"). The title is the name of his most-acclaimed novel and derived from carvings left by the conquistadors at Inscription Rock (El Morro). The ranch is now on White Sands Missile Range. **1.0**

39.5 Milepost 76. The Organ–San Andres–Oscura mountain ranges to the west contain more than 129 km of nearly continuous Proterozoic exposure along their eastern flanks. Hembrillo Canyon, at approximately 2:30 to 3:00, contains a thick metasedimentary sequence of crossbedded quartzite, schist and phyllite (Condie and Budding, 1979). **1.0**

40.5 Milepost 75. Entrance to Laborcita Canyon at 9:30. The escarpment at the top of the hills is a quartz diorite sill intruded into the upper half of the Laborcita Formation (Otte, 1959). **1.3**

41.8 Golden Spur Lounge on right. Crossing large arroyo. **0.7**

42.5 Milepost 73. Pistachio farms on right. **1.2**

43.7 Intersection with NM-545 to La Luz (to left in distance under trees). **Continue straight** ahead. **0.2**

43.9 Bowlin's Running Indian curio shop on right. **0.6**

44.5 Milepost 71. Holder reef complex in hills at 10:00 above highway. **1.0**

45.5 Milepost 70. Bill's Collectables on left. **0.5**

46.0 Intersection with US-82 (to Cloudcroft). **Continue south** to Alamogordo on US-54, -70 and -82. Small phylloid-algal mudmound exposed in side of hill at 9:00 (see Toomey, 1991, this guidebook). **0.4**

46.4 Entering Alamogordo (Spanish for "large cottonwood tree"). Town was established in 1898 by brothers John and Charles Eddy. They purchased land and laid out the town in an effort to increase development in the Tularosa Basin. Alamogordo is now the largest town in the basin and a center for aerospace and weapons research. **0.9**

GEOMORPHOLOGY AND ENVIRONMENTAL CONCERNS ALONG THE SACRAMENTO ESCARPMENT, EASTERN ALAMOGORDO

John W. Hawley

New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico 87801

The Space Hall of Fame area in eastern Alamogordo is an excellent vantage point for viewing the piedmont landscape at the edge of the Tularosa Basin. The adjacent Sacramento escarpment marks the boundary of the Mexican Highland and Sacramento sections of the Basin and Range physiographic province (Hawley, 1986), and it forms the eastern edge of the Rio Grande rift structural province (Chapin and Seager, 1975). The Space Hall of Fame and the nearby NMSU-Alamogordo campus are on the upper part of the broad piedmont slope formed by coalescing alluvial fans that spread out from canyons in the western Sacramento Mountains. This bajada surface is dissected by major arroyos near the mountain front, but to the west it forms a smooth constructional plain that merges with eolian and lacustrine deposits of the basin floor west of Alamogordo. As is the case in many other parts of the Basin and Range Province, the abrupt basin-mountain boundary is formed by a narrow fault zone, with the basin dropping thousands of meters relative to the uplifted mountain range during the past 5 to 10 Ma. Differential movement has continued through the Quaternary and even fan deposits of Late Pleistocene age have been significantly deformed (Machette, 1987). The NMSU campus and Space Hall of Fame are on or near the most recent (late Quaternary) scarp produced by this tectonic activity (Fig. 1.12). Basin structure and basin-fill stratigraphy are discussed by Lozinsky and Bauer (this road log).

The historical record (since 1849) of earthquakes in New Mexico (Sanford et al., 1981; Stover et al., 1988) indicates that, at present, Alamogordo is in an area of relatively low seismic activity. No earthquakes with intensities (modified Mercalli) greater than IV or local magnitudes (Richter) greater than 3 have been recorded. The recurrence interval of large seismic events associated with displacement of major basin-bounding faults appears to be relatively long (≥1000 yrs) based on recent investigations in the Tularosa Basin and adjacent parts of the Hueco Bolson (Gile, 1987; Machette, 1987).

FIGURE 1.12. View north from Indian Wells Road at Lincoln National Forest boundary toward Space Hall of Fame (upper right) and NMSU-Alamogordo campus (upper center). Piedmont scarp (3–5 m) produced by late Quaternary faulting (down-to-west) extends from center foreground through the NMSU campus. Western slopes of the Sacramento Mountains (escarpment) form the skyline.

Arid to semiarid climatic conditions, similar to or slightly more moist than the present, have prevailed during the Pliocene-Quaternary interval (past 5 Ma) of Basin and Range tectonism. Intense rainstorms and rapid snowmelt have been very effective in providing runoff needed to erode the deep mountain canyons and have produced the thick alluvial-fan deposits that form much of the coarse-grained basin fill at the foot of the escarpment. Piedmont surfaces include many drainageways that are sites of recurrent flooding and alluvial sedimentation, particularly in the late summer and early fall. Landslides, rock falls, and concentrated flows of mud, sand and coarser debris also contribute to the basin-filling process along the mountain front. In addition, past earthquake activity caused landslides and rockfalls, increased valley incision upstream from fault scarps, and local downstream aggradation of low-lying areas.

Rapid basin-filling has been enhanced by the internal drainage of the Tularosa Basin. More than a thousand meters of lake beds, with gypsiferous evaporites and wind-deposited sediments, underlie the broad floor of the central basin. Wind-transported sand and dust removed from the extensive lake plains and older dune-sand deposits have also been added to the generally coarse-grained deposits near the mountain front. Other significant components of piedmont basin-fill facies are gypsiferous and calcareous soils and spring deposits. They occur in narrow zones where soil moisture or ground-water discharge is depleted by evapo-transpiration. However, in much of the eastern Alamogordo area, the water table is from 60 to 105 m below the surface and ground water is not an active geomorphic agent at present. Both ground- and surface-water resources in the basin were described by Orr and Myers (1986).

Because of the above-mentioned processes, the surficial geologic materials and soils in the upper piedmont area are usually quite variable in texture (boulder gravel to clay) and are poorly consolidated (Derr, 1981). Partly indurated zones of secondary carbonate and gypsum accumulation add to the internal complexity of the fan-piedmont deposits. At some home-building sites this variability in basin fill has contributed to serious foundation problems, such as differential soil compaction, surface subsidence and earth-fissure formation.

Urbanization of many areas with similar geomorphic and climatic settings is occurring throughout the western United States. Such development can be accomplished in an economically and environmentally sound manner only if geologic, hydrologic and geotechnical components of the natural system are recognized as key factors in the planning process. Since 1985 the environmental and engineering staff of the New Mexico Bureau of Mines and Mineral Resources has actively assisted both public officials and private interests in resolving geotechnical and environmental problems that relate to the piedmont geomorphic setting of urban areas in the Tularosa Basin.

47.3 Traffic light. Crossing Fairgrounds Road, continue south on US-54 and -70. **0.7**

48.0 Intersection with Indian Wells Road (and traffic light). **Turn left (east)** on Indian Wells Road. New Mexico School for the Visually Handicapped on the right as we turn. **0.5**

48.5 Traffic light. Crossing Florida Avenue. **0.4**

48.9 **Caution. Road narrows abruptly ahead. Move to center lane (left). 0.6**

49.5 Begin divided highway. Museum of Archeology on right. **0.5**

50.0 Intersection. **Turn left (north)** on to Scenic Drive toward Space Hall of Fame. Crossing Alamogordo fault scarp. In this area, throw on the fault is about 2400 m; the scarp is approximately 9 m high. This scarp was produced by multiple faulting events as shown by sequentially younger alluvial deposits having lower fault-scarp heights. Machette (1987) conducted morphometric studies of the scarp and concluded that the most recent displacement along the fault occurred in early(?) Holocene or latest Pleistocene time. **0.2**

OLIVER LEE MEMORIAL STATE PARK

Virginia T. McLemore

New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico 87801

Oliver Lee Memorial State Park, at the mouth of Dog Canyon on the western escarpment of the Sacramento Mountains (Fig. 1.13), opened in 1980, but the area has attracted visitors for several thousand years. The 180-ac state park has a flowing stream and forms an oasis on the edge of the harsh desert of the Tularosa Valley. The park is named for Oliver Lee, a prominent rancher and state legislator who settled at the mouth of Dog Canyon in the late 1880s. Oliver Lee's ranch is one of the many exhibits at the state park. The visitor's center contains exhibits of the geologic and cultural history of the canyon area. In 1989, about 30,000 people enjoyed camping, hiking and picnicking in the park (Peter Green, New Mexico State Park and Recreation Division, written comm., August 1990). An interpretative trail along lower Dog Canyon allows visitors a glimpse of vegetation and wildlife in the oasis as well as several cultural sites. The Dog Canyon Trail starts at about 4000 ft in the state park and climbs the steep escarpment of the Sacramento Mountains to join the Eyebrow Trail to Joplin Ridge at an elevation of 7753 ft, for a total distance of about 6 mi. The state park has both primitive and RV campsites with electrical hookups, showers, drinking water and a dump station.

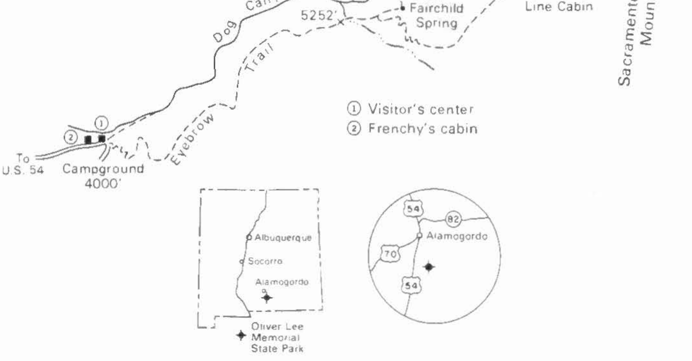


FIGURE 1.13. Location of Oliver Lee Memorial State Park and surrounding area.

The Dog Canyon Trail has been a major route from the Tularosa Valley on the west to the highlands of the Sacramento and Guadalupe Mountains to the east for several thousand years (Fig. 1.13). Thousands of artifacts, including pottery shards, stone implements and spear points attest to human occupation in the canyon area (Eldred, 1989). Mortars, small smooth-sided cylindrical holes, are found in the rocks throughout the canyon. These mortars are sometimes called "Indian wells" because water collects in the holes. They were formed by prehistoric Indians who ground seeds in them with stone manos over many years. Natural caves in the canyon provided shelter for visitors.

About 300 yrs ago, Apache Indians migrated into the area and prevented serious settlement by the Spanish and Anglos until the late 1800s. Dog Canyon became one of many Apache strongholds. The Agua Nueva Apaches lived in the canyon, and other tribes are known to have traveled through it. Numerous U.S. Army military reports during the mid-1800s document Apache raids throughout southern New Mexico and often the raiding Apaches were tracked to Dog Canyon, which provided easy access to the eastern highlands. Several encounters between the Indians and settlers from 1840 to 1880 occurred in the canyon; a few locations are marked on the trail. About 1850, a group of settlers tracking raiding Apaches lost the trail in the canyon and found only a dog left behind by the Apaches. Since then the canyon has been called Dog Canyon (Pearce, 1965). By the 1870s the Apaches were placed on reservations, raiding ended and a wave of settlers arrived.

One of the early settlers of the Dog Canyon area was "Frenchy," actually Francois-Jean Rochas. Frenchy was born in 1843 in France and immigrated to New Mexico in the 1880s. Remnants of Frenchy's two-room adobe-rock house are visible near the visitor's center. He built mortarless stone walls to corral his livestock; portions of the walls still snake along the slopes at the mouth of Dog Canyon. Frenchy raised cattle and tended an orchard and vineyard. Soon after Christmas 1894, Frenchy was found dead in his cabin (Young, 1984). A coroner's jury concluded it was a suicide, but some evidence and hearsay suggest it was murder. Some accounts suggest Oliver Lee and Frenchy were disagreeing over the water ownership at this time. Other accounts suggest field hands did Frenchy in. No one was ever charged with the murder and the mystery of his death was never solved.

Oliver Lee settled in the Dog Canyon area about the same time as Frenchy. Oliver Milton Lee was born in Buffalo Gap, near Abilene, Texas on November 8, 1865 (Keleher, 1962) and came to New Mexico Territory in the fall of 1884 with his half brother, Perry Altman. Altman was attracted to New Mexico by the open range and free land. Oliver, already an established horseman and adept with a revolver, insisted on coming. Thus began the Dog Canyon Ranch.

Oliver and Frenchy jointly developed an irrigation system at Dog Canyon. Ditches carried the precious water to the ranch house and grazing pastures. This was one of several irrigation systems Oliver established along the western escarpment of the Sacramento Mountains. Some of these systems remain in operation today.

During the late 1800s, as competition for open rangeland and water increased, violent rivalries sometimes ensued. The Lincoln County War is an example of these violent times. Oliver often became involved. In 1896, A. J. Fountain, a prominent judge and local rancher, and his son were murdered while traveling through the Tularosa Valley and Pat Garrett, sheriff of Doña Ana County, charged Oliver with the murder. Oliver evaded capture and refused to surrender, believing that he would not receive a fair trial in Doña Ana County. It was at this time that a bill was in the state legislature to create Otero County from part of

Doña Ana County. Oliver's friends in the legislature pushed the bill through and Otero County was established in 1899. The change in county shifted jurisdiction of Oliver's case from Doña Ana to Otero County. Later that year Oliver surrendered to authorities and was acquitted of the Fountain murders. The murders of Fountain and his son were never solved.

Oliver Lee continued to prosper as owner of one of the largest ranching operations in southern New Mexico. He served as a representative or a senator in the New Mexico State Legislature several times from 1918 to 1931 (Young, 1984). Oliver died in Alamogordo on December 15, 1941 (Keleher, 1962) and his children and grandchildren still maintain some of his ranches. In 1971, Oliver's ranch house was partially rebuilt for a movie called *Scandalous John* and the tampering disqualified it from designation as a national historical site. However, in 1983 the house was declared a state archaeological site and restoration of the house began.

Dog Canyon is one of several rugged box canyons that drain the western Sacramento Mountains. The Tularosa Basin is floored by evaporites and Quaternary alluvial fan deposits shed from the steep escarpment. In the canyon, a section of sedimentary rocks ranging in age from Early Ordovician to middle Permian is exposed (Fig. 1.14; Pray, 1961; Kottlowski, 1981). North of Dog Canyon two large biohermal mounds crop out in the Mississippian limestone (Kottlowski, 1981). Two Tertiary(?) trachyandesite to diabase porphyry sills have intruded the sedimentary rocks (Fig. 1.14) and can be seen along the Dog Canyon Trail. The geology of these units is described elsewhere in this guidebook as well as by Pray (1961) and Kottlowski (1981).

Some of the information presented in this summary is from printed handouts and exhibits at Oliver Lee Memorial State Park. Special thanks to Robert Colpitts and Frank Kottlowski for reviewing this manuscript.

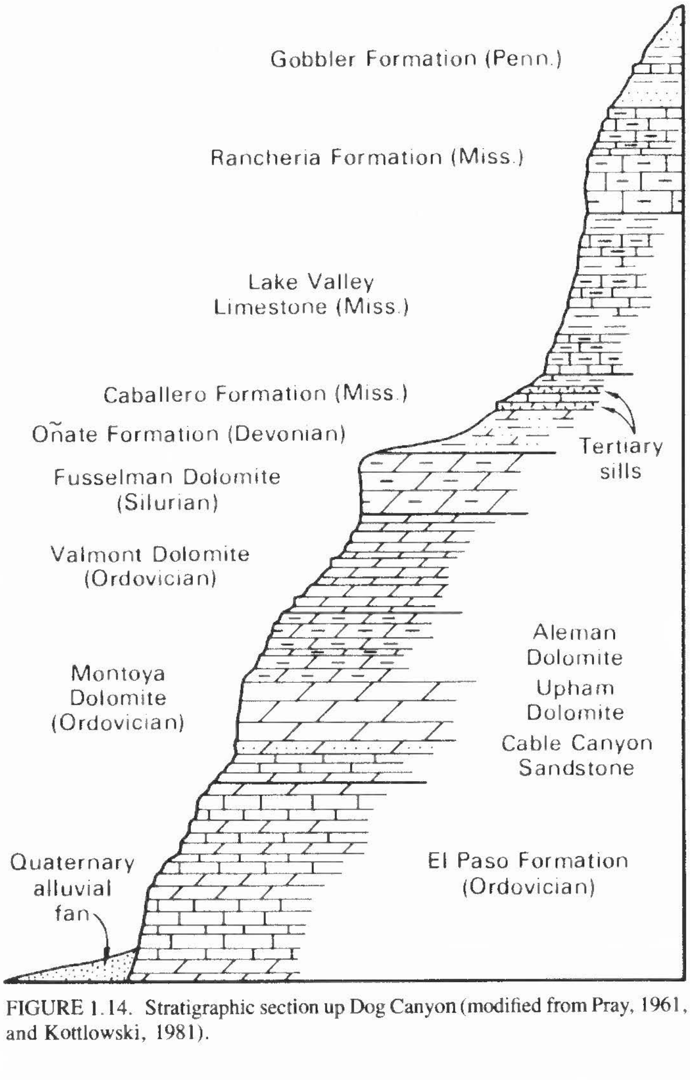


FIGURE 1.14. Stratigraphic section up Dog Canyon (modified from Pray, 1961, and Kottlowski, 1981).

50.2 Intersection. **Turn right** on to NM-2001 toward Space Hall of Fame. New Mexico State University, Alamogordo Branch on left. **0.3**

50.5 **Turn left** into parking lot for **STOP 3 and lunch** (or is it launch?).

After visiting the Space Hall of Fame (Fig. 1.15), the Clyde W. Tombaugh Theater, with its 2700-ft^2 screen for the Omnimax and planetarium shows, and discussing Pennsylvanian stratigraphy on the outcrops, return to buses for the trip to Stop 4. **0.3**

50.8 Intersection with stop sign. **Turn right (north)** onto Scenic Drive. **0.5**

51.3 Road narrows. **1.8**

53.1 Intersection with stop sign. **Turn right** onto Florida Ave. Algal mounds visible at 2:30. **1.0**

54.1 Holder reef complex visible above tank at 2:00; Beeman Formation exposed in slope at 3:00. **0.5**

54.6 Intersection with stop light. **Turn right (east)** onto US-82 toward Cloudcroft. **0.1**

54.7 Milepost 2. **0.6**

55.3 Crossing Alamogordo fault zone, which bounds the west side of the Sacramento Mountains. Faults have down-to-the-west displacement. **0.2**

55.5 Beeman Formation (Pennsylvanian) in outcrop to left. **0.2**

55.7 Milepost 3. **0.1**

55.8 Sandstone, limestone and shale in roadcut belong to Beeman Formation. **0.1**

55.9 Small bioherm at head of canyon at 9:00 is Yucca Mound, part of the Holder Formation. **0.3**

56.2 West end of Holder reef complex to left of road and above. Beeman Formation is at road level. **0.1**

56.3 Section of bioherm visible above road to 12:00. Small bioherm at 3:00 is southern extension of Holder reef. The reef is cut by Dry Canyon, which helps provide an excellent cross-sectional view of the different facies associated with the complex. **0.2**

56.5 Entering Lincoln National Forest. **0.2**

56.7 Milepost 4. Holder reef at 9:00 above road. Dry Canyon

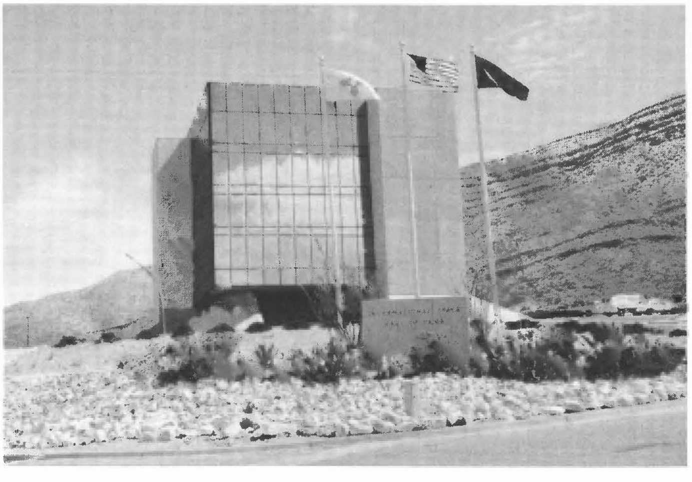


FIGURE 1.15. Space Hall of Fame at foot of the Sacramento Mountains at Alamogordo. The Clyde W. Tombaugh Space Theater with Omnimax and planetarium facilities is located to the left, west of the Space Hall of Fame.

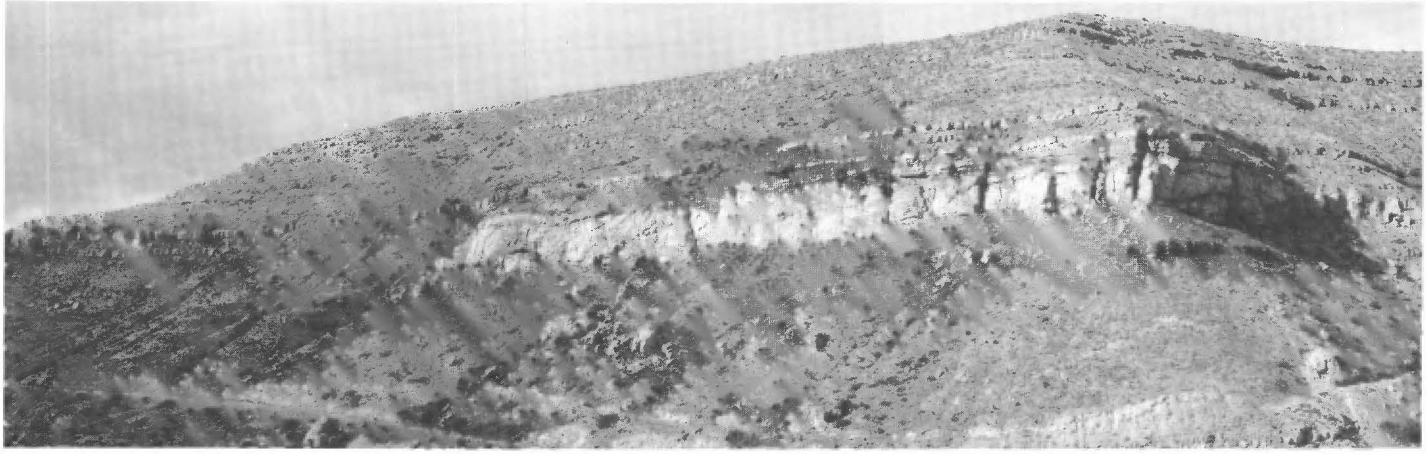


FIGURE 1.16. Panorama of Pennsylvanian Holder reef (Yucca Mound) in Dry Canyon north of Stop 4.

is on the right. South extension of Holder reef at 3:00. Sandstones, impure limestones and shales next to road on left are part of Beeman Formation. **0.8**

57.5 Entering back reef facies of Holder reef complex. We are now crossing Beeman/Holder contact. **STOP 4. Pull off to right side of road onto pullout.** The purpose of this stop is to look at features of the lagoon between the shore and reef complex. This stop will entail a 0.25-mi walk up the north shoulder of the highway. **Be extremely careful and watch for traffic.**

At Stop 2 we looked at a shelf-edge bioherm formed during Permian time. Here at Stop 4, we will be looking at the back reef facies of a mound complex deposited in Late Pennsylvanian (Virgilian) time on the edge of a marine shelf. Above and to the west of us is the Dry Canyon reef complex, also known as Holder reef and Yucca Mound (Fig. 1.16). The Upper Pennsylvanian stratigraphic units here represent several levels of micritic mounds with platy (phylloid) algae. Each mound appears to have developed and grown thickest at the edge of a shallow shelf in this area. The shelf was narrow; its landward side was only 3–5 mi to the east. Locally, the mounds developed within this shelf down the west flank of the growing La Luz anticline to the south and east, and the sedimentary units in which they formed prograded across the shelf over a basinal facies of Missourian age. The early Virgilian shelf margin lies about here and the Missourian shelf edge was about 2 mi east of here. Details of the algal-bioherm complex are presented in the following minipaper.

LATE PENNSYLVANIAN (VIRGILIAN) PHYLLOID-ALGAL BIOHERMS, HOLDER FORMATION, DRY CANYON

Donald Francis Toomey
Consultant, 2451 Tramway Terrace Court NE, Albuquerque, New Mexico

At Stop 2 we are directly below a massive, lenticular algal buildup complex (Fig. 1.17). The Holder Formation extends to the ridge skyline, and the prominent limestone cliffs above the main bioherm horizon are cyclic or repetitive sediments comprising a variety of carbonates and clastics in which small algal bioherms and algal biostromes are relatively common. Higher in the section clastics are more conspicuous.

Plumley and Graves (1953) first recognized and described this biohermal complex and noted that it was composed principally of colonial algae, which they referred to *Cryptozoon*? Detailed field mapping of the Sacramento Mountains escarpment by Pray (1961) defined the Pennsylvanian formations exposed within the range (from bottom to top) as Gobbler, Beeman and Holder. The Holder Formation contains bioherms up to 75 ft thick in the lower interval of the formation. Coeval bioherms had previously been reported from the San Andres Mountains to the west by Kottlowski et al. (1956).

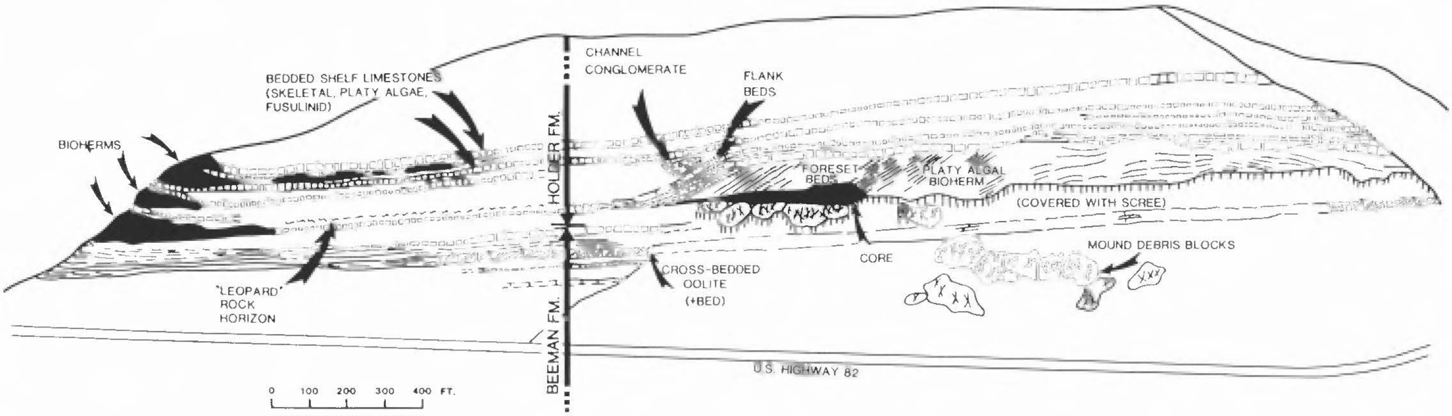


FIGURE 1.17. Sketch showing Dry Canyon biohermal complex in the Late Pennsylvanian (Virgilian) Holder Formation at Stop 2. Diagram emphasizes bioherm/flanking bed relationships, in addition to some of the key beds exposed in the north wall of the canyon.

In 1961, Pray noted that while stromatolitic algae do occur in the Holder bioherms, Wray (1959) had demonstrated that the dominant biohermal algal component was a variety of green alga. These algae were later described by Konishi and Wray (1961) as the phylloid alga *Eugonophyllum,* for which this is the type locality. Wray (1962) gave a more detailed description of the Holder bioherms and their algal composition.

In the early 1960s, J. L. Wilson and various colleagues from Shell Development Company initiated a long-range detailed field mapping project, concentrating their efforts on the Late Pennsylvanian Holder sediments and bioherms so well exposed in the Sacramento Mountains. The results of those efforts are documented in a series of papers: cyclic and reciprocal sedimentation (Wilson, 1967), influence of local structure and tectonics (Wilson, 1969), an overall summary paper (Wilson, 1975), and a paper on the paleogeography and distribution of late Paleozoic phylloid-algal bioherms in southern New Mexico (Wilson, 1977).

During Pennsylvanian time the Sacramento Mountains area was situated between a positive area to the east (Pedernal landmass), and a relatively negative area to the west (Orogrande basin). The degree of differentiation of these tectonic elements varied from slight at the beginning of the Pennsylvanian to a role of major significance by the end of the period.

By Late Pennsylvanian (Virgilian) time the presence in this area of a shallow-water platform or shelf on the east, with cyclical/repetitive sediments ranging from shallow marine to terrestrial, and a basin to the west with thick terrigenous sediments had become abundantly clear (Kottlowski et al., 1956). Conspicuous cyclic/repetitive sedimentation in the Holder Formation during Late Pennsylvanian time is probably related to local changes in sea levels effected by spasmodic tectonic pulses occurring on the nearby Pedernal landmass. Uplift in the positive area would rapidly flood the area with clastics. As the shelf area subsided, in adjustment to sediment load, and as the amount of terrigenous sediments decreased, a "normal" marine biota would develop on the shelf, and would eventually predominate. Continued clearing of the shelf area waters permitted the deposition of shallow water and shoal limestones. The cycle would be repeated with further tectonic activity on the nearby positive area.

The overall morphology of the Holder biohermal complex can be seen by projecting outcrops to the southeast (Beeman and Indian Wells Canyons) and to the northwest at Dry Canyon. Accordingly, the Holder biohermal complex appears to be a Y-shaped body comprising two prominent elongated "fingers." Those extend northwest-southeast for a distance of 3 mi. The projected width of the biohermal complex is approximately 0.75 mi. Within the bioherm proper, internal bedding is a characteristic feature. These beds dip as much as 30°, are generally less than 2 ft thick, and are superficially similar to foreset beds.

The bioherm is composed principally of the codiacean phylloid alga *Eugonophyllum,* scattered skeletal debris, lime mud, sparry calcite mosaic, and rather poor fans of radial fibrous submarine cements. Algal content is less than 25%. Some have speculated that *Eugonophyllum* was an erect plant, perhaps attaining a height of up to 5 in. This plant consisted of broad lettuce-like "leaves," a feature that would necessarily exclude them from providing a substantial "reef" framework. Instead, these phylloid algae were both efficient sediment-baffling agents and sediment particle producers, and probably grew most proficiently in a zone somewhat below that of appreciable wave action. To date, only fragmented "leaves" have been found, and neither a root system nor a stem have been retrieved. The plant's internal structures, when preserved, exhibit bilateral symmetry, but it appears that only the outer surface of the plant was carbonate-encrusted. In thin section, the internal portion of the algal blade is generally recrystallized to sparry calcite mosaic. When recrystallization destroys diagnostic utricular structures, located along the leaf margin, confusion of those fragments with mollusc fragments can be a problem. Rare finds of silicified algal plates (Toomey, 1976; Toomey and Babcock, 1983) suggest that when the plants died, the "leaves" fell to the sea bottom, where they accumulated in piles, perhaps somewhat analogous to piles of dead leaves on the forest floor.

It should be noted that phylloid algae, similar to some Recent algae, appear to have had relatively accelerated growth rates, possibly turning over a new crop every few weeks (Toomey, 1981). Accordingly, once the algae were established on the sea bottom they probably grew in great profusion, eventually occupying and dominating the immediate substrate. As a consequence, they were able to exclude most typical marine organisms from the biotope, and molded a unique plant-dominated and plant-controlled community with relatively low biotic diversity. Organisms able to offer biotic competition were restricted to those that could encrust the plant "leaves" (various encrusting forams, worms and bryozoans); those that could live under the plant umbrella (grazing snails and echinoids, and opportunistic pedunculate brachiopods), and infaunal components such as burrowing pelecypods. A reconstruction of this community is shown in Fig. 1.18. These plants functioned as myriads of very effective baffling agents on the sea bottom, trapping finely suspended sediment that normally might have been carried away by current action.

Examination of numerous Holder phylloid algal bioherms shows that most possess a distinctive "core." At the base of the Dry Canyon biohermal complex there is approximately 10 ft of porous, vuggy-appearing core rock. The vuggy appearance is misleading. When blocks of core rock are broken open it is apparent that the distinctive vuggy appearance is the result of leaching of numerous brachiopod shells (*Composita*). In reality, the core rock is a shelly wackestone that was the hardground foundation on which the bioherm was initiated. This probably occurred in quiet subtidal waters where abundant gregarious brachiopod communities clustered. This shelly interval undergoes an upward falling-out as more and more algal plates dominate the overlying beds, until the rock becomes an algal plate packstone/bafflestone, with only a sparse shelly component. As rapid phylloid algal growth continued, the bioherm grew upward into increasingly shallower waters, to a point at which water depth was no longer optimal for phylloid algae. With additional shoaling the bioherm was capped by encrusting tubular foram grainstones and/or oolitic grainstones, thus marking the terminal phase of bioherm growth. Evidence of subaerial exposure, i.e., red-colored weathering zones and *in situ* clast brecciation on the mound crest, attests to a probable concluding event in which the bioherm was elevated out of water. The subsequent overlying cycle commences with a basal siltstone/sandstone. This biohermal growth sequence is diagrammatically shown on Fig. 1.19.

In Dry Canyon, flanking beds are best exposed on the west (ocean-facing) side of the bioherm, and are of limited horizontal extent. Their type and distribution is schematically shown on Fig. 1.20.

Those beds at the base of the bioherm (Fig. 1.20, Section 1) are flat-

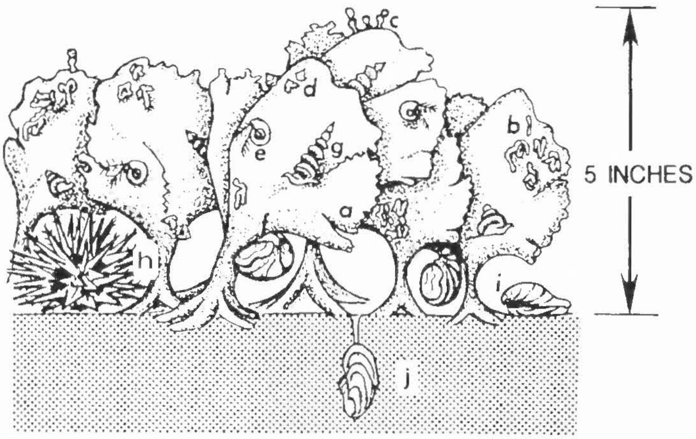


FIGURE 1.18. Schematic reconstruction of a phylloid algal community, with phylloid algae (a) dominating the sea bottom; various foraminifers (b, c, d) and worm tubes (e) encrusting the algal "leaves," and pedunculate brachiopods (f) attached to the upright plants. Various snails (g) and echinoids (h) graze the algal meadow; a few pelecypods, both epifaunal (i) and infaunal (j) round out and balance this unique plant-dominated community.

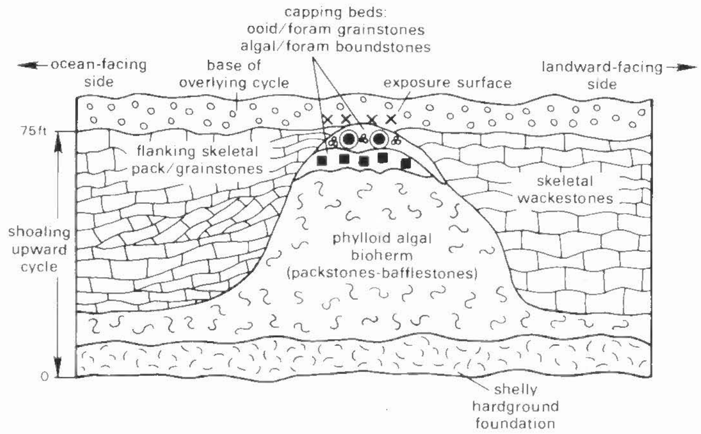


FIGURE 1.19. Schematic representation of vertical and lateral facies distribution within the Holder phylloid-algal biohermal complex, Dry Canyon, Sacramento Mountains, New Mexico.

lying, thin-bedded peloidal/foraminiferal packstone to wackestones, containing a relatively diverse biota. These grade laterally into massive biohermal rock. Slightly to the west are small, isolated, mound-like blotchy masses that have been called "leopard rock" (Wilson, 1975). Those miniherms are sporadically exposed along this horizon to the west end of Dry Canyon (see Fig. 1.17). Petrologically, they are composed of algal/foraminiferal boundstones (encrusting algal and foraminiferal components) with entrapped dasyclad algae (*Macroporella*) and mollusc shells. "Leopard rock" miniherms formed in very shallow waters, adjacent to, and downslope from the primary biohermal mass, probably when the latter were subaerially exposed. Flank beds above this interval (Fig. 1.20, Section 2) are rather steeply dipping (up to 35°) beds of skeletal wackestones containing fusulinids and dasyclad algae, some of which show remnant current alignment along bedding plane surfaces. Higher in this section the flanking beds comprise intraclastic/peloidal/skeletal packstones to wackestones. Close to the edge of the bioherm's surface "red zones" appear. These conspicuously colored zones have been interpreted as surfaces of subaerial exposure, and are probably residual clay zones that have accumulated in sheltered areas across the biohermal complex. The highest flanking beds (Fig. 1.20, Section 3) consist of steeply dipping, thin-bedded skeletal/peloidal packstones to wackestones containing a biota not found on the bioherm proper. That biota comprises myalinid pelecypods, worm tubes and ostracodes. Toward the top of this section the beds become progressively sandier. Tracing one skeletal carbonate laterally downslope, toward the west, indicates that the unit undergoes facies change to a greenish, flaggy, silty skeletal wackestone containing an abundant molluscan fauna that apparently flourished in the deeper inter-biohermal waters, nourished by nutrients swept off the bioherm. A hydrographic relief, perhaps on the order from 75 to 100 ft, can be reasonably projected for this interval.

Use caution in re-entering highway. 0.2

57.7 Milepost 5. **0.1**

57.8 Run-away truck escape ramp (for trucks, not motorists) on left. **0.2**

58.0 Interbedded reddish strata and limestone are part of the eastward extension of the back-reef facies of Holder reef complex. **0.2**

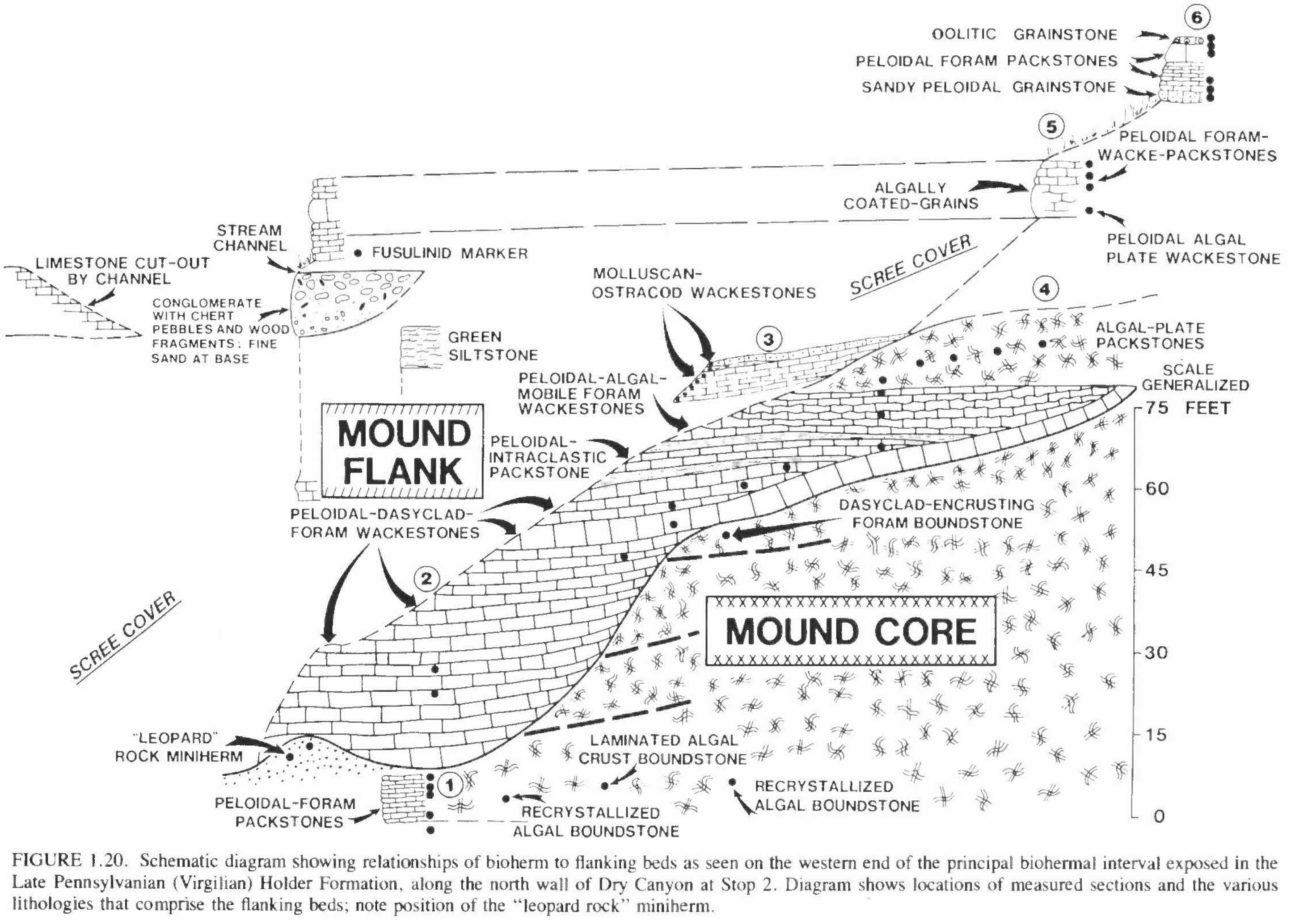


FIGURE 1.20. Schematic diagram showing relationships of bioherm to flanking beds as seen on the western end of the principal biohermal interval exposed in the Late Pennsylvanian (Virgilian) Holder Formation, along the north wall of Dry Canyon at Stop 2. Diagram shows locations of measured sections and the various lithologies that comprise the flanking beds; note position of the "leopard rock" miniherm.

58.2 Side road to right leads south into Dry Canyon. The canyon follows the axis of Dry Canyon syncline (Pray, 1961) at this point before taking sharp bend to the west. We are now crossing from the Holder Formation (Pennsylvanian) into the Laborcita Formation (Permian). **0.1**

58.3 Mafic dike cutting red beds of lower Laborcita Formation crosses road. Strike of dikes in this area approximately N20°E. **0.4**

58.7 Milepost 6. **0.1**

58.8 Carbonate bed in roadcut to right is part of Laborcita Formation. **0.2**

59.0 Red beds in roadcut ahead are part of Laborcita Formation. **0.1**

59.1 Steeply dipping, contorted strata at 12:00 are part of a west-verging, overturned fold that follows high-angle faults along west flank of Sacramento Mountains (Fig. 1.21). These upturned strata provide a cross section (east-to-west, ascending stratigraphic order) of the Gobbler, Beeman and Holder Formations. **0.5**

59.6 Steeply dipping purplish nodular limestones are part of the Beeman Formation. Ripple-marked, crossbedded sandstone in Beeman on right. **0.1**

59.7 Milepost 7. Tunnel Vista ahead. Crossing Fresnal fault zone (Fig. 1.22). **0.1**

59.8 Steep limestone cliffs on right are part of the Bug Scuffle Member of the Pennsylvanian Gobbler Formation. **0.1**

59.9 **Turn left** into Tunnel Vista parking lot for **STOP 5.** This stop provides an excellent view of Holder Formation reef and lagoon deposits, viewed basinward from near the edge of the uplift during Holder time. The purpose of this stop is to discuss Paleozoic tectonics and sedimentation off the west flank of the Pedernal uplift.

Immediately west of here is the Fresnal fault zone, which marks the edge of uplift during Paleozoic time. This zone comprises a series of normal faults that dip 65° to 70° west and have down-to-the-west displacement. West of this structure, the Pennsylvanian Beeman and Holder, and Permian Laborcita Formations are present. East of the zone, the Holder and Laborcita are missing and the Beeman is reduced to less than 18 m beneath the Permian Abo Formation (Pray, 1961). Approximately 1.5 mi south of this point, in SW¼ sec. 7, T16S, R11E, Ordovician and Devonian strata are exposed in the core of a small (0.5 mi diameter) dome on the Caballero anticline. Two mi farther southeast along the axis of the Caballero anticline, in NE¼ sec. 20, T16S, R11E, Ordovician, Silurian, Devonian and Mississippian strata are exposed in the core of another small dome cut by Arcente Canyon. The southern and eastern sides of this dome are overlapped by red beds of the Permian Abo Formation (Pray, 1961). The Abo strata are also slightly tilted around the dome, suggesting Permian reactivation of this feature. Post-Abo reactivation on this fault is suggested by several hundred feet of throw on the base of the Abo Formation across this fault. Because younger strata are missing, an exact age for this reactivation other than post-Abo is not available. It does seem likely that some movement may have occurred during Tertiary time.

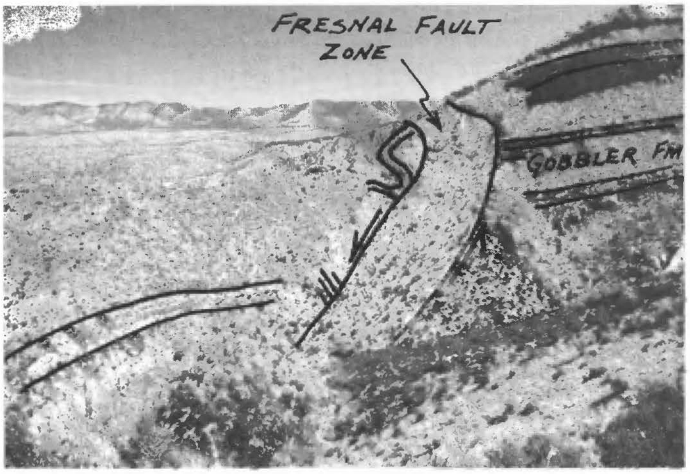


FIGURE 1.22. View north from US-82 along the trace of the Fresnal fault, near mile 59.7.

Return to US-82 and turn left toward tunnel. Watch for traffic coming out of tunnel on left and coming from blind curves on right. 0.1

60.0 Entering tunnel (Fig. 1.23). This is cut through the Bug Scuffle Member of the Gobbler Formation. Altered mafic dikes cut section at mouth of tunnel and at parking area (Pray, 1961). **0.2**

FIGURE 1.21. Looking southeast from near Stop 4 toward the Caballero anticline in the Sacramento Mountains.

FIGURE 1.23. View east from Stop 5 toward US-82 tunnel cut at mile 60.0 in the Bug Scuffle Member of Pennsylvanian Gobbler Formation.

60.2 Exiting tunnel. Massive-bedded carbonates of Gobbler Formation in walls of canyon and next to road. **0.1**

60.3 Climbing out of canyon, we are approaching Gobbler-Abo contact; the Pennsylvanian Beeman Formation and Permian Laborcita Formation are missing in this area because of uplift, tilting and erosion prior to deposition of the Abo Formation. **0.4**

60.7 Milepost 8. Crossing cattle guard. Entering High Rolls, elevation 6750 ft. Intersection with Westside Road on right. **0.6**

61.3 Road to Karr Canyon on right. Crossing Abo-Beeman contact. **0.4**

61.7 Milepost 9. Red beds in roadcut to right are part of the Abo Formation. **0.3**

62.0 Entering Mountain Park, elevation 6750 ft. **0.7**

62.7 Milepost 10. Crossing Abo-Yeso contact. Outcrop ahead and to left displays leached Yeso Formation. Travertine reported by Pray (1961) suggests that dissolution of evaporites may have lead to karst development in this area. **0.6**

63.3 Outcrop of leached and weathered Yeso Formation carbonate. **0.4**

63.7 Milepost 11. **0.1**

63.8 Rubbly outcrop on left is limestone slope wash from Yeso Formation carbonates, covering pink Yeso sandstone. **0.2**

64.0 Steeply dipping Yeso Formation to left. **0.3**

64.3 Thick Yeso Formation carbonate beds exposed in roadcut are slumped down across sandstone. Slump structures apparently predate highway roadcuts. Possible future geologic hazard? **0.3**

64.6 Grandma's Attic on left. **0.1**

64.7 Fractured and jumbled Yeso Formation on left. **0.2**

64.9 Intersection with Pine Valley Drive to right. **0.1**

65.0 Leached outcrop of San Andres(?) Formation, slumped down over Yeso Formation sandstone to left. **0.1**

65.1 Turnout to right. **0.2**

65.3 Steeply dipping Yeso and possibly San Andres Formations as toreva(?) blocks. **0.1**

65.4 Side road to left. **0.2**

65.6 Leached San Andres(?) Formation to left. **0.1**

65.7 Milepost 13. Outcrop on left is thin-bedded San Andres Formation. **0.3**

66.0 Outcrop on left appears to be a leached, collapse breccia cemented with chalky travertine (Fig. 1.24). **0.7**

FIGURE 1.24. Leached collapse breccias in San Andres Formation west of Cloudcroft at mile 66.0. Slumping of these materials in roadcuts causes problems for the Highway Department.

66.7 Milepost 14. **0.3**

67.0 Lincoln National Forest marker on right. **0.2**

67.2 Large unstable slope at left may be part of a collapse structure. Highway Department has a problem with slope stabilization here. **0.4**

67.6 More leached and possibly collapsed San Andres with caliche-cemented talus to left. **0.1**

67.7 Milepost 15. **0.1**

67.8 Caliche-cemented gravel being eroded to left. Gravel contains large blocks of San Andres carbonate. Talus? **0.4**

68.2 Old wooden trestle for "Cloud-Climbing Railroad" spur of the El Paso and Southwestern is visible at 2:30 (Fig. 1.25). Sign on right describes the "cloud-climbing railroad"; see the following minipapers for details. Yellow gash ahead and to left in roadcut exposes a fault cutting San Andres carbonates (Fig. 1.26). **0.1**

THE "CLOUD-CLIMBING RAILROAD"— THE ALAMOGORDO AND SACRAMENTO MOUNTAIN RAILWAY

Russell W. Jentgen

Bureau of Land Management, P.O. Box 1449, Santa Fe, New Mexico 87504

This short railroad, which ran from Alamogordo through Cloudcroft and south to the town of Russia, was by no means unimportant. For example, it was standard, not narrow gauge, throughout its life. More importantly, the railroad was a significant factor in the life and economy of the area it served. It started life as a railroad built to build a railroad.

The Alamogordo and Sacramento Mountain (A&SM) was built by Charles Eddy in 1898–1903 to haul timber out of the Sacramento Mountains for railroad ties and bridges (Fig. 1.27). Eddy needed the timber to extend his El Paso and Northeastern Railroad from Alamogordo to its connection with the Rock Island Railroad at Santa Rosa. Lumber was always the backbone of the A&SM, but tourism became its heart. Bright yellow excrusion cars, similar to the ones operating today on the tourist railroads to Chama and Silverton, quickly became popular for moving weekend crowds to the mountains to escape the summer heat in El Paso.

To accommodate the crowds, the A&SM established Cloudcroft as a resort town. It divided the town into three zones. North Cloudcroft was the commercial community of stores and stables. Cloudcroft was the residential area, and had restrictions against liquor, commercial operations and animals except for pets. Cloudcroft Park was the outlying section, with larger lots for large houses and for those preferring more seclusion. The only restrictions in this part of town were against liquor and commercial operations. Hotels and boarding houses were allowed in all parts of town. The railroad company owned the only bar, all the better to protect the morals of the community. History makes no mention of how profitable the bar was. With a town full of tourists and lumberjacks, one can imagine.

Construction of the railroad was difficult, requiring steep grades, sharp curves, one switchback and many remarkable timber-trestle bridges. Some of these bridges were built on curves, and at least one was an S-curve bridge. The wood used in the bridges was untreated, requiring replacement as often as every three years in some cases. A crew of thirty or more men were constantly busy replacing bridge timbers, cross ties and making other repairs on the railroad. Even so, the swaying of a bridge set up by the passage of a train was terrifying to most first-time passengers. Today, only one of these bridges remains. The other bridges became houses and fences in La Luz, High Rolls and Cloudcroft when the railroad was dismantled.

Many logging railroads were built north from Cloudcroft and south from Russia by several lumber companies that operated in the mountains. These were hastily constructed roads, often laid in the bottoms

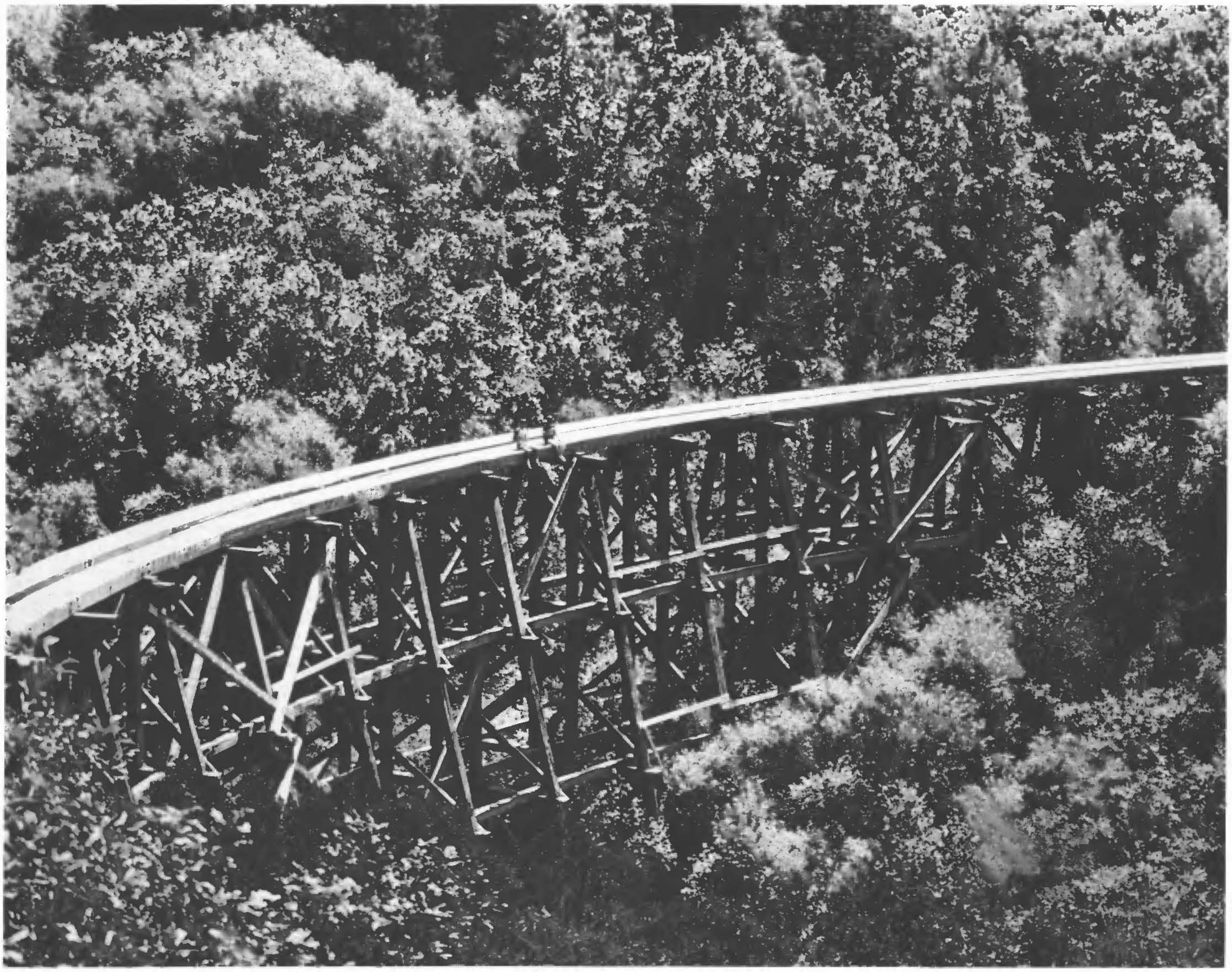


FIGURE 1.25. Only remaining trestle of the El Paso and Southwestern Railroad line, west of Cloudcroft, at mile 68.2.

of the canyons so that logs could be easily skidded down to the loading tracks. These logging railroads typically used a unique geared steam engine, the Shay, to obtain sufficient pulling power on the steep and crooked rails. The reduction of speed caused by the gears would make the locomotives sound like they were making 60 mph when they were really only going six! Once the logs were hauled from a canyon, the rails were quickly removed, only to be relaid in some nearby canyon.

The last of the summer excursion trains to Cloudcroft ran on the A&SM on September 30, 1930. By May 27, 1934, regular passenger service, once three trains per day, was down to three trains per week. No passenger trains ran after Febraury 13, 1938, when the mail contract was dropped. Logging trains continued to run until September 12, 1947. By then, the lumber companies had shifted all of their log hauling to trucks. Trucks could handle the 40-ft logs, which increased productivity, while the A&SM was limited to 20-ft logs by its sharp curves and short cars.

Tourism and timber are still the major industries of the Sacramento Mountains. However, whistles in the woods have long been replaced by the convenience and flexibility of cars and trucks. A single wooden trestle near the highway is all that remains to remind us of the glorious days of the cloud-climbing railroad from the desert.

FIGURE 1.26. Faulted and collapsed San Andres Formation near Cloudcroft, on north side of highway at mile 68.3. Some of this faulting is probably due to cavern collapse in the underlying Yeso Formation.

ADDITIONAL COMMENTS ON THE "CLOUD-CLIMBING RAILROAD"

Allen L. Bowman

10 Encino, Los Alamos, New Mexico 87544

The Alamogordo and Sacramento Mountain Railway (A&SM), described in Jentgen's minipaper above, was an interesting little railroad that was insignificant in size, but very important to the economy of the

FIGURE 1.27. Logging train in New Mexico's Sacramento Mountains near Cloudcroft. The locomotive is a geared, Heisler type. The log loader, here just behind coal tender, was steam powered, and traveled from car to car on rails. To unload, the process was reversed, hence the need to bring the loader along in the consist (from postcard collection of Spencer Wilson).

region that it served. The following comments add to Jentgen's discussion.

One useful reference (Allen, 1916) provides operation timetables, from which we find, for the year 1916, one daily train, leaving Alamogordo at 0800, arriving at the end of the line (Russia) at 1205, and then starting the faster downhill trip at 1240, arriving at Alamogordo at 1600. One can speculate that this schedule was not followed very carefully, but the numerous freight trains (mostly logs heading to the mill in Alamogordo) probably forced some adherence to the published schedule. The mileage and elevation figures show a climb of ~4300 ft in only 26 miles between Alamogordo and Cloudcroft, which defines very well the kind of grades that were required.

Station	Miles	Elevation	Times	
Alamogordo	0.0	4320	0820	1600
Toboggan	20.6	7728	1045	1400
Cloudcroft	26.1	8600	1120	1325
Cox Cañon	28.0	8500	1135	1305
Russia	32.5		1205	1240

Glover (1984) also gives details on completion dates for the A&SM track, with the start at Alamogordo Junction in July 1898, and completion to Toboggan in November, to Cloudcroft in January 1900, to Cox Cañon in June, and to Russia in June 1903. It appears that the railroad progressed as needed to haul logs out of the mountains. The lumber company spur tracks (or trams, as they were sometimes called) made their connections with the A&SM as it progressed in leisurely fashion to Russia. From that point, the lumber railroads extended to the south and east for 25 to 30 mi at their greatest extent. Another lumber company line extended north and east from Cloudcroft into the Mescalero Apache Reservation for a similar distance. As the logging operations moved farther from the A&SM line, the logging company railroads began to operate in a more formal manner, with a main line and short spurs into the timber areas.

Glover's roster of locomotives shows nine different Shay-geared locomotives, two of which were tried on the A&SM main line with a notable lack of success, and two Heislers, along with a variety of rod locomotives. The Shays were the preferred motive power for most of the lumber company railroad operations.

A second edition of Myrick's book on New Mexico railroads (Myrick, 1990) was recently published. There is no change in the text describing the A&SM rail system, but one photo has been added.

68.3 Sewage treatment plant for Cloudcroft visible at right. **0.1**

68.4 Entering Cloudcroft, elevation 8650 ft. **0.2**

68.6 Roadcuts ahead are in rubbly San Andres Formation. **0.1**

68.7 Milepost 18. **0.3**

69.0 Entering developed part of village of Cloudcroft. Intersection with NM-130 to right. **Continue straight** ahead on US-82. Watch out for traffic from side roads and school children from schools on left side of road. **0.8**

CLOUDCROFT, NEW MEXICO: "THE BREATHING SPOT OF THE SOUTHWEST"

Spencer Wilson

Humanities Department, New Mexico Institute of Mining and Technology, Socorro, New Mexico 87801

In June 1899 the *El Paso Times* carried an advertisement for Cloudcroft as a vacation resort. The editor of the paper extolled the climate and the sylvan beauty of the area—cool nights, pine forests, flowers and a luxury hotel for the hot, tired traveler. The town was 9000 ft above sea level in the Sacramento Mountains and was served by a railroad. Before the month was out, residents of El Paso were fleeing the hot desert for relief from increasing summer heat. The editor's flowery description as "The Breathing Spot" was appropriate and welcome.

Cloudcroft was the outgrowth of a much larger project, a railroad from El Paso to the northeastern part of New Mexico, the El Paso and Northeastern Railroad Company (EP&NE). This railroad project was promoted by Charles Bishop Eddy, a developer of irrigation and town projects in southeastern New Mexico. Eddy County is his namesake there. Other railroads were planned for the area but not much was done until Charles Eddy and brother John bought out previous developers. The lure for such a railroad was the vast lumber and mining potential in the mountains. Towns like Capitan and White Oaks, as well as the mature trees of the Sacramentos, promised big profits after development. The area's potential as a vacation resort was also recognized early on.

In December 1897, construction of the railroad was started toward the Sacramento Mountains, and by June of the next year tracks reached the new town of Alamogordo. The need for construction timber for the railroad and the new town meant that another railroad was projected from Alamogordo east into the mountains toward Cloudcroft.

By the middle of 1898 construction began on a standard-gauge railroad, the Alamogordo and Sacramento Mountain Railway (A&SM). The route was through very steep and rugged country. It took almost a year to complete the 26 mi of railroad, requiring steep grades, sharp curves, switchbacks to gain elevation, special brakes on the locomotives and rolling stock, and extensive wooden trestles to bridge canyons (Fig. 1.28). The trestle at Mexican Canyon is visible from the present highway.

At Cloudcroft the railroad company then proceeded to build a grand hotel, the Pavilion, as it was then called, served directly by the railroad. The Pavilion was 170 ft long and 50 ft wide and had a kitchen and dining areas capable of serving hundreds of travelers. It also had a reception room and a ballroom. Early travelers used tents but later ones occupied hotels and cottages.

The timber developers built other railroad spurs into the surrounding mountains. These projects were connected with the A&SM Railway, which in turn connected to the parent EP&NE at Alamogordo. A lively lumber industry continued to operate in the area until after World War II, and minor logging is still carried out via trucks.

The present Lodge at Cloudcroft is a replacement for the previous structures. The Pavilion was opened in 1899 as a summer resort surrounded by pine forests, ferns and wildflowers. General Superintendent A. S. Greig of the EP&NE Railroad labeled Cloudcroft "The Breathing Spot of the Southwest." June 16 was the gala opening and it was an immediate success. Excursion trains brought the sweltering folks from

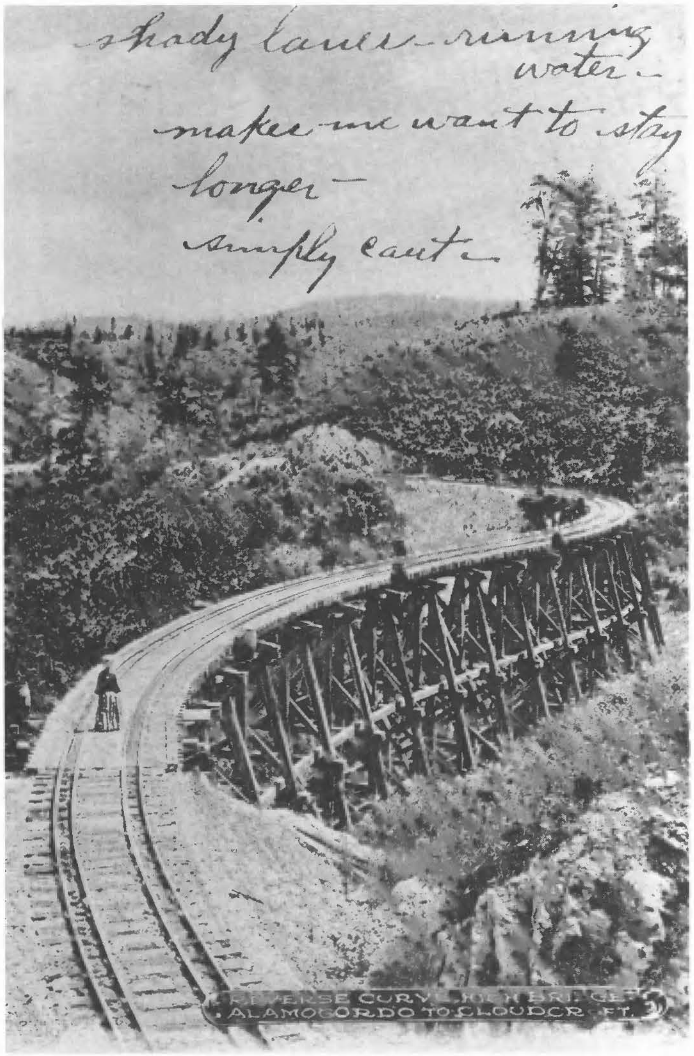


FIGURE 1.28. The S-curve—reverse curve—trestle just before entering Cloudcroft. A very difficult engineering feat. Gravel was spread on the roadbed between rails to prevent fire (from postcard collection of Spencer Wilson).

El Paso and Alamogordo, together with organizations such as the El Paso Fireman's Excursion, to the cool heights (Fig. 1.29).

The first year was so successful that people flocked to buy the available lots and began building cottages. Special rates on the railroad and free lodging in tents were provided by the developers. In June 1900, Charles Eddy visited the area and moved his brother John and family into a new cottage.

In early 1901 work was progressing on a grander tourist facility, The Lodge, the predecessor to the present building. On June 1, 1901, this new lodge was opened—a gala occasion. *The Alamogordo News* announced: "The new hotel at Cloudcroft opens today. The formal blowout will take place later." This new building was 212 ft long and 80 ft wide, surrounded by a porch. Some of the second-floor rooms had balconies. The formal lobby was complete with Navajo rugs, and the dining room tables were set with linen and silver. During this first year, the hotel was renovated in preparation for the formal opening a year later.

On June 1, 1902, the grand, formal opening of the Lodge took place. The railroad put on a special train that left El Paso at 1:15 p.m. and was timed to arrive at Cloudcroft at 6:30 p.m.—a distance of 102 mi! The train arrived just in time for dinner; actually dinner was delayed until the train arrived. Guests stayed overnight and departed Monday at 7:30 a.m., arriving in El Paso at 12:45 p.m. The railroad offered the first excursion in 1903 at $3.00, which included a free barbecue and picnic, and a reported 600 people rode.

FIGURE 1.29. "On the Way to Cloudcroft Near the Turn of the Century." Think of arriving in the cool pines in June after leaving El Paso! The rod-type locomotive is equipped with special backup systems of brakes for the 6% grades on the railroad (6% means a gain in elevation of 6 ft for every 100 ft of travel). This train (consist) is made up of special tourist cars plus one more-standard combination car—able to accommodate passengers, mail and small amounts of freight—just behind coal tender (from postcard collection of Spencer Wilson).

Cloudcroft continued to serve as a resort for people from west Texas and part of New Mexico. The facilities at the Lodge were improved to attract the folks during the sweltering summer months. The game of golf was new in the United States, and in a short time the first links were constructed for what is still the highest golf course in the United States. The Lodge became a rest stop for the famous and infamous. New Mexico politicians, including the governors, were joined, at one time or another, by visitors from Houston, San Antonio and Dallas. Ex-Governor and Mrs. L. Bradford Prince attended the New Mexico Bar Association Convention and danced with the others at the Pavilion.

In 1907 a new, 80-by-40-ft dining room and kitchen were added to the Lodge. The dining room was finished in weathered oak, with windows of a French design. There was a balcony for musicians to entertain the diners and for dancing. More mundane services, such as heat and hot water for the entire building, made the accommodations even more up to date.

That August the patronage of the Lodge topped previous records. The Lodge became a community center. Travelers came from nearby and from several other states, as many as 2500 people. In addition to dancing (every night except Sunday) many other recreational programs—bowling, billiards, golf, baseball and tennis—were available. All of these activities were rounded out by an amphitheater for amateur productions. On Labor Day 1907, the 19th Infantry Band from Ft. Bliss at El Paso entertained the folks. A masquerade ball was also part of the festivities on that weekend. The Lodge and Cloudcroft continued to draw visitors for many occasions, 4th of July celebrations, railroad excursions, and apparently any other excuse for a party.

In 1909, disaster struck! On June 13, at 2:30 a.m., the Lodge burst into flames. The *El Paso Times* reported that people fled in the June night with only their night clothes. The origin of the fire was never established and nothing was saved. The *Times* noted, "So fast did the great wooden building burn that few if any had time to secure any outer garments. . . ." For a while the people of Cloudcroft were fearful that a new lodge would not be built. However, plans were laid immediately for the construction of another lodge.

The present Lodge was built on the crest of the mountain, providing a view of the basin below, including Alamogordo and White Sands. Construction of the new building began in the summer of 1910. An architectural firm from Chicago designed the building in a style and manner quite different from the former lodge. The new lodge is described by architects as Jacobean, a form of one of the Renaissance revival styles (Kabot, 1988). The central tower rises between two lower sections. This observation tower rises five flights above the entry with windows on all four sides with spectacular views of the entire countryside.

The grand opening of the new Lodge was on June 1, 1911. A new railroad spur was built to serve the hotel with a connecting boardwalk. Dignitaries from all over, including the Mexican revolutionary Francisco "Pancho" Villa, came to celebrate. Also present were the grandparents of astronaut Michael Collins.

The next decades were uneventful. In the mid-1930s Conrad Hilton operated the hotel and dining room. In 1936 the Southern Pacific Company sold the lodge, the Sacramento Mountain Railroad, and its lumber interests to the Southwest Lumber Company. During World War II resort business suffered everywhere. With the rise in automobile use, railroad passenger business declined in the postwar years. The logs were being hauled by truck, and business on the railroad to Cloudcroft dropped dramatically. By 1945 the end was in sight. The line lasted another two years but in 1947 the railroad to Cloudcroft was scrapped. The Lodge, however, stayed on.

In 1953 another owner of the Lodge embarked on a renovation and remodeling plan that gave the structure new life. A new physical plant, among other improvements, helped revive patronage and the hotel remained open from then on. Subsequent alterations, additions, and "improvements" have added to the Lodge (Fig. 1.30). Indeed the 1970s saw a revival of interest in things that look Victorian. A final improvement was to the golf course. The first hole is a terror to behold, but the golfers keep coming and the Lodge provides them with accommodations. Visitors today, as they did yesterday, come to the high Sacramento Mountains and the Lodge for the cool summer and fresh, pine-tinged air. Truly the newspaper was correct in calling Cloudcroft "The Breathing Spot of the Southwest."

69.8 Leaving Cloudcroft development area. **0.6**

70.4 **Junction** with NM-244; **turn left (north)** on to NM-244 Toward Apache Summit. Cross cattle guard. Lincoln National Forest marker on right. **0.1**

70.5 San Andres Formation in roadcuts on right. **0.2**

70.7 Entrance to Pines Campground on left and Fir Group area on right. **0.2**

70.9 Outcrops of San Andres Formation in roadcuts. **0.3**

71.2 Side road to left leads to undeveloped camping area. **0.2**

71.4 Milepost 1. San Andres Formation in roadcuts ahead. **0.6**

FIGURE 1.30. The present Lodge at Cloudcroft. The railroad to Cloudcroft was scrapped in 1947, but the Lodge stayed on. Courtesy of Spencer Wilson.

72.0 Road to left leads to Air Force Observation Facility (closed to public). **0.1**

72.1 Roadcut to left in San Andres Formation. **0.2**

72.3 Silver-Saddle Apache Campground to right. **0.2**

72.5 Cross cattle guard. Outcrops on left are San Andres Formation. **0.4**

72.9 Outcrops to left are San Andres Formation. **0.4**

73.3 San Andres outcrops ahead and on left. **0.5**

73.8 Cattle guard. Road to left leads to Wofford Lookout and La Luz Canyon. **0.3**

74.1 Cattle guard. **0.1**

74.2 Small pond on right. **0.2**

74.4 Milepost 4. Outcrop ahead and on left is in red siltstones and sandstones of the Permian Yeso Formation. Yeso is up-faulted into valley. **0.3**

74.7 White Gazebo ahead at 2:00 with small pond. Entering Silver Springs area. Camping and fishing available. **0.3**

75.0 Four small ponds in valley to right were built for water storage. **0.2**

75.2 Cattle guard. High Meadows Ranch sign to right. **0.2**

75.4 Milepost 5. Yellowish outcrops ahead are either Grayburg or Yeso Formation. **0.2**

75.6 San Andres Formation in roadcuts ahead. Formation is badly leached in this area (karst development?). **0.4**

76.0 Cattle guard. Outcrops on left are San Andres Formation. Outcrops are locally leached and covered with yellowish, calcareous soils and sands. **0.4**

76.4 Milepost 6. Leaving Lincoln National Forest. **0.1**

76.5 Road to left leads down Tularosa Canyon to Mescalero. **0.1**

76.6 Cattle guard. Limestone outcrops along road are San Andres Formation with local cavern development. **0.5**

77.1 Cattle guard. Entering Mescalero Apache Reservation. Black soils in streambed on right are probably old lake deposits and are similar in nature to deposits in Pumphouse Canyon, east of Cloudcroft ski area. **0.3**

77.4 Milepost 7. Yeso outcrops on left display considerable leaching. **0.6**

78.0 Orange-colored Yeso Formation. **0.1**

78.1 Carbonate bed in Yeso Formation in outcrop. Until further notice, outcrops will be Yeso Formation. **0.3**

78.4 Milepost 8. **0.3**

78.7 Two outhouses on left are in Silver Lake Campground (run by the Mescaleros). **0.1**

78.8 Silver Lake Dam on left. **0.3**

79.1 Entrance to Silver Lake Campground on left. **0.8**

79.9 Note old railroad grade to right in valley. Old ties are still in place. **1.9**

81.8 Old railroad grade on left is probably from logging railroads feeding the El Paso and Southwestern line at Cloudcroft. **1.6**

83.4 Milepost 13. **0.5**

83.9 Cattle guard; weather-beaten buildings on right are part of abandoned settlement of Elk-Silver. **Caution! Road takes sharp turn to left up Elk Canyon. 6.2**

90.1 Crossing small fault (down to the west) from upper part of Yeso Formation to lower part of San Andres Formation (Moore et al., 1988). We will be on San Andres Formation for several miles. **0.3**

90.4 Milepost 20. **1.3**

91.7 Cattle guard. **1.3**

93.0 Leached San Andres displays vugs and cavities. **0.4**

93.4 Milepost 23. Road curves sharply to left ahead. San Andres Formation in outcrops to right. Terrace on left may be part of an old railroad grade. **1.1**

94.5 Head of steep downgrade. Road begins sharp curve to right. **0.3**

94.8 Roadcuts in lowest part of San Andres Formation are grading into the upper part of the Yeso Formation as we descend down the canyon. **0.5**

95.3 Leached and rubbly Yeso Formation on the right side of the road is evidence of extensive dissolution of strata along the crest of the Sacramento Mountains. **0.1**

95.4 Road curves sharply to left; we are still descending steep grade. **2.0**

97.4 Milepost 27. **0.3**

97.7 Road curves left. Crossing normal fault between Permian Yeso and San Andres Formations and Cretaceous Dakota Formation. Fault has down-to-the-north displacement (Moore et al., 1988). **0.5**

98.2 Houses ahead; road curves right. **0.2**

98.4 Milepost 28. Housing development at crossroads ahead. Side road to left. **0.7**

99.1 Side road to right up unnamed tributary canyon. **0.3**

99.4 Milepost 29. Approaching intersection with US-70. **0.2**

99.6 Cattle guard; **intersection** with US-70. **Turn right and proceed east on US-70** toward Apache Summit and Ruidoso. **0.6**

100.2 Milepost 250. **1.2**

101.4 Well house and state storage shed on right. **0.4**

101.8 Road on right leads to Bureau of Indian Affairs Branch of Forestry. **0.3**

102.1 Outcrop of Dakota Formation overlain by Mancos Shale to right. **0.1**

102.2 Milepost 252. **0.2**

102.4 Apache Summit, elevation 7591 ft (2314 m). **0.1**

102.5 Intersection to right. **1.0**

103.5 Outcrops in roadcuts are leached San Andres Formation. Yellowish material is silt and clay cavern fill. **0.3**

103.8 Sierra Blanca Peak at 12:00 and sign on right. This peak, with a summit elevation of 12,003 ft (3658 m), is the highest point in southern New Mexico, and has the distinction of being the most southerly glaciated peak in the United States. A single cirque on the north side of the peak is cut into syenite quartz porphyry (Richmond, 1986). Located up to 2 mi down-valley from the cirque is a sequence of moraines that Richmond (1986) correlated with the Pinedale and Bull Lake glaciations of late Pleistocene age. Today, the area around the summit is a major ski resort operated by the Mescalero Apache Tribe. **0.4**

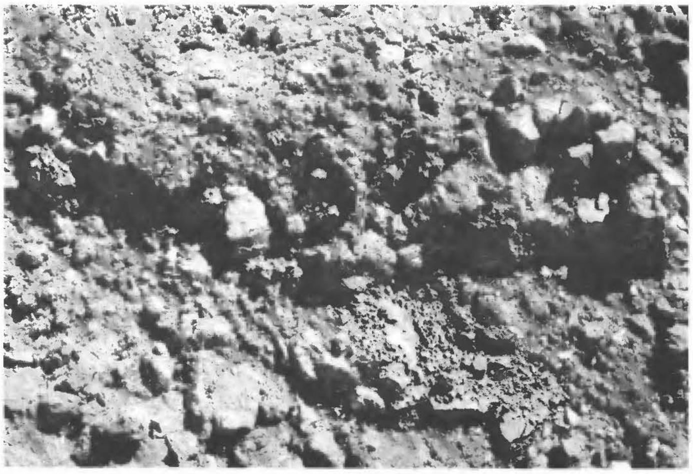


FIGURE 1.32. Travertine-cemented rubble breccia at south end of Stop 6. Scale is approximately 15 cm long.

104.2 Milepost 254. **0.3**

104.5 **STOP 6. Pull off onto the right shoulder. Be alert for passing traffic.** The purpose of this stop is to examine a roadcut (Figs. 1.31 to 1.33) through a debris-filled sinkhole recently quarried for road metal and base course (see following minipaper by Hahman and Colpitts for more discussion). Other evidence for karst and unstable ground related to active karst features are visible immediately adjacent to the quarry site. East of this stop was a small, low area south of the old highway grade, with no apparent outflow except during periods of heavy runoff. Several drainages enter this low area from the west. This area is probably a small sinkhole, in that water flows in on the surface but apparently does not flow out on the surface. Other evidence of instability includes slumping in the quarry face and development

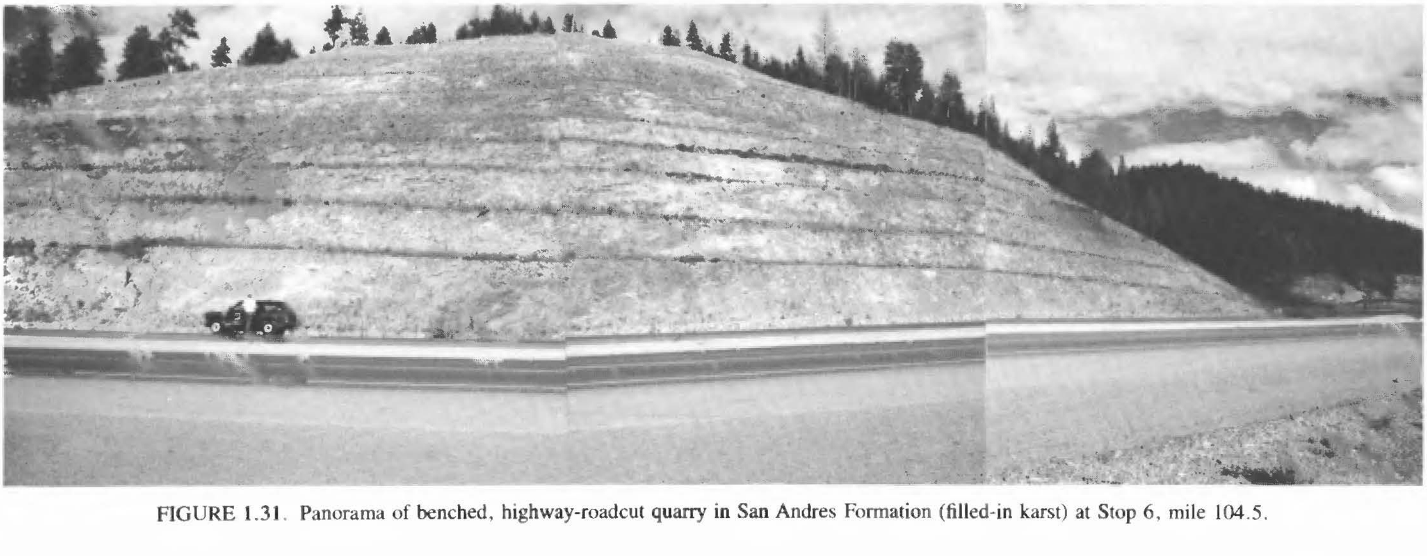


FIGURE 1.31. Panorama of benched, highway-roadcut quarry in San Andres Formation (filled-in karst) at Stop 6, mile 104.5.

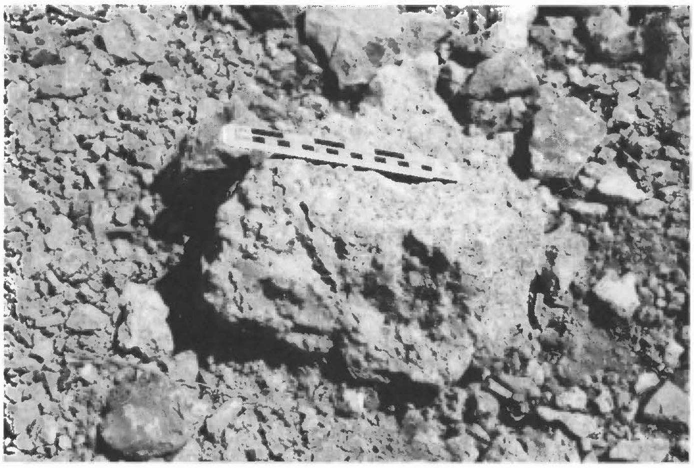


FIGURE 1.33. Travertine-cemented breccia at south end of Stop 6 is characteristic of breccias throughout this old quarry. Scale is in cm and inches.

of "rolls" in the once-smooth road surface. These "rolls" have developed only within the past 2 yrs and were not apparent when the roadcut quarry was being studied by Hahman and Colpitts in 1988. Age of this feature is possibly Pleistocene or older. A bone fragment found in a stream channel deposit partway up the slope was identified by Donald Wolberg (New Mexico Bureau of Mines and Mineral Resources) as an unidentifiable Pleistocene mammal rib fragment. Age of karst in other areas is variable. Some debris-filled sinkholes near the Capitan Mountains apparently predate that intrusion, suggesting an early to pre-early Tertiary age for those features. It is also conceivable that some features may date back to Guadalupian time (Permian), when part of the upper San Andres Formation was removed by erosion prior to deposition of the Grayburg Formation.

ENGINEERING GEOLOGY OF KARST COLLAPSE FEATURES IN A HIGHWAY ROADCUT QUARRY, OTERO COUNTY, NEW MEXICO

W. Richard Hahman[1] and Robert M. Colpitts[2]

[1]Consulting Geologist, 4227 Lost Lane, Las Cruces, New Mexico 88005;
[2]Consulting Geologist, 502 2nd St. NE, Lot 2, Socorro, New Mexico 87801

This paper summarizes the results of a detailed study of a contract-mandatory roadcut quarry site along US-70 north of Apache Summit, Otero County, New Mexico. This roadcut was developed for two purposes; first, to remove a portion of a ridge so that US-70 could be straightened and widened, and second, as a source of fill, base course and road metal for the new roadbed. During quarrying operations, the contractor discovered that material removed was neither carbonate rock characteristic of the San Andres Formation, as mapped by Kelley (1971) and Moore et al. (1988), nor did it meet specifications established for the project. The contractor experienced considerable difficulty maintaining material quality and completing construction; he eventually had to seek other quarries with suitable materials.

The purpose of the study was to answer three questions: (1) in what stratigraphic unit was the quarry excavated, (2) were the problems encountered at the quarry related to faulting, and (3) why did quarry material degrade so much during excavation that it became unsuitable for construction purposes?

The quarry site lies on the crest of the Sacramento Mountains, north of the drainage divide separating Dark Canyon from the North Fork of Tularosa Creek, in the SE¼ NW¼ sec. 20, T12S, R13E, Otero Co., New Mexico. It is situated at the confluence of Dark, Pete Gaines and Cherokee Bill Canyons (Fig. 1.34).

Of the six stratigraphic units that crop out in the region surrounding the roadcut quarry, the most important to this study is the Permian San Andres Formation. This formation comprises 182 m (600 ft) of dark-gray limestone and dolomite with one or two thin, light-gray to yellowish-gray, medium-grained, well-sorted quartzarenite beds 15 to 30 m (50 to 100 ft) above the base of the unit (Hondo sandstone tongue of Lang, 1937). It is divided (in ascending order) into the Rio Bonito, Bonney Canyon and Fourmile Draw Members (Kelley, 1971). The Fourmile Draw Member is not present in the quarry area.

The Rio Bonito Member comprises gray, dark-gray and dark gray-brown limestone and dolomite (Kelley, 1971). Bed thickness ranges from 0.61 m to over 1.5 m. The Bonney Canyon Member comprises dark-gray and gray-brown dolomite and limestone. Bed thickness ranges from less than 2.5 cm to a maximum of 0.61 m. The top of the unit may be missing in this area due to erosion during Permian time.

The San Andres Formation displays extensive leaching, dissolution, cavern collapse and brecciation related to development of karst. Dissolution of carbonate rocks in the region is recorded by numerous authors (e.g., Kelley, 1971; Moore et al., 1988). San Andres carbonates are tough, compact, non-porous rocks used extensively in this region as crushed stone for aggregate and base course in highway construction. Our work shows the quarry is in the upper part of the Rio Bonito Member.

Faults and joint systems and karst features deform the rocks in the region surrounding the quarry site and control the position of surface

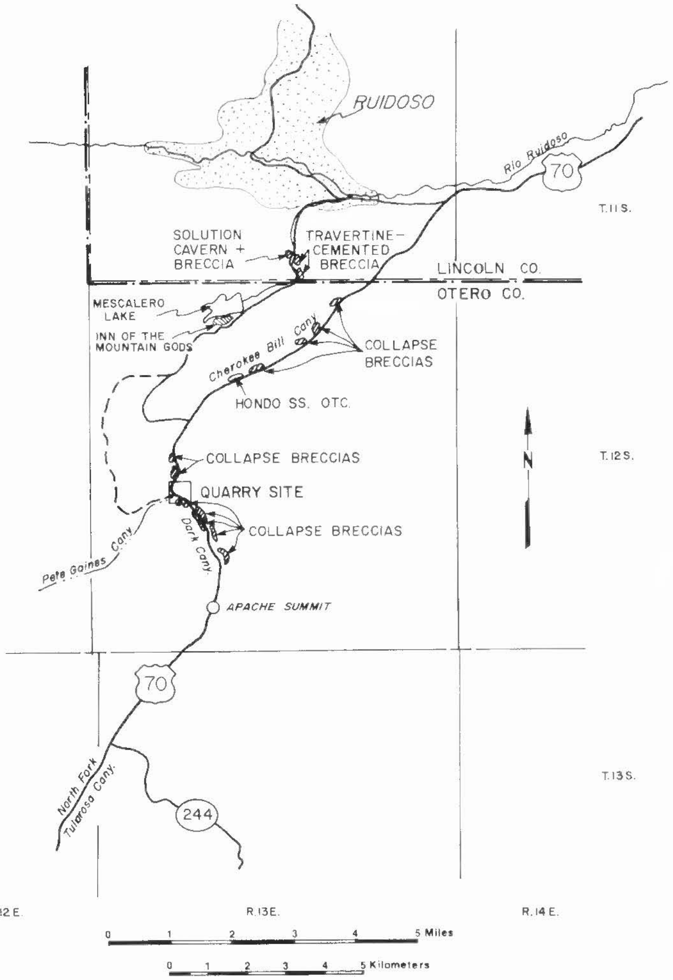


FIGURE 1.34. Occurrence of travertine-cemented breccias in region surrounding roadcut quarry site, Otero and Lincoln Counties, New Mexico.

stream drainage; folds play no important role here. The few major faults in the region around the quarry are all normal with a generally down-to-the-west displacement. They strike N40°W, N-S and N30°–40°E. Some faults are intruded by mafic to intermediate dikes (Kelley, 1971; Moore et al., 1988). Major joint sets have the same general orientations as the fault trends. Additional trends include N50°E, N65°E, N20°E and N50°W. Most drainages follow these trends, making them easy to map. Some major joints are intruded by intermediate to mafic dikes.

Karst development produces broken limestone and dolomite clasts that range from several tens of meters to granule gravel (>2 mm) in size. Clasts are either loose, cemented by banded travertine or surrounded by a silty or sandy calcareous matrix. Correlation of the occurrences of karst with location of faults, stream valleys and intersections of joint systems shows karst features occur along joint traces and at the confluences of streams. These confluences mark the locations of major joint system intersections. Previous workers often mistook extensive solution and collapse of carbonate lithologies, often with juxtaposition and/or removal of strata, for faulting. Fig. 1.34 illustrates the occurrence of travertine-cemented breccias in the region surrounding the quarry site.

The investigation of the quarry site comprised pre-quarry drilling, establishing of engineering parameters and the present post-quarry investigation to answer the questions noted above. Shallow (12 to 55 m; 40 to 180 ft) and deep (78 m; 255 ft) test holes were drilled with air-rotary and down-hole-hammer equipment, and several short cores were collected for engineering tests. Rust Tractor of El Paso subsequently ran a seismic velocity survey across the proposed quarry site and recorded velocities of approximately 1676 m/s (5500 ft/s). After quarrying began, no geologic sketch maps were made of the quarry floor to show changes in rock types or for correlation with the drill-hole data. This created a major gap in available data.

In 1988, the senior author mapped the benched roadcut in great detail. We both examined strata in the surrounding region to establish a stratigraphic framework for determining in what unit the quarry was excavated. This work showed that rocks exposed in the quarry are not characteristic of the strata in the surrounding region. Detailed mapping of the quarry face revealed that the central part of the quarry is rubble and collapse breccia, overlying a well-weathered clay "trash" zone. Clay-matrix rubble breccia with isolated blocks flank this rubble and clay trash. Travertine-cemented breccias, bedded terra-rossa clay, silt, sand and gravel channel-fill deposits occur throughout the system. The top of the hill to the south has terra-rossa clay and rubble breccia. The drainages on both sides of the highway contain travertine flow, rubble and collapse breccia. The unconsolidated nature of the deposit is supported by Rust Tractor's seismic velocity survey; normal dolomite and/or limestone should have velocities of 6100 m/s (20,000 ft/s).

Quarry mapping and regional reconnaissance combined with the low velocities obtained by Rust Tractor indicate the quarry was developed in a large debris-filled sinkhole. This alone explains why the contractor had trouble maintaining quality and integrity of material obtained from the quarry; collapse breccia fragments are quite porous because of percolation of weakly acidic ground waters through the system. Increased dissolution produced friable stone. This type of rock tended to disintegrate during quarrying, crushing, screening and transport. Mechanical weathering processes (freeze-thaw cycle) destroyed stockpiled crushed and sized rock during the winter. Degradation of the stocks was not apparent until work on the highway resumed in the spring. In addition to poor material integrity, aggregate that could be used would not take a coating of asphalt for paving; asphalt was absorbed rather than adsorbed. The contractor finally ran out of usable material at the quarry site and had to locate other sources for aggregate to complete the job.

Our study revealed (1) the roadcut quarry was excavated in a debris-filled sinkhole in the Rio Bonito Member of the San Andres Formation, (2) the breccias exposed in the roadcut resulted from karst processes rather than faulting, and (3) leaching of breccia fragments produced rock that was too porous and friable for road grading and paving. Problems arose because inappropriate drilling methods (air rotary versus coring) yielded poor to unusuable data, the unconsolidated nature of the material in the proposed quarry from Rust Tractor's seismic velocity survey was not recognized, and geologic maps of the pit site prior to quarry operations were not prepared.

After stop, continue east on US-70. 1.3

105.8 Intersection with Carrizo Canyon Road (Tribal Highway #4). **Turn left** toward Inn of the Mountain Gods. **0.1**

105.9 Cattle guard. **0.3**

106.2 Sierra Blanca at 12:00. **0.2**

106.4 Intersection with White Mountain Road to left; **continue straight ahead** on Tribal Highway #4. **1.6**

108.0 Cattle guard. **0.5**

108.5 Inn of the Mountain Gods Convention Center on left. Man-made Carrizo Lake at 10:30 in the background. **0.2**

108.7 Entrance to Inn of the Mountain Gods. **Turn right. 0.1**

108.8 Underpass. **0.1**

108.9 **Bear right and then follow road under pavilion** in front of Inn of the Mountain Gods.

End of First-Day Road Log.

Junction of Comanche and Costilla Creeks at Comanche Point on Day 1, Stop 3 of 1990 NMGS Fall Field Conference. Rock consists of Precambrian quartzite, muscovitic quartzite and muscovite schist. Illustration by Louann Jordan of Santa Fe, 1990.