Second-day road log: From Grants to El Malpais, Fence Lake, Zuni Pueblo and Gallup

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SECOND-DAY ROAD LOG, FROM GRANTS TO EL MALPAIS, FENCE LAKE, ZUNI PUEBLO AND GALLUP

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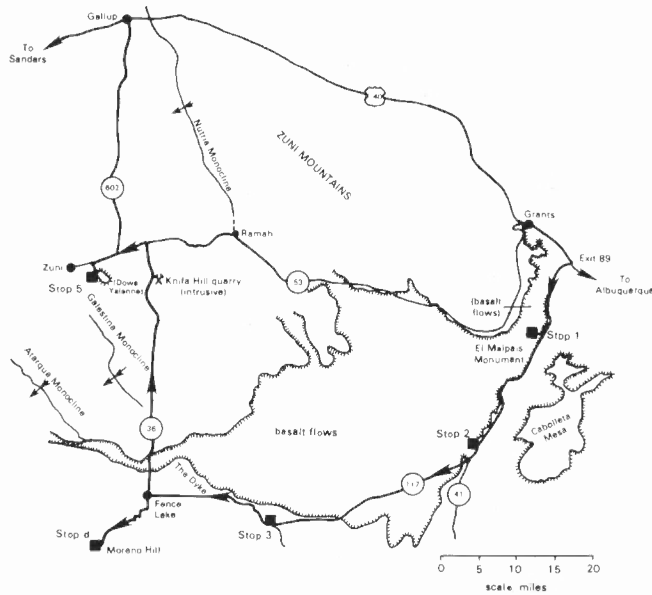
and DAVID W. LOVE

SATURDAY, SEPTEMBER 30, 1989

Assembly point:	Parking lot of The Inn, Grants, New Mexico.
Departure time:	8:00 a.m.
Distance:	182.7 mi
Stops:	5



SUMMARY

The second day's tour takes us southward from Grants along the west side of Las Ventanas Ridge and Cebolleta Mesa, both of which offer excellent exposures of Middle and Upper Jurassic rocks and Upper Cretaceous rocks. The Jurassic section changes rapidly going south as the Morrison and Todilto fms pinch out, and the Wanakah and Zuni (of Maxwell, 1976) become increasingly difficult to distinguish.

Again, we will see evidence that some normal faults along the east flank of the El Malpais have an earlier history of Laramide dextral shear. Between Stop 5 of Day 1 and Stop 1 of Day 2, a distinct shift in the orientation of Laramide microthrusts can be observed and permits discussion of their relationship to the Zuni uplift. A small antithetic normal fault at Stop 1 is cited as a probable example of a newborn Neogene rift fault.

Quaternary geology abounds with the presence of the extensive El Malpais lava field on our right side for about half the day. Quaternary to Pliocene fault scarps will be visible at several points along the route.

The first stop is at an overlook in the newly created El Malpais National Monument. In addition to discussing the establishment of the monument, the stop offers a view of the El Malpais lava field which is composed of multiple flows dating from 3.7 my to as young as 600 yrs.

Stop 2 (optional) places us at a borrow pit within the Hickman fault zone of Wengerd (1959) and enables us to take a close look at evidence for dip-slip movement superimposed on strike-slip movement. Again, we will be on the edge of the El Malpais lava field with an excellent view of the NNE-trending cinder cones known as the Chain of Craters.

Stop 3 gives us a look at anomalously colored Upper Cretaceous rocks that were deeply weathered and oxidized prior to the deposition of the overlying fluvial Baca Fm. (Eocene). The Baca, also well exposed here, is at the northwestern limit of its outcrop area. Good stratigraphic control indicates a Miocene to Pliocene age for a NNE-striking normal fault near Stop 3. The south end of the El Malpais–North Plains basin is a shallow Neogene rift basin.

Stop 4 is our lunch stop at a scenic overlook where coarse-grained volcanic-rich sediments of the Miocene Fence Lake Fm. rest on the coal-bearing Upper Cretaceous Moreno Hill Fm. The character of the southeastern margin of the Colorado Plateau in New Mexico and a comparison to the southwestern margin in Arizona is presented from this vantage point.

This afternoon takes us northward through the length of the Gallup-Zuni basin. The changes in the stratigraphy of the Turonian age (Upper Cretaceous) intertongued marine-nonmarine sequence are highlighted as we go north, and the evidence for compartmental deformation is presented. The day culminates at Stop 5 on the west side of Corn Mountain near scenic Zuni Pueblo with a discussion of Middle Jurassic stratigraphy and depositional environments.

Mileage

0.0 Leave parking lot of The Inn by **turning right** (south) onto business loop and access to I-40. **0.5**

0.5 **Cross bridge** over I-40 and **bear right** onto ramp for I-40 eastbound. **0.3**

0.8 Overpass. **1.7**

2.5 Grants monocline at 9:00, exposing moderately NE-dipping intertongued Dakota-Mancos sequence. Source area for the basalt flows visible on the right is El Calderon volcano, 16 mi to the southwest. **2.5**

4.9 Slow and **prepare to exit;** highway cuts across bulbous upwelling of the Holocene McCartys basalt flow where it was channeled along a narrow drainage at the northern end of the lava field. **0.1**

5.0 **Leave I-40** at exit 89, bearing right onto exit ramp; note basal Dakota Ss and a small thrust fault (Fig. 1-81.6h) on right in roadcut. **0.1**

5.1 **Stop sign; turn right** onto NM-117, cross **cattleguard** and proceed southward. **0.2**

5.3 Location of Stop 5 of first day; continue south on NM-117. **0.2**

5.5 Basal sandstone unit of the Dakota–Oak Canyon Mbr caps Las Ventanas Ridge to left. Brushy Basin Mbr, the grayish-green mudstones with white sandstone and conglomerate, is exposed in cliff with a pale yellow crossbedded sandstone at base near road level. Thaden et al. (1967) called this lowest, crossbedded unit the "yellow sandstone" and tentatively equated it with the Cow Springs Ss; Maxwell (1986) called it the Zuni Ss. Note the crossbeds which generally dip northeastward. (See stratigraphic nomenclature chart at beginning of road log section, or inside back cover.) **0.3**

5.8 Borrow pit for roadbed material at 9:00, note highly crossbedded Zuni Ss exposed in hill beyond pit. **0.4**

6.2 Light-colored, thick sandstone at 9:00 to 10:00 is Zuni Ss (Fig. 2-6.2). The distinctly fractured Zuni, below and left of the point, lies within the Las Ventanas fault zone where it locally forms a narrow graben bounded by normal faults. Within the graben are several strike-slip microfaults that strike about 030 and 050 and show slickensides plunging at less than 10° from the horizontal. By the criteria of Angelier et al. (1985), their sense of shear is dextral. These strike-slip microfaults are reasonably interpreted as first and second order Reidel shears within the Las Ventanas fault zone, which locally strikes 010. Chamberlin and Anderson (this guidebook) interpret the Las Ventanas fault zone as a Laramide zone of dextral shear later reactivated by Neogene extension. **0.2**

6.4 High on cliff face at 9:30, southward thinning wedge of Morrison Fm can be seen between Zuni Ss and the cap of Dakota Ss. **0.2**

6.6 Reddish Entrada Ss at 9:00 near road level. Thin gray beds above it (and east of road for next 0.3 mi) are Todilto Fm. The Todilto is only a few inches thick, and the southward pinchout is nearby. **0.4**

7.0 Truncation of Morrison Fm by Dakota Ss at 9:00–11:00, just below mesa top. **1.2**

8.2 Basal Dakota Ss on bleached Zuni Ss visible below mesa top at 9:30. **0.5**

8.7 Milepost 53. Windmill at 9:00; on mesa behind windmill is Dakota-Zuni contact. Sandstone on skyline is Paguate Tongue of Dakota. **1.0**

9.7 Milepost 52; Zuni Ss at base of section on left, overlain by Oak Canyon Mbr at sharp color change midway upslope, and in turn by the Cubero Tongue of Dakota and the Clay Mesa Tongue of Mancos. The Paguate Tongue of the Dakota caps the sequence. **0.8**

10.5 Crossbeds sets in the Zuni Ss outcrops on the left have southerly dips, in contrast to the northerly dips seen earlier. **0.3**

10.8 Midway upslope at 11:00, light colored Zuni overlain by Oak Canyon and Cubero, slope of Clay Mesa, with Paguate Tongue forming the skyline (Fig. 2-10.8). **0.9**

11.7 Milepost 50. Entering El Malpais National Monument. In 1987, Congress officially designated 114,000 acres south of Grants as the El Malpais National Monument. A 262,000-acre area surrounding it is the El Malpais National Conservation area (Fig. 2-11.7). Northeast-trending diabase dike forms dark colored low wall near base of slopes at 9:00, but only the sharpest eye will catch it. This undated dike has been used by several authors as a post-5-my stress indicator (e.g., Aldrich et al., 1986), presumably because it was mislabeled on the map of Thaden et al. (1967) as "Qtb" instead of "QTb." Its texture and position in the landscape demonstrate that it is Pliocene or older, and it should be labeled as a Tertiary dike on future maps. **0.8**

12.5 At 10:00, note the small sandstone cuesta of Paguate

FIGURE 2-6.2. View of prominent point along Las Ventanas ridge from near mile 6.2. The light-colored, well-exposed sandstone is Zuni (of Maxwell, 1986), overlain by slope-forming Brushy Basin Mbr of Morrison with Dakota Ss capping the mesa. The highest sandstone caprock lies within a narrow graben along the Las Ventanas fault zone.

FIGURE 2-10.8. View southward from highway 117 of light-colored Zuni Ss low in mesa overlain unconformably by the intertongued Dakota-Mancos sequence with the Oak Canyon Mbr at base, Paguate Tongue at the top.

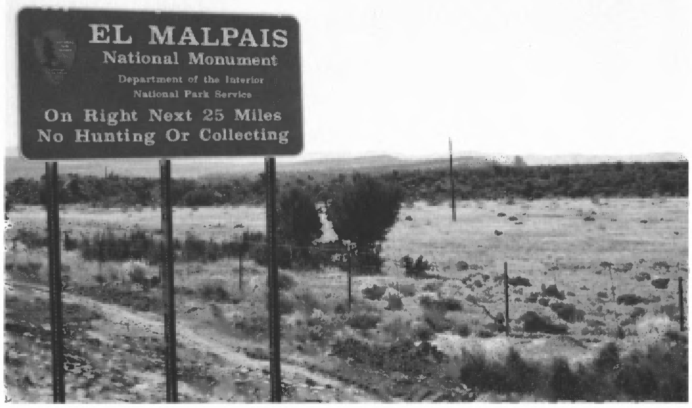


FIGURE 2-11.7. Sign announces the El Malpais National Monument, recently established in 1987. Eastward dip slopes on Dakota Ss, visible in middle distance, are near Stop 1.

that dips about 10° to the north, nearly orthogonal to the local structural grain as mapped by Maxwell (1986). Chamberlin and Anderson (this guidebook) interpret this anomalous dip as part of a small transpressional fold associated with a quarter-mile stepover (to the left) in the main strand of the Las Ventanas fault. The relationship is consistent with the dextral sense of shear observed 5 mi to the north.

At 11:00 to 12:00 on SW side of basalt-capped Mesa Negra, Cretaceous strata, in descending order, are: Crevasse Canyon Fm, cliff-forming Gallup Ss, D-Cross Tongue of Mancos Sh, Tres Hermanos Fm and the slope-forming Rio Salado Tongue of the Mancos. The Dakota forms the lowest cliff. Drainage on the alluvial apron of Las Ventanas ridge and the broad flat valleys ahead are ponded against the McCartys flow and form miniature playas. **0.6**

13.1 Dakota-Zuni contact on north point of mesa at 11:00; darker colored Dakota over bleached Zuni Ss. Cubero Tongue has pinched out, and slope is Oak Canyon Mbr overlain by shale of the Clay Mesa Tongue, capped by Paguate Tongue. **1.2**

14.3 Road parallels main strand of Las Ventanas fault zone (here down to west) which repeats the Zuni-Dakota sequence; bluffs at 12:30 are Paguate Tongue, bluffs to left of road are Zuni Ss capped by Basal Oak Canyon Mbr. Stop 1 is on the far rim of the east-tilted downdropped block, west of highway. **0.6**

14.9 **Turn right** onto sandstone bluff overlook road and proceed to overlook at Stop 1. **0.5**

15.4 Route ascends dip slope on lower Oak Canyon Mbr; note Paguate Tongue from 9:00 to 11:00. **0.7**

16.1 Road makes sharp bend to right. **0.5**

16.6 **STOP 1,** park at south end of overlook parking lot. Overlook point is at top of cliff developed on Zuni Ss (see panoramic index, Fig. 2-16.6a for Stop 1). Road and parking lot is on Oak Canyon Mbr. Maxwell (1986) has mapped a small displacement (30–40 ft) down-to-the-east normal fault here (Fig. 2-16.6b). Most astute observers, who happen to be crawling along the west periphery of the parking lot, will spot dip-slip slickensides on a 10-inch-high ledge of Dakota Ss that marks the fault trace. The slickensides plunge about 76° to the

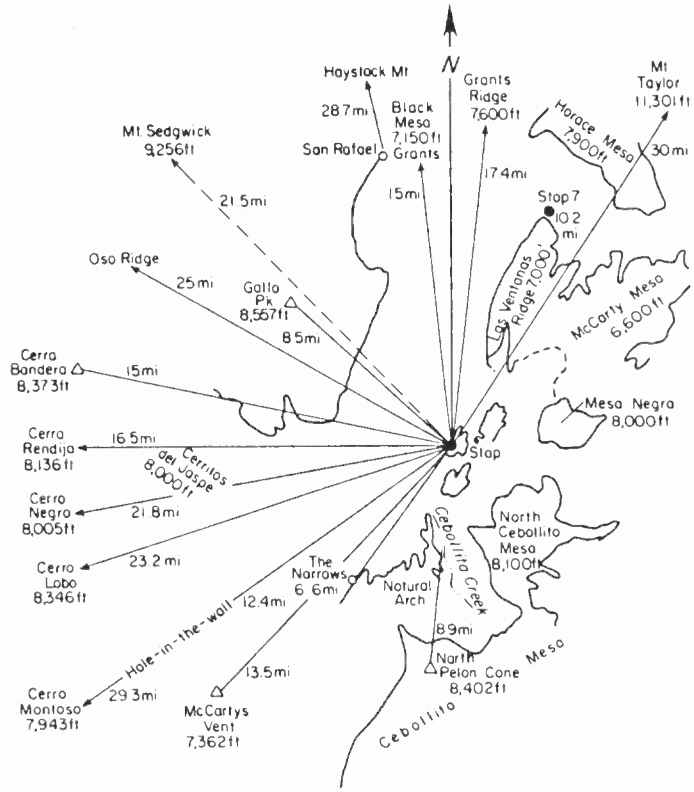


FIGURE 2-16.6a. Panormaic index of topographic features at Stop 1, the sandstone bluff overlook (from Hawley et al., 1982).

ESE, nearly parallel to the dip of the fault. In contrast to other faults in the Las Ventanas Ridge area, no evidence of strike-slip displacement can be observed in better exposures of this fault that occur within a half-mile to the south and north of the parking lot (Fig. 2-16.6c). Because of its antithetic relationship to the Las Ventanas fault zone, we suggest this unnamed fault at the overlook is a newborn Neogene rift fault.

Walk south from parking lot about 250 ft to the rim of Dakota Ss lying on the bleached top of the Zuni Ss. Numerous moderately dipping microthrust faults (Fig. 2-16.6d), similar to those seen at Exit 89, are well exposed along the Dakota rim (east of here) over a distance of 0.5 mi. The plunge of slickensides on these milky white and mullioned shears is consistently at moderate

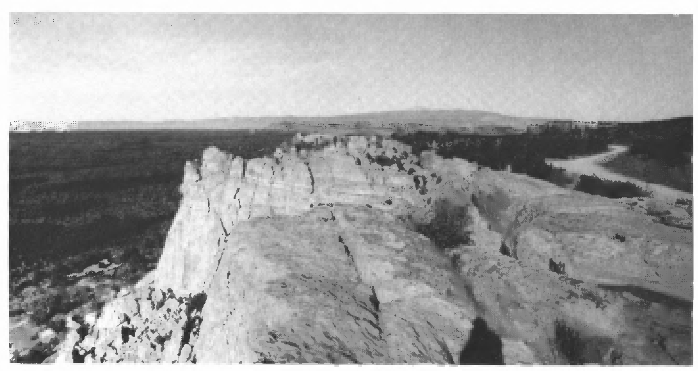


FIGURE 2-16.6b. View to north from sandstone bluff overlook at Stop 1. Road is on downfaulted block of Dakota Ss; Zuni Ss of Maxwell (1986) forms the light-colored cliffs. Mt. Taylor in distance.

FIGURE 2-16.6c. View looking to south along down-to-the-east normal fault which juxtaposes Dakota Ss (left) and the lighter-colored Zuni Ss (right). Location is about one-half mile north of parking area at sandstone overlook.

FIGURE 2-16.6e. View to west from Stop 1 across the basalt flows of the El Malpais toward the southeastern end of the Zuni Mountains. Just left of center, Mt. Sedgwick (9256 ft), marks the Precambrian core of the Laramide Zuni uplift.

FIGURE 2-16.6d. Slickensides (light-colored surface) developed on southeast-dipping microthrust in basal Dakota Ss; location is about 150 ft south of parking area at sandstone overlook.

angles to the ESE or WNW. About 0.25 mi from the parking lot, well developed conjugate sets of microthrusts bound long prismatic blocks that jut out from the eroded Dakota rim like fallen pillars. Twenty-one observations of microthrusts southeast of the parking lot yield an average direction of local crustal shortening toward $110 \pm 10°$. Except for two oddball observations in the ENE quadrant, there is no overlap between these orientations from the overlook and those made at Exit 89, 10 mi to the north. In combination with other observation points on the NE flank of the Zuni uplift, these observations suggest that the microthrusts formed in a secondary stress field in which the secondary maximum compressive stress was oriented radially away from the bullet-shaped northern nose of the uplift (see Chamberlin and Anderson, this guidebook).

The broad basalt-covered basin floor to the west (Fig. 2-16.6e) is underlain by Triassic Chinle Fm which is as much as 2000 ft thick locally. Regional dip is eastward from the southeastern end of the Zuni Mountains toward Cebolleta Mesa. The basalt covering the basin floor is a composite of several different flows (Maxwell, 1986) and is called El Malpais lava field. It has also been called the Bandera field (Laughlin et al., 1972, 1982) and the Zuni field (Thaden et al., 1967). The field is a mostly Quaternary feature that is about 30 mi long (SW-NE), about 5 mi wide at the northern end and 20 mi wide at the southern end. According to Laughlin et al. (1972), both alkalic and tholeiitic basalts were erupted within a short period of time, both as fissure flows and cinder cones. The Malpais field covers part of an older and much more extensive basalt lava field, part of which will be traversed today, between stops 2 and 3, and crossed again north of Fence Lake, and crossed yet again on day 3. Reported ages of these older flows include 3.7 my on North Plains at about mile 43 of today's log (Baldridge et al., 1989), 1.41 my near Fence Lake (Laughlin, 1979) and 1.38 my near El Morro (day 3) (Luedke and Smith, 1978). Laughlin et al. (1979) reported an age of 1.57 my for the "Laguna" flow of Nichols (1946; and Laughlin et al., 1972) from where it underlies the McCartys flow near Stop 5 of Day 1. This implies that the older flows also extend north to the Grants area and should not be confused with the younger flows from El Calderon (Maxwell, 1982b, 1986). However, magnetic polarity of the "Laguna" flow is reported to be normal, suggesting that it was extruded in the present polarity epoch (less than about 0.7 my ago) according to the original estimates by Laughlin et al. (1972). It is possible that the northern part of the Malpais field is composed of several flows of varied ages that are morphologically indistinguishable because of the eolian deposits and soils that mantle them. Its geomorphic position along the floor of the valley suggests that the "Laguna" flow is younger than flows that rest on intermediate surfaces above the valley floor to the east. The "Laguna" flow is probably not correlative with the basalt flow at Laguna Pueblo and Mesita.

The youngest flow is the extremely fresh McCartys flow seen at Stop 5 of Day 1, and immediately below the overlook at this stop. The McCartys flow was originally described by Nichols (1946), later by Renault (1970), Laughlin et al. (1972), Carden and Laughlin (1974) and Maxwell (1986). The flow is about 30 mi long, nearly 6 mi wide near its source but narrows to the north and is confined to a narrow canyon at Stop 5 of Day 1. Geomorphic expression and stratigraphic relationships with respect to adjacent valley-fill deposits indicate that the flow should be of late Holocene age (possibly less than 1000 yrs); the post-A.D. 700 age estimate of Nichols (1946), based on Indian legends and indirect archeological dating, is quite reasonable. Maxwell (1986) has stated that it "could be as young as 400 years old." Pueblo I (A.D. 700–900) pottery reportedly was found on top of the flow, however.

The high basalt-capped mesas to the east are Mesa Negra (Putney Mesa), and to the southeast, North Cebolleta Mesa, and to the south, Cebolleta Mesa. The bounding escarpments and slopes of the mesas are covered by landslides, tier upon tier of large slide blocks, some exceeding a mile in the horizontal dimension and locally cover the entire 1000 ft of vertical rise. The concealed units below the basalt cap, in descending order, include the Crevasse Canyon Fm, Gallup Ss, D-Cross Tongue of Mancos Sh, Tres Hermanos Fm, the Rio Salado Tongue of the Mancos, Twowells, Whitewater Arroyo, Paguate, and lower Mancos tongues of the intertonguing Dakota-Mancos sequence and the Oak Canyon Member of Dakota Ss resting on the Zuni Ss.

In 1987, the Congress created the 262,000-acre El Malpais National Monument, and surrounding it, El Malpais National Conservation Area (Fig. 2-16.6f). This stop is near the northeastern corner of the Monument, and the view from the overlook to the south and west encompasses most of the monument, and much of the surrounding wilderness area. Only Congress, in its collective wisdom, could put to such good use what the Spaniards called El Malpais, "the badland." After the stop, follow the loop road around the parking lot and **return to NM-117. 1.8**

18.4 Rejoin NM-117, **turn right** and proceed south. **0.2**

18.6 Note Paguate Tongue on west side of highway dipping eastward into fault, across which the Zuni Ss reappears on the east side of highway. **0.6**

19.2 Milepost 46. **0.6**

19.8 Paguate Tongue exposed on right; enter Acoma Indian Reservation. **0.3**

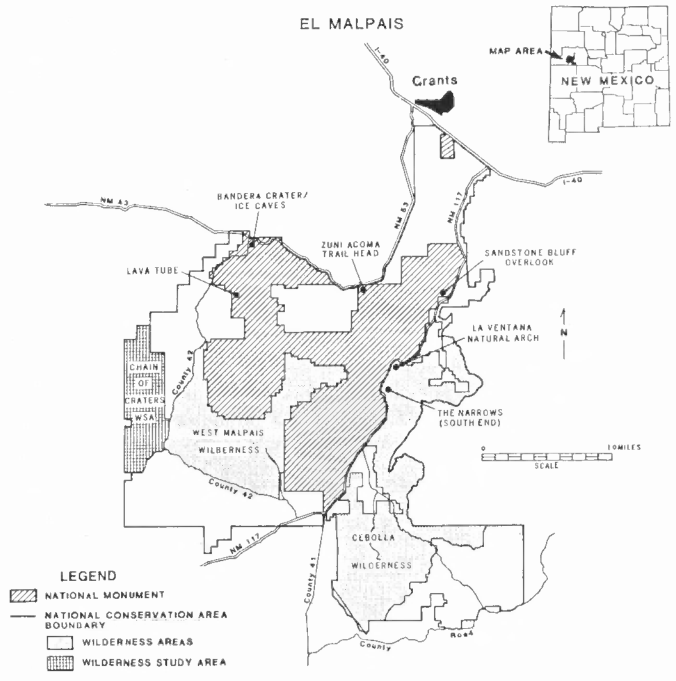


FIGURE 2-16.6f. Map of El Malpais National Monument and surrounding wilderness area.

WELL DRILLING, WATER-QUALITY SAMPLING, AND AQUIFER TESTING ON ACOMA PUEBLO LANDS, 1 NOVEMBER 1988 TO 8 MARCH 1989

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As part of a cooperative agreement between the Acoma Tribe and the U.S. Geological Survey, three wells were drilled between 1 November 1988 and 19 January 1989; water from two of these wells was sampled for chemical analysis; and aquifer tests were completed (Fig. 2-19.8). The purpose of this effort was to collect data pertaining to the hydrologic properties of the San Andres–Glorieta aquifer in order to

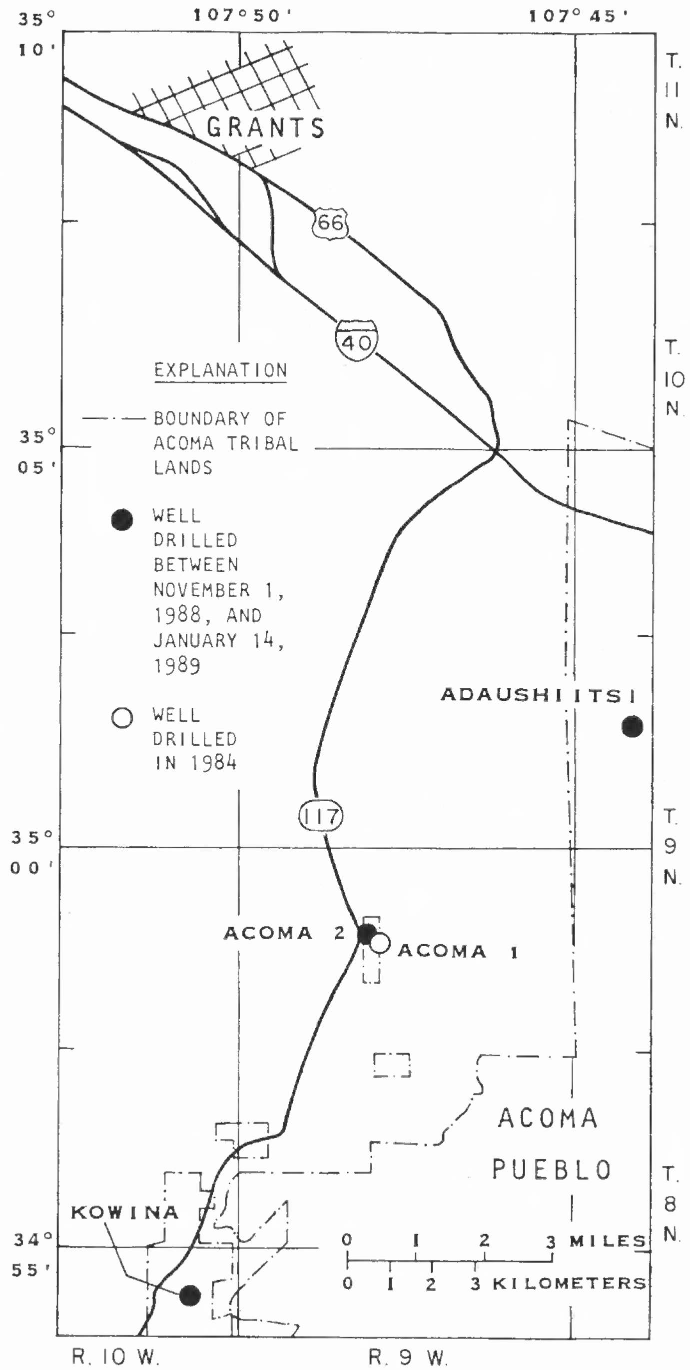

FIGURE 2-19.8. Map of northwestern Acoma Pueblo and Grants area showing location of recently drilled or tested wells.

determine the ground-water potential of the aquifer in the study area. This paper presents a description of recently completed work and preliminary information obtained during the study.

The three wells were completed using threaded-and-coupled carbon-steel casing and liner. For each well, a 12- to 13-inch-diameter borehole was drilled from land surface into consolidated rock and cased with 10.75-inch (outside diameter) casing. A 10-inch-diameter borehole was then drilled from below the surface casing through the top of the San Andres Limestone and cased with 7.0-inch (outside diameter) casing. The surface and intermediate casing were cemented into place. Cement was pumped down the interior of the casing and up the annular space between the casing and borehole until cement returns were observed at land surface. The deepest part of each well, the production borehole in the San Andres–Glorieta aquifer, was drilled with a 6-inch-diameter bit. A freestanding 4.5-inch (outside diameter), torch-slotted liner was set in the open borehole. This liner extends about 10 to 20 ft inside the lower part of the 7.0-inch casing. Each well was developed with compressed air.

The first well, named Adaushiitsi (Acoma for "boiling pot" or "boiling kettle"), is in the NE¼ sec. 12, T9N, R9W (4 mi south and 2 mi east of exit 89 on I-40). The Adaushiitsi well was drilled from 1 November 1988 to 4 December 1988 to a total depth of 3170 ft. There were lost-circulation problems during drilling of the upper 620 ft of the well. At the end of 8 hours of development, this well was producing 6 gpm of water with a temperature of 17°C and a specific conductance of 3400 uS/cm. The land-surface altitude at the well is 6510 ft. The depth to water in the well on 7 December 1988 was 96.04 ft.

The depth of formation or geologic-unit tops penetrated by Adaushiitsi well are as follows: alluvium, 0 ft; Mancos Shale and Dakota Sandstone, 26 ft; Morrison and Wanakah formations, 163(?) ft; Todilto Limestone Member of the Wanakah Formation, 870 ft; Entrada Sandstone, 891 ft; Chinle Formation, 1283 ft; San Andres Limestone, 2825 ft; Glorieta Sandstone, 3074(?) ft; and Yeso Formation, 3167 ft.

The second well, named Kowina (Acoma for "moss"), is in the SW¼ sec. 24, T8N, R10W (0.6 mi east of NM-117 along a dirt road that intersects the highway 0.25 mi south of mile marker 43). The Kowina well was drilled from 10 December 1988 to 1 January 1989 to a total depth of 2596 ft. During drilling, a 2- to 4-ft cavity was penetrated at 2498 ft. After 19.5 hours of development, the well was producing about 200 gpm of water with a temperature of 28.0°C and a specific conductance of 1400 uS/cm. Just prior to completion of development of the Kowina well, water in the well was sampled for analysis of major ions, radionuclides and total organic carbon. On 1 March 1989, during an aquifer test, water in the well was sampled for analysis of a variety of chemical constituents and isotopes including: major ions, radionuclides, total organic carbon, carbon-13, carbon-14, oxygen-18, sulfur-34 and trace metals. The land-surface altitude at the well is 6865 ft. The depth to water in the well on 6 January 1989 was 437.33 ft.

The depth of formation or geologic-unit tops penetrated by the Kowina well are as follows: alluvium, 0 ft; Wanakah Formation, 179(?) ft; quartz-conglomerate unit, 353 ft; Entrada Sandstone, 374 ft; Chinle Formation, 532 ft; San Andres Limestone, 2262 ft; Glorieta Sandstone, 2500 ft; and Yeso Formation, 2588 ft.

The third well, named Acoma 2, is in the NW¼ sec. 28, T9N, R9W (0.3 mi south and 0.2 mi east of NM-117 mile marker 49). The Acoma 2 well was drilled from 3 to 14 January 1989 to a total depth of 2391 ft. A 10-ft cavity was penetrated at 2378 ft. After 6 hours of development, the well was producing about 360 gpm of water with a temperature of 35.0°C and a specific conductance of 1200 uS/cm. Water in the well was sampled for major ions, radionuclides and total organic carbon just prior to the end of development. The land-surface altitude at the well is 6635 ft. The depth to water in the well on 16 January 1989 was 211.71 ft.

The depth of formation or geologic-unit tops penetrated by the Acoma 2 are as follows: alluvium, 0 ft; Morrison(?) and Wanakah formations, 126 ft; Todilto Limestone Member of the Wanakah Formation, 332 ft; Entrada Sandstone, 335 ft; Chinle Formation, 662 ft; and San Andres Limestone, 2338 ft.

On 7 February 1989, a step-drawdown test was conducted in Acoma 1 (Fig. 2-19.8), a well drilled into the San Andres Limestone in 1984. The well was pumped at 750, 1000, and 1200 gpm for 90 minutes at each step. An aquifer test was begun on 9 February 1989. The well was pumped at 900 gpm for 6 days and 19 hours, and water levels were monitored in the well and in the Adaushiitsi, Kowina and Acoma 2 wells during the pumping period and for 7 days after the pump was shut off.

A step-drawdown test in the Kowina well was begun on 26 February 1989. The well was pumped at 80, 120, 150, 180 and 250 gpm for 75 minutes at each step. Two days later, an aquifer test was begun in the Kowina well. The well was pumped at 220 gpm for 48 hours. Water levels in the well and in the Adaushiitsi, Acoma 1 and Acoma 2 wells were monitored during the pumping period and for 24 hours after the pump was shut off. Water-level monitoring was halted at the Adaushiitsi, Acoma 1 and Acoma 2 wells on 8 March 1989. Water-level monitoring in the Kowina well is scheduled to continue until 4 May 1989. Analysis and interpretation of data derived from this study are in progress.

20.1 Note the bleached and altered zone in the Zuni Ss under the Dakota at 3:00. The basal sandstone and conglomerate of the Dakota in this area and on to the south may be correlative with the Encinal Ss, as opposed to the marine (or paralic) sandstone that formed the base of the Dakota at Stop 5 (Day 1). **0.6**

20.7 Bluffs of Zuni Ss to left of road here and for the next few miles show extensive kaolinitic alteration and bleaching of the uppermost part of the unit. Is this a pre-Dakota weathering zone or a post-Dakota zone of ground-water alteration? Its regional extent, uniform thickness, parallelism to an ancient land surface and crosscutting relationship to the underlying Morrison and Zuni fms favor its origin as a weathering zone (Leopold, 1943). **0.7**

21.4 Bold cliffs of Zuni Ss on left. Buildings on mesa top at 12:30 are the museum and work shops associated with excavation of a large Indian pueblo ruin. **1.8**

23.2 Isolated spires and pillars of Zuni Ss along road are Los Pilares ("the pillars"). **0.3**

23.5 La Vieja ("the old woman") at 2:00. **2.1**

25.6 Leaving Acoma Indian Reservation. **0.3**

25.9 Sign and road to left for La Ventana ("the window") at 8:00, New Mexico's most famous natural arch (Fig. 2-25.9). **0.3**

26.2 The reddish sandstone on left side of road is Entrada Sandstone overlain by a 4-to-8-ft-thick pebble conglomerate probably occupying the position of the Todilto Fm,

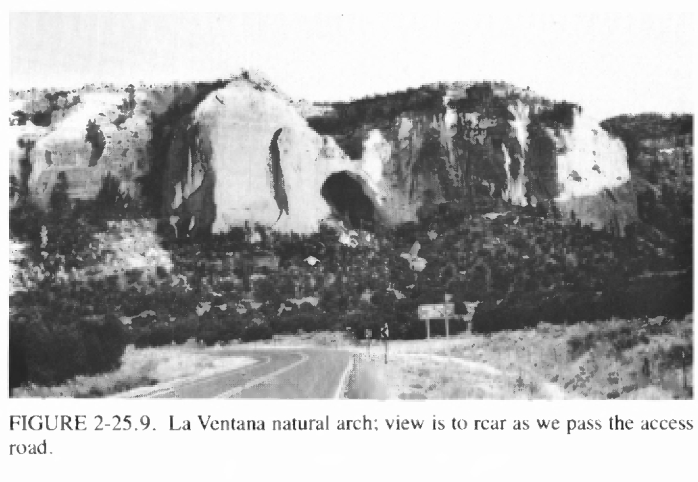

FIGURE 2-25.9. La Ventana natural arch; view is to rear as we pass the access road.

and indicating an unconformity between the Entrada and the Zuni—which here contains unmappable temporal equivalents of the Wanakah Fm. Enter The Narrows, a narrow strip of land between the lava flows on the right and the bluffs of Zuni Ss. **1.5**

27.7 Thick basal Dakota Ss caps bluffs on left. **1.3**

29.0 Milepost 36. The narrowest spot of the narrows, only about 150 ft of separation between the lava flow to the right and the Zuni bluffs to the left. **0.3**

29.3 Highway bends sharply to left, leave The Narrows. **0.2**

29.5 In cliff on left, note the contact between the light-colored, crossbedded Zuni Ss and the overlying darker colored Dakota. The southern Narrows area may have been a neutral zone in the Laramide stress pattern; the Dakota contains no shear fractures here, only dilational joints. **1.5**

31.0 Milepost 34. For the next several miles road traverses Quaternary alluvium in the vegetated playa of North Pasture, locally bounded by the McCartys flow. Note the extensive landslide cover on slope of Cebolleta Mesa to left. **1.2**

32.2 Sand Canyon at 10:30; ridge to right of highway is dip slope on basal Dakota Ss. **1.8**

34.0 Milepost 31. Lava flows on right; low mesa at 11:00 capped by Atarque Ss Mbr of Tres Hermanos Fm, overlying the Rio Salado Tongue of Mancos Sh. **0.2**

34.2 The yellowish sandstone in hills to right at 1:30–3:00 is Tres Hermanos Fm that has been downdropped about 500 ft. The ridges to the north and south are east-dipping Dakota and Zuni Ss; the Tres Hermanos block on the right dips west (Maxwell, 1986). West dips mark this faulted zone for several miles to the south and can be clearly seen at Stop 2 where the west dips locally form an anticlinal buckle against the east dips of Cebolleta Mesa. **1.5**

35.7 Crossing fault that juxtaposes Tres Hermanos Fm and Dakota Ss; small sandstone knob near road on the right is a block of Tres Hermanos Fm, bounded on its west side by Oak Canyon Mbr of Dakota Ss; 500 ft of vertical separation is indicated. **1.8**

37.5 **STOP 2** (optional). Bear right and park alongside highway about 100 yards past ruins of abandoned shack on the right. Cross fence and walk 400 ft west to borrow pit, a source for road metal when NM-117 was being paved in the 1970's. **Caution, the eastern highwall is locally unstable and should be approached accordingly.** A panoramic index map showing landmarks visible from the southern end of the pit is presented in Figure 2-37.5a. This stop provides a good view of the Quaternary cinder cones called the Chain of Craters on horizon to west. This NNE-trending vent zone is considered to reflect a deeply penetrating fracture system with the same orientation.

The "117 borrow pit" lies within a north-trending zone of normal faults, most of which are downthrown to the west, as mapped by Maxwell (1986). Maxwell has postulated a right lateral component on this fault zone, largely based on the geometry and displacement of the wedge-shaped block of Tres Hermanos Fm found 3 mi to the north of this stop. Wengerd (1959) named this fault zone the Hickman fault system, which, as he stated, forms the western margin of a synclinal horst

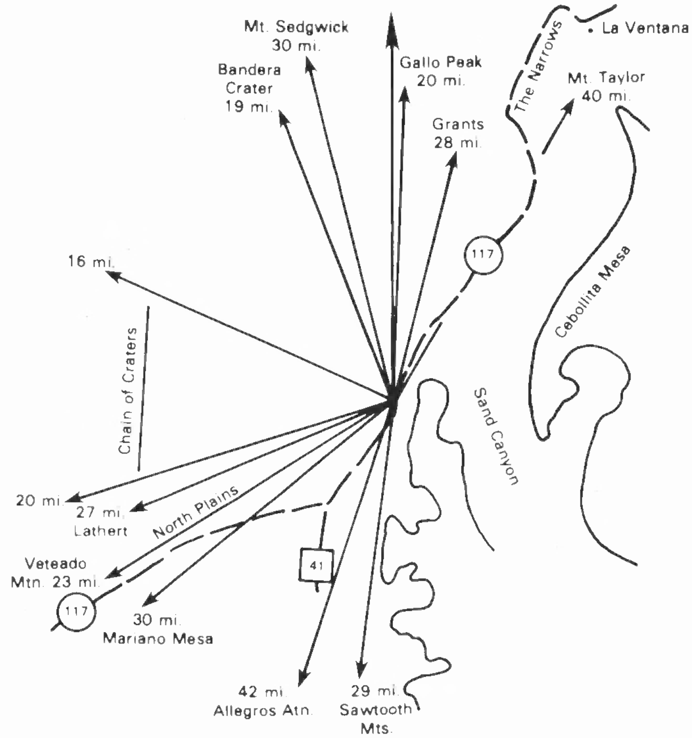

FIGURE 2-37.5a. Panoramic index for Stop 2.

between it and the Red Lake fault zone. Cather and Johnson (1984) and Cather (this guidebook) interpret the Hickman as an up-on-the-west reverse fault in Laramide time with a possible component of right slip. The southern continuation of the Hickman zone, just west of Pie Town, is expressed as an asymmetric anticline that sharply warps Eocene and Miocene strata down to the northwest (Chamberlin, 1981). This monoclinal-like drape fold, with 30° dips on the NW limb, is associated with small down-to-the-southeast normal faults antithetic to the basement structure. A similar pattern of strong downwarping to the west, and related antithetic faults, are present in blocks of Dakota and Zuni Ss that are exposed in the narrow drainage about 0.5 mi north of Stop 2. On the west edge of the zone, the Dakota Ss dips 40° to the west.

The "117 borrow pit" is about 150 ft wide, 400 ft long and 30 ft deep along the eastern highwall and parallels the north-trending crest of the hill. The pit provides excellent exposures of silicified and sheared basal Dakota Ss. Several steeply dipping shear surfaces that strike NW (320–330) and N (355 to 010), show strike-slip slickensides plunging less than 20°. A few of these also exhibit highly polished dip-slip slickensides of small normal faults. The best examples of superimposed slickensides are present along the eastern highwall of the pit. Several east and west dipping low-angle microthrusts are also well exposed on the NW wall of the pit. In contrast to the Exit 89 area (Day 1, Stop 5), the microthrusts are distinctly truncated by a NW-striking (330) crushed zone about 3 ft wide that exhibits a dextral sense of shear. The crushed zone is well exposed in the north wall of the pit near the west edge (Fig. 2-37.5b). The dextral sense of shear is indicated by mm-scale offsets of the microthrusts and by short synthetic Reidel shears.

FIGURE 2-37.5b. Looking north at a 3-ft wide crushed zone in Dakota Ss on north wall of borrow pit at Stop 2.

A small normal fault, about 10 ft east of the crushed zone, displaces a reddened bed at the top of the outcrop about 1 ft down-to-the-east, against normal colored Dakota. Bedding on three sides of the pit dips gently at about 6° to the ENE; but at the SW corner of the pit the dip reverses toward the WSW at 12°. This change in dip appears to occur sharply, like a buckle, adjacent to a poorly exposed crush zone at south end of the pit.

In summary, the observations at this stop indicate an early period of nearly horizontal dextral shear along the Hickman zone followed by a later period of dip-slip normal faulting. Based on regional patterns, these periods are most likely related to Laramide shortening and Neogene extension, respectively.

The basal Dakota here may be correlative with the Encinal Canyon Ss Mbr. The hill and slope north of the stop is Oak Canyon Mbr of Dakota, composed of sandstone, siltstone and paludal shale, grading westward into the lower part of the Mancos Sh (Landis et al., 1973). The Cubero and Paguate tongues of Dakota Ss are not present. The Twowells Tongue is exposed at the base of the mesa about 0.7 mi SSE of this area.

On the east side of the highway near the wash is the site of an oil test drilled in 1959 by Southland Royalty Corporation; TD 4638 ft after penetrating 268 ft of Precambrian granite. Thicknesses of units penetrated by the hole are: Pennsylvanian limestone, 120 ft; Permian Abo Fm, 400 ft, Yeso Fm, 1011 ft, San Andres Ls (and some Glorieta Ss), 456 ft; Triassic Chinle Fm (and some Moenkopi), 2080 ft; Jurassic Zuni Ss and Cretaceous rocks, 305 ft. Jurassic rocks are truncated not far south of here, and the Cretaceous then rests on Chinle Fm. After stop, **continue south** on NM-117. **1.5**

39.0 Milepost 26. Road descends across Quaternary fault scarp masked by eolian sand. **0.9**

39.9 **Junction just ahead.** County road 41 to left goes to Pie Town; **continue on NM-117.** Sawtooth Mts and Datil Mts at 9:30. Southern end of El Malpais lava field on right; road ahead for the next 17 mi is on the North Plains section of the Quaternary lava field. **0.1**

40.0 Milepost 25. From 8:00 to 9:30 note gullied break in slope that is southward continuation of Quaternary fault scarp in alluvium crossed at mile 39.0. **0.2**

40.2 Leaving El Malpais National Monument; however, we are still in Cibola Co., New Mexico's newest (1980), which has not yet produced a U.S. President. **0.5**

40.7 Gus Raney estate on right. **0.6**

41.3 A thin veneer of eolian sand covers the North Plains lava flows; longitudinal dunes and sheets with WSW trend occur throughout this region **1.7**

43.0 Milepost 22. Highway rises onto upper surface of flow. Basalt from roadcuts near here has yielded an age of 3.7 my (Baldridge et al., 1989). The low position in the landscape for this Pliocene(?) flow is problematical. **1.0**

44.0 Milepost 21 (Fig. 2-44.0). Panorama of landmarks visible from this point, clockwise from 10:00, are: (1) western edge of Sawtooth Mountains, (2) Alegres Mountain at about 10:30 is highest point in view (10,280 ft), (3) Mariano Mesa with gentle southward slopes at about 11:30, (4) Techado Peak at 12:00, (5) twin peaks of Veteado Mountain at about 12:15 and (6) Mujeres Mountain at about 1:00. Also note the chain-of-craters area from 1:30 to 3:30. **3.0**

47.0 Milepost 18. **0.5**

47.5 Vesicular basalt in roadcut on right. **2.0**

49.5 Nonmarine Cretaceous rocks (Dakota?) exposed in hills at 9:00 to 9:30. **0.6**

50.1 Veteado Mountain at 11:45; the north peak is capped by a 12.6-my-old basalt (Baldridge et al., 1989) conformably over Miocene Fence Lake Fm, which disconformably overlies Eocene-Oligocene Spears Fm. The lower slope of the mountain is underlain by Eocene Baca Fm. **4.4**

54.5 Pressure ridges of basalt mantled by eolian deposits and soil visible both sides of road. **1.6**

56.1 Milepost 9. Scoria and lava cones at 3:00. **0.5**

56.6 Veteado Mtn at 11:00, elev. 8525 ft; Upper Cretaceous rocks exposed sparingly around base. **0.6**

57.3 Highway drops off edge of North Plains basalt field. **2.1**

59.4 Mujeres Peak at 2:30; note edge of North Plains basalt flow behind ranch in middle distance. **1.3**

60.7 Mesa ahead at 11:00 to 12:30 is composed of Upper Cretaceous Moreno Hill Fm overlain by an erosionally thinned interval of Eocene Baca Fm and capped by the Miocene Fence Lake Fm. **2.4**

FIGURE 2-44.0. Part of the road-log crew, deeply engrossed, but content to discuss the local geology from a safe distance; near mile 44.0.

63.1 Milepost 2. Small scar at 1:00, on left side of Gobbler Knob, exposes Baca Fm capped by the Fence Lake Fm. Gobbler Knob is the northernmost known occurrence of the Baca Fm. Notch at 12:00 marks a NNE-trending normal fault, which passes east of Gobbler Knob. This fault drops the Fence Lake down about 40 ft to the east and preserves about 120 ft of Baca Fm on the downthrown side. Thus, both pre– and post–Fence Lake movement is demonstrated for this fault. **2.0**

65.1 **Junction** with NM Highway 36; **stop sign. Park** on NM-117 at stop sign and **walk 0.3 mi to right** up NM-36 to Stop 3. Note yellowish sandstones and gray shales, typical of Upper Cretaceous rocks, in this case the Moreno Hill Fm, near the bottom of the hill. **0.3**

65.4 **STOP 3.** Lathert Canyon. This stop permits close examination of three rock-stratigraphic units and one (less than obvious) mappable paleosol of regional extent (Chamberlin, 1981; Guilinger, 1982; and see mini-paper by Chamberlin for this stop). The rock units are the middle to late Turonian Moreno Hill Fm, the Eocene Baca Fm and the Miocene Fence Lake Fm. The unnamed lateritic paleosol, very tentatively assigned a late Paleocene age, is represented here by an anomalously reddened and mottled zone in the uppermost 30 ft of the Moreno Hill Fm. This ancient weathering zone is informally referred to as the pre-Baca paleosol.

In his book on pedology, Birkeland (1974) pointed out that one person's buried soil horizon (paleosol) is another person's geologic deposit—or another person's post-burial zone of ground-water alteration. Criteria for the distinction of these possibilities are summarized in the mini-paper by Chamberlin. Important observations to make here are: (1) the unconformity at the top of the reddened Moreno Hill Fm is well defined by a sharp increase in grain size to coarse-grained and conglomeratic sandstone at the base of the Baca Fm (Fig. 2-65.4a); (2) mudstones of the uppermost Moreno Hill Fm grade downwards from pale red (hematitic) to pale red mottled with yellowish brown (limonitic) to "normal Cretaceous" colors of pale gray (ferrous iron); and (3) thin red sandstones occur in the gray shales near the base of the zone.

It is well established that the oxidation of ferrous iron minerals (e.g., siderite and marcasite) to red ferric iron (hematite) requires an intermediate hydration step represented by yellowish brown limonite (Adler, 1970). The dehydration of limonite to hematite requires time and heat and is irreversible under surface weathering conditions. Thus, the typical yellow-brown color of Cretaceous sandstones represents modern oxidation and weathering on the outcrop. In contrast, red hematitic colors represent ancient oxidation prior to weathering of the modern outcrop. In other words, red beds in the outcrop are red beds in the subsurface.

Because of the wick effect (high capillarity), mudstones in an unsaturated zone have a greater hydraulic conductivity than adjacent sandstones. The red and mottled mudstones are therefore interpreted to represent ancient oxidation in an unsaturated zone. The red sandstone in gray mudstone represents oxidation in a saturated zone where the sandstone was preferentially oxidized due to relatively high permeability.

FIGURE 2-65.4a. Roadcut along north side of Lathert Canyon at Stop 3. Person is pointing to unconformable contact of Moreno Hill Fm (Upper Cretaceous) with the overlying Baca Fm (Eocene).

The Eocene Baca Fm is a fluvial and lacustrine unit, deposited dominantly by east-flowing streams in an east-west-trending basin along the southern margin of the Colorado Plateau (Cather and Johnson, 1984). The main source of sediment was the Laramide Apache uplift in east-central Arizona. Near the center of the basin, on the north flank of the Datil Mountains, the Baca is 1800 ft thick. There it contains a basal unit derived from the Zuni uplift on the north and an upper unit derived from the Morenci uplift on the south. Lacustrine beds near the Gallinas Mountains reflect damming of the general easterly flow by the north-trending Sierra uplift near Socorro.

The Baca Fm here at Lathert Canyon consists of about 120 ft of coarse-grained conglomeratic sandstones and interbedded red mudstones (see measured section, Fig. 2-65.4b). Pebble imbrications and crossbedding indicate easterly paleocurrent directions. Quartzite pebbles are dominant, but reddish-brown quartz porphyry (rhyolite) pebbles are also common. They are most likely Mesozoic rhyolites from southwestern Arizona. A waxy (hornfelsic?) luster distinguishes these older rhyolites from glassy, sanidine-bearing rhyolite tuffs of the Mogollon-Datil field. Near the fence at the top of the roadcut,

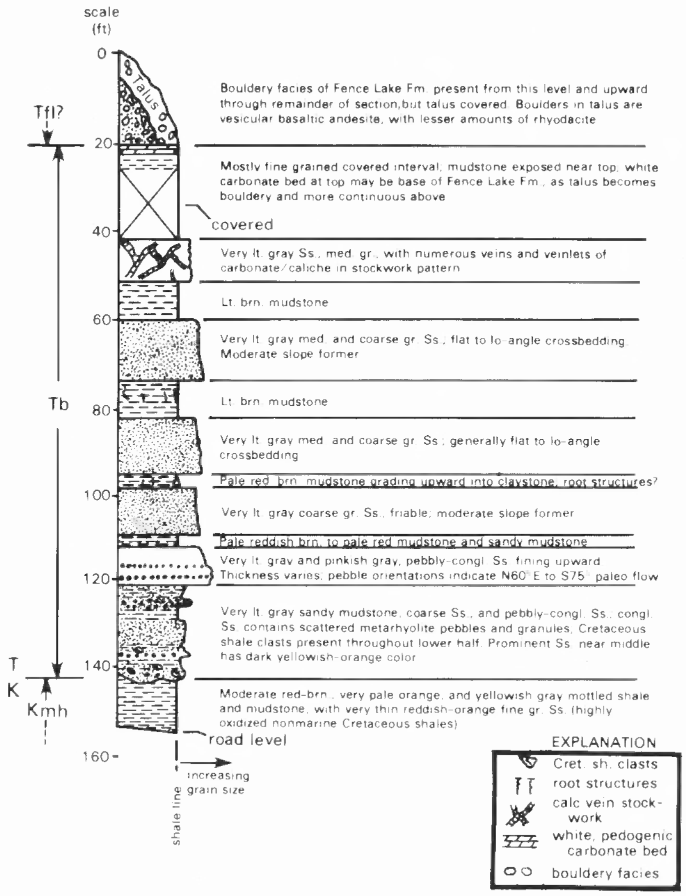

FIGURE 2-65.4b. Measured section of Baca Fm exposure in Lathert Canyon. Section measured by O. J. Anderson and R. M. Chamberlin.

micritic carbonate veinlets (caliche) in the Baca Fm suggest a period of arid weathering prior to deposition of the overlying Fence Lake Fm.

The Miocene Fence Lake Fm of McLellan et al. (1982) locally consists of proximal basalt-boulder deposits at the base (debris flows?) that grade upwards into pinkish-gray conglomeratic sandstones. Pebbles are mostly basalt and andesite; sanidine rhyolite and quartzites (latter reworked from Baca Fm) are sparse to rare. Clast lithologies, outcrop distribution and a few current observations generally indicate deposition by a northwesterly-trending braided channel system flowing off the northern margin of the Mogollon-Datil volcanic field. The Fence Lake Fm unconformably buries the Pie Town dike system, dated as 27.7 my by Laughlin et al. (1983). At Veteado Mountain and Tejana Mesa, the Fence Lake Fm is conformably overlain by basalt flows that yield K-Ar ages of 12.6 my and 6.7 my, respectively (Baldridge et al., 1989; Dethier et al., 1986). Based on these constraints, the Fence Lake Fm is considered to be early to late Miocene in age.

The 120 ft of Baca Fm at Lathert Canyon most likely reflect local uplift and erosion prior to Fence Lake deposition. The original depositional thickness of the Baca Fm at Mariano Springs Mesa, 6 mi to the south, was 600 ft (Guilinger, 1982). At the head of Lathert Canyon, one-half mile to the west, the oxidized top of the Moreno Hill is repeated on the upthrown side of a NNE-trending normal fault. This is the same fault as previously described at mile 63.1. Only 30 ft of Baca are preserved on the upthrown block, which implies a mostly Miocene age for this fault. This unnamed fault is but one of a series of NNE-striking Neogene normal faults that form a shallow, asymmetric graben at the south end of the El Malpais–North Plains lava field. From Santa Rita Mesa to Pie Town, the graben is 40 mi wide. Displacements on these faults are about 120 ft, but the Hickman fault at Pie Town may have as much as 500 ft of Neogene displacement. After stop, **continue west** on NM-36. **0.5**

CRITERIA FOR THE RECOGNITION OF A PRE-EOCENE LATERITIC WEATHERING PROFILE, WEST-CENTRAL NEW MEXICO

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Buried soils and ancient weathering profiles characteristically: (1) parallel an ancient land surface (unconformity or diastem), (2) consist of epigenetic alteration zones that *cut across bedding*, (3) display vertical zonation related to weathering processes and (4) often contain unique textures and minerals (Birkeland, 1974, p. 24–26). Paleosols also predate the overlying deposit. Therefore, channels obviously scoured into the zone of alteration and regolithic concentrations of weathered debris above the altered zone will help distinguish paleosols from post-burial zones of ground-water alteration. Most geologists observing the Lathert Canyon section would simply include the mottled red mudstones, below the basal Baca conglomeratic sandstones, with the Baca Formation as part of the Eocene rock-stratigraphic unit. However, this alternative interpretation soon falters because the Eocene-Turonian unconformity then appears to look gradational or even intertonguing. Several geologists who mapped this problematical contact in west-central New Mexico called it a "transition zone" (see Chamberlin, 1981, p. 15, for references).

The objective of this brief paper is to summarize the regional characteristics of the "transition zone" and document key outcrop areas where field relationships demonstrate that it is the subsolum ("C" horizon) of a pre-Baca lateritic paleosol. These observations are based on detailed mapping of the paleosol in the Datil Mountains area (Chamberlin, 1981) and in the Tejana Mesa area (Guilinger, 1982) and unpublished reconnaissance work of the author.

In west-central New Mexico, regionally reduced (carbon-rich and ferrous iron-rich) coastal plain deposits of the Crevasse Canyon Formation (late Turonian to Coniacian) and the Moreno Hill Formation (middle to late Turonian) are unconformably overlain by regionally oxidized (carbon-poor and ferric iron-rich) intermontane basin deposits of the Baca Formation (middle-late Eocene). Reconnaissance and detailed mapping along the 100-mi-long outcrop belt (from Riley to the Arizona border) have revealed a stratiform zone of strongly oxidized (hematitic) mudstones and sandstones in the uppermost 25 to 150 ft of the Cretaceous section. Altered Cretaceous mudstones are light purplish-gray to maroon, and often mottled with yellowish-brown. Altered sandstones do not exceed upper medium grain size; and most are pale red to lavender, but some are brick red or bleached white. Where present, small spherical concretions of hematite-cemented sandstone (after early diagenetic iron sulfide) are particularly diagnostic of sandstones in the ancient oxidation zone.

The basal redox boundary of the oxidation zone dominantly follows oxidized sandstone/reduced mudstone contacts. However, redox boundaries also locally cut across sandstone beds. The most revealing outcrop that led to the recognition of the pre-Baca paleosol is a C-shaped fossil roll front exposed near Alamocita Creek on the north flank of the Datil Mountains (NW¼ NE¼ sec. 12, T2N, R11W; in draw at elevation of 7700 ft). This one outcrop clearly demonstrates that the red, lavender and white sandstones of the "transition zone" are altered equivalents of the yellowish sandstones typical of the unaltered Crevasse Canyon Formation.

In the Datil Mountains area, preferential oxidation of sandstones over mudstones in the lower third of the zone (30–50 ft) is consistent with alteration by oxidizing ground waters. This contrasts strongly with relatively equal oxidation of sandstones and mudstones in the upper two-thirds, which is consistent with alteration by oxidizing soil waters in the vadose zone. Near Remuda Canyon, a southeast-trending paleovalley in the basal Baca Fm has completely scoured through the upper vadose section of the oxidation zone. Clasts of banded hematite (texturally similar to hardened laterite) and variably oxidized Cretaceous rocks (both red and yellow) are common in basal conglomeratic beds of the Baca Formation. North of Red Hill the oxidation zone is completely truncated by cobble conglomerates in the basal Baca, yet it reappears 10 mi to the west at the first roadcut entering Arizona on Highway 60.

Near the structurally depressed margin of the Baca basin at Riley, the oxidation zone is locally mantled with large slabs of solid hematite (as much as 6 inches across and 1 inch thick). The crustiform hematite displays polygonal desiccation cracks and is interpreted to be derived from a hardened laterite crust. A "B" horizon of the lateritic paleosol must have been preserved near here; more work is needed at this locality.

These regional observations indicate that the stratiform oxidation zone is most reasonably interpreted as the "C" horizon of a pre-Baca lateritic soil, which reflects a widely recognized transition from a warm-wet climate to a warm-dry climate in early Tertiary time. The pre-Baca paleosol is tentatively correlated with a late Paleocene period of inter-Laramide tectonic stability (ca 60–55 my ago) defined by Chapin and Cather (1981). Early Tertiary lateritic weathering profiles, similar to the pre-Baca paleosol, are widespread from Wyoming to Georgia. The base of the pre-Baca paleosol is the host for a small uranium deposit at the Red Basin mine, which was described in the 1959 NMGS guidebook to west-central New Mexico (Anonymous, 1959).

65.9 Culvert; approximate location of NNE-striking fault which drops the Moreno Hill/Baca contact down to the east as much as 100 ft. **0.2**

66.1 Roadcuts in highly oxidized (red and orange) strata of the Cretaceous Moreno Hill Fm. On the south side, the Baca Fm is present at top of roadcut, but considerably thinned. **0.5**

66.6 Borrow pit at top of hill, at 2:00, is in Fence Lake Fm. **0.5**

67.1 Outcrops of Fence Lake Fm at 3:00–4:00 in disturbed ground. **1.6**

68.7 Herman Towner Ranch on left; the nearly flat land locally creates an irresistible temptation to practice dryland farming, but the average annual precipitation of 13 to 14 inches severely limits productivity; it is piñon-juniper country. **0.6**

CLIMATE OF WEST-CENTRAL NEW MEXICO

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There are ten long-term weather stations operating in the field conference area. These stations and the years of record used in this discussion are: El Morro National Monument (1938–1983), Fence Lake (1933–1983) (Table 1), Gallup (1948–1979) (Table 2), Grants (1953–1983) (Table 3), Laguna (1981–1983), McGaffey (1932–1983), San Fidel (1931–1976), San Mateo (1939–1983), Thoreau (1953–1983) and Zuni (1949–1983) (Table 4). Unless otherwise cited, all data are from the Office of State Climatologist, 1988.

Among the ten stations, Laguna has the lowest elevation (5800 ft) and the highest mean annual temperature (53.3°F). By contrast, McGaffey

TABLE 1. Temperature and precipitation averages, Fence Lake, New Mexico, 1933–1983.

	Temperature (°F)			Precipitation (inches)				
	Max	Min	Mean	Mean	High--Yr		Low--Yr	
January	43.6	14.4	29.0	1.00	2.65	39	0.00	72
February	47.5	17.9	32.7	1.13	2.96	80	0.00*	72
March	53.7	22,8	38.3	1.21	3.46	81	0.00*	74
April	61.6	27.2	44.4	0.65	1.52	41	0.00*	82
May	72.5	35.0	53.8	0.61	1.79	41	0.00*	77
June	82.9	43.4	63.1	0.48	2.56	72	0.00*	82
July	86.3	52.3	69.3	2.12	5.16	65	0.54	70
August	82.9	50.2	66.6	2.35	5.68	82	0.42	73
September	76.7	43.5	60.2	1.56	4.36	75	0.44	79
October	67.5	31.9	49.7	0.97	5.77	72	0.00*	80
November	54.4	21.5	38.0	0.87	2.14	82	0.00*	70
December	46.4	16.2	31.3	1.03	3.04	40	0.02	81
Annual	64.7	31.4	48.0	13.97	19.99	65	8.26	66
Winter	45.8	16.2	31.0	3.16	6.03	80	0.94	71
Spring	62.6	28.3	45.5	2.46	6.37	81	0.00*	74
Summer	84.0	48.6	66.3	4.95	7.93	34	2.16	73
Fall	66.2	32.3	49.3	3.40	8.20	72	1.23	73

Source: State Climatologist 1988 * Also earlier years

TABLE 2. Temperature and precipitation averages, Gallup, New Mexico, 1948–1979.

	Temperature (°F)			Precipitation (inches)				
	Max	Min	Mean	Mean	High--Yr		Low--Yr	
January	43.5	13.5	28.5	0.56	1.65	57	0.00*	76
February	48.6	17.9	33.3	0.45	2.26	62	0.00*	76
March	54.8	23.3	39.1	0.54	2.39	54	0.00*	76
April	64.9	29.1	47.0	0.36	2.36	52	0.00*	79
May	74.2	36.7	55.5	0.41	1.46	54	0.00*	74
June	84.8	44.7	64.8	0.47	1.54	67	0.00*	74
July	88.3	53.2	70.8	1.65	4.41	55	0.00*	68
August	85.1	51.8	68.4	1.49	3.18	63	0.09	50
September	79.7	44.4	62.0	0.94	3.35	71	0.00*	79
October	69.3	33.2	51.3	1.28	5.75	72	0.00*	75
November	54.9	21.4	38.2	0.64	3.12	78	0.00*	77
December	45.9	13.8	29.9	0.60	2.67	65	0.00*	77
Annual	66.2	31.9	49.1	9.38	14.55	57	4.39	56
Winter	46.0	15.1	30.6	1.61	4.47	62	0.04	76
Spring	64.7	29.7	47.2	1.30	4.04	54	0.27	50
Summer	86.1	49.9	68.0	3.60	6.73	48	1.00	78
Fall	68.0	33.0	50.5	2.87	7.34	72	0.48	55

Source: State Climatologist 1988 * Also earlier years

TABLE 3. Temperature and precipitation averages, Grants, New Mexico, 1953–1983.

	Temperature (°F)			Precipitation (inches)				
	Max	Min	Mean	Mean	High--Yr		Low--Yr	
January	44.4	13.7	29.1	0.43	1.06	79	0.00	76
February	49.7	17.6	33.7	0.45	1.66	82	0.03	70
March	55.9	22.8	39.4	0.48	1.71	82	0.00*	74
April	65.7	29.2	47.5	0.34	1.33	80	0.00*	78
May	74.5	37.7	56.1	0.47	1.96	69	0.00*	75
June	85.2	47.0	66.1	0.54	3.07	65	0.00*	80
July	86.7	55.1	70.9	1.83	3.91	65	0.40	63
August	83.5	52.5	68.1	2.11	4.54	55	0.47	56
September	78.3	44.4	61.4	1.34	4.23	75	0.00*	57
October	68.1	32.5	50.3	1.09	4.69	72	0.05*	75
November	55.2	21.5	38.4	0.45	1.47	78	0.00	74
December	46.2	14.3	30.3	0.56	2.70	65	0.00*	81
Annual	66.1	32.4	49.3	10.11	17.11	65	4.41	56
Winter	46.8	15.2	31.0	1.45	3.32	66	0.45	70
Spring	65.4	29.9	47.6	1.30	3.04	69	0.09	63
Summer	85.2	51.5	68.4	4.48	8.92	65	1.84	78
Fall	67.2	32.8	50.0	2.88	6.91	72	0.29*	56

Source: State Climatologist 1988 * Also earlier years

TABLE 4. Temperature and precipitation averages, Zuni, New Mexico, 1949–1983.

	Temperature (°F)			Precipitation (inches)				
	Max	Min	Mean	Mean	High	Yr	Low	Yr
January	45.7	16.3	30.8	0.87	2.55	80	0.06	72
February	49.4	20.2	34.7	0.73	2.74	80	0.02	72
March	54.7	25.5	40.1	0.91	3.27	81	0.00	72
April	64.2	31.2	47.8	0.52	2.01	52	0.00	82
May	73.5	38.6	56.1	0.40	1.94	79	0.00*	66
June	84.0	47.4	65.7	0.35	1.51	72	0.00*	82
July	87.7	55.0	71.4	1.97	3.73	57	0.56	78
August	84.4	53.7	69.1	2.07	5.53	63	0.07	50
September	79.2	46.9	63.1	1.18	3.54	71	0.00*	57
October	69.5	35.8	52.7	1.18	6.65	72	0.00*	52
November	56.2	24.8	40.5	0.67	1.84	52	0.00	80
December	47.1	17.4	32.3	0.85	1.95	67	0.00	81
Annual	66.3	34.4	50.4	11.70	17.03	69	4.41	50
Winter	47.4	17.9	32.6	2.45	6.53	80	0.54	59
Spring	64.2	31.8	48.0	1.82	4.94	81	0.41	77
Summer	85.4	52.0	68.7	4.39	7.98	67	1.17	78
Fall	68.3	35.8	52.1	3.04	8.68	72	0.17	55

Source: State Climatologist 1988 * Also earlier years

has the highest elevation (7800 ft) and the lowest mean annual temperature (43.1°F). The other eight stations are clustered between 6200 ft and 7250 ft and have mean annual temperatures of between 47.5°F and 51.8°F. Tuan (1969) found that the average vertical temperature gradient for New Mexico is 5°F for every 1000 ft. In the field conference area, the vertical gradient averages 4.9°F per 1000 ft. Mean annual temperature range, the difference between the warmest month and coldest month, ranges from 42.3°F at Gallup to 38.3°F at Zuni. Record high temperatures are: 98°F (Fence Lake, San Mateo, Thoreau), 99°F (McGaffey), 100°F (El Morro), 101°F (Gallup, Grants, Zuni), 102°F (Laguna) and 104°F (San Fidel). Record low temperatures range from –18°F at Laguna to –40°F at Fence Lake, although Tuan (1969) reports an unofficial low of –57° at Ciniza, near Gallup, on 13 January 1963. Eight of the ten stations recorded their record low temperatures during the period 6–8 January 1971.

Precipitation is modest throughout the region. Annual averages are: 8.40 inches (San Mateo), 9.23 inches (Laguna), 9.38 inches (Gallup), 9.44 inches (San Fidel), 10.11 inches (Grants), 10.61 inches (Thoreau), 11.70 inches (Zuni), 13.13 inches (El Morro), 13.97 inches (Fence Lake) and 17.39 inches (McGaffey). The driest year on record is 1.96 inches at Laguna in 1956. The wettest year on record is 26.60 inches at McGaffey in 1982. Late summer–early fall is the season of maximum precipitation, most of which is derived from thunderstorms. August is the wettest month at nine of the ten stations. Winter fronts, however, provide a secondary maximum of precipitation, some of which falls as snow. McGaffey, at an elevation of 7800 ft, averages 64.9 inches of snow annually; its record snowfall is 143.6 inches in 1952.

Although average annual precipitation in the region is comparable to that received over much of New Mexico, rainfall intensity is among the lowest in the state. For example, it is estimated that a 24-hour, 100-year storm will produce 2.6–3.0 inches of rainfall across the region. In eastern New Mexico, the precipitation from a 24-hour, 100-year storm is estimated at 5.0–6.0 inches (Miller et al., 1973). The difference in intensity between the two areas can be explained in part by the fact that the field conference area has less access to moist and unstable air from the Gulf of Mexico during the summer thunderstorm season.

69.3 The obscure tree-covered edge of the North Plains basalt field is about 0.5 mi to the right. Cinder cones at 3:00 in distance. The basalt field begins to neck down very rapidly westward from this point. Where we cross it again north of Fence Lake it is less than 3 mi wide, but it extends across the state line into Arizona. **1.8**

71.1 Cerro Blanco at 10:00 composed of Fence Lake Fm. Lower elevation of Fence Lake–capped surface at 9:00 is an expression of the NNE-trending Continental Divide fault, another of the down-to-the-east faults described at Stop 3. **0.4**

71.5 Milepost 28. Cross Continental Divide fault, a NNE-trending late Cenozoic fault that drops Moreno Hill Fm down to the east. The low scarp in Quaternary basalt at 2:30 and the "sag pond" at 5:00 nearer the road are probably Quaternary expressions of the fault. **0.2**

71.7 Roadcuts in Moreno Hill Fm. **0.3**

72.0 Escarpment at 10:00, at head of Puertecito Draw, exposes yellow Moreno Hill Fm overlain by gray Fence Lake Fm. **3.3**

75.3 Roadcuts in Moreno Hill Fm just ahead. **0.9**

76.2 At 9:30 on crest of small hill is a NW-trending mafic dike, at the northwesternmost limit of the 27.7-my-old Pie Town dike system (Laughlin et al., 1983). About 10 mi north of here, the same NW-structural trend is expressed by the Laramide Atarque monocline. Thus this is a tempting place to draw a line between an extended zone on the periphery of the Colorado Plateau and an unextended(?) core of the Colorado Plateau. **0.6**

76.8 At 3:00, a thick fluvial sandstone of the Moreno Hill Fm forms a low bench. **0.2**

77.0 Crest of hill; flat surface of Santa Rita Mesa, on the skyline at 12:00, is capped by Fence Lake Fm. **0.7**

77.7 Fluvial sandstones of Moreno Hill Fm in roadcuts. **0.2**

77.9 Highway descends into headwaters of Jaralosa Draw; note good exposures of Moreno Hill Fm on right as we descend. **3.6**

81.5 Milepost 38. Thin alluvium covers Moreno Hill Fm. **1.7**

83.2 Enter **Fence Lake;** elev. 7070 ft. A high school was maintained here until 1948 when they graduated a class of six. **0.1**

83.3 **Stop sign—turn left** and **proceed south** on NM-32. Fence Lake Mercantile on right (Fig. 2-83.3). New genera and species of lower Turonian ammonites collected from the Fence Lake area are described in Cobban and Hook (1983). **0.1**

83.4 Pavement ends. **1.9**

85.3 **Cattleguard;** road makes sharp right turn. Relatively flat surface we are traversing is gentle northern flank of Santa Rita Mesa, here developed on a thin residuum of

FIGURE 2-83.3. Downtown Fence Lake, New Mexico.

the Fence Lake Fm which is the source of scattered cobbles and boulders of basalt and basaltic andesite. **1.0**

86.3 Road makes sharp left turn; local access road from right. **0.1**

87.3 Road makes sharp right turn. **0.4**

87.7 Road makes sharp left turn. **1.1**

88.8 Road makes sharp turn to right. **0.2**

89.0 East-facing escarpment, 0.5 mi ahead, marks the western edge of the shallow North Plains/El Malpais graben, described at Stop 3. This fault zone, cutting across Santa Rita Mesa, displaces the base of the Fence Lake Fm about 130 ft down to the southeast. **0.6**

89.6 Good outcrops of bouldery Fence Lake Fm along road as it climbs the fault scarp. **2.4**

92.0 **STOP 4.** Stop at crest of Moreno Hill, near borrow pit on left. Elevation here is 7320 ft. Walk 0.2 mi down hill along the road to examine unconformable contact between the Miocene Fence Lake Fm and the Turonian Moreno Hill Fm (Fig. 2-92.0a).

The Miocene gravel clasts are dominantly basalt with less abundant pyroxene andesite, hornblende rhyodacite, minor rhyolite and sparse quartzite. Pebble imbrications here indicate northwesterly paleocurrents. These observations, coupled with the volcanic highlands visible to the south, demonstrate their origin as deposits of a northwesterly flowing stream system that drained the northern flank of the Mogollon-Datil volcanic field in Miocene time.

The broad erosional valley immediately to the south contains the drainages of Hubbell Draw and Largo Creek, tributaries to the WNW-flowing Little Colorado River of central Arizona. Obviously, the Fence Lake Fm has long been cut off from its source. Across the valley to the SE, Tejana Mesa is capped by a 6.7-my-old basalt that flowed NW down the paleogradient on top of Fence Lake stream gravels. This mesa and underlying gravels are now gently tilted to the SE, presumably a reflection of late Neogene extension across the graben bounding the El Malpais–Omega basins.

The upper Fence Lake Fm and lower Bidahochi Fm of Repenning and Irwin (1954) are both of late Miocene age and considered to be temporally equivalent. Scarps and inset relationships locally separating these deposits are indictive of late Cenozoic uplift, erosion and backfilling to new base levels, and penecontemporaneous normal faulting. The details of Neogene landscape evolution remain unclear, but the Fence Lake and Bidahochi formations can be safely interpreted in general as deposits of the ancestral Little Colorado River system (see Love, this guidebook).

Walk back to the top of the hill. This is a good place to enjoy the view (weather permitting) while you read discussions of the southern margin of the Colorado Plateau and the Salt Lake Coal Field, as presented in the following mini-papers.

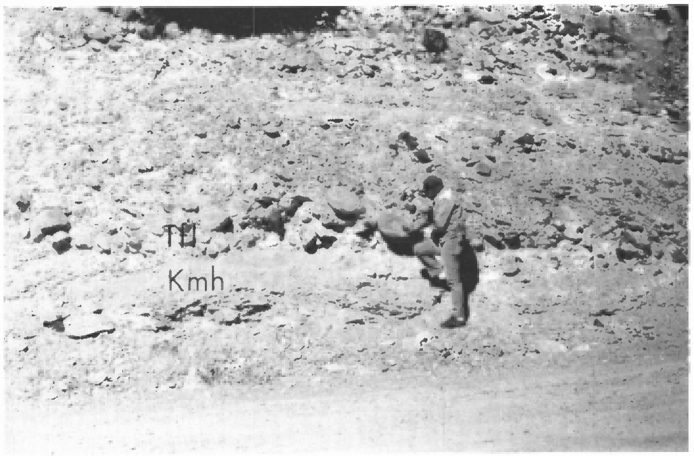

FIGURE 2-92.0a. Contact between Upper Cretaceous Moreno Hill Fm (Kmh) and the lower Miocene Fence Lake Fm (Tfl). Bouldery facies characterize basal Fence Lake sediments.

THE SOUTHERN MARGIN OF THE COLORADO PLATEAU: A RAGGED EDGE BOUNDED BY NEOGENE DOMAINS OF CRUSTAL EXTENSION

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Geologists, geophysicists and physiographers now generally agree that the Colorado Plateau (CP) is a *relatively* rigid crustal block (microplate) surrounded by *relatively* mobile orogenic belts. Regional geophysical data show that from the plateau interior (Four Corners area) outwards toward the Rio Grande rift (RGR) and the Basin and Range (BR), indicators of crustal strength typically decrease (Heinz and Braille, 1988; Thompson and Zoback, 1979). Lithospheric thickness, crustal thickness, upper-mantle seismic velocity, crustal seismic velocity and magnetic intensity (depth to Curie isotherm?) are the parameters cited that reflect crustal strength.

From Albuquerque (A) to the Grand Canyon (GC), the southern margin of the CP is bounded by Neogene domains of crustal extension generally assigned to the RGR and the BR. Figure 2-92.0b(a) shows an interpretative map of extensional domains (shaded) as expressed by grabens filled with Neogene sediments and volcanic rocks. The distribution of the extensional basins is taken primarily from the geologic map of the United States (King and Beikman, 1974) and then plotted on the shaded relief map of Harrison (1969). Continuous shading represents the classic BR where extensional strain (crustal lengthening) is generally over 30%. Lined areas in the Arizona BR are metamorphic-core complexes where total extension is over 60% (Davis, 1981). Lined areas in New Mexico symbolize domains of inferred domino-style crustal extension (Chamberlin, 1983) where extension is estimated to be 25 to 50%. From the BR, extensional domains grade inward toward the CP as narrow asymmetric grabens bounded by high-angle normal faults, many of which appear to be moderately listric. Extensional strain in the region of narrow grabens is estimated to range from about 15% to less than 1% where they terminate. Many individual grabens appear to die out toward the north, suggesting that they opened from south to north.

Isolated extensional basins like the El Malpais (M), the Omega (O), the Estancia (E) and the Vaughn (V) basins are interpreted as incipient grabens with less than one percent extensional strain across them. The El Malpais basin appears to terminate abruptly near Grants. Individual mapped normal faults of indicated Neogene age within the CP are shown as hachured lines. The innermost of these faults may outline an unextended interior of the CP. We suggest that when viewed with regard to extensional strain, the southern margin of the CP is a ragged edge, like the splintered edge of a plywood sheet torn from the side of a building. Extension has evidently followed pre-existing (mostly Laramide) lines of weakness into the resistant microplate.

Cross sections of Figure 2-92.0b allow comparison of the traditional CP boundaries in New Mexico and Arizona. Peirce (1985) describes Mazatzal Peak as a structurally high block (Laramide uplift) in his

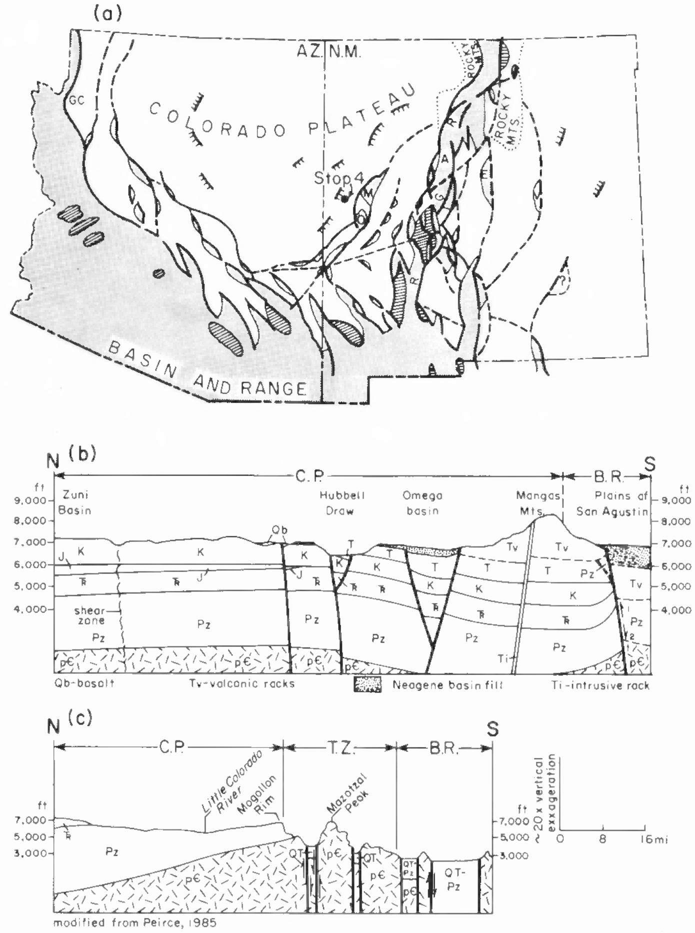

FIGURE 2-92.0b. Map (a) of New Mexico and Arizona (from Harrison, 1969) showing inferred domains of Neogene crustal extension around the southern Colorado Plateau. Cross section (b) from the Zuni Basin to the Plains of San Agustin shows zone of incipient crustal extension within classic Colorado Plateau. Concealed fault block of Paleozoic rocks (Pz) in section (b) is inferred from exposures at Horse Mountain and projected to line of section. Schematic cross section (c) across Arizona "Transition Zone," modified after Peirce (1985). See text for description and abbreviations.

"Transition Zone" (TZ) that did not collapse back into the BR during the subsequent extensional regime. We support Cather and Johnson's (1984) interpretation that the San Agustin arm of the rift (Chapin, 1971) generally represents the collapsed crest of the Laramide Morenci uplift (Chapin and Cather, 1981). The Moreni uplift was a local source of sediment in late Baca time and defines the southern structural margin of the Baca basin (Cather, this guidebook). The Baca basin has recently become an oil exploration frontier similar in setting to the San Juan sag of SW Colorado.

We pick the area from Horse Mountain southward into the San Agustin Plains as New Mexico's closest structural equivalent to the Mogollon rim. On the south flank of Horse Mountain, the base of the volcanic pile appears to rest unconformably on Permian rocks interpreted as an unfoundered piece of the Morenci uplift.

The Jemez volcanic lineament (coincident with our El Malpais–Omega-graben) has been interpreted as a linear zone of late Neogene extension and magmatism within the classic boundary of the Colorado Plateau (Aldrich and Laughlin, 1984; Aldrich et al., 1986). We generally agree, but suggest that the view of Baldridge et al. (1983)—namely that of an incipient zone of extension *concentric* to the CP interior—is just as likely. Peirce's 1985 cross section (Fig. 2-92.0b–c) does not indicate Neogene extension north of Mogollon rim. We believe, however, that if another cross section were drawn from Leupp Comer to Gila Bend, AZ, using the new geologic map of Arizona (Reynolds, 1988) for control, then an inner zone of incipient Neogene extension well north of the Mogollon rim would be apparent. Late Miocene to Quaternary volcanic centers generally define this incipient zone within the southern CP from Mt. Taylor west to Mt. Turnbull, near the Grand Canyon. Quaternary volcanic centers generally lie inboard of Pliocene and late Miocene volcanic centers implying that extension and magmatism has slowly migrated toward the unextended(?) core of the CP during late Neogene time. Small normal faults that are reported to cut the Bidahochi Fm near Sanders, AZ (Howell, 1959) may represent the innermost Neogene extension of the southern CP. Zoback (1988) describes the Four Comers region (CP interior) as being in a zone of weak NNE-directed extensional stress, nearly orthogonal to the stronger WNW-directed extension in the surrounding BR, which would include the incipient zone of extension as defined here. We suggest the shallow strike-slip events triggered by hydraulic fracturing (Zoback, 1988) may represent relict Laramide stresses, not yet relieved from the core of the plateau.

The most significant difference between the ENE-trending classic CP boundary in NM and the NW-trending CP boundary of AZ appears to have been their respective orientation to generally NE-directed Laramide compression and predominantly WSW-directed extension in the southern BR. The SSE-facing boundary in NM has been at a small angle to both compression and extension, thereby favoring development of a strike-slip shear zone along this boundary. In contrast, the NW-trending CP boundary in Arizona has generally acted as a buttress to Laramide compression and Neogene extension, directed at right angles to it. For additional discussion of the CP boundary in Arizona, see Potochnik (this guidebook).

UPPER CRETACEOUS ROCKS OF THE SALT LAKE COAL FIELD, WESTERN CIBOLA COUNTY, NEW MEXICO

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The eastward-pointing wedge-shaped area of Upper Cretaceous and Tertiary sedimentary rocks bounded on the north by the North Plains basalt flow and on the south more or less by US-60 is called the Salt Lake coal field. In the purest sense, the coal field would be limited to the area which Dane and Bachman (1965) designated as Mesaverde Group (Fig. 2-92.0c). This is convenient because these are the rocks that are of specific interest to us here.

Coal occurrences in this vicinity were noted by Shaler (1907), who originally applied the name Salt Lake coal field (after nearby Zuni Salt Lake) to this resource area, separate and distinct from what he designated the Durango-Gallup coal field. He assigned the coal-bearing strata to the lower part of the Mesaverde sequence, and that age assignment was found acceptable to Dane and Bachman (1965), who also used Mesaverde (by then elevated to group rank) to designate these rocks on the state geologic map. The rocks were not traceable in outcrop northward because of the North Plains flow and because of structure (monoclines), so their relationship to the Gallup–Crevasse Canyon sequence in the southern end of the Zuni basin wasn't clear (Fig. 2-92.0c). Furthermore, biostratigraphic detail had not evolved to the point where it could be used to correlate the rocks with the better known sequence to the north; thus, the safe but vague Mesaverde Group assignment.

Molenaar (1973) considered the regressive sequence seen here at Moreno Hill to be part of the Gallup Sandstone. More specifically, he recognized two distinct units—a regressive coastal barrier sandstone at the base overlain by a carbonaceous mudstone and coal-bearing unit that accumulated on the lower coastal plain. He referred the entire sequence to the Atarque Member and considered it to be the lower part of the Gallup. This worked well (except for minor details of correlation with the offshore section) and represented a clarification of how the Moreno Hill section related to the main Gallup to the north—it represented a minor regressive or progradational event older than the main Gallup regression.

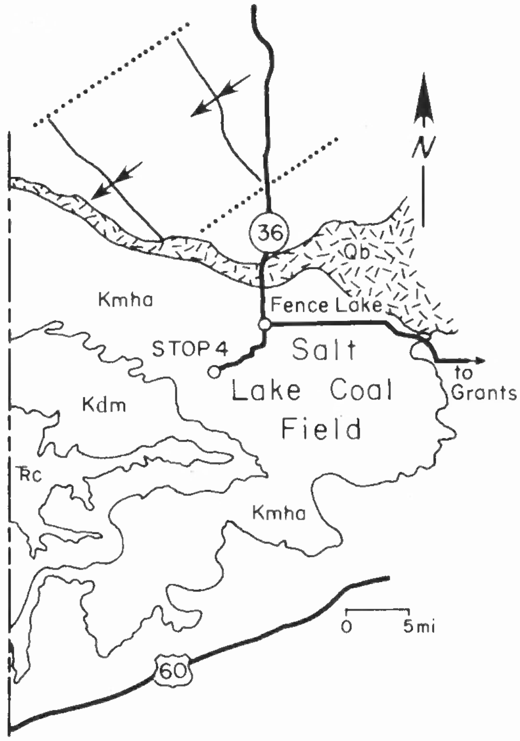

FIGURE 2-92.0c. Map of Salt Lake coal field area showing outcrop pattern of Cretaceous rocks of the Atarque and Moreno Hill fms (Kmha), formerly referred to as Mesaverde Grp by Dane and Bachman (1965). A westward-pointing tongue of the North Plains basalt flow (Qb) separates the coal field from the Zuni basin on the north. The Zuni basin is characterized by northwest-trending monoclines, northeast regional dips and by more complex Cretaceous stratigraphy than the Salt Lake coal field. Kdm = Dakota-Mancos, Trc = Chinle Fm.

Hook et al. (1983), through detailed biostratigraphic work using ammonite zonations and regional stratigraphic cross sections, provided additional clarification. They established that the lower Gallup of Molenaar (1983) was significantly older than the "main Gallup," and separated from it by the Pescado Tongue of the Mancos Shale. They furthermore established that this "lower Gallup" regression was far more extensive than originally thought and could be recognized as far eastward as the Carthage area in eastern Socorro County. It was also recognized that the rocks associated with this regressive-transgressive pre-Gallup event had been observed in Socorro County by Herrick (1900), who had applied the name Tres Hermanos to them. The name Tres Hermanos was a valid one, and Hook et al. (1983) extended it into the Zuni basin as a formation rank unit with three members. The Atarque Sandstone Member at the base included only the marine and deltaic facies and was much more restrictive as used by Hook et al. (1983) than the sense in which Molenaar (1973) used the term. The two overlying member names, the Carthage and Fite Ranch, were taken from near the old coal-mining town of Carthage in eastern Socorro County.

The concept of a Tres Hermanos Formation, though essential to our understanding of the section here at Moreno Hill, does not apply directly to it. The uppermost member of the Tres Hermanos—the Fite Ranch—represents deposition associated with the transgressive part of the cycle, but that transgression never reached this far southwest (Fig. 2-92.0d). We thus have represented here only the lower two members. McLellan et al. (1983) addressed the stratigraphic nomenclature problems presented by these two "remaining members" during the course of a mapping and coal resource evaluation project carried out jointly with the U.S. Geological Survey and New Mexico Bureau of Mines and Mineral Resources. McLellan et al. (1983) recognized the stratigraphic continuity and thus used the name Atarque Sandstone (here raised in rank from member to formation), but opted for a local name for the overlying coastal plain sequence, and used Moreno Hill Formation. Only the lower part of the Moreno Hill is equivalent to the Carthage Member.

We now have several lines of evidence that illustrate just how close the marine transgression associated with deposition of the Fite Ranch Member came to the Moreno Hill area. Mapping by the New Mexico Bureau of Mines and Mineral Resources just to the north (Anderson, 1987) recognized the Fite Ranch Member 200 ft stratigraphically above the top of the Atarque Member. The projected landward pinchout of the marine facies represented by the Fite Ranch and overlying Pescado Tongue was estimated as occurring 5 mi to the southwest. That would place the shoreline at maximum transgression within 7 to 8 mi of this locality, perhaps closer. Thus, a paralic environment may reasonably be assumed for this area during the high sea-level stand—or maximum transgression.

How and where is that reflected in the local section? A palynologic investigation of the Moreno Hill by Kelley (1987) indicated a flora with definite marine affinities below the middle sandstone member in the Rabbit coal zone (Fig. 2-92.0d). This coal is approximately 290 ft above the top of the Atarque Sandstone (Roybal and Campbell, 1981).

The thickest coals of the Moreno Hill Formation occur in a lower zone, approximately 200 ft above the Atarque Sandstone (Roybal and Campbell, 1981), and isopachs of the thickest beds in the zone have a northwest trend, parallel to the projected shoreline trend. These thicker coal beds, some of which reach 11 ft, occur just to the east on the Cerro Prieto quadrangle mapped by Campbell (1981). The thicker coals in paralic and coastal plain settings commonly lie just landward of a major marine sandstone buildup or shoreline turnaround (see Fassett, this guidebook), and the stratigraphy here provides another example of that relationship (Fig. 2-92.0d). Beaumont (1971) has suggested this relationship might be due to the greatly reduced rates of shoreline migration at these times, which then allows thicker and more extensive paralic peat swamps to develop.

Bear in mind as we travel north, not only is the Zuni basin more complex stratigraphically (another marine cycle) and structurally (the monoclines), it stands structurally higher. Therefore as we enter the basin at mile 106.5 we will be in Cenomanian age rocks, versus Turonian here. This, plus the presence of thick Jurassic sandstones forming bold cliffs, and the disappearance of the volcaniclastic Fence Lake Fm, create a landscape more typical of the Colorado Plateau.

After stop, **turn around and return to Fence Lake. 4.8**

96.8 Light-colored rocks in the distance at 11:45 are Zuni Ss, the southernmost outcrop of Jurassic rocks in this region. **3.7**

100.5 Enter village of **Fence Lake,** pavement begins; **continue straight** ahead. The seasonal lake that lent its name to this community lies 2 mi to the SE. Being an important source of water to early settlers, it was fenced to prevent livestock from altering the quality. **0.1**

100.6 Fence Lake Mercantile on left. **0.2**

100.8 Milepost 40. **1.0**

101.8 Milepost 41. Highway is on surface developed on Moreno Hill Fm, covered by a thin veneer of alluvium. McLellan et al. (1983) showed numerous low-displacement normal faults in this area. **0.8**

102.6 Low bluffs at 11:00 are another Los Pilares, composed of Rock Point Mbr of Chinle Fm at the base, overlain by about 90 ft of Zuni Ss, capped by Dakota Ss just north of old townsite of Atarque. This is the southernmost exposure of Jurassic rocks in west-central New Mexico. It is at the same latitude as Silver's (1948) pinchout of the Jurassic in the Acoma basin. **1.2**

103.8 Milepost 43. Ascend Jaralosa Draw lobe of North Plains basalt field. This flow necked out here as it was funneled into a Pleistocene valley that flowed across the struc-

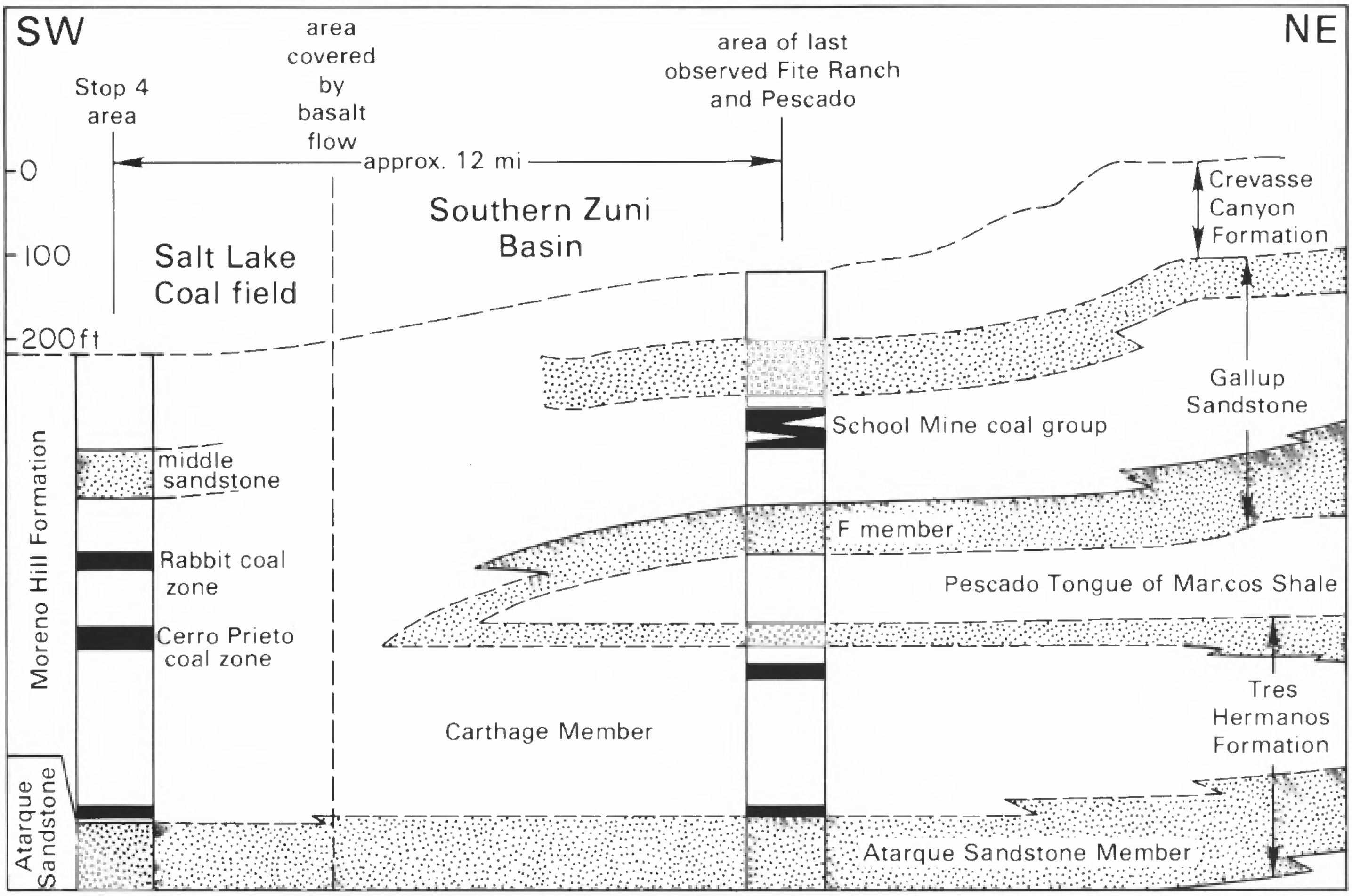

FIGURE 2-92.0d. Diagrammatic cross section illustrating relationship of thicker coals in Salt Lake coal field with the landward pinchout of marine facies in upper part of Tres Hermanos Fm.

turally and topographically high southern end of the Zuni basin. The Zuni basin area to the northwest has undergone more crustal shortening during the Laramide, and the El Malpais basin to the southeast has undergone more extension during the Neogene. Thus, the basalt flow nicely delineates the margins of the Laramide and Neogene basins. **1.1**

104.9 Basalt flow exposed in roadcut yielded an age of 1.41 ± 0.29 my (Laughlin et al., 1979). **0.4**

105.3 At 10:00, good view of Los Pilares (Fig. 2-105.3a). Excellent outcrops of Zuni Ss here near the southern pinchout of the unit reveal large scale, southwest-dipping eolian crossbed sets (Fig. 2-105.3b). **0.9**

106.2 Abandoned village of **Atarque** (Fig. 2-106.2a) at 9:00 about 2 mi distant on valley floor below cliffs of Zuni and Rock Point Mbr. Atarque was the headquarters for employees of the local sheep ranches, and a post office was maintained here until 1955. It was a thriving village in the 1920's (Fig. 2-106.2b). The name comes from the Spanish word for "stock tank." **0.3**

106.5 Begin descent from basalt flow into Terrero Draw and enter the southern end of the Zuni basin. McLellan et al. (1983) mapped a fault here that parallels the draw. There appears to be no offset of the Zuni Ss–Dakota Ss contact across the draw. However, the basal facies of the Dakota changes somewhat across the draw. **0.3**

106.8 Milepost 46. Roadcut on right in Dakota Ss. **0.2**

107.0 Floodplain of Terrero Draw; the draw has developed along the margins of the basalt flow. **0.5**

107.5 Crest of hill. Mesa from 1:00 to 2:30 is capped by Tres Hermanos Fm which records a regressive-transgressive sequence that is not present in the Fence Lake–Moreno Hill areas (see stratigraphic cross section, Fig. 2-107.5).

FIGURE 2-105.3a. Outcrops of Rock Point Mbr of Chinle (TrCR), the light-colroed Zuni Ss (Jz) and the Dakota Ss (Kd) at Los Pilares are the only exposure of these units locally. The Zuni, 90 ft thick here, pinches out a few miles to south in the subsurface. Photo was taken from a point 2 mi west of field trip route.

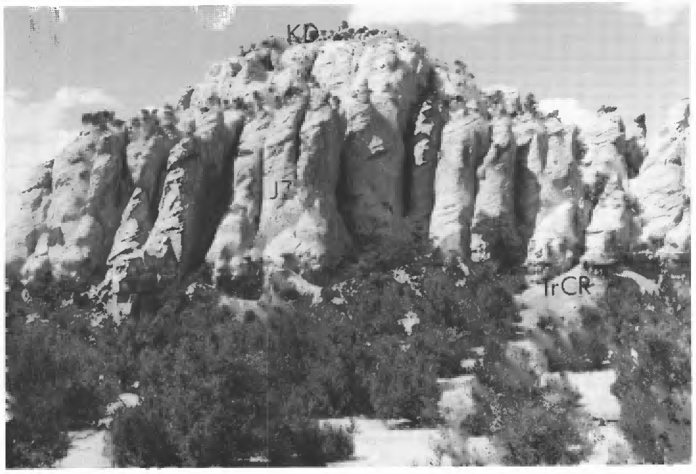

FIGURE 2-105.3b. Thick sets of high angle crossbeds in Zuni Ss at Los Pilares. Units same as Figure 2-105.3a.

Highway is traversing the approximate landward limit of the Pescado Tongue of Mancos Sh, the marine shale tongue associated with the transgressive, upper part of the Tres Hermanos Fm. **0.5**

108.0 Paguate Tongue of Dakota Ss exposed on right side of road. **0.2**

108.2 Mesita de Yeso at 10:00 is capped by reworked gravels

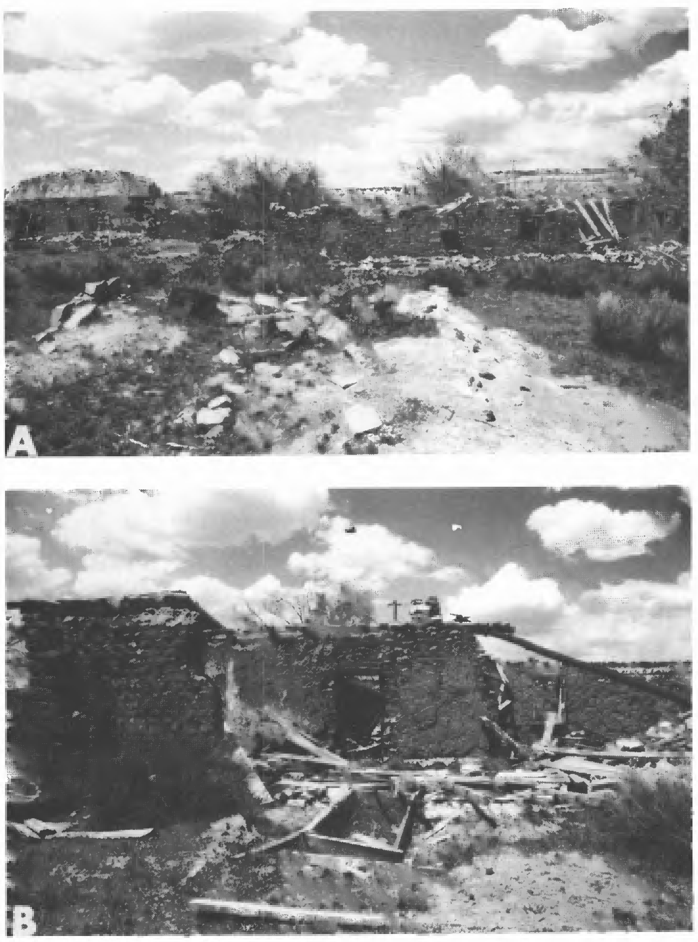

FIGURE 2-106.2a. Abandoned village of Atarque 2 mi west of route at mile 106.2. Photo (A) shows stonework residential building. Photo (B) shows adobe, stonework and stonework plastered with adobe.

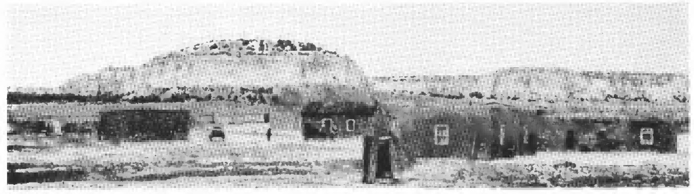

FIGURE 2-106.2b. Atarque as it appeared in 1928. The large structure at right may in part still be standing, and in Figure 106.2a (from Darton, 1928).

of the Fence Lake Fm that are here included in the Bidahochi Fm. **0.6**

108.8 Milepost 48. Roadcut on left exposes Twowells Tongue of Dakota. **0.3**

109.1 Crest of hill; at 10:00, about 300 ft from highway, is thin Bridge Creek Limestone Mbr of Greenhorn Fm containing inoceramid debris. **0.8**

109.9 Whitewater Arroyo Tongue of Mancos exposed in roadcut on left; descend into Pinitos Draw onto surface developed on Dakota Ss. **0.9**

110.8 At 1:30 to 3:00, light-colored ledges are Paguate Tongue, bolder ledges above them are Twowells Tongue (Fig. 2-110.8). Mesa behind is capped by Tres Hermanos Fm consisting of the regressive Atarque Ss Mbr, overlain by the Carthage Mbr (about 200 ft of nonmarine strata) capped by the Fite Ranch Mbr which is associated with the transgressive part of the cycle. **0.4**

111.2 Dirt road to left to Atarque Ranch. **0.5**

111.7 Unpaved road to right is County Road 32, to Mountainview and the Ramah Navajo Reservation. This side road climbs through the Tres Hermanos, Pescado Tongue of Mancos Sh, Gallup Ss and Crevasse Canyon Fm and

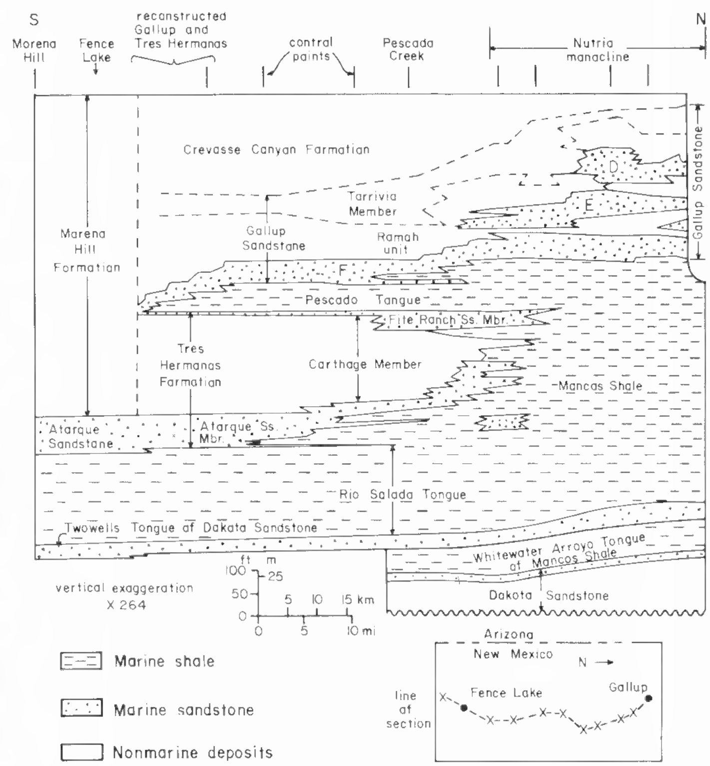

FIGURE 2-107.5. Stratigraphic cross section from Moreno Hill to Gallup showing nomenclature change at landward extent of Fite Ranch Ss Mbr of Tres Hermanos Fm (modified from Hook et al., 1983).

FIGURE 2-110.8. Top of Twowells Tongue of Dakota Ss 1.5 mi east of route near mile 110.8; the opposed crossbed sets may indicate tidal influence in the depositional basin.

offers good exposures of each. Continue straight ahead on NM-36. **0.7**

112.4 Bottom of Pinitos Draw (in Dakota Ss), which follows a northeast-trending compartmental fault (Anderson, 1987). A compartmental fault is a strike-slip accommodation zone between two crustal blocks that have undergone a different amount of compressive deformation. They commonly offset or terminate folds. Movement here is likely to be left-slip and distributed among several faults trending N55°E. This is the explanation based on local detailed mapping. For a discussion of how this structure relates to the regional Laramide stress field, see Chamberlin and Anderson (this guidebook). **0.8**

113.2 Twowells Tongue at 10:00–11:00. This outcrop clearly shows the SW dips (opposed to the NE dips that typify the Zuni basin) and marks the southeast end of the Galestina monocline, terminated by a compartmental fault in Pinitos Draw. These types of faults appear to truncate structure and create segmented folds. A more obvious example is the southern termination of the Atarque monocline 10 mi west of here (Anderson, 1987). **2.4**

115.6 Low mesa at 2:00–3:00 is capped by Twowells Tongue; higher mesa with radio towers at 1:00 is capped by Atarque and Carthage Mbrs of Tres Hermanos Fm. **0.5**

116.1 Top of Dakota main body at 3:00 low in arroyo. **0.3**

116.4 Paguate Tongue exposed along east side of road. *Exogyra levis* is found locally at the top of the Paguate. **0.6**

117.0 Mesa at 11:30 to 12:00 is capped by Twowells Tongue of Dakota. **0.9**

117.9 Twowells Tongue caps low bluffs on right. **0.3**

118.2 Enter Zuni Indian Reservation. **0.6**

118.8 Cuesta at left is capped by Twowells Tongue of Dakota; highway is on surface developed on Whitewater Arroyo Sh Tongue. **0.3**

119.1 Low mesa at 2:00 is capped by Twowells Tongue. **0.5**

119.6 Cross drainage rimmed by Paguate Tongue of Dakota Ss. **1.4**

121.0 Roadcuts just ahead are in Twowells Tongue of Dakota Ss. **0.9**

121.9 **Leave Cibola County, enter McKinley County. 0.9**

122.8 Bridge crosses small canyon cut in Dakota Ss. The canyon is tributary to Galestina Canyon which lies 2 mi to the west. **0.8**

123.6 Roadcuts in Whitewater Arroyo Tongue; road ascends to surface capped by Twowells Tongue of Dakota Ss. **1.3**

124.9 Milepost 64. **0.4**

125.3 Mesa across valley on right is capped by Atarque Ss Mbr of Tres Hermanos. **0.5**

125.8 Roadcuts in Whitewater Arroyo Tongue. At 2:30, contact between Rio Salado Tongue of Mancos Sh and overlying Atarque Ss Mbr of Tres Hermanos Fm is well exposed. **1.7**

127.5 North-trending elongate dome from 1:00 to 3:00 one-half mile from road is formed by intermediate intrusive rock with biotite phenocrysts (a minette). Knife Hill Quarry on NE side of dome exposed the intrusive which was used as a source of aggregate locally until 1984. The intrusive lies on a N56°E-trending line that connects the endpoints of the Atarque, Galestina and Nutria monoclines, and provides further evidence of a strike-slip fault in the basement that accommodated compartmental deformation. **1.1**

128.6 Gravel road to right leads to Knife Hill Quarry. **0.3**

128.9 Mesa at 3:00 is capped by Atarque Ss. **0.7**

129.6 Horsehead Canyon at 9:00 exposes top of basal Dakota Ss. Increasing northeastward structural dip is the southern expression of the Piñon Springs anticline. **1.3**

130.9 Dip slope on left side of highway ahead is formed on Dakota Ss dipping 3–5° to NE. Note the Dakota over light yellow Zuni contact exposed in a small but clean outcrop on north side of arroyo. Mesa at 1:00–3:00 is capped by Tres Hermanos Fm. **0.2**

131.1 Landslide scar at 2:30 exposes thick sequence of carbonaceous shale of Carthage Member of Tres Hermanos Fm. **0.6**

131.7 Dakota Ss at 9:00 in Horsehead Canyon. **1.3**

133.0 **Stop sign—intersection** with NM Highway 53. **Turn left** toward Zuni Pueblo. Valley extending eastward from intersection is Pescado Creek. North side of valley is Pescado Creek reference section of Tres Hermanos Fm, capped by Gallup Ss. **0.5**

133.5 **Junction** with NM-602; **continue straight** (west) on NM-53. Water gap at 12:00 was cut by the Zuni River, which begins immediately to the right at the confluence of the Rio Nutria and Rio Pescado. **0.5**

134.0 At 1:30–2:30 are Dutton's (1885) "spectacularly banded Zuni sandstones." Color banding does not reflect changes in lithology; sequence is capped by Dakota Ss. Basalt flow visible along Zuni River. **1.5**

135.5 At 9:30, note color break (red above, gray below) on lower cliff in middle distance, thought to be Entrada–Cow Springs contact. Foster and Ostrander (1962), in their NMGS road log, called the upper, lighter-colored unit the Thoreau Ss of Smith (1954). At 2:30 a small northeast-trending normal fault drops the Dakota/Zuni contact about 40 ft, down to the southwest side. **0.4**

135.9 Red beds in mesa at 11:00 are Rock Point Mbr of Chinle Fm (previously of Wingate Ss; see Dubiel, this guidebook). **0.3**

136.2 Roadcut in Owl Rock Mbr of Chinle Fm. **0.7**

136.9 Paved highway to right is NM-604, a shortcut to Gallup for residents of Zuni Pueblo; Zuni Buttes are at 1:00 with the red beds of the Rock Point Mbr exposed around base. Note breached crest of Piñon Springs Anticline from 1:00–2:30. The board-bedded nature of the Rock Point may be seen at 9:00 to 9:30 on north side of mesa of Chinle Fm. **0.9**

137.8 Milepost 17. Prominent mesa from 11:00 to 12:00 is Dowa Yalanne (Corn Mountain) capped by Dakota Ss overlying approximately 500 ft of Zuni Ss. Bosque to right developed on delta of Black Rock Reservoir. **1.0**

138.8 Government housing project at Black Rock on right has all been built since 1981. **1.2**

140.0 Rio Pescado lobe (a.k.a. Black Rock basalt) of North Plains basalt flow over Chinle Fm or on alluvium derived from Chinle on right of highway. **0.6**

140.6 Zuni rodeo and fair grounds at 2:00. **0.1**

140.7 Zuni Pueblo Historical Marker on right (Fig. 2-140.7). Zuni Buttes at 2:00 are on crest on Piñon Springs anticline. Prepare to turn left. **0.1**

ZUNI PUEBLO

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As one drives into Zuni Pueblo today, the grid of streets, scattered houses, businesses, schools and other public buildings give the impression that the town is similar to other small towns in New Mexico. But Zuni Pueblo has undergone a well documented and remarkable change in outward appearance during the past century while the people have retained many of their traditions and close-knit society. The changes in architecture are due to a combination of traditional attitudes favoring remodeling and renewal of older structures and the acceptance of new ideas and materials for construction, changing relations with surrounding peoples, an increase in population and a change in modes of transportation. The population of Zuni Pueblo has increased from 1600 in the 1880's to more than 7500 today. While the area occupied by the town has expanded from 14 acres to more than 7 mi^2, less than 50 structures in the center of Zuni Pueblo predate the 1930's. The following summary is excerpted from articles by Ferguson (1981) and Ferguson and Mills (1987).

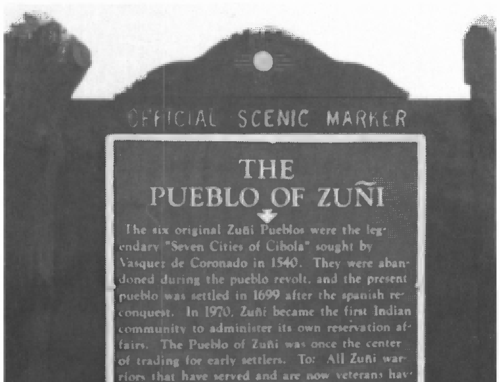

FIGURE 2-140.7. Zuni Pueblo historical marker.

The construction of pueblos as above-ground masonry rooms began by A.D. 700 in the region. Larger numbers of connected and stacked rooms and local building styles evolved over the next two centuries. According to Ferguson (1981), as many as 30 large pueblos with at least 250 rooms and central plazas were built east of present-day Zuni in the Pescado–El Morro areas by A.D. 1275–1350. Each Pueblo apparently was occupied only 30–40 years. By A.D. 1450, the ancestral Zuni people had moved downstream and occupied six pueblo villages. The villages occupied slightly elevated land near permanent water. Unlike the brief occupancies at earlier pueblos, these villages continued to be inhabited until the 17th century. During the 300 years of occupation, the villages were built and rebuilt in massive multistoried clusters with narrow passages and few ground-level entryways.

In 1540, Coronado conquered one of the western Zuni villages near Ojo Caliente, but moved eastward to the Rio Grande before the end of the year. Until 1629, the Zunis were visited only briefly by a few Spanish explorers. In 1630, Catholic missions were established at two of the pueblos, including Zuni. The Zunis resisted cultural, political and military influences, discouraged Spanish settlements and took part in the Pueblo Revolt of 1680. The Zunis abandoned their villages during and after the revolt, and took refuge on Dowa Yallanne, the large mesa to the southeast. By 1692, when the Zunis returned, the revolt, deprivation, reconquest and introduced European diseases had substantially reduced the population, and only Zuni Pueblo was reoccupied. The survivors began using pre-formed adobe bricks, metal tools, draft animals and new cultigens (oats, wheat, fruit trees) introduced by the Spanish. Draft animals allowed the use of larger timbers in construction. Metal tools made wood work easier and better joints possible. With wheat came the introduction of domed masonry ovens for bread. Spanish contact continued after reconquest, but the Zunis were left alone much of the time.

The first accurate map of Zuni Pueblo was made by Victor Mindeleff, an Anglo architect, in 1881. The pueblo was built on top of a rounded natural hill and took advantage of the topography. The pueblo consisted of seven large blocks of rooms surrounding the church and several plazas. Each block of rooms was constructed in a series of levels up to five stories high, the roofs of lower rooms providing floors or terraced patios for the overlying rooms. There were few lower entrances. Most entryways were via ladders through roofs. The massive appearance and few openings within the pueblo were in part the result of repeated attacks by Apache and Navajo. "The massive, terraced architecture form and dense population of nineteenth century Zuni Pueblo led many Anglo observers to compare it to an immense beehive or anthill. . . . In this regard, it is worth noting that the Zuni name for the village, *halona:wa*, is derived from the Zuni word for red-ant, *halo*" (Ferguson and Mills, 1987, p. 247). "The rooftop terraces were one of the most distinctive features of Zuni architecture in the nineteenth century, and their construction provided a great deal of individualized and variable open space. Due to the unevenness of the hill underlying the village, and to the varying dimensions of the component houses, a great variety prevailed in the height and configuration of terraces. . . . Low walls, many of them remnants of former rooms or extensions of underlying room walls, separated the rooftop terrace used by one extended family from that of another. Since the terraces were used as public walkways for access around the pueblo, the low walls had breaks in them, usually toward the edges of the roofs. Shaped sandstone slabs were used as gates" (Ferguson and Mills, 1987, p. 249). Lighting and ventilation to interior rooms was provided by small oblique openings through the ceilings similar to small clerestories. The area surrounding the pueblo was taken up with fields and corrals for livestock. Seasonally occupied farming villages and homesteads occurred in a radius of about 25 miles.

"The north/south and east/west coordinate axes used in the architectural plan of Zuni Pueblo reflect the symbolic directionalism important in the Zuni conceptualization of space, with its emphasis on the cardinal points. Use of these coordinate axes also enabled the Zunis to construct the rooftop terraces to take maximal advantage of the eastern and southern exposures optimal for passive solar heating. The largest room block in Zuni Pueblo was at the west end of the village at the crest of the hill. This room block had a high west wall with very few terraces or openings. . . . The location and form of this massive room block acted to shield the rest of the village from the prevailing westerly winds. These winds are especially strong in the spring during the Zuni months of *Li'dekwakkya Ts'ana* ('Little Sandstorm') and *Li'dekwakkya ɬana* ('Big Sandstorm'), resulting in a significant amount of aeolian deposition at *So'biyahna:wa* ('where the sand drops off'), at the northwestern edge of the village" (Ferguson and Mills, 1987, p. 248).

In the 1860's, the threat of raids by Navajos and Apaches ended. In 1881, the railroad was constructed along the Puerco valley to the north, providing access to glass, milled lumber and tools. As a result, ground-level rooms were opened with new doors and windows, and were preferred living quarters. Upper level rooms accessible only by ladders were relegated to the poor and to storage. Upper levels were eventually abandoned and dismantled. Old construction materials were recycled into new ground-level dwellings. At the same time, more space was opened up for passageways and plazas within the pueblo. In some places, whole rows of rooms were abandoned and buried by sand in order to create more open areas. Other ground-level structures were dismantled and moved. The net effect was to make the pueblo less compact and massive. The pueblo shrank in height and expanded laterally. "Kroeber (1917:194) commented, 'The rapidity with which a pueblo like Zuni changes in detail, while preserving the same general outline and appearance for generation after generation is really remarkable. . . . This general conservatism is, however, offset by the readiness with which changes of a few feet are made in the lines of any particular house. Kroeber estimated that the exterior walls of virtually every house in the pueblo were rebuilt along new lines every 30 to 40 years. He attributed much of this reconstruction to the Zuni Shalako ceremony. Each year six to eight houses are either substantially reconstructed or built anew to host the Shalako and attendant gods who come to bless the Zuni village. During the last century, Shalako has thus resulted in the construction or improvement of 600 to 800 houses. Kroeber noted that when houses were improved to host the Shalako they were invariably enlarged, and the roof was raised to admit the giant figures, substantially increasing the size of the rooms" (Ferguson and Mills, 1987, p. 256).

Families also began construction of new houses away from the traditional pueblo. By 1915, more than 50 room blocks had been built on both sides of the Zuni River in the area surrounding Zuni Pueblo. Individual family dwellings consisting of small blocks of rooms for two or three related families were common. "One of the primary architectural principles applied during the expansion of the pueblo was that all the outlying houses were oriented to face inward with their doors toward the village center. Kroeber (1917:198) also noted that when a family moved its residence to the suburbs, it normally settled in the part of the outlying village that corresponded to the section of town it was moving from. For instance, people from the northeast room blocks of the old pueblo generally moved to the northeast suburbs. The basic orientation of the pueblo was retained, even as it was greatly expanded. The lateral expansion and suburbanization of the pueblo is closely correlated with the architectural reduction of the original room blocks. As more open space was created in the pueblo interior, and the preference for larger ground story houses increased, more and more people moved to the suburbs" (Ferguson and Mills, 1987, p. 256–257).

In contrast with the earlier smooth adobe plaster surfaces on the walls of the room blocks, stone masonry became popular. Ashlar-style stone masonry was introduced on several large-scale governmental and religious projects on the Zuni Reservation in the early twentieth century. Zunis learned to become excellent stone masons, using the locally available, naturally blocky Rock Point Member of the Chinle Formation to great advantage. In the 1920's and 1930's, ashlar-style stone masonry dominated construction.

By 1945, only one third-story structure remained on the largest room block of the pueblo. Almost all the roof-top hatchways had been replaced with ground-level doors. After World War II, flat roofs on the terraces away from the plazas were replaced with pitched roofs. Electricity was introduced in 1950, with its attendant poles, wires, street lights and TV antennas. Water lines were installed in 1954, and sewer lines in 1961. "The contemporary wage labor economy of Zuni means it is now easier for many people to buy cinderblock and milled lumber than it is to take the time to quarry stone and cut roof beams. Thus many houses built in the traditional way are now constructed out of nontraditional materials. While the gray cinderblock that has been popular since the 1960's has a different aesthetic than quarried sandstone, it is still a masonry element that can be laid up into walls by local masons. As such, it is much more congruent with Zuni culture than the woodframe houses constructed with federal assistance by outside contractors" (Ferguson and Mills, 1987, p. 262).

"The trend toward suburban living has continued, accompanied by a rapid growth in the population of the Zuni Tribe. . . . At the same, seasonal occupation of the farming villages has been relinquished in favor of vehicle-supported commuting on a daily basis. The majority of the tribe now resides in Zuni Pueblo and its suburbs year around. Several hundred non-Indians and Indians from other tribes now reside in Zuni Pueblo. . . .

"The old pueblo is now surrounded on all sides by outlying houses, room blocks, public buildings, and government subsidized subdivisions. New architectural materials and forms such as sliding aluminum windows and wood-frame and cinderblock houses with ridges and gabled roofs have greatly diversified the once-cohesive architectural character of the village. . . . The impact of the automobile has been immense, and virtually all exterior space except for . . . the smallest plaza used for sacred dances, has been modified so that it can be used as a roadway" (Ferguson and Mills, 1987, p. 258–259).

"Today, the historic core of Zuni Pueblo is experiencing severe structural problems. Contemporary houses sit on top of 12 m or more soft cultural debris . . . , and it is difficult to build a house there with solid foundations. Many houses in the old pueblo have settled, necessitating their reconstruction" (Ferguson and Mills, 1987, p. 259).

In summary "Zuni Pueblo began as a small prehistoric pueblo situated at the crest of a low hill. In the historic period, this settlement was reconstructed into a massive architectural complex of multistoried, terraced room blocks, several of which were constructed entirely of adobe bricks, a construction technique introduced by Spaniards. Historic Zuni architecture incorporated both defensive features and elements of solar design. During the last century, the massive architectural edifice of Zuni Pueblo has been dramatically transformed as the multistoried room blocks were replaced by one-storied houses, and more open space was created within the core pueblo. The boundaries of the village have greatly expanded through a process of suburbanization associated with population growth.

"New contruction materials and architectural forms have altered the appearance of the pueblo, but continuities in spatial form and function persist. Religious pathways and plazas provide stable architectural spaces, and the pueblo has been reconstructed around these reference points. The Zuni population has more than tripled in size in the last century, and the pueblo has grown into a small town, but the core pueblo still serves as a residential area as well as the ceremonial center for the Zuni Tribe. For the Zuni people, their pueblo is a place to nurture and support their current lives, not a relic of the past. As the Zunis move into the future, they will build and rebuild Zuni Pueblo so that it will continue to play its role in Zuni culture and society" (Ferguson and Mills, 1987, p. 263).

140.8 **Turn left** at intersection with paved road. This intersection is starting point of supplemental road log 2, to Ojo Caliente (see p. 000). **0.4**

141.2 **Turn left** onto paved road. **0.3**

141.5 **Take right fork** in road. Note exposures of reddish brown, flat-bedded Rock Point Mbr at lower levels. Also note that the section on Corn Mountain on left ahead displays a medial notch in the Zuni Sandstone that may be equivalent to the Todilto Formation. **0.4**

141.9 At 3:00, slide blocks of upper part of Chinle Fm overlie laminated sandy limestone and nodular freshwater limestone beds in lower Chinle. **0.9**

142.8 **STOP 5** at dirt road to left. This stop offers excellent exposure of Middle Jurassic sandstones that were deposited mainly as eolian units in an arid coastal plain along the southern margin of the Todilto embayment or salina lake.

The large mesa immediately to the east is Dowa Yalanne, or DY Mountain (Fig. 2-142.8a). The reddish brown, flat-bedded, fine-grained silty sandstone at the base is the Rock Point Mbr of the Chinle Fm. Overlying is 500 ft of massive and highly crossbedded sandstone that Anderson (1983) has designated the Zuni Ss. A medial notch in this unit consists of up to 1 ft of maroon sandy mudstone (Fig. 2-142.8b). Laterally traceable throughout much of the Gallup-Zuni basin, the notch perhaps represents a depositional break associated with the encroachment of the Todilto embayment (lake) and the associated bay marginal (arid coastal plain) deposits.

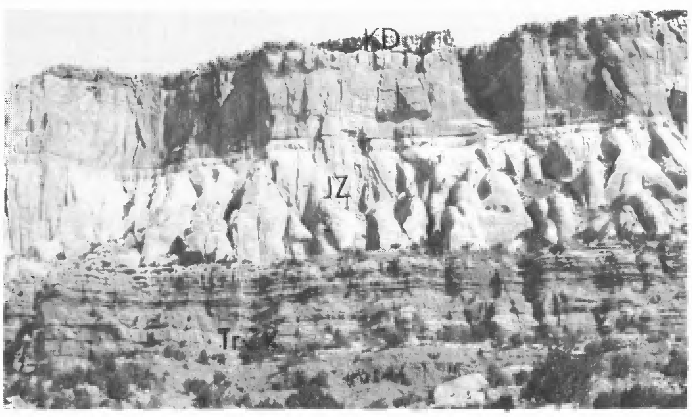

FIGURE 2-142.8a. Looking eastward at DY Mountain from vicinity of Stop 5. Trcr = Rock Point Mbr of Chinle; Jz = Zuni Ss, note medial notch; and Kd = Dakota Ss.

FIGURE 2-142.8b. View of southwest side of DY Mountain from Galestina Wash. Note good development of medial notch in Zuni Ss. Darker layer at top is Dakota Ss.

If so, then the section below the notch is equivalent to the Entrada Ss and the section above equivalent to the Cow Springs Ss that Harshbarger et al. (1957) extended into west-central New Mexico from the Black Mesa area. Locally the notch disappears, and these two units become indistinguishable. Thus the undivided equivalent is referred to as the Zuni Ss, a name that was originally applied to these rocks by Dutton (1885).

The Cow Springs Ss intertongues with the Beclabito Mbr of the Wanakah Fm (formerly Summerville—see Condon, this guidebook) to the north and northwest. Thus, the Cow Springs is older than the Horse Mesa Mbr (formerly Bluffs Ss—see Condon, this guidebook) in the southwestern and southern parts of the San Juan Basin. This indicates that the Zuni Ss here is an older unit than Maxwell's (1982) Zuni which overlies the Horse Mesa Mbr in the Acoma basin.

The Zuni Ss is truncated along a line that trends N50–55°W in a broad arc from Fence Lake, NM to approximately Chambers, AZ. That line passes 20 mi to the southwest of here. Thus, the rate of westward or southwestward thinning of the Jurassic section is 25 ft/mi. This reflects the influence of the Mogollon highlands on mid-Jurassic depositional patterns. Eastward from Fence Lake, the Jurassic truncation line trends nearly due east. Hunt and Lucas (1987) have discussed the southern pinchout of Jurassic sediments to the east, and concluded that in Late Jurassic time at least, little or no evidence exists to support the concept of a Mogollon highland. In the Zuni area and southward, chert and quartzite conglomerate beds (Fig. 2-142.8c) at several levels within the Zuni Ss (Anderson, 1987) suggest a source of coarse clastics to the west and south during mid-Jurassic time.

After stop return to NM-53 (at mile 140.0). **1.9**

144.7 **Junction** with NM-53; **turn right. 4.0**

148.7 **Junction** with NM-604; **turn left. 1.3**

150.0 Color-banded Zuni Ss forms cliffs on right, capped by Dakota Ss. Road ascends through gently NE-dipping Zuni Ss for next several miles. **2.1**

152.1 Crossing approximate contact of Zuni and Dakota. **1.0**

153.1 Note carbonaceous sh in basal part of Dakota in roadcuts. **0.4**

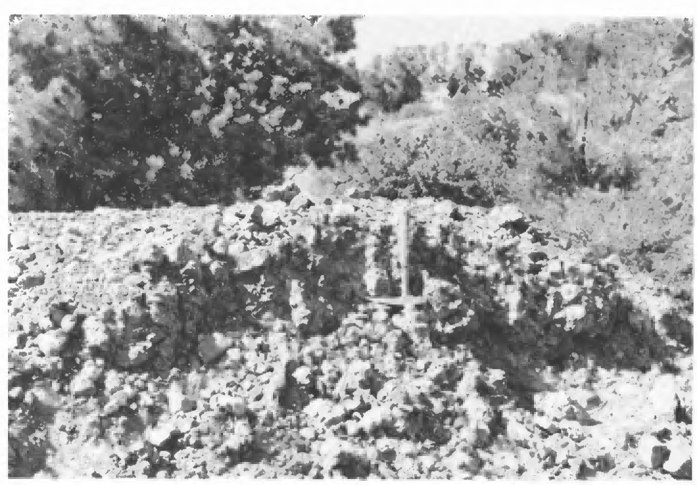

FIGURE 2-142.8c. Chert and quartzite conglomerate bed in Zuni Ss, up to 6 ft thick locally on Plumasano Basin quadrangle immediately to south of Zuni quadrangle.

153.5 **Junction** with NM-602; **turn left** (north) to Gallup. **0.2**

153.7 The mesa on the right is capped by the Tres Hermanos Fm, with the Pescado Tongue of the Mancos and Gallup Ss present just back behind the rim. The Pescado Tongue thins and grades northward into marginal marine sandy mudstones in a short distance. Talus-covered slopes below the Tres Hermanos are developed on Rio Salado Tongue of Mancos; road is on a Mancos Sh strike valley. **3.4**

157.1 Road ascends to surface capped by Late Miocene-Pliocene Bidahochi Fm, the reddish-brown outcrops to left of road at 11:00. The Bidahochi cover here is most unfortunate because it conceals the northward pinchout and facies change of the Pescado Tongue of Mancos Sh. With no recognizable Pescado, there is no basis for distinguishing the Tres Hermanos Fm from the overlying Gallup Ss; thus to the north of this area the regressive marine ss pile above the Mancos is lumped as the Gallup Ss (Anderson, 1989). **4.2**

161.3 Village of **Vanderwagen** on left; the nonmarine uppermost member of the Gallup—the Torrivio Mbr—is well exposed immediately to the west of the village and in Nelson Wash south of the village. The Vanderwagen quadrangle was mapped by Anderson (1989); fossils collected from the Gallup Ss in this quadrangle suggest a Juana Lopez age which demonstrates that the Gallup is much older here than in the southern and southeastern San Juan Basin. **1.2**

162.5 Bridge over Whitewater Arroyo; road is on Cretaceous rocks which here have gentle NE dips; sandstones to left are uppermost Gallup, to right is Crevasse Canyon Fm with thin alluvial cover. **1.2**

163.7 Good outcrops of Bidahochi in roadcuts. **2.5**

166.2 Bidahochi outcrops on right side of road. **0.9**

167.1 Pinehaven Road to right (see Day 3 supplemental road logs); continue north on NM-602, on a thin (<100 ft) cover of Bidahochi Fm. **2.5**

169.6 Road descends into Crevasse Canyon Fm. At 1:00 the high point is the northern end of the Nutria monocline. **2.3**

171.9 Milepost 23; road descends into valley of Bread Springs Wash; outcrops of Crevasse Canyon Fm on both sides of highway. **1.2**

173.1 Bridge over Bread Springs Wash. Road continues for next 5 mi through mudstone-dominated Crevasse Canyon Fm. **4.4**

177.5 **Stoplight** at south end of Gallup, NM; **turn left** and follow NM-602 to west end of Gallup. **Gallup,** elev. 6508 ft, was founded in 1881, and named after David Gallup, paymaster and auditor for the A&P Railroad, later to become the AT&SF. The town is the Indian capital of the nation and the selection of Native American–produced items is the finest to be found. **0.2**

177.7 Roadcut exposes carbonaceous shale section in Crevasse Canyon Fm. Within next 0.3 mi note west-dipping rocks on the western limb of the Gallup anticline. **0.6**

178.3 At 3:00 in the valley is the (now closed) entrance to the Southwestern coal mine, approximately 0.4 mi from highway. An underground operation, the main adit or haulageway extended for more than a mile to the south. Mine was closed in March 1947.

HERBERT C. STACHER AND THE GALLUP-SOUTHWESTERN COAL COMPANY

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Hard work, honesty, perseverance and dedication describe Herbert C. Stacher, longtime Gallup resident and last president/general manager of the Gallup-Southwestern Coal Company. The following discussion chronicles the growth and decline of that company and was taken largely from Mr. Stacher's unpublished manuscript describing the company and the history of its founders. The manuscript is in the Gallup Public Library.

USE
100% HEAT
GALLUP SOUTHWESTERN COAL
100% VALUE
PRODUCED BY
GALLUP SOUTHWESTERN COAL CO.
"Since 1908"

Gallup-Southwestern was formed in 1908 with capital put up by an Englishman named Samuel Atherton. The company initially lost money, but Atherton had faith, and in 1912 things began to change. The coal market was good, New Mexico has just gained statehood, and the company leased an adjacent coal property through which they could access their coal reserves and which provided access to a loading tipple on the railroad. Later in the year, Atherton, on one of his many trips to this country, learned of an Englishman named Sharp Hanson who had worked the coal mines at Madrid, New Mexico. Hanson was found, promptly hired, and Atherton gave him $3000.00 working capital to increase coal production and turn the company's loss record around. This was the last capital outlay Mr. Atherton had to make. The mine under new operators began to show a profit, slowly but surely. Even so, some investors were not impressed and sold their shares to the new operators for a fraction of what they had paid. During 1916 and 1917, these new operators (Hanson and two others) assisted the company in acquiring additional nearby property and purchased some on their own. They later sold their holdings to the company, which by then was a thoroughly profitable enterprise. All the company coal production, now in the 150 to 180 ton/day range, was coming from the Southwestern mine with an entry in sec. 21, T15N, R18W, just 0.5 mi east of mile 178.3 in the road log. The entry and loadout facilities in sec. 21 would eventually become something of a problem, because that was the parcel of land the company had leased in 1912 from Victor-American Fuel Company (Victor-American in 1917 sold out to Gallup-American Coal Company, a company name that has been around ever since).

Meanwhile, Southwestern continued to grow. In 1921, Mr. Hanson bought all the stock owned by Mr. Atherton, who finally retrieved his American investment plus a good profit. Early in 1922, the board of directors declared a 2-for-1 split, making a total of 1000 shares, the majority of which was owned by Hanson who was by then president and general manager.

In November 1922, Herbert Stacher, then only 21 yrs old, joined the company as a mine clerk in charge of the office and all business, records, payroll, deliveries and billing. Essentially all sales were to the railroad and to copper smelters, particularly the one in Santa Rita, New Mexico. For a time Stacher even acted as safety man, doing the underground inspections. Management's versatility and dedication made for a very efficient operation. Everyone benefited from this, and Christmas bonuses or gifts were routinely given to each employee.

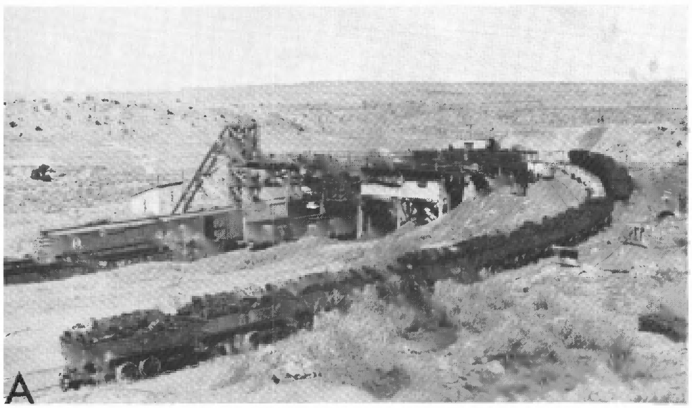
In 1923, at the height of prosperity (with respect to local coal mining) the company had 184 men on the payroll. The average for the time, however, was about 160.

In 1924, Stacher, who had by this time proved himself to the president, was made an officer of the corporation. In the following year, J. D. Sears of the U.S. Geological Survey assigned stratigraphic names to the local coal-bearing units and the coal that Gallup-Southwestern was mining became the Black Diamond bed of the Dilco coal member. This event went largely unnoticed.

In 1926, Mr. Stacher purchased 136 shares of company stock from a former associate of Mr. Hanson and that made Stacher the largest stockholder next to Mr. Hanson. Between the two, they had 93% of the stock that had been issued. Additional coal land was purchased in 1931 but never developed.

Beginning in 1932, the slackening in demand for coal was felt in the Gallup area. The railroads and copper smelters were changing to oil. Mr. Stacher places part of the blame for the decline on labor unions who found new strength in the administration of President Roosevelt and through his National Labor Relations Board.

A much more local and immediate crisis arose in May 1932 when the property lease and sales contract with the Gallup-American Coal Company expired. Gallup-American did not wish to renew the lease.



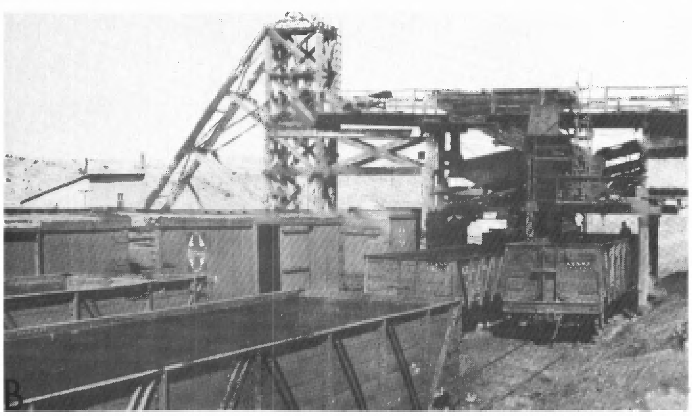


FIGURE 2-179.3. **A,** Southwestern coal mine tipple in operation on 5 April 1933. Loaded mine cars from the underground slope. At the tipple each car is uncoupled, pushed onto the scales, weighed, then pushed to the dump; the front end is opened, and a lever drops the front end of the car so that the coal goes onto shaker screens that have various-sized holes to separate and load the coal into railroad cars. Lump coal goes into box cars on the left track. Engine coal goes into open cars on the middle track and slack coal goes into open cars on the right track. The loaded mine cars go to the tipple under their own momentum afer being released from the steel haulage rope that pulled them from the underground slope. Storage-battery-operated locomotives were used inside the mine to push the loaded mine cars to the main slope from the various entries. **B,** Southwestern coal mine tipple; lump coal was loaded into box cars on the spur railroad track to the left. Engine coal or mine run was loaded into open hoppers or caswells on the center track. Slack coal was loaded into open caswells on the track to the right. This picture was taken on 5 April 1933.

To avoid being forced out of business, Gallup-Southwestern filed a lawsuit in district court to get a right-of-way concession through Gallup-American's land so the company could continue to access the loading tipple on the rail spur. The district judge ruled in favor of Gallup-Southwestern. The defendant appealed to the New Mexico Supreme Court which promptly reversed the lower court's decision, ruling that a coal company cannot establish right-of-way over someone else's land. Lawyers for Gallup-Southwestern then submitted a request to the State Corporation Commission for the formation of their own railroad. They were successful, and the Gallup and Southern Railway Company was formed in 1935 to haul coal from the Southwestern mine to the tipple on the Santa Fe Railroad spur (Figs. 2-179.3). Since Gallup-American could not now keep the Southwestern mine closed, they negotiated another property lease and sales contract with them. This was a 5-yr contract, but called for restricted production. The mine and tipple was operated only 2 days per week for several years, however, employees were given odd jobs and clean-up work for 2 days, to make for a 4-day work week. The railroad was dissolved in 1938 after only 3 yrs of existence, as it was no longer needed.

During the next year, in the face of limited production, the company was forced to deal with a bank failure that resulted in loss of all corporate funds. It survived that with creative financing, but sales continued to decline into the early 40's. In 1942, Mr. Stacher purchased all the outstanding stock in the company. Gallup-Southwestern then became a family-owned company with Stacher as the President and general manager. Production was intermittent and variable. In 1946, Stacher requested that the Gallup-American Company (now Gamerco) renew a sales contract beyond a March 1947 expiration date. They refused to do so, and on 31 March 1947, Mr. Stacher closed the mine and began the disposition of his equipment.

He did manage to purchase from Gamerco the land on Southwestern Hill where his house and office were built. He still resides there on Elva Drive (a street named after his wife) with his many fond memories of the early coal mining days in Gallup. His nearby office with all the equipment and records has been donated to the Gallup Historical Society.

As the following correspondence from 1933 illustrates, even small mining companies in the hinterlands of western New Mexico were aware of the services offered by the New Mexico School of Mines (now New Mexico Institute of Mining and Technology).

NEW MEXICO SCHOOL OF MINES

SOCORRO, N. M.

E. H. WELLS,
PRESIDENT

January 23, 1933

Gallup Southwestern Coal Company
Gallup, New Mexico

Analysis of coal samples submitted:

	#1 Run of Mine	#2 Slack	#3 Screened Mine Run
As Received			
Ash, per cent	5.26	5.83	5.80
Moisture, per cent	8.85	7.37	7.00
B.T.U.'s per pound	11,975.	11,310.	12,070.
Moisture free, Dry Coal			
Ash, per cent	5.78	6.29	6.23
Sulphur	0.74	0.71	0.27
B.T.U.'s per pound	13,050.	12,215.	14,050.
Volatile matter, %	57.1	54.5	54.3

CERTIFIED CORRECT:

Professor of Chemistry

179.1 **Stoplight; turn left** onto access for road for old "Route 66." **0.1**

179.2 **Stop sign; turn right** and **proceed north. 0.2**

179.4 Junction with old "Route 66" (or Business Loop of I-40) at **stoplight; turn left** and **proceed west** "for some kicks on Route 66." **3.3**

182.7 **Turn left** into parking lot of The Inn of Gallup.

End of Second-Day Road Log.