Third-day road log: From Carlsbad to Dark Canyon, Last Chance Canyon, Sitting Bull Falls, Rocky Arroyo and return tp Carlsbad

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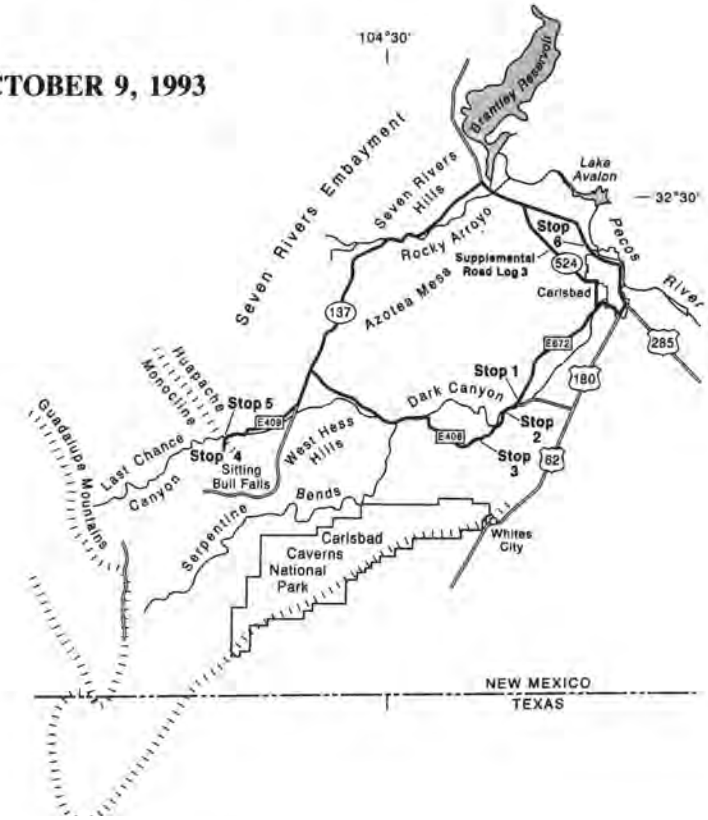
THIRD-DAY ROAD LOG, FROM CARLSBAD TO DARK CANYON, LAST CHANCE CANYON, SITTING BULL FALLS, ROCKY ARROYO AND RETURN TO CARLSBAD

JIM W. ADAMS, DAVID W. LOVE and JOHN W. HAWLEY

SATURDAY, OCTOBER 9, 1993



Assembly point: Carlsbad Civic Center parking lot, National Parks Highway.
Departure time: 8:00 a.m.
Distance: 84.8 mi
Stops: 6

SUMMARY

Today's tour traverses Permian basinal, shelf-edge, shelf-crest, inner-shelf and evaporite-shelf facies. It provides a cross section from the eroded edge of the Ochoan evaporite complex of the Delaware basin across the mid-late Guadalupian reef and back-reef dolomites and evaporite/clastic red beds to the early Guadalupian margin and slope complex in Last Chance Canyon. Recently developed sequence-stratigraphic concepts provide new interpretations of these classic localities. The return to Carlsbad traverses the transition from evaporite shelf to dolomitized shelf crest in Rocky Arroyo and domal Tansill and Yates draped over underlying reef mounds.

The route heads west from Carlsbad up the lower segment of Dark Canyon across the eastern part of the Cueva Escarpment and northeastern prong of the Guadalupe Mountains. Stops and optional stops allow examination of the reef, shelf edge and shelf crest facies. The route then continues westward on NM-137 and Eddy-409, traversing the low-relief, erosional Seven Rivers Embayment west of the cuestas of Azotea Mesa to Last Chance Canyon, cut across the northwest-trending Huapache monocline on the east flank of the northern Guadalupe Mountains. The lunch stop at Sitting Bull Falls provides the opportunity to see the highly scenic canyon as well as major active and inactive travertine deposits. Afternoon hikes and optional stops in Last Chance Canyon allow examination of upper San Andres depositional sequences with siliciclastic and carbonate facies reflecting lowstand, transitional and highstand systems tracts. After retracing the route east across the Seven Rivers Embayment, the tour skirts the northwest sides of many prongs of Azotea Mesa to the Seven Rivers Hills and Rocky Arroyo. The route descends eastward along Rocky Arroyo and its distal fan toward the Pecos River and US-285. Optional stops along Rocky Arroyo allow examination of abrupt facies transitions from evaporite shelf to dolomitized shelf crest and details of eolian sandstones. The tour then returns to Carlsbad past the domal Avalon and Ocotillo Hills. The final stop allows examination of the Tansill Formation near its type locality in the Carlsbad Springs area.

Mileage

0.0 Milepost 32 on US-62/180 westbound. **Turn right (west)** on Hidalgo Road (Eddy County-672) on geomorphic surface correlated with the Orchard Park plain by Horberg (1948). Route to Stop 1 at mouth of Dark Canyon is mainly on alluvium deposited by Dark Canyon Draw and its local tributaries, possibly starting as early as the late Miocene (Ogallala time). See minipaper by Hawley in First-Day Road Log. **0.4**

0.4 Boyd Road intersection. Continue west on Eddy-672. **0.9**

1.3 Cattle guard. Caliche pit on left. Geology mapped on West Carlsbad Quadrangle by Motts (1962). To north and on skyline is Ocotillo Hills anticline with 200 ft of structural closure with Tansill on the surface and Yates exposed in drainages. Dips on the east flank are from 3° to 10°. West flank dips are from 2° to 4°. The Ocotillo Hills anticline is 4 mi long. **0.3**

1.6 Cross Dark Canyon drainage. **0.1**

1.7 Outlier of Rustler Formation to south. At 3:00 is Hackberry Hills anticline, which trends northwest-southeast with 400 ft of closure. **0.4**

2.1 Junction with Standpipe Road to right. **Continue to southwest** along Hidalgo Road (Eddy-672) on lowest terrace of Dark Canyon Arroyo. **0.5**

2.6 Cattle guard. Outcrops to the west are Tansill. Frontier Hills to the south and east are east-dipping cuestas capped by Culebra dolomite (Rustler Formation). **0.8**

3.4 Junction; land fill to left; Eddy-429 to right leads to Little McKittrick Draw. **Continue west** on Eddy-672. **0.2**

3.6 Canyon of Little McKittrick Draw to right. Tansill-capped Cueva Escarpment (11:00-2:00) marks the easternmost extension of the Guadalupe Mountains and the eastern edge of the shallowly buried Capitan reef. **0.5**

4.1 Cattle guard. Oil field to west. The Carlsbad South (discovered in 1969) and Sheep Draw (1976) pools are in secs. 32, 33 and 34, T22S, R26E. The Sheep Draw pool (Strawn) has produced 0.004 MMB oil and 0.7 BCF gas while the Carlsbad South (Morrow at 11,200 ft) has produced 0.08 MMBO and 235.4 BCF gas. **0.1**

4.2 Route follows higher terrace surface capped with gravelly calcrete included in Orchard Park plain by Motts (1962). **0.7**

4.9 Cattle guard. **OPTIONAL STOP.** Red beds in small quarry here are Salado-Rustler dissolution residue capped by Culebra dolomite. Motts' (1962) West Carlsbad Quadrangle map shows the Capitan Reef emerging from the subsurface along the base of the Cueva Escarpment 2 mi west of this area (1:30). Kelley (1971) mapped these outcrops as all Tansill. **1.1**

6.0 Route continues on terrace east of Sheep Draw. **0.4**

6.4 Gravel pit to left. **0.3**

6.7 Curve to left; skirting low Rustler ridge to left. Sheep Canyon cut into Cueva Escarpment to right (3:00). **0.8**

7.5 Cattle guard. Deep gas well to west. Near this location the Byrnes Tank (discovered in 1976), Sheep Draw (1976) and Carlsbad South (1969) pools are in secs. 5, 6, 7 and 8, T23S, R26E. The Dark Canyon West pool (discovered in 1983) is sec. 13, T23S, R25E. The McKittrick Canyon pool is in secs. 23 and 24, T22S, R25E. The Dark Canyon West and Byrnes Tank produce from the Delaware and have yielded 0.02 and 0.0006 MMB oil and 0.02 and 0.02 BCF gas repectively. McKittrick Canyon is in the Upper Pennsylvanian and has yielded 0.002 **MMB** oil and 0.04 BCF gas. **1.2**

8.7 Mouth of Dark Canyon (12:00) near eastern end of Cueva Escarpment. **0.4**

9.1 Cattle guard. At curve **prepare to stop. 0.2**

9.3 **STOP 1. Pull off to right** beyond cattle guard. Capitan Reef outcrop at mouth of Dark Canyon. **Please do not take rock hammers.** This is one of two outcrops of the reef readily available to a paved road. For that reason it is studied by almost all industry and academic field trips. These outcrops on Bureau of Land Management acreage were recently vandalized by a graduate student who brought a diamond saw and removed the most spectacular fossils, particularly crinoids with calyxes attached. Bring water to wet remaining fossils and **Please do not remove what is left.**

The reef here is the same age (Tansill equivalent) as the one we saw at the entrance to Walnut Canyon. Large algal heads and *Archaeolithoporella* are present in growth position, together with *Tubiphytes, Mizzia,* dasyclad algae, calcareous sponges, gastropods, pelecypods, cephalopods, brachiopods and collenella (hydrocoral? or stromatoporoid?) which grew in colonies up to 1 m high (Fig. 3.1).

The lithology of the Capitan here is predominantly limestone. Delicate long crinoid stems look like they were bent over and preserved in place in a north-south alignment by currents parallel to the ancient reef front. The Capitan Reef probably developed down the slope (below wave base?) from exposed islands.

Also present at this outcrop are Indian grinding holes worn into bedrock and nearby are many rock middens. Both holes and middens are thought to be related to the processing of mesquite beans, possibly by Mescalero Apaches as well as earlier groups.

The Tansill Formation is the uppermost subdivision of the Guadalupian Series. Our route west traverses east-dipping strata to outcrops progresssively lower in the section, into the Yates, Seven Rivers, Queen, Grayburg and San Andres Formations at the base of the Guadalupian Series in Last Chance Canyon. Thus we will be in Guadalupian strata for the rest of the day. The Tansill Formation equivalent to the Capitan Reef is about 300 ft of bedded limestone and dolomite. The Tansill thins to about 125 ft in the area 4 to 6 mi shelfward behind the reef, where its lithology has changed to anhydrite, dolomite, silt, fine-grained sandstone and shale.

After stop continue southwest to Dark Canyon Road across Dark Canyon Arroyo. A large flood in 1941 crested at 20-30 ft at the mouth of Dark Canyon, depositing boulders well beyond the obvious floodplain/terrace. **0.2**

9.5 Junction with Dark Canyon Road (Eddy-408). **Turn right (west)** into Dark Canyon with bedded Tansill Formation exposed on both sides. Route for next 17 mi is westward across the low northeastern prong of the Guadalupe Mountains, following Dark Canyon and two of its major tributaries, Mosley and Last Chance Canyons. Additional details and locations of stops along this route may be seen in the West Texas Geological Society 1988 field seminar and in Toomey and Babcock (1983). **0.4**

9.9 Crossing Dark Canyon Arroyo. **OPTIONAL STOP** at quarry south of road. Fractures on east side of these cliffs of dark limestone are filled with tan-colored dolomite. The backreef beds change from limestone to dolomite a short distance west from the reef facies. **0.6**

10.5 Ascending Pleistocene gravel terrace. **OPTIONAL STOP** at "Watch for Water" sign; 185 yds to northwest, the Yates Formation consists of an ooid-pisolite-grapestone-grainstone facies. During a major Guadalupian glacioeustatic fall in sea level, solution cavities formed, which later filled with subarkosic sands having spectacular current ripples. **0.1**

10.6 Slow down, curve left at channel crossing and **park on right. 0.1**

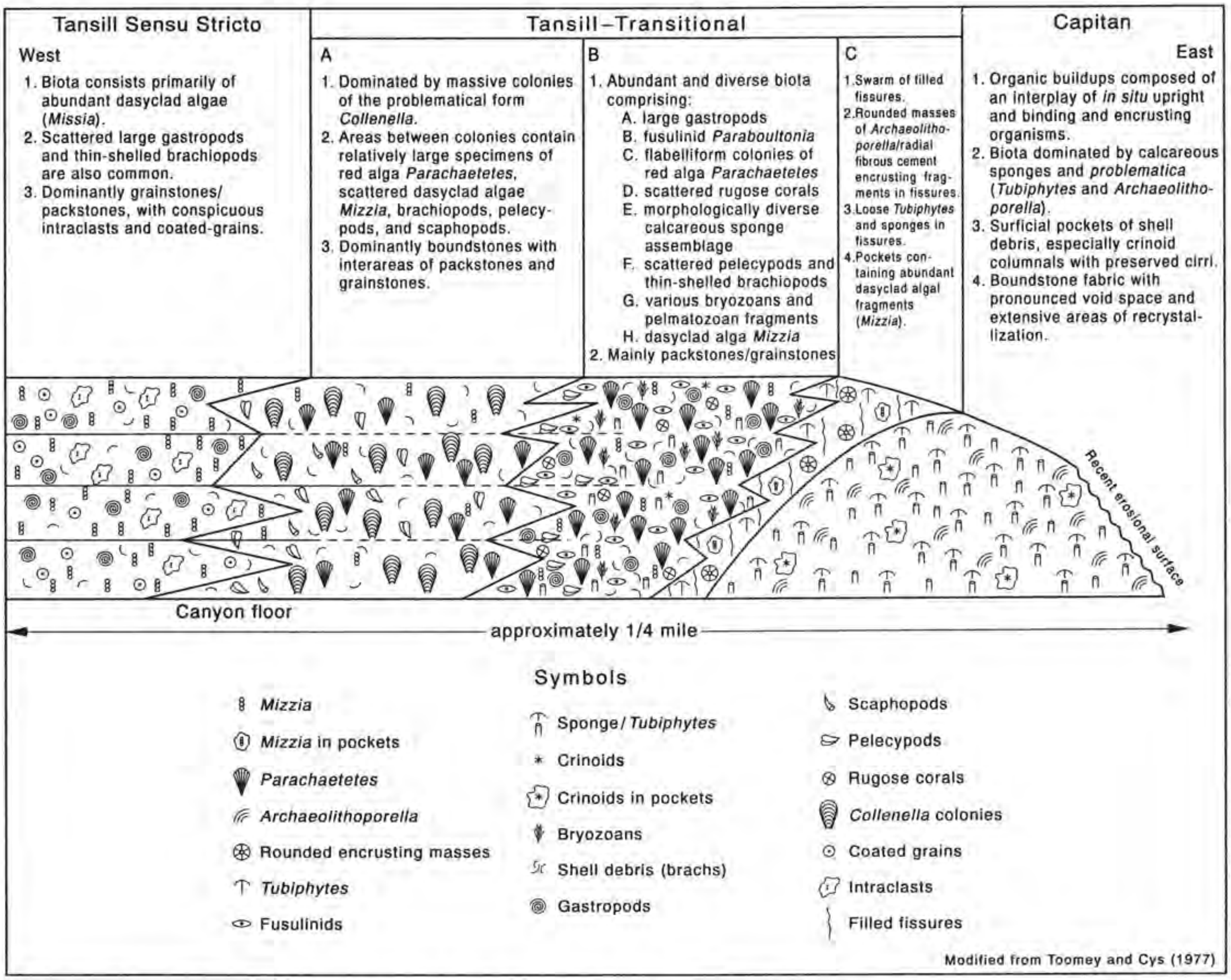


FIGURE 3.1. Schematic diagram of biotic relationships in shelf-to-shelf-margin transition at the mouth of Dark Canyon (from Toomey and Cys, 1977). According to Toomey and Babcock (1983), Zone "C" is probably a swarm of filled fissures. The "heads" of *Archaeolithoporella* are rounded masses of *Archaeolithoporella*/RFC crusts that dropped into the fissures.

10.7 **STOP 2** at Tansill-Yates contact. Note tepee structures above Yates sandstone in cliff (Figs. 3.2, 3.3). When early geological investigators sought a shallow, laterally persistent horizon easily recognized on well logs to display the shallow structure of the Permian Basin, they chose the abrupt lithologic change from the Tansill dolomite with the underlying Yates siltstones such as we see here. During Guadalupian time, deep water (up to 1800 ft) was present only in the Delaware Basin. The Tansill, Yates (on down to part of the San Andres) are shelfal ("backreef") lithologies deposited not only on the Northwestern Shelf of the Permian Basin in New Mexico, but also on the Central Basin Platform, across the shallow Midland Basin and the Eastern and Northern shelves. These units were not deposited in the Delaware Basin; their equivalents there are the sandstones and shales of the Delaware Mountain Group. The top of the Yates Sandstone is still recognized as one of the best

FIGURE 3.2. Cliff exposure of Tansill dolomite over Yates siltstone in lower Dark Canyon. Note lateral continuity of orange Yates siltstone just above channel, and tepee structures in lower part of Tansill.

FIGURE 3.3. Tepee structure in Tansill dolomite overlying orange Yates siltstone and Yates dolomite.

FIGURE 3.4. Conical hills of thin-bedded dolomites and siltstones of Yates Formation.

shallow subsurface structural markers in those vast areas of the Permian Basin where it was deposited.

Indian grinding holes (likely for mesquite beans, not corn) occur at base of cliffs. **0.2**

10.9 Dark Canyon to right. Continue south on paved road across alluvial apron at the confluence of Dark and Mosley Canyons. **0.4**

11.3 Cattle guard. Route is in Mosley Canyon for next 5 mi. Outcrops on both sides of road are Yates Formation, with highest hills capped by thin Tansill. **0.4**

11.7 OPTIONAL STOP. Cliff exposure of Yates dolomite to left (southeast) is in the ooid-pisolite grainstone belt located 1.5 mi shelfward from the Capitan Reef. **0.1**

11.8 Cross Mosley Canyon Arroyo. **0.3**

12.1 Yates Formation exposed in arroyo. Dolomite cliffs 30 yds upstream were studied by Jacka (unpublished), who found vadose diagenetic features such as cavities filled with dolomitized dripstone and red siltstone. **0.5**

12.6 Cross drainage; windmill on right. Yates has regional dip of 2° to 3° to the east. First Yates red beds are in hills to the north, with thin Tansill cap on top of hills. Massive dolomite beds at arroyo level are uppermost Seven Rivers with Yates above. **0.3**

12.9 Lowest ledges on cliff to left are uppermost Seven Rivers Formation. **0.1**

13.0 Park at arroyo crossing ahead. **0.1**

13.1 **STOP 3.** Mosley Canyon. Walk upstream 30 yds to low ledges of Yates dolomites. This locality is in grapestone-grainstone facies belt about 3 mi shelfward from Capitan Reef. By analogy with similar grapestone facies being deposited in the Bahamas today, the Yates here was probably deposited in a low-energy, subtidal lagoon about 10 ft deep. **0.3**

13.4 Gas well on right (sec 34, T23S, R25E) is in the Horseshoe Bend pool discovered in 1976. It has produced 0.1 BCF of gas from the Morrow. **0.2**

13.6 **OPTIONAL STOP.** Ledges 35 yds to the left (southeast) are grapestone-grainstone dolomites, similar to the last stop. 1.1

14.7 Junction with White Ranch Road to left; **continue on Eddy-408.** Sweatergirl Mountain ahead (Fig. 3.4) has thin-bedded Yates dolomites making transition into thin siltstones and gypsum. Evaporites increase in the section as we drive west. We are now 4 to 5 mi from the reef front. **0.2**

14.9 Crossing Mosley Canyon Arroyo. Note flood gauge. Yates dolomite 35 yds to southwest is in a pelgrapestone-wackestone-packstone facies 4.5 mi from the Capitan Reef according to Jacka (unpublished). This facies belt is about 10 mi wide and was deposited in a quiet-water lagoon. Between the wackestone-packstone facies and the reef was a grainstone facies belt about 4 mi wide. **0.3**

15.2 Cattle guard. Ranch house to right. **0.2**

15.4 Junction with ranch road. **Bear right** on Eddy-408. **0.4**

15.8 Gas well to right. **0.8**

16.6 Drainage divide between Mosley and Dark Canyon basins, also crossing the Yates-Seven Rivers contact (elevation 3849). The hills to the northwest are Yates overlying thin-bedded Seven Rivers dolomite. Ahead (mi 19.5) we will see undulatory bedding in the Seven Rivers caused by solution of gypsum as the formation grades into evaporites. **0.5**

17.1 Flowing gas well to north is Amoco IZ State Comm. No. 1. The Dark Canyon (discovered in 1964) and Baldridge Canyon (1964) pools are in sec. 36, T23S, R24E and sec. 31, T23S, R25E. The Dark Canyon pool (Penn.) has produced 0.008 **MMB** oil and 2.9 BCF gas. The Baldridge Canyon (Morrow at 10,810 ft) has produced 0.0009 MMB oil and 25.9 BCF gas. **0.4**

17.5 Cattle guard. Still on Yates. **0.8**

18.3 Eddy-408A to right to Elvis and Ila Mae Caudill's Dark Canyon Ranch. **0.4**

18.7 Back in valley of Dark Canyon Arroyo. Continue west on Eddy-408. **0.2**

18.9 Cattle guard. Optional Stop ahead. **0.2**

19.1 Dip (ford) at Crooked Creek. **OPTIONAL STOP.** Walk several hundred yards to outcrops in draw to south. These outcrops are in the Crooked Creek limestone, which is red, laminated, quartzose, microsucrosic detrital to micritic and dolomitic. Early guidebooks called this outcrop Seven Rivers, but later workers have mapped it as Yates. Jacka (unpublished) interprets the red sandstones and siltstones as eolian deposits. The grains are coated by ferriargillans (iron-rich clay coatings). Adhesion ripples and the wispy lamination pattern are indicative of wind blowing over a moistened surface. These sedimentary structures are also common in the older Queen sandstones to the north in Rocky Arroyo. The sandstones contain interclasts of supratidal dolomite. The overlying dolomites contain molds of anhydrite crystals. **0.4**

19.5 Note gypsum solution folds to north in Seven Rivers dolomite. **0.3**

19.8 High-level terrace gravels cap erosion surface on lower Yates; route crosses Yates/Seven Rivers contact to left. **0.8**

20.6 Crossing Dark Canyon Arroyo. **0.1**

20.7 Junction with road to Chevron Well and Middle Dark Canyon. **Continue west** on paved Eddy-408 up valley of Last Chance Arroyo. Prominent cliff exposure of solution folds in Seven Rivers to left. Leaving West Carlsbad Quadrangle mapped by Motts (1962). **1.3**

22.0 Ranch road to left. Note red beds transition in Seven Rivers at 3:00. **0.2**

22.2 Cross Last Chance Arroyo. **0.1**

22.3 Cattle guard. East Hess Hills at 9:00-11:00. The Seven Rivers changes facies to northwest from dolomite to evaporites and red beds (Fig. 3.5). **0.3**

22.6 Route crosses intermediate-level geomorphic surface formed on terrace and tributary fan gravels east of Last Chance Draw. 1.1

23.7 Radio tower to left; quarry to right in Seven Rivers Formation. **0.6**

24.3 Cattle guard. **OPTIONAL STOP** (a favorite of Jacka's Texas Tech field trips to the Guadalupes, but too long a hike for our trip). Red beds in stream channel to the left are in the basal Seven Rivers Formation. Walk southwest about 210 yds to Last Chance Arroyo, then southeast along the stream channel about 220 yds to see collapse breccias in the Seven Rivers dolomites. Red sediment fills the voids between collapse blocks. **0.7**

25.0 Note levels of gravel terraces overlying Seven Rivers Formation to right. The Humble Oil and Refining Co. No. 1 Bandanna Point gas well was drilled in the 1950s in sec. 13, T23S, R23E. Reported tops are San Andres (750 ft), Bone Springs (2815 ft), Wolfcamp (7150 ft), Pennsylvanian (7550 ft), Mississippian (10,234 ft), Woodford (10,868 ft), Devonian (10,932 ft), Montoya (11,622 ft), Simpson (11,995 ft), Ellenburger (12,050 ft). After drilling to 12,262 ft in the Ordovician Ellenburger, the well was plugged back for completion in a Morrowan (Pennsylvanian) sandstone for a calculated absolute open flow potential of 1800 MCFGPD. **0.4**

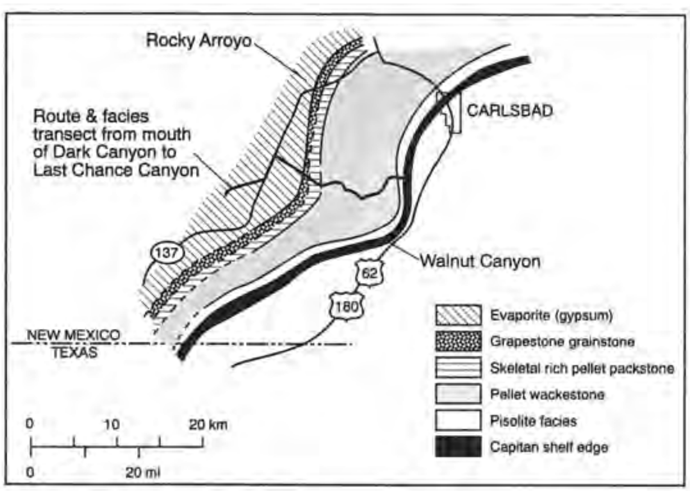


FIGURE 3.5. Facies distribution in lower Seven Rivers Formation (modified from Dunham, 1972; and Sarg, 1981).

25.4 High terrace to left has a thick bouldery fill with (stage IV) calcrete cap (Fig. 3.6). Enter valley of Wagontire Draw. **0.6**

26.0 Cattle guard. Cross Wagontire Draw; ranch trailer to right. To the south are dolomites of the Seven Rivers Formation. **0.3**

26.3 The road crosses the Seven Rivers-Queen contact. A bouldery high terrace with calcrete cap covers Queen bedrock. **0.4**

26.7 Route traverses bouldery high terrace with calcrete cap. Bandanna Point at western end of Azotea Mesa to the right (2:30) is Seven Rivers gypsum capped by a prominent resistant dolomite, the Azotea Tongue of the Seven Rivers Formation (Lang, 1937). On the horizon to the west (10:00), Queen and Grayburg strata are folded on the Huapache monocline. We are leaving the northeastern prong of the Guadalupe Mountains and entering the Seven Rivers Embayment. This is actually a topographic erosional basin, not a depositional embayment during Guadalupian time, or a structural embayment. Because the shelf-crest (backreef) dolomites grade northward into inner shelf red beds and evaporites (Fig. 3.5), the valley known as the Seven Rivers embayment developed by differential erosion of these soft evaporites. **1.4**

28.1 Cattle guard. Stop sign ahead. **0.1**

28.2 Junction with Queen Highway (NM-137). Queen Formation beneath road (poor outcrops). **Turn left** and continue southwest on NM-137. This road is one of the earliest built by the Civilian Conservation Corps (CCC) in New Mexico. It connects US-285 (mi 68.9) with the Queen, El Paso Gap and Dog Canyon areas of the western Guadalupe Mountains (Supplemental Road Log 2). **0.7**

28.9 Milepost 34. Crossing Sotol Basin on high terrace of Wagontire Draw. **1.0**

29.9 Milepost 33. Route is on high terrace between Wagontire and Last Chance Canyon draws. Calcrete (stage IV-V) caps boulderly alluvium. **0.7**

30.6 Descend from terrace. **Slow!** Right turn ahead. **0.3**

30.9 **Turn right** onto Eddy-409 to Last Chance Canyon and Sitting Bull Falls. Route continues southwest across low-intermediate terrace of Last Chance Draw. Coarse carbonate-cemented gravels of the terrace fill are uncomformable on the Queen Formation. **0.4**

31.3 Note calcrete to right on rise to slightly higher terrace surface. Steep-sided draw to left has excellent exposures of thick bouldery fill of low-intermediate terrace capped with stage V calcrete (Fig. 3.7). The extensive surficial deposits and geomorphic surfaces in this area have never been studied (or mapped) in detail. However, the high to intermediate terrace levels along Last Chance Arroyo noted in this road log (mi 22.6-33.6) appear to be in the middle Pliocene to middle Pleistocene age range (30.3 Ma) and are generally correlative with the Gatutia

FIGURE 3.6. View west showing Last Chance Canyon drainage and intermediate terrace to north with stage IV pedogenic calcrete cap.

Formation as defined by Bachman (1976, 1980, 1981) in the lower Pecos Valley region. Route continues on lowest intermediate terrace with strong stage IV to V calcrete. **1.1**

32.4 Cattle guard. Note stage V calcrete caprock in bar ditch to right. **1.2**

33.6 Route on rise to high terrace on right. Colluvium on Queen Formation is cemented with stage V calcrete. **0.2**

33.8 Red beds and dolomite in Queen Formation in roadcuts ahead. **0.9**

34.7 Sharp curve to left. Crossing the contact of the Queen with the underlying Grayburg. The best oil-producing facies of the Queen are the basal sandstones on top of the Grayburg. **0.2**

34.9 Cattle guard. Descending into Last Chance Canyon past dolomites in Grayburg Formation. **0.2**

35.1 Sharp curve at windmill. Entering Lincoln National Forest. **0.5**

35.6 Crossing channel. Dip in Grayburg increases to 12° on the northwest-southeast-trending Huapache monocline. Route follows Last Chance Canyon cut by this drainage through the monocline. In upper part of cliff to northeast k a orwrlnli.v of aran..etnnn hare pinnaatp nnrthunaet-

FIGURE 3.7. Bouldery low-intermediate terrace of Last Chance Canyon drainage with stage V pedogenic petrocalcic horizon (calcrete) at top.

southeast in the Grayburg Formation. According to Meader-Roberts et al. (1991, p. 9) "internal cross-strata dip NW, indicating that these giant truncated ripples were deposited by flood-tide currents. Prior to truncation, these bars probably were subaqueous dune complexes with large-scale trough cross-stratification. Water depth was about 10 to 20 ft." Small alcoves in Grayburg show faint Indian markings. **0.5**

36.1 Parking area for Meader-Roberts et al. (1991) excellent walking tour of upper San Andres and Grayburg section, examination of depositional environments changing from outer shelf to peritidal facies, the white sandstone marker (see below), ooid grainstone cycles of the lowstand through transgressive systems tract of the Grayburg and other details of sequence stratigraphy reported by Kerans and Nance (1991). **0.1**

36.2 Gate across road. The casing to Humble #1 Huapache drilled on flat to left remains sticking out of ground. The well was a 12,631-ft test, completed as a dry hole in May 1955. It cut a fault and did much to clarify the structural concept of the fault system underlying the Huapache monocline. The well spudded in Cherry Canyon dolomite and sandstone; it penetrated basinal sediments at approximately 4700 ft where shelf-type Wolfcampian and Pennsylvanian were encountered. Top of the first Siluro-Devonian dolomite section is at 6820 ft, some 3800 ft lower than the Continental No. 1 Bass, 14 mi to the northwest. A second Siluro-Devonian top was found at 10,802 ft beneath the plane of a high-angle reverse fault or an overturned normal fault cut at about 10,205 ft. Indicated separation is nearly 4000 ft. A basement core (top at 12,620 ft) was described as biotite-quartz granite. Throw on the fault increases to 6300 ft farther northwest.

At the wellsite, massive beds across the canyon are fossiliferous carbonates of early Guadalupian age (or late Leonardian; San Andres and Cherry Canyon equivalent). To the northwest, just above the canyon floor, is a series of carbonate debris-flow deposits composed of reworked ooids, fusulinids and crinoid columnals. Lithoclasts up to 30 cm wide parallel the bedding. The depositional site is inferred to be in the axis of a submarine canyon, water depth about 100 to 150 ft and about 12 mi northwest of the Goat Seep—Getaway shelf margin. Sedimentary structures in the progradational fill are unidirectional southeast toward the basin. With infilling, canyon heads migrated down-canyon while the whole sequence was shoaling upward (Jacka et al., 1972). Long axes of fusulinids are oriented, indicating a paleocurrent S60°E. Here, in this transverse view, beds thin away from (to right of) the flow axis. **0.1**

36.3 Cross Last Chance Canyon drainage. **OPTIONAL STOP.** About three-fourths of the way up both canyon walls is a prominent resistant white sandstone 3 ft thick. According to Meader-Roberts et al. (1991, p. 74), "The white color is due largely to silica cement, as opposed to clay and dolomite cements typical of most Grayburg sandstones." Early petroleum geologists doing alidade and plane-table mapping used this sandstone as a horizon for making structure-contour maps. They placed the San Andres—Grayburg contact at the base of this sandstone. It is remarkably persistent and can be recognized near the top of canyon walls throughout this area. Hayes (1959) correlated this white sandstone marker bed through outcrops to the north and into the subsurface where it occupies the same stratigraphic position as the "Premier Sand" productive zone. Modern workers place the San Andres—Grayburg contact 50 ft lower in the section at a sequence boundary which here is at the top of cliff-forming dolomites in the San Andres. Farther west, the sandstone onlaps peritidal strata of the San Andres (Sonnenfeld, 1991 and this volume; Kerans and Nance, 1991). Below this sequence boundary the unidirectional burrowed sandy packstones of the upper San Andres prograded across the outer shelf. Above this sequence boundary, bidirectional tidalites characterize Grayburg deposition. **0.5**

36.8 Dip. Reef-looking massive beds across the channel in San Andres Formation are actually detrital carbonate debris. **0.6**

37.4 Sharp bend across Last Chance Draw. Note crossbedding in the Cherry Canyon sandstone to the left. **0.1**

37.5 Side road to west ahead, opposite mouth of Sitting Bull Canyon leads to Optional Stop after Stop 5 (mi 39.2). The existence of marine basinal sandstones of the Cherry Canyon Tongue here in Last Chance Canyon so far north (13 mi) from the earlier shelf margin in Leonardian (Victorio Peak) time requires a major marine transgression in San Andres (lower Cherry Canyon) time. At this interesting stop, we have evidence of this transgressive systems tract including a typical recessive condensed section several feet thick (see Sonnenfeld, this volume). Indian pictographs beneath cliffs on opposite side of canyon have been fractured due to spalling from the cliffs and mutilated by vandals. Please enjoy them, photograph them and leave them as they are. **0.2**

37.7 Dirt road to west is old ranch site completely removed by the U.S. Forest Service. Continue south on paved road up Sitting Bull Canyon. **0.1**

37.8 Stream bank to west is cut in Cherry Canyon sandstone tongue, which is 264 ft thick in this canyon. **0.3**

38.1 Ford creek. **0.2**

38.3 Cattle guard; entering New Mexico State Park day use area. 0.1

38.4 **STOP 4 (lunch).** Sitting Bull Falls State Park and picnic area (elevation 4648 ft). Massive travertine cliffs midway up canyon wall to west were deposited by ancestral Sitting Bull Falls. **Please leave hammers in vehicles.** The mini-environmental oasis of Sitting Bull Falls (Fig. 3.8) is a delightful surprise in the desert that surrounds us. During the Great Depression, the CCC built the picnic shelters and also cut steps in the travertine from the far left of the falls, underneath the falls to a 500-ft cave replete with deep pools of frigid clear water (watch your step!) and impressive stalactites. Cave pearls and grapestones are forming to the left of this cave entrance (leave them there!). Raincoats, hipwaders, or lifejackets, flashlights or lanterns and hardhats are recommended for exploring this cave.

A trail to the right of the parking area leads to plunge pools on top of the travertine and to the upper edge of the falls (watch that slippery moss! Don't throw things off the edge, there are visitors below!).

Sitting Bull never saw these falls. Legend has it that the falls were named in 1881 by cowboys chasing Apaches who had stolen some of their cattle. They felt like they had one "Last Chance" to catch the Indians before they

FIGURE 3.8. Sitting Bull Falls.

disappeared into the mountains. Hence the name Last Chance Canyon. When one of the cowboys reported the presence of the waterfall, his compadre looked at the dry boulder-bed stream channel nearby and said "if there is a waterfall in this dry canyon, my name is Sitting Bull." The name has stuck-to the cowboy and the falls.

After lunch at the falls, we will return vehicles to the pullout 0.7 mi north of the park to take two healthy hikes in Last Chance Canyon to examine results of mapping by Sonnenfeld (this volume). Put on your hiking boots, bring a canteen, camera and hammer. **0.7**

39.1 STOP 5 at site of razed ranch complex at junction of Sitting Bull Canyon and Last Chance Canyon. Hike up to Panorama Point to eyeball Mark Sonnenfeld's geologic interpretations of Last Chance Canyon. He has done amazingly detailed correlation of the interfingering San Andres carbonates with the Cherry Canyon tongue. He interprets two major depositional sequences in the upper San Andres. Siliciclastic and carbonate facies associations change progressively from lowstand, transgressive and highstand systems tracts within the sequences. If time permits, we will also hike west in Last Chance Canyon to a lower sequence boundary. **0.2**

39.3 OPTIONAL STOP at sharp (170°) turnout to Indian pictographs and transgressive systems tract condensed section (Fig. 3.9). **1.4**

40.7 U.S. Forest Service gate at the Humble 1 Huapache drill site. **0.1**

40.8 Large boulder on left. East of this point, the Cherry Canyon tongue has characteristics of shallow marine to tidal deposition, with sand waves having lateral-accretion laminae, endogenic feeding burrows, and wave-ripple laminae with flat tide-truncated tops. Indicators show bidirectional tidal currents with ebb currents directed to the southeast. Farther to the east are intertidal stromatolites and sand wave-ripple laminae. Also present is evidence of supratidal deposits such as sandstones cemented by anhydrite and rip-up clasts from desiccated mud polygons. **5.2**

46.0 Junction with Queens Highway (NM-137) at Milepost 32. **Turn left and continue northeast** on NM-137. Route to right across the Guadalupe Mountains and Salt Flat graben (via Queen, El Paso Gap and Dog Canyon) is described in Supplemental Road Log 2. **2.7**

48.7 Junction with Eddy County Road 408 down Last Chance-Dark Canyon drainages. Continue northeast on NM-137. **2.6**

51.3 Curve to right at H Bar Y Ranch Road (Eddy-405). Lookout Point at 11:00 is capped by dolomites of Lang's (1937) Azotea Tongue. Route for the next 14 mi skirts the northwestern edge of Azotea Mesa. **0.7**

52.0 Milepost 38. Note how Seven Rivers Formation has changed facies to red beds, shale and anhydrite, which are preserved from erosion by the Azotea Tongue at top of Lookout Point. **0.8**

52.8 Passing Lookout Point, we are at the approximate contact with the Queen Formation (to the west of the highway) and the Seven Rivers Formation in the slope to the right. The route stays near this contact for the next few miles. **0.4**

53.2 Entering the large Indian Basin Gas Field. **0.8**

54.0 Milepost 40. Cone Butte to right. **0.4**

54.4 Cattle guard. Old Ranch Knoll 2 mi to the northeast (12:00) is Seven Rivers gypsum and red beds capped by Azotea Tongue dolomite. The Queen crops out in the draw to the west. **1.6**

56.0 Milepost 42. Old Ranch Knoll at 1:00. The Seven Rivers here is red siltstone and gypsum with dolomite caprock. **1.0**

57.0 Milepost 43. **OPTIONAL STOP.** Flag-Redfern Winston Federal Comm. No. 1 (NE '/4 SW1/4 sec. 31, T21S , R24E) is in the large Indian Basin Gas Field that was discovered by Ralph Lowe in February 1963. Production is from Upper Pennsylvanian dolomite at 7000-8000 ft and from Morrow sandstones at 9000-10,000 ft. The late Hugh Frenzel (1988) described this field for many guidebooks. It covers 86 mi^1 with spacing of one well per 640 acres. Cumulative production to December 1992 has been 1,322,492,225 MCFG plus 8,286,883 barrels of condensate (= 15.4 BCFG per well). Remarkably,

FIGURE 3.9. Lower Last Chance Canyon from optional stop. Lower cliffs are San Andres late highstand, overlain by Grayburg lowstand through transgressive systems tracts and highstand systems tract at top.

this gas field is composite: structural, hydrodynamic and stratigraphic in nature (regional dip in the Pennsylvanian is 2.5° to the northeast). Although first drilled on a seismic closure, the production exists across 1450 ft of homoclinal dip, far beyond actual closure. Lateral extent of production is controlled by permeability pinchouts; where the productive dolomite turns to limestone, porosity and permeability deteriorate. Northeast flow of water through the porous dolomite pay tilts the gas-water contact from —3138 ft below sea level on the west to —3770 ft below sea level on the east, forming a total gas column of 632 ft with average pay thickness of 207 ft (Frenzel, 1988, p. 170). **1.0**

58.0 Milepost 44. Leaving Seven Rivers Embayment. Park ahead on right for Optional Stop at the Tepee. **0.4**

58.4 **OPTIONAL STOP.** To the north is the famous Tepee (Fig. 3.10) preserved from erosion by an outlying caprock of thick resistant dolomites of the Seven Rivers underlain by the red bed—sulfate facies of the same formation. Jacka (1988, p. 93) described the sediments of the Tepee:

At the base is a laminated dolomite (20 cm thick) with small molds of anhydrite. Above it is a 5 m thick red bed interval with dense, nodular, chicken-wire anhydrite. Most of the original anhydrite was altered to hemihydrate, which in turn has been altered superficially to gypsum. Near the top of the red bed—sulfate unit is a set (15 cm thick) of irregularly layered gypsum. Principal layers are 5 cm thick and consist of vertical needles of tan gypsum 3 mm wide separated by dark carbonate material 1 mm wide. Intercalated are discontinuous layers of white hemihydrate 1 to 5 mm thick. The vertical-needle fabric cuts across stratification, probably as a result of hemihydrate being replaced by gypsum. At the top is another dolomite unit 40 cm thick. Much of the dolomite was replaced by sulfate, as shown by lenses and small pockets of dolomite in hemihydrate. Along the top surface, anhydrite molds in the dolomite are filled with red internal sediment, indicating subaerial exposure.

Jacka (1988) interpreted these sediments as showing an upward transition from a shallow lagoonal carbonate deposit to a deflation flat and inland sabkha. Sarg (1988) on the other hand, interpreted both dolomite and evaporite-mudstone facies of the Seven Rivers formation as being deposited in a broad, shallow lagoon. Art Salter (personal comm. 1993) suggests that sequence stratigraphic principles be applied to the units to interpret parasequential pulses within the lagoonal-?subaerial facies. **0.6**

FIGURE 3.10. The Tepee, a conical outlier of dolomite-capped red bed–sulfate facies of the Seven Rivers Formation.

59.0 Milepost 45. Dropping into valley of Rocky Arroyo. **1.0**

60.0 Milepost 46. **OPTIONAL STOP** at junction with Marathon Road (Eddy-401) to Marathon's Indian Basin Gas Plant (to west) and Carlsbad (to the east). The valley of Rocky Arroyo separates Azotea Mesa (southeast) from the Seven Rivers Hills (north). The type locality of the Seven Rivers Formation, named by Meinzer et al. (1926), is in the latter area. We are back in the West Carlsbad (15') Quadrangle area mapped by Motts (1962).

Route begins 5 mi traverse of famous transition area of Seven Rivers dolomite and evaporites. A spectacular facies change occurs within one mile as route continues east. This is the area of Sarg's (1976) doctoral dissertation. The prominent ledge at the level of Rocky Arroyo is formed by dolomites in the Queen Formation, overlain by the Shattuck Sandstone. The Shattuck Member is the uppermost member of the Middle Guadalupian Queen Sandstone. The sandstone is a very fine- to fine-grained, well-sorted subarkose. In the view to the north, the Shattuck Member is the yellow-brown weathering, medium to thick bedded sandstone forming the slope above the low cliff of upper Queen dolomites and below the reddish evaporite and mudstone and light brown dolomite of the Seven Rivers Formation. Member thickness ranges from about 75 to 150 ft (Sarg, 1977), or 50 to 75 ft (Bates, 1942; Ball et al., 1971) in this area. The difference in measured thicknesses is due to different interpretation of the position of the base of the Shattuck Member. At the western end of Rocky Arroyo, the Shattuck Member thickens as it incorporates gypsum beds in a manner similar to that of the overlying Seven Rivers Formation (Ball et al., 1971).

A nearly complete section of Seven Rivers overlying the Shattuck Member (Artesia red sand) of the Queen is exposed in the north slope of Rocky Arroyo. Here, 200 ft of Seven Rivers gypsum with red siltstone stringers begins to grade laterally into bedded dolomite. One mile farther east down the arroyo the section is almost completely dolomite. This transition from evaporite to carbonate facies is also characteristic of the Tansill, Yates, Queen and Grayburg Formations.

Sarg (1988) noticed a lack of typical sabkha depositional structures in these Seven Rivers red beds. The upper third of the hill to the north contains a skeletal-rich pellet packstone including the Azotea tongue indicative of "a deeper, moderate-energy environment .. . containing a relative abundant mesohaline (salinity 36120%0) biota of molluscs, ostracodes, encrusting forams and calcispheres" (Sarg, 1988, p. 96). He interpreted the Seven Rivers dolomite and evaporite facies as both being deposited subaqueously in a broad lagoon. **0.3**

60.3 On complex of higher terrace and fan surfaces flanking inner valley of Rocky Arroyo. **0.7**

61.0 Milepost 47. Roadcut ahead in Seven Rivers Formation dolomite. Note two prominent Pleistocene terrace levels above arroyo-valley floor to north. **0.5**

61.5 Seven Rivers/Queen contact in roadcut. **OPTIONAL STOP.** Shattuck Sandstone of the Queen Formation is exposed in river bed below the highway and in roadcuts. Loucks and Brown (1988) interpreted the upper Shattuck Member as showing changes in depositional environment from the Queen Sandstone into the Seven Rivers Formation. At creek level, the sandstone consists of discontinuous beds formed by channels, bars and horizontally layered sheet-flood deposits, interpreted as a braided stream deposit. Thinner, more continuous beds above this contain adhesion ripples and beds with other features suggestive of eolian transport. At the base of the roadcut section, the sandstones include some burrows as well as gypsum crystal molds. This upper part of the section is interpreted as a clastic sabkha deposit. All of the sand in the Shattuck Member at this outcrop is fine to very fine grained and well sorted. This suggests initial transport by eolian processes prior to reworking by braided stream and sabkha deposition.

In the dolomites of the lower Seven Rivers are stromatolites (intertidal) and flat-pebble conglomerates (supratidal). Anhydrite-crystal molds are abundant throughout the carbonate sequence. Anhydrites were dissolved to form a collapse-breccia zone that is probably of regional extent. After the sulfate and halite (?) were dissolved, internal sediment was deposited. Leaching may indicate a change to a pluvial climate during this part of the Permian Period. Sea level fell at least 5 ft, but the lowstand position has not been documented.

The Queen grades into the upper part of the Goat Seep Reef. The Shattuck Sandstone may lap up the back side of the Goat Seep Reef and pinch out between the Goat Seep and the Capitan. **0.2**

61.7 Carbonate-cemented Pleistocene colluvium in cut to right. **0.3**

62.0 Curve to right at Milepost 48. Note solid dolomite in Seven Rivers in cliffs beyond ranch at 12:00. **0.5**

62.5 Cattle guard on low (Holocene?) terrace of Rocky Arroyo. **0.1**

62.6 Water crossing (Rocky Arroyo). Late Quaternary travertine deposits in roadcut and cliff to east. **0.1**

62.7 Ranch entrance to right. Highway crosses the Queen-Seven Rivers contact (Seven Rivers Formation to the east and in the massive cliff across Rocky Arroyo). **0.3**

63.0 Milepost 49. Rocky Arroyo cemetery ahead on right. **0.6**

63.6 Roadcut exposures to left of "crinkle beds" (cyanobacterial stromatolites, Fig. 3.11) in Seven Rivers dolomite. Park in turnout ahead on left for Optional Stop. **0.3**

63.9 **OPTIONAL STOP.** Walk with care back along roadcut in Seven Rivers Formation to examine the "crinkle beds" and then visit the large exposures of late Quaternary travertine along Rocky Arroyo south of the highway (Fig. 3.12). According to field seminar notes by Jacka (1988, p. 97) crinkle beds:

> . . . in the lower part of the exposure are dolomites with cyanobacterial stromatolites in laterally linked domes or hemispheroids, representing the intertidal, stromatolitic facies. The thickness of the stromatolite zone, 60 cm, is approximately the same as the paleotidal range. The stromatolites were covered by thin, discontinuous layers of silt and sand, probably deposited by dust storms.
>
> Above, there are sabkha-type dolomites with flat-pebble intraclasts indicating an upward shoaling to a supratidal environment. Next above is another intertidal stromatolitic unit.
>
> The dolomites contain scattered molds of anhydrite nodules. Molds are filled with calcite. Near the top some molds contain dead oil. Uranium minerals in the dead oil have been dated radiometrically as Permian.

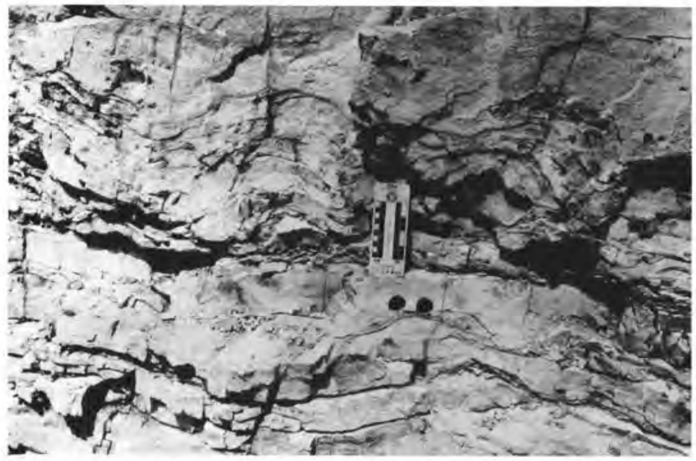


FIGURE 3.11. Cyanobacterial stromatolites ("crinkle beds") in Seven Rivers dolomite. Core plugs taken for porosity study.

The stratigraphic sequence here is micritic dolomite overlain by pelletal dolomite overlain by crossbedded grainstones indicative of high wave energy. These are overlain by stromatolites probably built by cyanobacteria. The vuggy porosity here is due to the solution of anhydrite crystals. In the stream bed, there are travertine deposits and Indian corn grinding holes. **0.4**

64.3 Site of Rocky Arroyo School. Southeast edge of Seven Rivers Hills to left and northeast prong of Azotea Mesa to right. Yates/Seven Rivers contact in slopes to right and left. Alluvial cover thickens to east. **0.5**

64.8 Ranch house on right. East of here, the highway crosses the Seven Rivers-Yates (subcrop) contact. **0.2**

65.0 Milepost 51. Leaving valley of Rocky Arroyo. Route from here to Carlsbad is along the western margin of the Pecos River Valley. This part of the Pecos Valley is separated from the Roswell artesian basin to the north by the Seven Rivers Hills. The geology of the valley area has been mapped by Cox (1967), with emphasis on geohydrologic conditions between the former site of Lake McMillan and Carlsbad Springs (mi 75.7). Brantley Reservoir (mi 67.9) inundates the Lake McMillan area. **0.4**

65.4 Cross Deadman Arroyo, with good exposure of upper terrace gravels. Calcrete cap exhibits early stage IV morphology. **0.6**

66.0 Milepost 52. High-level gravels, with locally well-developed pedogenic calcretes (stage IV-V), cover a broad and irregular erosion surface cut on the Yates Formation. The surface here is about 75 ft above Rocky Arroyo. Meinzer et al. (1926) were the first to describe the major valley-fill units in this area, which they thought were of post-Ogallala, Quaternary age. They (p. 6) described three terrace levels 15 to 30 ft, 75 ft and 150 ft above

FIGURE 3.12. Vuggy Quaternary travertine overlying Seven Rivers dolomite in Rocky Arroyo.

the Pecos channel between Lakes McMillan and Avalon. Meinzer et al. (1926, p. 8-10) also subdivided an older "conglomeratic" part of this valley fill into two informal rock units, the "quartzose" and "limestone conglomerates" that are as much as 75 ft thick. They were mapped in detail by Cox (1967) in the area near the Rocky Arroyo—Pecos confluence. The quartzose (lower) unit "consists of pebbles of chert, quartzite, limestone and igneous rocks (including porphyries) with a siliceous sand matrix cemented with calcium carbonate. . . . The overlying limestone conglomerate contains more limestone pebbles than the quartzose conglomerate and it contains abundant subangular to subrounded limestone cobbles. . . . Although well indurated, it is not as resistant to erosion as the underlying quartzose conglomerate" (Cox, 1967, p. 19). The conglomeratic zone in the basal valley fill could be as old as late Miocene and certainly includes deposits of Plio-Pleistocene age. Workers since Bretz and Horberg (1949a) have correlated the "quartzose conglomerate" with both the Ogallala and Gatufia Formations. (See Hawley, this volume and First-Day Road Log discussions). **2.0**

68.0 Milepost 54. New Brantley Dam at 10:30-11:00. **0.6**

BRANTLEY LAKE STATE PARK

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Brantley Lake State Park, officially opened in November 1989, is New Mexico's newest addition to the state park system. The lake is designed to hold 348,540 acre-ft of water. Although the primary function of the lake is to store water for irrigation and water commitments to Texas and Mexico, the lake is best known for its water recreation.

The state park offers camping, picnicking, boating, fishing and hiking. Thirty-two developed picnicking sites and 49 camping sites are available (Fig. 3.13). Primitive camping is also allowed along the shores of the lake. The park has two boat ramps, restrooms, a playground, a

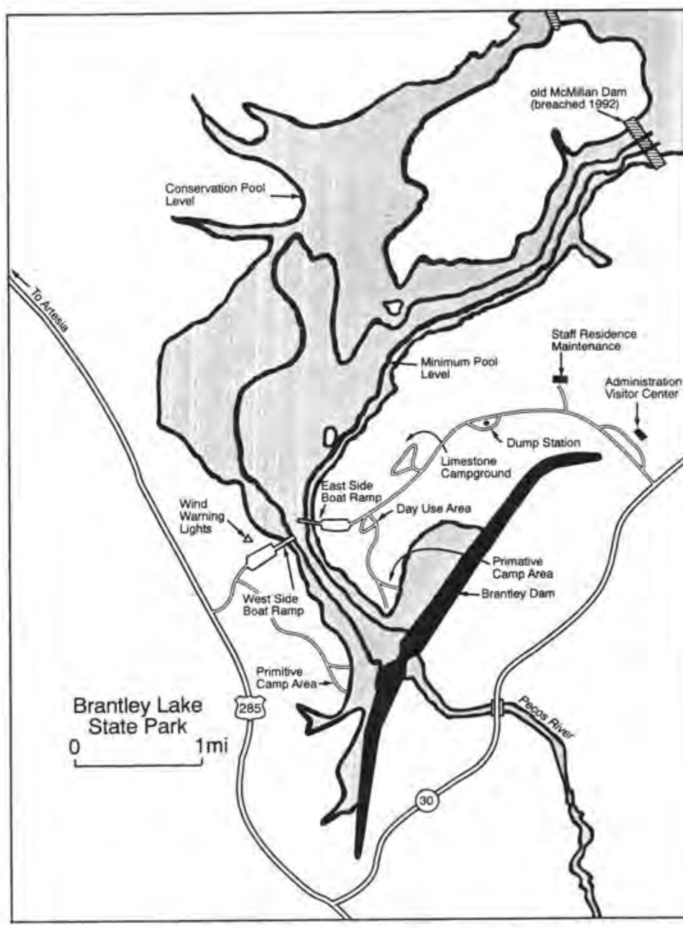

FIGURE 3.13. Map of Brantley Dam State Park.

visitors center and a nature trail. A hiking trail connects the campground with the lake shoreline. Some of the fish stocked by the New Mexico Game and Fish Department include sunfish, walleye, bass, channel catfish, blue gill and trout. In 1992, 54,000 people visited the park.

Construction on Brantley Dam began in 1984 by the U.S. Bureau of Reclamation. The purpose of the project was to replace McMillan Dam, upstream on the Pecos River, which has impounded a large amount of silt. Brantley Dam consists of a concrete section that is 730 ft long and an earthern embayment 3.9 mi long. The maximum height is 140 ft. Over 442,000 tons of rip-rap was used in building the earthern embayment and over 8000 yds' of concrete was used in building the concrete dam. Total cost was $44.3 million (New Mexico Game and Fish Department, press release, Oct. 25, 1988).

In 1991 McMillan Dam was breached and Lake McMillan was allowed to drain into Brantley Lake. McMillan Dam was built in 1908 and was considered unsafe for maximum floods; heavy silting had decreased its storage capacity (Fig. 3.14). The area once covered by Lake McMillan will be rehabilitated and revegetated for use as a wildlife refuge called the Brantley Wildlife Management Area. This is the first large lake bed in the western United States to be rehabilitated. The U.S. Bureau of Reclamation will continue to own the land, and jointly manage it with the New Mexico Game and Fish Department (New Mexico Game and Fish Department, press release, June 16, 1987).

The area under water was near the Goodnight-Loving cattle trail. The town of Seven Rivers (now underwater) was one stop along the trail. Seven Rivers was settled in 1867 after the Indians were driven out. It was first called Dogtown because of the large number of prairie dogs. A trading post was established by Dick Reed and in 1878 the town was renamed Seven Rivers. Apparently the town was moved periodically because of water shortages (Pearce, 1966). In 1877 a post office was established, which remained open until 1895. Such infamous travelers such as Billy the Kid, cattle rustler Bob Edwards and John Chishum passed through the town. The town was typically violent for its day; the first four people buried in the cemetery died of gunshot wounds. The graves from the cemetery were relocated to the Twin Oaks Cemetery in Artesia.

Brantley Lake lies along the Pecos River where the Seven Rivers Formation (Permian) crops out (Kelley, 1971). Much of the northeast side of the lake consists of ancestral Pecos deposits of late Cenozoic age. The eastern shore consists of local outcrops of limestone, dolomite, mudstone and gypsum of the Seven Rivers Formation.

68.6 Truitt Evans Ranch to south. **Right turn at stop sign ahead. 0.3**

FIGURE 3.14. In 1912 the teamsters of the valley were hired to dike off the eastern part of McMillan Reservoir in an attempt to isolate the worst areas of sink holes in the lake bed. Courtesy of Southeastern New Mexico Historical Society at Carlsbad.

GLOBE PLASTER MINING CO. ORIENTAL, NEW MEXICO

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Oriental, New Mexico, south of Brantley Dam, is now a ghost town. However at the turn of the century it was the site of substantial plaster plant and gypsum mine. Oriental is 12 mi north of Carlsbad in sec. 18, T20S, R27E and is only $2^1/4$ mi southeast of the old lake McMillan Dam. About 1905-1906, the Oriental Cement and Plaster Co. began operations. Gypsum was mined from an open pit nearby (Fig. 3.15) and plaster was produced and sold to nearby markets. A high viscosity oil was required to cook the plaster, so the first oil well was drilled in New Mexico at Dayton (Brown Well) to fill that requirement. Oriental even had a post office from 1910 to 1916 (Pearce, 1961).

In 1912, the plant reorganized and became the Globe Plaster Mining Co. The plant hired 20-25 men. In 1921 the plant caught fire and burned down, but was rebuilt. The plant finally closed in 1923.

Gypsum was quarried from pits nearby in the Yates Formation (Permian). The gypsum, actually gypsite, is of poor quality and was probably a main contributor to the closing of the plant.

68.9 NM-137/US-285 junction. **Turn right** and continue southeast on US-285 toward Carlsbad (12 mi). Artesia and Roswell to left. **0.2**

69.1 Former Golden Eagle Field (Morrow) to the left (east) was consolidated into the Catclaw Field in 1972. **0.5**

69.6 Cross Rocky Arroyo. **1.0**

70.6 Milepost 44. Roadcut ahead in the Yates contains sandstones with carbonate flat pebble conglomerates and adhesion ripples. The small anticline is part of an arcuate fold belt called the Waterhole anticlinorium by Kelley (1971). 1.0

71.6 Milepost 43. Catclaw Draw field. Most of these 36 wells produce gas from the Pennsylvanian Morrow with minor gas production from the Strawn and Wolfcamp plus oil from Delaware sandstones. Total field production to De-

FIGURE 3.15. Sketch map of Globe Plaster Mining Company and Oriental, New Mexico, 1913–1923 (by W. H. "Bill" Balgemann).

cember 1992 is 90 BCFG plus 186,863 BO. The Springs pool (1966) has produced 0.7 MMBO and 23.4 BCF gas from the Upper Pennsylvanian at a depth of 8000 ft. The Catclaw Draw East pool produces from the Delaware (1991) and Strawn (1972). The Delaware has yielded 0.2 BCF gas and 0.08 MMBO. The Strawn has yielded 0.2 BCF gas and 0.0003 MMBO. 1.3

72.9 Truck Bypass (Happy Valley Road) to the right. **Stay on US285.** Supplemental Road Log 3 covers route to Carlsbad Civic Center, via NM-524, that bypasses the congested downtown area. **0.5**

73.4 Jacka (1988, p. 98) described this roadcut exposure of the Tansill Formation as follows: Carbonates were deposited as bio-pel-wackestones in the subtidal environment of the backreef lagoon. The Tansill lagoon was about 14 mi wide and this locality was about halfway between the reef and the shoreline. After dolomitization, hypersaline ground water transported sulfates in solution from beneath the coastal plain and emplaced them as anhydrite nodules and porphyroblasts [sic] in the dolomites. Later, fresh-water dissolution of the sulfates produced the spectacular collapse breccias.

At the northwest end of the road cut, the white, powdery material is hemihydrate (or bassanite, $CaSO_4$. '/2 H_20). Low salinity (meteoric) ground water caused anhydrite to be replaced by hemihydrate. Much of the hemihydrate was later replaced by gypsum. In the roadcut, hemihydrate at present is being altered to gypsum, even in the dry New Mexican climate. **0.4** 73.8 The Ocotillo Hills at 1:00 and the Avalon Hills at 11:00-12:00 are both formed of Tansill and Yates Formations. The hills are topographic expressions of anticlines that may be draped over reef mounds. The Ohio Oil No. 1 Tracy (sec. 34, T21S, R26E) was a 5810-ft dry hole drilled to the Bone Spring on Tracy Dome in the Ocotillo Hills. **1.1**

74.9 Road on Tansill Formation. To the east is the Avalon Gas Field. Most of this production is from Pennsylvanian Morrow sandstones at about 11,000 ft. **0.6**

PRODUCTION HISTORY AND GEOLOGY OF AVALON (DELAWARE) FIELD

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The Avalon (Delaware) field is located in central Eddy County, southeastern New Mexico (Fig. 3.16). The Yates Petroleum Stonewall "EP" State #3 was the first well in the area to prove production from the Delaware in October 1977. Production from the major productive zones began in October 1982, when Exxon completed the Yates "C" Federal #3 for 308 BOPD, 1250 MCFGPD and 14 BWPD. This well was drilled primarily on the basis of good Delaware mudlog shows in an offsetting Morrow gas well. Field development proceeded rapidly, with the productive limits for primary recovery fairly well defined by late 1983. Wells typically were completed for greater than 100 BOPD, with watercuts up to 60%. All wells produced some water on initial completion and required fracture stimulation for economic production rates.

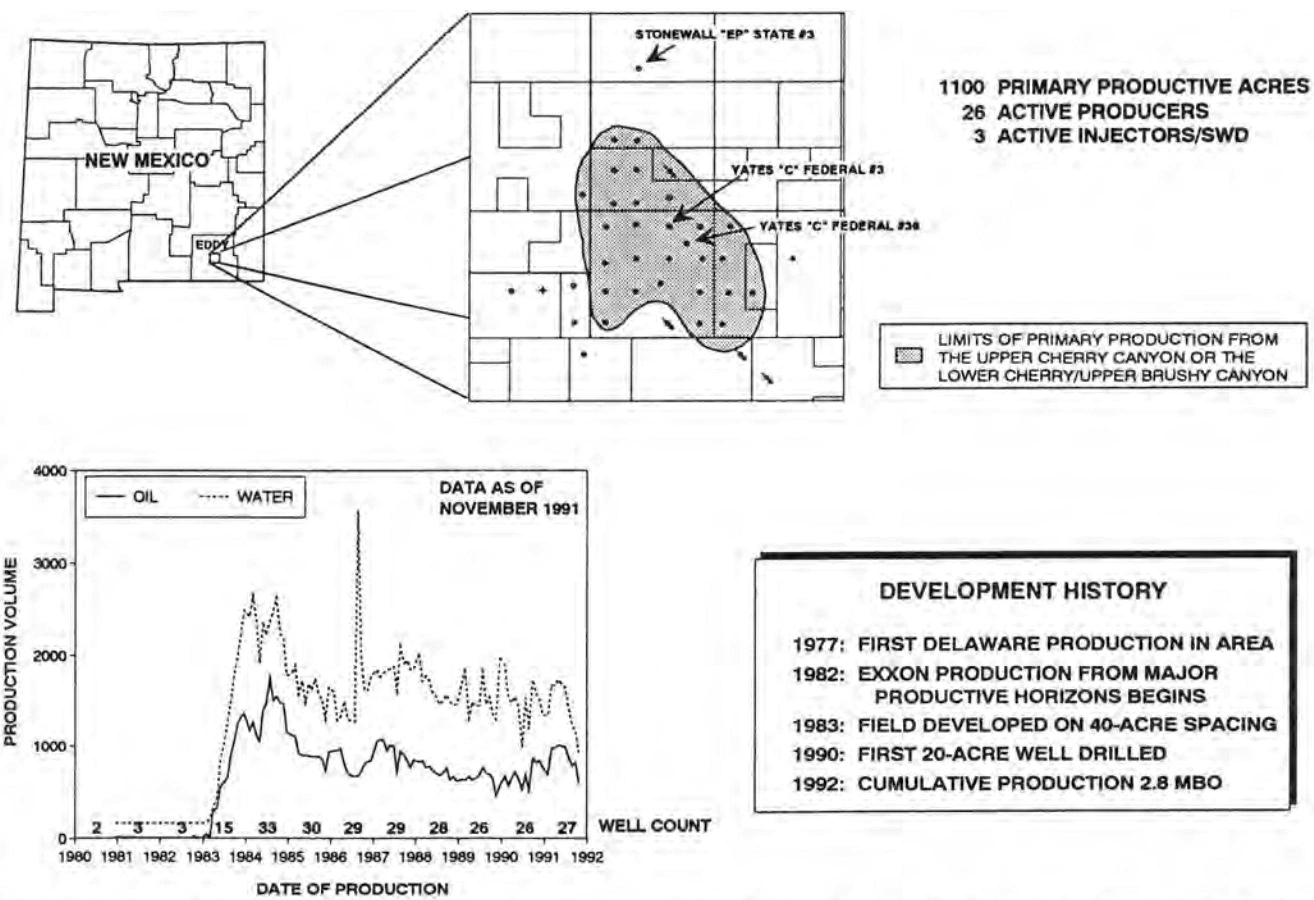


FIGURE 3.16. Summary of Avalon (Delaware) field production and development history. Field location: secs. 24, 25, 36, T20S, R27E; secs. 19, 20, 29, 30–32, T20S, R28E; sec. 1, T21S, R26E; and secs. 4–6, T21S, R27E.

Currently, the field is developed on a 40-acre spacing over a primary productive area of about 1100 acres. The first 20-acre infill well, the Exxon Yates "C" Federal #36, was drilled in August 1990. Current production (as of 1/92) from the Avalon (Delaware) field is 818 BOPD, 2725 MCFGPD and 1207 BWPD from 26 active producers. A total of 35 producers have been drilled. Since discovery in 1982, Avalon has produced more than 2.8 MMBO with an average production of about 730 BOPD and watercuts typically of 60-65%.

Geologically, Avalon is located along the northwestern margin of the Delaware Basin, immediately seaward of the Goat Seep Reef shelf edge (Fig. 3.17). Avalon produces from low permeability fine sands and coarse siltstones of the Guadalupian Delaware Mountain Group, which at Avalon consists of the Cherry Canyon and Brushy Canyon Formations. No Bell Canyon is present, since it is upper Guadalupian and was deposited farther basinward.

Most of the production at Avalon comes from two separate reservoirs, the upper Cherry Canyon at approximately 2600 ft and the lower Cherry/upper Brushy Canyon at about 3400 ft (Fig. 3.17). Production in the upper Cherry Canyon is from fine-grained, bioturbated, subarkosic sandstones, whereas lower Cherry/upper Brushy Canyon production is from finely laminated, subarkosic siltstones. Within the productive portions of these lithofacies, primary interparticle porosities are as high as 20%, with permeabilities up to 25 md.

Siliciclastic sediments at Avalon represent part of an extensive lowstand wedge deposit that interfingers with shelf margin carbonates to the north and extends to the south (basinward). The Brushy Canyon reservoir interval exhibits little areal heterogeneity and consists of widespread suspension deposits that were probably deposited in a proximal basin floor setting. The Cherry Canyon reservoir exhibits much greater heterogeneity and consists of more localized suspension deposits within submarine channels that are interpreted to represent deposition in a low-relief submarine slope setting.

Reservoir mapping (Fig. 3.18) revealed that reservoir geometries and the nature of trapping mechanisms at Avalon are significantly different in the two reservoir intervals. Although the trap for the upper Brushy Canyon is stratigraphic, structural elevation controls the distribution of hydrocarbons in this interval. Mapped closure of about 300 ft results from depositional mounding. The upper Cherry Canyon is a more complex stratigraphic trap resulting from updip porosity pinchout into tight carbonates and is locally modified by erosion by a sequence boundary at the base of the overlying Goat Seep Reef.

75.5 Red beds in this roadcut may be in the Ocotillo siltstone member of the Tansill. **0.1**

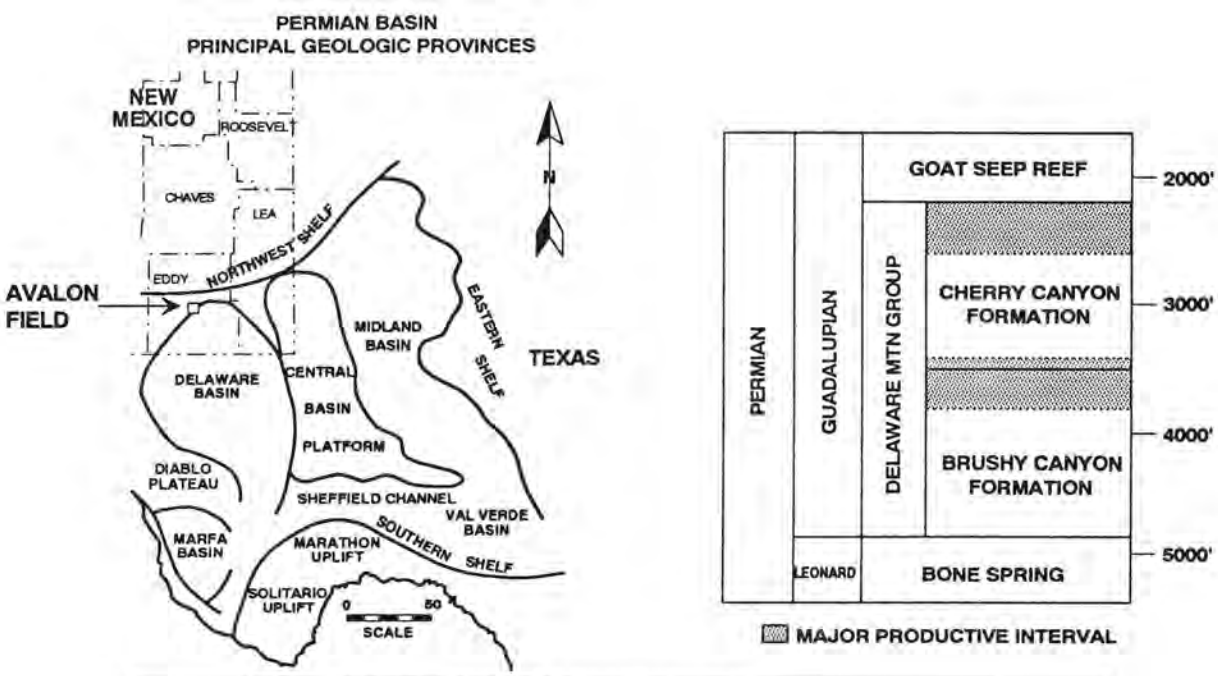
75.6 Roadcut in Tansill dolomite at Milepost 39. Ronald K. Deford and Cecil Riggs (1941) described the type locality of the Tansill in the Ocotillo Hills to the southwest. 0.3

75.9 To the right, the Tansill and underlying Yates are dipping east on the flank of Tracy Dome. **0.7**

76.6 Milepost 38. Irrigated land to east on Pecos Valley Floor ("Lakewood terrace" of Nye, 1933 and Horberg, 1949). **0.4**

77.0 Tansill dolomites overlying Yates sandstones and dolomite in the canyon to the west. **0.1**

77.1 Roadcut to right with about 6 ft of gravelly alluvium-colluvium that is disconformable on pink calcareous bedded siltstone of an uncorrelated older valley-fill unit.



RESERVOIR DESCRIPTION

PRODUCING FORMATION	UPPER CHERRY CANYON	LOWER CHERRY CANYON/ UPPER BRUSHY CANYON
DEPTH	2600 FT	3400 FT
RESERVOIR LITHOLOGIES	SAND	SAND & SILTSTONE
NET THICKNESS (PAY)	132 FT	272 FT
AVERAGE ϕ	14.4%	14.9%
AVERAGE K	2.3 md	1.1 md

FIGURE 3.17. Geologic overview of Avalon's paleogeographic setting, producing intervals and reservoir description summary.

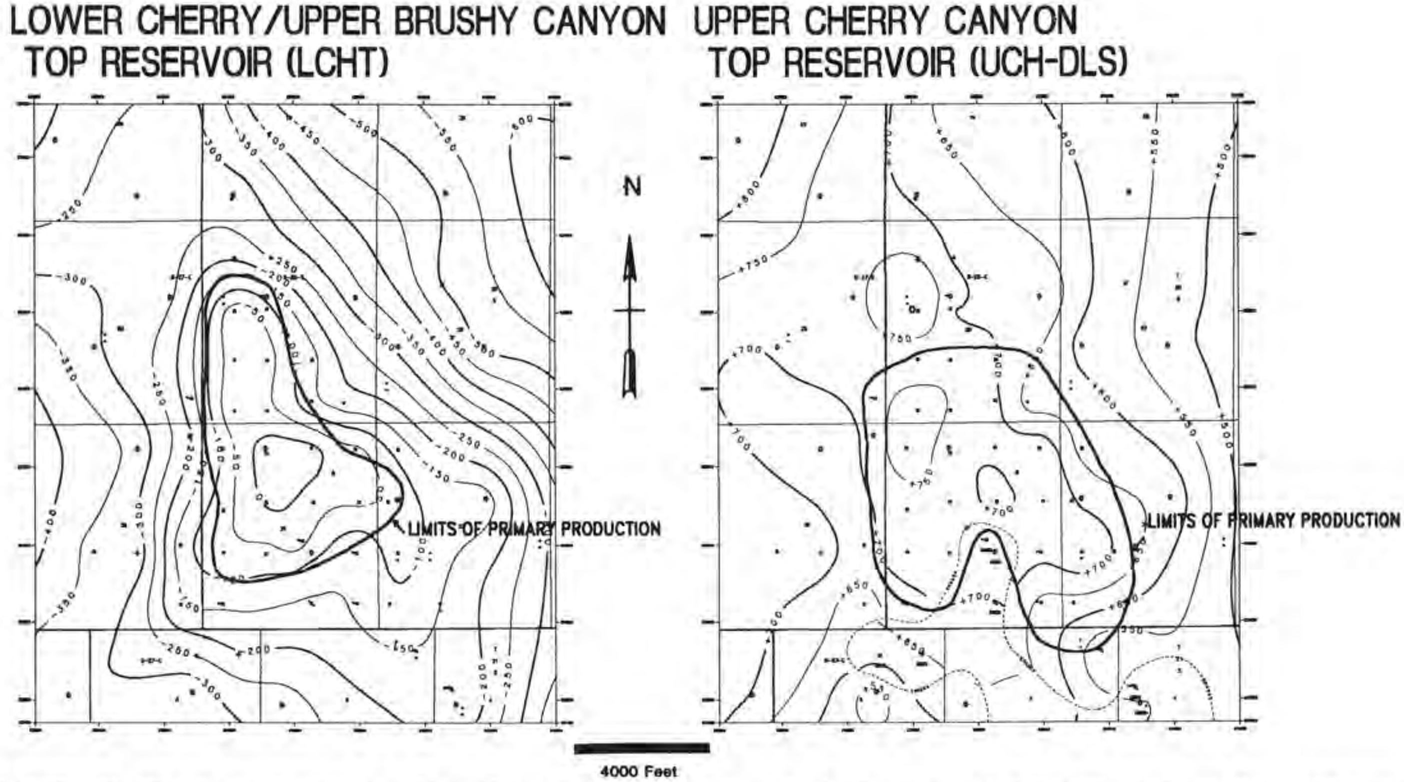


FIGURE 3.18. Maps showing the structure on the top of the lower Cherry Canyon/upper Brushy Canyon reservoir (left) and the structure on the top of the upper Cherry Canyon reservoir (right). Also annotated on these maps (bold lines) are the limits of known primary production from these reservoirs. Each of the squares shown on these maps is a section 1 mi on each side.

The upper beds are capped with a stage IV—V pedogenic calcrete. **Prepare to park on right** for final tour stop. **0.4**

77.5 **STOP 6** in roadcut north of Milepost 37. Dolomites of the Tansill Formation (uppermost Guadalupian) near its type locality. Dip is 10° east in the Pecos River east of the highway and also in the cliff (along strike) west of the highway. According to Jacka (1988, p. 98-99):

> This shallow-marine, outer-shelf facies was deposited about 3 mi north of the Capitan Reef in the pisolite-grapestone, packstone-grainstone facies belt. Such grain-rich carbonates are indicative of high-energy conditions in the backreef lagoon.
>
> In the lower part of the exposure, bedding generally is parallel in these shallow subtidal deposits. Some beds contain laminoid fenestrae (vugs elongate parallel to stratification) resulting from desiccation shrinkage and gas bubbles formed in stromatolitic layers within the intertidal-supratidal zone. The more irregularly distributed cavities are solution molds of smaller anhydrite porphyroblasts [early diagenetic displacive crystals], and larger nodules, which were emplaced during hypersaline diagenesis.
>
> In the middle part, lenticular bedding of dolomites indicates tidal channels with an uneven distribution.
>
> At the north end of the road cut, the upper 3 ft of the Ocotillo Member of the Tansill Formation are gray siltstone beds. These probably are eolian coastal plain sediments.
>
> The Ocotillo Silt Member of the Tansill Formation was named by DeFord and Riggs (1941). It can be correlated into the subsurface. At the Tansill type locality, the Ocotillo Silt Member is a blue siltstone 13 ft thick and can be traced into red oxidized siltstone outcrops along the Carlsbad-Artesia Highway. Erosion of the Ocotillo forms a small escarpment that can be traced for miles.

Walk south through Tansill cut to Milepost 37 for overview of Carlsbad Springs area of the Pecos River Valley (about 3 mi below Avalon Dam) mapped by Cox (1967). Carlsbad Main (irregular) Canal crosses the river on the large aqueduct at 11:00. This stone structure was built in 1902-3 (Fig. 3.19) to replace the original wooden flume (built 1889-90) that first was damaged by large floods in 1893.

Carlsbad Springs used to flow at over 2000 gallons per minute, but are now much diminished. It was here in about 1889 that Charles B. Eddy christened the springs with a bottle of champagne and proclaimed the beginning of the town he founded and named Eddy after himself. He started the successful irrigation projects in the Roswell-Artesia-Carlsbad area, harnessing prolific artesian springs along the Pecos River. After falling out with his chief financial backer, James J. Hagerman (who earned his riches mining in Colorado), Eddy moved on to El Paso where he built the El Paso Northeastern Railroad, the Alamogordo and Sacramento Mountains Railroad and along the way established the towns of Alamogordo and Cloudcroft. He went on to build railroads in Mexico and Spain. A bachelor all his life, he died in 1931 in New York City. Disgusted with Charles Eddy, J. J. Hagerman changed the name of the town to Carlsbad to imitate the famous Karlsbad Spa in Czechoslovakia, but the name Eddy stayed with the county (see following minipaper by Howard).

FIGURE 3.19. Construction begins on the concrete flume over the Pecos River near Carlsbad Springs (January 16, 1903). The earlier wooden flume (constructed 1889–90) at this site was ruptured numerous times by floods starting in 1893. Type Tansill area and Ocotillo Hills are beyond the flume on the west side of the river. Courtesy of Southeastern New Mexico Historical Society of Carlsbad.

STANDING ON SAND: A SHORT HISTORY OF THE CARLSBAD AREA

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From an origin in the Sangre de Cristo Mountains east of Santa Fe, the Pecos River flows southward across hundreds of miles of high desert plateau to arrive at a juncture with the Rio Grande. The middle section of that passage, from Roswell to south of Carlsbad in New Mexico, was first converted into a region of irrigated fanning in 1890. Only 25 years earlier the first Texas cattlemen, led by Goodnight and Loving, occupied this part of the Pecos Valley that had, until then, largely remained under the control of the Comanche and the Apache.

The Comanches were brought to the area by the buffalo herds that made an annual passage through the vast sand hill region to the east of the river. The Apaches, also, followed a nomadic existence and moved south in winter and north in summer for several hundred miles along the range of highlands that lay to the west. The two Indian groups were traditional enemies, but they did unite, in effect, to prevent Spanish and later Mexican incursions into the area. There is some indication that a number of Hispanic families had preceded the Texas cattlemen into the valley and were raising sheep and goats along the river, but this probably dates only from the 1850s when the U.S. Cavalry began to take some control over the region to protect western immigration routes to the south.

By the end of the Civil War, local Indians had been largely relegated to reservations and had ceased to be a factor in the valley's development. The buffalo, too, were soon gone from the region. Their last reported passage was in 1877.

In 1866, cattlemen found a virgin grassland lying between the Pecos and the western highlands. Smaller ranchers soon occupied the various tributaries and springs while John Chism and his cowhands established control of the Pecos for a hundred miles. To the east, lack of any tributaries largely prevented this ranching development. The clash between the small ranchers and Chism culminated in the Lincoln County War of the mid-1870s. At the time of that confrontation, Lincoln County, which was vast, encompassed the entire middle Pecos and extended to the New Mexico Territory's borders with Texas both to the east and to the south.

The cattlemen brought in vast herds and soon overgrazed the valley. By 1884, a third of their cattle were lost in the Big Die. Faced with that disaster, several of the men began to consider other ways to use the land. By 1887, the two Eddy brothers, who had a ranch in the area of today's Carlsbad, had found both funding and a place to take a small ditch from the deeply incised Pecos channel. They and their ever-increasing circle of partners soon extended both their plans and their dreams until they were attempting to bring ditch water to two hundred thousand acres along a hundred-mile stretch of the river south of Roswell. It was the largest irrigation project that had ever been attempted in the United States. It relied on several dams and canal systems that were designed and created by the West's corps of railroad engineers, since irrigation engineering did not yet exist.

During a brief period of unbounded optimism, millions of dollars from investors poured into the projects. A large townsite was laid out where no single building had ever stood before. Promotional literature flooded across the country and into Europe. The irrigation company assured potential land buyers that the sure availability of water made Pecos Valley fanning absolutely certain of success. A forty-acre farm, they were told, would guarantee wealth and prosperity to a family of six and that the land would grow virtually anything you could wish for except citrus fruit. Much of the early acreage was put into grape vineyards.

A railroad was brought north from Pecos, Texas and arrived at the new town of Eddy, today's Carlsbad, in early 1891. A very impressive bank building, a large hotel and a Victorian courthouse were erected to convey the long-term stability of the vast real estate scheme (Fig.

FIGURE 3.20. Little Eddy had a surprisingly large hotel. It was built by the Town Company to convince potential land buyers that Eddy, New Mexico, was here to stay. Photograph by Stringfellow, January 4, 1891 (neg. 14605), courtesy of Museum of New Mexico Collections.

3.20). Thousands of cottonwood wands were planted across the historically treeless plain. Buyers poured into the valley by the hundreds, including one colony of two hundred fifty Swiss. The only shadows on that time were cast by the continuing difficulty in finding an adequate supply of palatable drinking water and by the blinding sand storms that swept up the loose topsoil of the newly plowed plain.

Then the dream was gone. In early August 1893, a flood far beyond any in memory swept down the valley to destroy all of the major structures of the irrigation system. This flood, like the others that followed, was probably enlarged by the greater runoff that poured from the nearly grassless and partly gullied ranch lands of the area. Eddy was learning its first hard lesson about the long lasting effects of man-made change in a desert. Not only did the flood end the optimism that had drawn new farmers to the area, but its occurrence at the beginning of a national depression made it impossible to find funds for all ongoing developments. The irrigation company's vast plans were inevitably scaled back to one tenth their original size. Small farmers without water could not make their land payments and almost any who could afford to do so left the valley. The irrigation systems would be rebuilt, largely from the personal fortune of one James John Hagerman, but probably half the twenty thousand acres of cultivated land would remain abandoned for a decade. The irrigation dream had proven to be fallible.

Other problems soon surfaced as well. Desert irrigation, it turned out, could be easily overdone. Land in parts of the valley had become waterlogged and crusted with gypsum. The alkaline river water seemed to hurt some types of crops. Root diseases and insect pests appeared as well. The remaining valley farmers shifted for years from one crop to another seeking something that could be grown profitably. After the vineyards they tried canaigre, then sugar beets and then peach orchards and apple orchards. All failed. Eventually they would decide that alfalfa and cotton worked as well as anything. Today they have added some pecan groves. For a time they also placed great hopes in artesian wells, which were brought in in large numbers across the northern half of the Middle Pecos. These wells lasted about two decades at the turn of the century before most went dry and the dropping water table that the wells produced took out most of the area's tributaries and springs as well.

During these general agricultural doldrums, it was arranged for the federal government to take over the irrigation system at Carlsbad, which was losing money. The government rebuilt the system after a second major flood and ran it for the next forty years. In the late 1890s, with all of these agricultural troubles, ranching again became, for twenty years, the major economic support for the valley and the local economy swung with the frequent ups and downs of cattle and sheep prices. By this time, however, the successful drilling of stock wells had added the plains to the east as an additional large ranching area, although none of the area's ranch lands can support very many cattle per section. Today, ground water continues to be depleted from the region, and farmers in the Pecos Valley find themselves increasingly burdened with problems resulting from dropping water tables—and also in endless battles with Texas over who gets what from the declining river flow.

The endless search for other resources to develop in this fairly barren land drew the community into a false silver mining boom at one point and later into a name change. Told that the waters of a local spring were almost identical in mineral content to those of the famous health spa at Karlsbad, Czechoslovakia, the townspeople voted to rename their community Carlsbad in hopes that a boom in health seekers would appear. It did not. Earlier the town and the valley had benefited in a major way from a prevailing belief that persons infected with tuberculosis could most benefit from spending winters in high and dry climates. Many of the early investors and leaders of the community arrived here because they were tubercular. Changes in tuberculosis treatment and medical advances eventually brought the local TB colony to an end.

By 1903, guano was being taken from one tunnel of Bat Cave, today's Carlsbad Cavern. The claim would later be made that one hundred thousand tons were removed from there. Other smaller caves in the area, also, were tapped for their fertilizer resources. Most of this material was shipped to Arizona and California for use in the citrus groves. One of the guano miners was the Jim White, who is credited with exploration of the scenic areas of the Bat Cave. In 1923, when the federal government declared the cave a national monument, it was a major coup for the Carlsbad Chamber of Commerce that the official name was shifted from Bat Cave to Carlsbad Cave and later Carlsbad Cavern. Tourism began to emerge as an additional mainstay of the local economy, and new hotels and tourist courts began to appear both here and at privately owned Whites City.

Since the 1920s, it has been a source of some frustration to the local businessmen that so many thousands of the tourists who visit Carlsbad Caverns National Park pass through the area without stopping at Carlsbad. Many efforts have been made to capture more of that market. Several dude ranches were tried, but none survive. Major effort has been expended to develop the town's beach and river park. In the 1960s, there was also an attempt to create large-cast nightly entertainment that would attract more of the tourists, but the effort failed after two seasons. Most recently, conversion of the town's river front into a San Antonio–type development of outdoor restaurants, shops, fountains and canals extending into the downtown area was strongly promoted. Local voters, unconvinced, turned down the bond issue for that project.

More successfully, local politicians and benefactors were able to bring the state's zoological and botanical garden, now called the Living Desert, to Carlsbad in 1971. In addition, the recent discovery of the huge Lechuguilla Cave system immediately adjacent to Carlsbad Cavern briefly interested town leaders as a second possible tourist attraction of major proportions. So far, difficulties in public access appear to limit the possibilities for development of the Lechuguilla system as a tourist attraction. The town does hope, however, to get a proposed National Cave Institute located here because of the proximity of the Guadalupe cave region. Carlsbad also helped in creating Guadalupe Mountains National Park about 45 mi to the southwest.

The Carlsbad area has an 80-year history of development of mineral resources. From 1912 to 1923, a gypsum deposit 6 mi north of town was worked by the Globe Plaster Company (see McLemore minipaper). Oil was first discovered in today's Eddy County in 1913. An earlier oil discovery on the plains 80 mi to the east led to the successful secession from eastern Eddy County of what became Lea County. Across the decades, the oil and natural gas extractive industries, shifting through cycles of greater and lesser expansion, have played an increasingly important role in the local economy. When the greater oil patch hit its hard times in the 1980s, Carlsbad was hurt as well.

In 1925, a group that was exploring for oil discovered, instead, the county's only major potash deposits 30 mi to the east. Carlsbad was able to avoid much of the general poverty experienced in the rest of the country during the Great Depression because of the development of large-scale mining operations by several companies. Potash has been a major source of funds for this community ever since. The more recent sulfur development to the south in Texas has also brought economic benefit to the area.

Heavily relying on these industries in depletable resources, the community's population peaked at about thirty thousand. In the late 1960s, however, the potash industry began to experience hard times and town leaders began to launch major efforts to attract replacement industries. Part of this activity centered on a continuing campaign to bring in small industries, but most of the companies that did slowly arrive, amidst great fanfare, soon folded. Additional efforts centered on attracting retirees and our most visible successes in that area are two quite large Protestant retirement facilities.

Carlsbad got its first major taste at the federal feed trough during World War II when an army airbase and a bombardier school were located on the southern outskirts of town. In the 1950s, the federal government returned to the area to sink the Project Gnome shaft into the vast salt beds that underlie this part of the Permian Basin. The site is located about 10 mi southwest of the present WIPP operations. Originally conceived as the first major project in America's pursuit of peacetime uses for atomic energy (Operation Plowshare), the 1961 Gnome detonation produced a ruptured chamber that left all of the planned experiments undone (see Supplemental Road Log 1).

By the 1970s, the federal government was again searching for a deep salt bed. The pursuit of the Waste Isolation Pilot Plant (WIPP), a federal nuclear-waste disposal project has been a major community activity since then. Public Law 96-164 authorized the WIPP project "for the express purpose of providing a research and development facility to demonstrate the safe disposal of radioactive waste resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission." Carlsbad launched its efforts to attract the WIPP program at about the same time that community leaders were also in Washington attempting to get federal construction of Brantley Dam 18 mi upriver (see McLemore minipaper). Both efforts have been successful. Many millions of dollars have poured into the local economy because of WIPP; and while environmentalist battles, mostly from outside, continue around the project, Carlsbad is overwhelmingly committed to its new money source.

If this brief history seems somewhat of a near endless search for each next dollar, that, of course, goes with the place and times. Intensive human habitation of a desert is predictably temporary; and this desert, like the others, is already littered with the debris of homes and of communities that at one time were here but are no more. We live along a thread of a river within a sparse world that could not, without a systematic using up of its resources, have supported so large a community as we have sought and attained. We have, with great dedication, exploited everything that we have found exploitable—but how else could this size of community ever have survived here, however briefly, standing on sand?

[Editors' note: The author of this very stimulating historical review is a native of Carlsbad and a longtime teacher of history, economics and government at Carlsbad High School.] 0.3

77.8 Living Desert State Park to right. **0.3**

78.1 Carlsbad Campus of New Mexico State University to right. **0.4**

78.5 Carlsbad Mall to left. **0.2**

78.7 Traffic light at Pate. Route continues east on West Pierce Street. **0.2**

78.9 Crossing Carlsbad Main Canal. **0.2**

79.1 Pecos Acres Drive to left leads to Carlsbad Spring. Cuts ahead (left) in older terrace fill with cap of gravelly calcrete. **1.0**

80.1 US-285 curves right (south) and merges with Canal Street. **0.5**

80.6 Traffic light at Church Street. Riverside Park and Lake Carlsbad Recreation Area to left. **0.5**

81.1 Traffic light at Stevens, Eddy County Court House to left and Museum and Library to right. **0.2**

81.3 Traffic light at Greene. Route joins US-62/180 (Hobbs to El Paso). See First-Day Road Log (mi 202.3). Route continues south on National Parks Highway to Carlsbad Civic Center. **3.5**

84.8 Carlsbad Civic Center Parking Area.

End of Third-Day Road Log and formal tours of the 1993 joint field conference of the New Mexico and West Texas Geological Societies. See Supplemental Logs 1 to 3 and the Carlsbad Cavern trail log (Hill, this volume) for additional information on areas not included in the three main road logs.