Third-day supplemental road log 2

Lewis Land

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BOTTOMLESS LAKES STATE PARK, ACROSS THE PECOS SLOPE AND INTO THE NORTHERN SACRAMENTO MOUNATINS TO FORT STANTON CAVE.

THIRD-DAY SUPPLEMENTAL ROAD LOG 2

LEWIS LAND

Begin: Visitors Center at Bottomless Lakes State Park, next to Cottonwood Lake.

Distance: 79.1 miles

Three stops and two optional stops

SUMMARY

This supplemental road log provides details of the geology of the Seven Rivers Escarpment, Pecos Valley, and Roswell Artesian Basin in the vicinity of Roswell, New Mexico. The trip continues across the Pecos Slope, with two stops to examine the Six Mile and Border Buckles, wrench fault zones that extend SW-NE across the Slope, and then enters the northern Sacramento Mountains. The route crosses several fold and fault belts in the eastern Sacramentos, including the Tinnie anticlinorium and the Lincoln folds, and terminates at the entrance to Fort Stanton Cave, the third longest cave in New Mexico and the site of the recently discovered Snowy River passage, which contains what may be the world's longest known cave pool deposit.

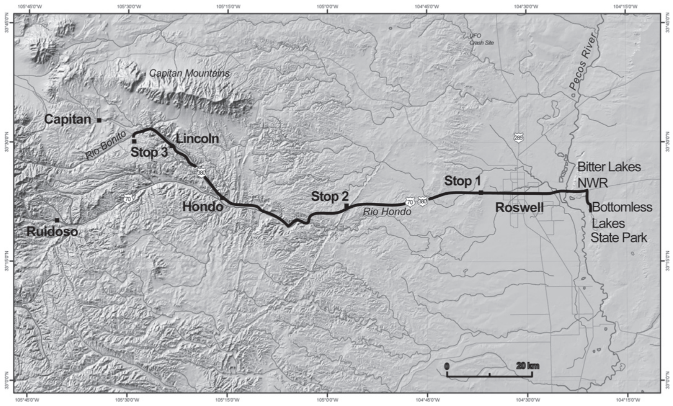
0.0 Trip begins in parking lot of Bottomless Lakes State Park visitors center near Cottonwood Lake.
Set odometers to zero at stop sign, intersection of park road and NM 409. Note brown sign to left: Visitors Information Center: Bottomless Lakes State Park. Turn right onto NM 409. *0.3*

0.3 Dry sinkhole formed in Seven Rivers Escarpment at 3:00. *0.5*

0.8 Lazy Lagoon sinkholes to left. *0.2*

1.0 Lazy Lagoon turnoff to left. See Day 3 roadlog optional stop for discussion. Note massive rotated slump blocks at 11:00 composed of Seven Rivers Formation gypsum and mudstone. *0.2*

1.2 NM 409, MP 10. *0.1*



1.3 Begin ascent of Seven Rivers Escarpment, past large gypsum slump blocks to right. *0.6*

1.9 Skidmarks BLSP mountain bike trailhead to left. *0.3*

2.2 Fork in road. **Bear left** and continue north on NM 409. *0.6*

2.8 Crossing Comanche Draw karst solution valley. *0.1*

2.9 River Road Rd. to left follows Pecos River back to US 70-380. **Continue straight** on NM 409. Now leaving Bottomless Lakes State Park. The route continues for the next several miles across an irregular surface underlain by Seven Rivers gypsum and redbeds. *2.4*

5.3 Junction of NM 409 with US 70-380. **Turn left** onto US 70-380. *0.4*

5.7 Pecos Valley at 10:00. *0.3*

6.0 Seven Rivers gypsum and red mudstone exposed in roadcuts to left and for next ~1.5 miles. Begin descent into karst solution valley. *1.1*

7.1 Crest of Seven Rivers Escarpment, which forms the steep eastern margin of the Pecos River valley. Seven Rivers gypsum and redbeds in roadcuts to left and right. *0.1*

7.2 Begin descent down Seven Rivers Escarpment into Pecos Valley and the Roswell Artesian Basin. For expanded discussion of the karst hydrology of the Artesian Basin, see minipaper by Land (2006). Approximately 2 km to the north, large dry sinkholes occur at the top of the escarpment, possibly formed when hydraulic head in the Artesian Basin was substantially higher during Pleistocene interglacials. *1.0*

8.2 Crossing Pecos River, lined with Tamarisk (salt cedar), the "water vampires of the southwest". *1.1*

9.3 MP 161. Now driving across Quaternary alluvium of the Orchard Park Terrace of the Pecos River. *0.9*

10.2 Roswell Test Facility to right, the site of a desalination pilot plant in the 1960s and 70s. The plant is located on the saline side of the freshwater-saltwater interface in the Artesian Aquifer. A flowing artesian well at this site, used to provide feedstock for the desalination facility, has a measured chloride content of >7,000 mg/l [EPA Secondary Standards for water intended for human consumption recommend that chloride concentrations not exceed 250 mg/l]. *1.4*

11.6 Junction with NM 254. **Continue straight.** *0.7*

12.3 Junction with CR 106-Red Bridge Rd. Bitter Lakes National Wildlife Refuge is 7 miles to north. **Continue straight** on US 70-380. *0.1*

12.4 Young pecan orchard to left. Pecans are an important cash crop in the largely agricultural economy of the lower Pecos Valley. *1.1*

13.5 Entering city of Roswell. Offices of the Pecos Valley Artesian Conservancy District to right. PVACD, an independent agency of the state of New Mexico, is responsible for metering irrigation wells in the Roswell Artesian Basin. *1.0*

14.5 Crossing Rio Hondo, one of the principal tributaries of the Pecos River, now dry most of the year except during occasional flash flood events. *0.8*

15.3 Intersection of 2nd St. and Main, the UFO district of downtown Roswell. The Roswell UFO Museum and Research Center is about ½ block south on Main St. **Continue straight** on 2nd St/US 70-380. *2.4*

17.7 Bureau of Land Management, Pecos District-Roswell Field Office to right. **A BLM permit is required to visit Fort Stanton Cave.** *1.1*

18.8 Junction of 2nd St/US 70-380 with US 285 Relief Route. **Continue straight.** Still driving on Quaternary alluvium of Pecos River floodplain. *2.0*

20.8 Begin ascent of Six Mile Hill. *0.5*

21.3 Stop 1: Six Mile Buckle. Junction with Loma Vista Rd to right.

Park on shoulder and cross road to examine roadcut. **Caution, traffic may be heavy at this site. Be extremely careful crossing highway.** The following discussion is modified from Kelley (1971a; 1971b).

Six Mile Hill is the topographic expression of the Six Mile Buckle, one of four fold-fault zones that extend in a NE direction for several tens of kms across the Pecos Slope. The buckles are remarkably straight, spaced at intervals of 13 – 32 km, and are the most distinctive structural features between the Sacramento Mountains and the Pecos River, readily identifiable on air photos and satellite images (See shaded relief map of this log). The term "buckle" is commonly applied to these features because their surface expressions are in some places folds, elsewhere faults, and often combinations of the two, and there is considerable evidence of strike-slip movement. Bedding on both sides of a buckle is often turned up sharply in a zone that may range from a few m to as much as 1200 m wide. An area of wider uplift may occur outside a narrower zone of intense deformation, as is the case with the Six Mile Buckle, where the broader anticline is in places greater than 6 km in width. The buckles generally plunge northeastward diagonally across the regional eastward dip. The nature of deformation along the strike of a buckle may change abruptly over a short distance, from folding to faulting. Age of the buckles is somewhat ambiguous. Most workers (e.g., Havenor, 1968) consider them to be Laramide in age, but there is subsurface evidence of displacement as early as Pennsylvanian.

The Six Mile Buckle has a traceable length of ~130 km, from exposures near the Pecos River NE of Roswell extending SW to a junction with the Dunken syncline. At this stop the Six Mile Buckle is developed in the Fourmile Draw member of the San Andres Formation (Figure S2.1). The crest of the buckle is probably a fault, although it is not visible from the road. Instead, the crest of the anticline at this stop is occupied by several small folds. Note extensive development of secondary porosity, ranging in scale from microvugs, giving some beds a "worm-eaten" appearance, up to small shelter caves.

Sinkholes and solution-enlarged fractures associated with the Pecos Buckles provide zones of enhanced groundwater recharge

FIGURE S2.1. Roadcut exposure of Six Mile Buckle, west of Roswell, New Mexico.

to the San Andres limestone aquifer in the Roswell Artesian Basin. Groundwater flows east and southeast, downgradient from the recharge area. The small percentage of groundwater flow not intercepted by irrigation wells in the Basin ultimately discharges into karst springs and sinkhole lakes along the Pecos River. *1.1*

22.4 Crossing Eight Mile Draw. Capitan Mountains batholith on horizon at 1:00. The Capitan Mountains are a 50 km long, EW-oriented igneous intrusive body of Tertiary age. The batholith is one of several Tertiary igneous centers in east-central New Mexico, referred to by Kelley and Thompson (1964) as the Lincoln County porphyry belt because of the distinctive porphyritic texture displayed by many of the lithologies at these centers (Allen and McLemore, 1991). *2.0*

24.4 Gypsum of Fourmile Draw member of San Andres Formation exposed in subdued roadcut to left. *1.7*

26.1 MP 321. Hills at 10:00 contain rocks of Fourmile Draw member of San Andres Formation. *1.6*

27.7 Crossing Blackwater Draw. Rocks in roadcut at 10:00 are Fourmile Draw limestones. *0.4*

28.1 Turnoff to left goes to Two Rivers Reservoir, a flood control dam on the Rio Hondo and Rocky Arroyo. **Continue straight.** Quaternary terrace gravels are exposed in roadcut to right and ahead for the next several miles. Some of the gravels are quite thick, and include abundant igneous cobbles derived from Sierra Blanca, a mid-Tertiary complex of volcanics and igneous intrusive rocks 88 km to the west.

The broad, flat valley to the right is the product of solution-collapse processes in the San Andres Formation. The valley is referred to as the Menecke Sag because limestone beds in the ridge east of the valley are draped toward the valley floor. The sag probably began to form in early Pleistocene time (Kelley, 1971b). *5.0*

33.1 MP 328. Rest area to left, parking area to right. *1.9*

35.0 Crossing poorly exposed contact between Fourmile Draw and Bonney Canyon members of San Andres Formation, overlain by thin gravel pediment. Capitan Mountains batholith at 1:00. *1.0*

36.0 Road to right leads to old missile silo on private land. Several missile silos are located in the vicinity of Roswell, relicts of the cold war. About here the road leaves pediment of caliche-capped terrace gravels. Outcrops ahead are formed in Bonney Canyon member of San Andres. Crest of Border Hills on skyline ahead. *0.1*

36.1 Chaves-Lincoln County line. *0.8*

36.9 Bonney Canyon limestones exposed in roadcut to left. Tan to yellow beds near the base of the outcrop may have been recrystallized by circulating groundwater (Kelley, 1971b). A broad disrupted zone ~18 m wide near the center of the roadcut appears to be a collapse feature, or paleosink, the position of which may be controlled by faulting. *0.9*

37.8 Broad syncline formed in Bonney Canyon limestones in roadcut to left. Just beyond curve the road passes from Bonney Canyon to Rio Bonito member of the San Andres Formation, which forms the steeply-dipping east limb of the Border Buckle. *0.3*

38.1 Small-scale faulting in roadcut to left associated with Border Buckle. *0.6*

38.7 Small thrusts and folds in Rio Bonito and overlying Bonney Canyon members. Enhanced vuggy porosity can be observed in fault zones. Begin ascent of Border Hills. *1.1*

39.8 Stop 2: Border Buckle. Junction with CR E034/Border Hill Rd to right.

Park on shoulder. **Caution! Oncoming traffic has limited visibility rounding curve. Be extremely careful crossing road.** The following discussion is modified from Kelley (1971a; 1971b).

The Border Buckle is the most prominent and intensely deformed of the Pecos Buckles. At this stop the Border Buckle is formed in the lowermost Rio Bonito member of the San Andres limestone. A tongue of Glorieta sandstone, a siliciclastic member sometimes present in the lower San Andres, is visible in the east limb of the fold. The Border Buckle has an exposed length of ~95 km and is prominently expressed by a long series of ridges known as the Border Hills, which rise in places 60 – 90 m above the adjacent plains and mesas (See shaded relief map for this log). The southeast limb of the fold overrides the central fault zone over most of the length of the buckle south of highway 70. However, north of the highway the overriding side changes four times in just 11 km.

FIGURE S2.2. Vertial to overturned strata, Rio Bonito Member of the San Andres limestone, near core of Border Buckle.

The overall configuration of the Border Buckle at this stop is of a broad, more or less symmetric anticline. However, as one walks from east to west along the outcrop the rocks become increasingly deformed. Small thrust faults are visible at the east end of the roadcut, followed by an intensely brecciated and chaotic central core. Some beds are displaced to vertical, and large open fractures are present (Figure S2.2). It is difficult to locate the fault precisely because of the chaotic nature of deformation in the center of the structure, but it presumably occurs near the breccia and vertical beds. By the time the viewer reaches the west end of the roadcut, relatively undeformed beds dip gently west ~15° on the west limb of the fold. *0.2*

40.0 Road curves left and passes west for the next several miles across multiple outcrops of Bonney Canyon member of San Andres Formation. *4.7*

44.7 MP 302. Sierra Blanca at 12:00. Capitan Mountains batholith at 2:00. Bonney Canyon in roadcut to right. Border Hills at 9:00 extend to SW for many km. Road curves left and begins descent into Hondo Valley. Now entering Sacramento Mountains. *0.5*

45.2 To left and right, the first of several roadcuts of Rio Bonito limestone we will pass during descent into Hondo Canyon. *1.4*

46.6 Village of Riverside at bottom of hill, now not much more than a signpost. Road curves right up Hondo Canyon. More exposures of Rio Bonito in roadcuts ahead. Kelley (1971b) identifies the contact of the Rio Bonito with the overlying Bonney Canyon at the base of a prominent shoulder or ledge in the hills ahead. *0.7*

47.3 Old Riverside café and store to left. *0.1*

47.4 Rio Bonito limestone and underlying Glorieta sandstone exposed in roadcut to right, dipping east. *0.1*

47.5 Fault zone to right. Note drag fold rolling into fault zone on west side of fault. *0.9*

48.4 Passing the first of many exposures of the Yeso Formation to right. The Yeso is a heterogeneous unit that consists of tan, yellow and reddish sand, silt and mudstone with occassional dolomite beds. The Yeso also contains abundant gypsum, but this lithology is rarely visible in roadcuts due to surface dissolution or masking by hillside slumping. Local folding of incompetent units within the Yeso can be observed in many places along the canyon walls. The base of the Rio Bonito occurs several meters to tens of meters up the canyon walls on both sides of the road. *1.5*

49.9 Carbonate beds in Yeso at base of roadcut. *0.5*

50.4 Rio Bonito-Bonney Canyon contact visible at break in slope on sides of cone-shaped hills ahead at 9 – 10:00. *2.7*

53.1 Village of Picacho post office to left. Yeso exposed in sides of valley ahead. Steeper overlying ridges are formed in Rio Bonito member of San Andres limestone. The axis of the Picacho anticline crosses the western end of the valley ahead. Two exploratory wells have been drilled on the Picacho anticline, both dry holes. One well, the Stanolind No. 1 Picacho (sec.10-12S-18E, elev. 1816 m), was drilled to total depth of 866 m, and encountered Glorieta at 106 m, Yeso at 125 m, Abo at 686 m, and Precambrian igneous rock at 795 m. *1.3*

54.4 Optional stop. Pratt Truss bridge. Turn left onto CR E028.

Road to left (CR E028) crosses bridge over Rio Hondo and leads to Casey Canyon. The old truss bridge next to the modern bridge was originally built in 1902 on the Pecos River, and was later moved to this site. This Pratt Truss bridge is the longest and oldest of its kind remaining in New Mexico. Gentle dip on the west flank of the Picacho anticline can be seen in lower beds of the Rio Bonito at ~9:00. *0.7*

55.1 Begin descent into Talley Basin, a synclinal trough between the Picacho anticline and the Tinnie anticlinorium farther west. The Yeso-San Andres contact dips down to near the valley bottom in this area, before rising again westward toward the Tinnie anticlinorium. *3.0*

58.1 Tinnie Silver Dollar Restaurant and Saloon to left. *0.3*

58.4 Tinnie general store, and junction with NM 368 (Arabela Highway). NM 368 leads north to the tiny community of Arabela, following a narrow valley along the axis of the Tinnie anticline. The valley is eroded into softer beds of the Yeso Formation, which make up the core of the fold. When the road first enters the anticline, Rio Bonito beds on the limbs of the fold dip away from the fold axis at 10 - 15°. Farther north the limbs of the anticline steepen and the fold becomes closed, isoclinal, and eventually overturned on both limbs into a fan fold. **Continue straight** on US 70-380. *0.6*

59.0 West-dipping strata of Rio Bonito, Glorieta, Yeso, and a Tertiary igneous sill in roadcut to right. *0.3*

59.3 Optional stop. Permian Stratigraphy.

Park on shoulder to right and walk back to roadcut. Be extremely careful of traffic, as visibility is poor at this stop. The stratigraphic sequence at this roadcut, from top to bottom, is (1) Rio Bonito carbonates containing an upper tongue of Glorieta sandstone (note abundant steeply-dipping fractures and slickensides); (2) yellowish Glorieta sandstone at base of San Andres; (3) tan to reddish-brown Yeso siltstone; (4) a Tertiary igneous sill ~8 m thick; (5) dark-gray Yeso carbonates; and (6) more Yeso siltstones at the east end of the roadcut. Kelley (1971a) observes that diabasic to monzonitic sills occur in many places along the Hondo drainage, usually near the top of the Yeso Formation. *0.1*

59.4 MP 287, and junction with NM 395. **Continue straight.** Entering Hondo Basin and village of Hondo. Strata in canyon walls become more gently-dipping than they were in the Tinnie fold belt. *2.3*

61.7 Junction with US 380. **Bear right** onto US 380 and proceed up canyon of Rio Bonito. *2.4*

64.1 First of several roadcuts to right exposing Yeso Formation in Rio Bonito valley. *2.8*

66.9 Bridge over Rio Bonito. The Rio Bonito-Yeso contact is exposed at the base of the cliff on the west side of the bridge. *2.2*

69.1 Note Yeso exposed in lower valley walls to right. *0.6*

69.7 Canyon walls to right provide the first good view of the Lincoln Folds, which mainly deform incompetent Yeso beds while the overlying Rio Bonito carbonates capping ridges remain unfolded. The origin of these folds is controversial, but the consensus seems to be that they are not crustal folds. Yuras (1991) proposed a gravitational gliding origin of the folds associated with subsidence of the Sierra Blanca Basin to the west during Laramide time. Foley (1964) considered the folds to be of only local significance, the result of mass slumping due to large amounts of glacial outwash from Sierra Blanca peak during the early Holocene. Undeformed San Andres limestone can be seen ~2/3 of the way up the canyon walls. *1.0*

70.7 Lincoln cemetery to right. *0.1*

70.8 Lincoln historic marker to right (Figure S2.3). *0.2*

71.0 Entering village of Lincoln. The legend of Billy the

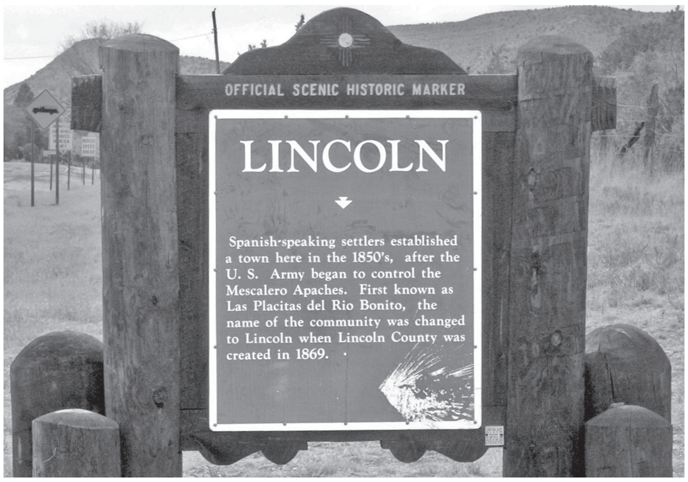


Figure S2.3. Village of Lincoln historic marker, Lincoln County, NM.

Figure S2.4. Overturned fold in Yeso strata, part of the Lincoln fold belt, north wall of Rio Bonito Canyon west of Lincoln, NM.

Kid was first established here during the famous Lincoln County War of the 1870s (Austin, 1991). *1.0*

72.0 Tightly-folded and overturned Yeso strata in canyon walls at 9:00 (Figure S2.4). *0.8*

72.8 Steeply-dipping Yeso carbonates in roadcuts on both sides of road (possibly a very tightly-folded and overturned syncline). *0.1*

72.9 Crossing Priest Canyon. Kelley (1971a) shows a normal fault here, downthrown to the west, controlling the orientation of Priest Canyon. *0.1*

73.0 More steeply-dipping Yeso carbonates on west limb of strongly assymetric anticline. Fold axis visible in roadcut to left. *2.2*

75.2 Yeso in roadcut to left. *0.1*

75.3 Side road to right follows Salazar Canyon, crossing steeply-dipping San Andres limestone tilted up against Capitan batholith. **Continue straight.** *0.7*

76.0 Rio Bonito-Yeso contact exposed in roadcut to left. *0.9*

76.9 Another exposure of the San Andres-Yeso contact in roadcut to left, dipping gently to the west. This area marks the approximate position of the crest of the Mescalero Arch, a broad structural divide that seperates the long regional inclination to the east into the Pecos country from steeper westward dip into the Sierra Blanca Basin. The Mescalero Arch defines the structural crest of the Sacramento Mountains uplift, and also roughly coincides with the axis of the late Paleozoic Pedernal uplift. From this point on, regional dip (although interrupted by local folding) is down to the west into the Sierra Blanca Basin. *0.3*

77.2 USGS stream gaging station to right. Government Spring, obscured by brush, occurs on south bank of Rio Bonito

~ 5 m west of stream gaging station. Rio Bonito limestone visible in prominent bluffs at 9:00, dipping gently to west. *0.6*

77.8 Descending into Rio Bonito valley. **Prepare to turn left.** *0.1*

77.9 **Turn left, cross cattle guard, and bear right** on gravel road. Follow gravel road south toward Fort Stanton Cave. *0.5*

78.4 Sierra Blanca at 1:00. Rio Bonito to right. San Andres limestone in ridges to left. *0.5*

78.9 **Turn left** into Cave Canyon campground. *0.1*

79.0 Sinkhole entrance to Fort Stanton Cave behind chain link fence to right. *0.1*

79.1 Stop 3: Fort Stanton Cave. Park cars and prepare to enter cave.

Be advised that a BLM permit is required. Note abundant solution collapse breccia formed in San Andres limestone in walls of Cave Canyon arroyo.

Fort Stanton Cave is an undeveloped cave. Although most trails are flagged, caving equipment is necessary to tour the cave, including caving helmets, sturdy boots, and at least three sources of light. Fort Stanton Cave is formed primarily in the Rio Bonito member of the San Andres limestone and, unlike most caves in the Guadalupe Mountains, to the southeast, appears to have been excavated by carbonic acid rather than sulfuric acid. With some exceptions, the cave is not heavily decorated. Features to note include extensive solution-collapse breccia, which forms the walls and ceiling of many parts of the cave. For expanded discussion of the geology of Fort Stanton Cave, see Davis and Land (2006).

Field trip ends.

For those continuing west toward Socorro and Albuquerque, the route crosses successively younger strata dipping west into the Sierra Blanca Basin, including (beginning with a left turn onto US 380) the Rio Bonito member of the San Andres limestone; poorly exposed redbeds and sandstones of the Grayburg Formation/Artesia Group; Triassic Santa Rosa sandstone; and Chinle mudstones. Lucas (1991) has described what may be the southeasternmost outcrops of the Jurassic Morrison Formation east of the village of Capitan. Lower Cretaceous Dakota sandstone forms the prominent ridges east of town. Capitan itself is located in a valley underlain by upper Cretaceous Mancos shale. West of Capitan, roadcuts of upper Cretaceous Mesa Verde sandstones and the Cretaceous-Tertiary Cub Mountain Formation are cut by impressive lower Tertiary dikes.