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# *Third-day road log: From Gallup to Upper Nutria, Ramah, El Morro and Grants*

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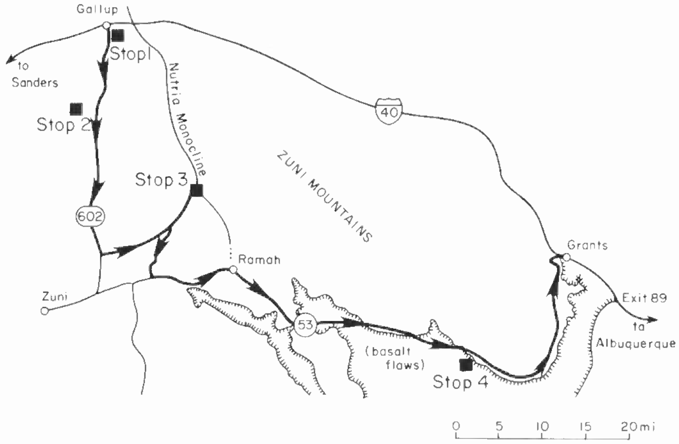
# THIRD-DAY ROAD LOG, FROM GALLUP TO UPPER NUTRIA, RAMAH, EL MORRO AND GRANTS

ORIN J. ANDERSON, SPENCER G. LUCAS, DAVID W. LOVE, CHARLES H. MAXWELL
and RICHARD M. CHAMBERLIN

## SUNDAY, OCTOBER 1, 1989

| | |
|---|---|
| **Assembly point:** | Parking lot of *The Inn,* west Business Loop I-40 (old US-66), Gallup, New Mexico. |
| **Departure time:** | 8:00 a.m. |
| **Distance:** | 140.1 miles |
| **Stops:** | 4 |



## SUMMARY

The third day's route takes us through the hogback on the eastern edge of Gallup where Jurassic and Upper Cretaceous rocks are boldly displayed with dips up to 70° in the northern segment of the Nutria monocline. We will be on the structurally high side of the monocline only briefly as we double back through the structure and head to the southern edge of Gallup to the Carbon No. 2 mine (inactive) for Stop 1 (optional). Time and circumstances permitting, a Carbon Coal Co. representative will discuss the multiple seam mining operation that existed here in the Dilco Coal Mbr for two years. This will be followed by a discussion of the local stratigraphic and structural setting. Stop 2 will be a brief one 10 mi south of Gallup to view and develop an appreciation for the late Tertiary Bidahochi Fm which, as it turns out, conceals the Upper Cretaceous rocks at a most critical juncture.

The Nutria monocline provides the main attraction at Stop 3 (lunch stop) near the village of Upper Nutria. This stop will be in two parts, the first allowing for a good look at the fluvial-paludal-lagoonal Dakota Ss and an interesting conglomerate at the base of the mostly eolian Jurassic section. The top of the Triassic (Rock Point Mbr) is also exposed. A 0.7 mi walk across a Chinle Fm strike valley takes us to part 2 of this stop, which is in the Paleozoic, for a look at the fossiliferous San Andres Ls and the Glorieta Ss. Other attractions are springs, an outcrop of a thin, middle Triassic Moenkopi Fm and scenic Nutria Canyon. Basement fault models for the monocline will be presented and discussed. On the way back to Albuquerque via Highway 53, a stop will be made at Bandera Crater, a Quaternary cinder cone and/or the Ice Caves.

**Mileage**

0.0 **Turn left** onto old US-66 and **proceed west. 0.4**

0.4 At 10:30 note Twin Buttes, an Oligocene intrusive that is utilized as a source of aggregate for asphalt batch plants by Hamilton Bros. Beyond Twin Buttes, 2 mi west, is the Torrivio anticline (Fig. 3-0.4a). The anticline gives its name to the upper, nonmarine, Torrivio Mbr of the Gallup Ss. The anticline also offers excellent outcrops of the marine portion of the Gallup (Fig. 3-0.4b). For discussion of structure in this area see Millgate (this guidebook). **Stay in left lane. 0.5**

0.9 **Turn left** onto I-40 eastbound on-ramp. **0.6**

1.5 Highway overpass, crossing Santa Fe Railroad tracks. **0.3**

FIGURE 3-0.4a. Aerial view to west from above old US-66. Twin Buttes at left with crushing plant visible, Torrivio anticline is just behind (to the west), identified by the U-shaped notch at center of photo. I-40 overpasses US-66 near right center, and the Santa Fe RR tracks are at far right. Photo by O. J. Anderson.

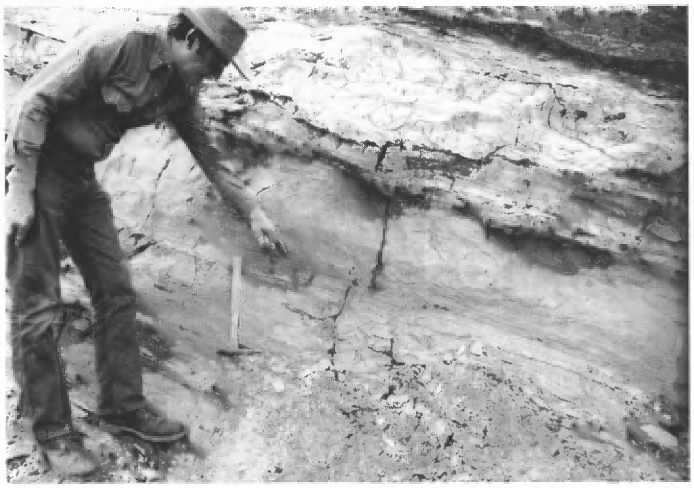


FIGURE 3-0.4b. Gallup Ss exposed along I-40 in cut through Torrivio anticline. The uppermost marine Gallup, here a regressive (bay protected) shoreface sandstone, shows evidence of an extensive burrowing infauna; the trails, dwellings and feeding structures are collectively called "burrows" or "trace fossils" and come in many forms and configurations. Marvin Millgate of the U.S. Geological Survey directs attention to a U-shaped burrow.

1.8 Milepost 17. On the left note the gently eastward dipping Dilco Coal Mbr of the Crevasse Canyon Fm (Upper Cretaceous, Coniacian). **1.1**

2.9 On left the low mesas and cuestas expose the Bartlett Barren Mbr of the Crevasse Canyon Fm, so called because it lacks coal-beds thick enough to constitute a resource. The member names of the Crevasse Canyon Fm, the Dilco (from Direct Line Coal Co.), the Bartlett (from the Bartlett shaft 2 mi N of downtown Gallup) and the Gibson Coal Mbr, just ahead, were first used by Sears (1925), and accepted and formalized by Beaumont et al. (1956). **0.5**

3.4 Roadcuts ahead expose paludal shale and coal beds in the Gibson Coal Mbr of the Crevasse Canyon Fm. Within the next half mi look for red clinker on left, north of highway, which indicates burned out coal beds. **1.1**

4.5 The structural dip reversal seen ahead on the left is due to the N-trending, asymmetric, Gallup anticline, better developed to the south. The anticline is an intrabasinal fold in the northern part of the Gallup-Zuni basin. **0.8**

5.3 Exit 20 on the right leads to NM-666 north. The old coal mining community of Gamerco and abandoned power plant is 3 mi N of this point. Continue straight ahead on I-40. **0.7**

6.0 Downtown Gallup on the right. Gallup, which is built on the Gallup anticline, was founded in 1881 and named after David Gallup, paymaster and auditor for the A&P Railroad, later to become the AT&SF, referred to now as the "Santa Fe Railroad." **0.8**

6.8 Milepost 22. Roadcuts just ahead expose Torrivio Mbr of Gallup Ss near axis of Gallup anticline. **0.7**

7.5 Overpass. At 12:00 the notch in the hogback is an artificial one created for the I-40 bypass. At 12:30 is the natural gap created at much less expense by the Puerco River. **0.4**

7.9 At 9:30 to 10:30 note the abandoned coal-mine dumps. The Thatcher, Otero, Rocky Cliff, and Crown Point mines were scattered through this area and produced from 4-ft-thick coal beds in the Dilco Coal Mbr. The Crown Point and the Thatcher were listed as abandoned in 1920 (Sears, 1925); the others were abandoned by 1948. Many of the mines were in the production range of 20–40 tons per day; the larger mines were near Gamerco. Coal production from the Gallup-Gamerco area in 1882 was 33,373 tons, most of which was used as railroad fuel. Heaton Canyon extends off to the north. **0.4**

8.3 From 9:00 to 1:00, the northern end of the hogback exposes Gallup Ss dipping up to 75° WSW (Fig. 3-8.3). **0.4**

8.7 Crossing synclinal axis of northern end of Zuni basin, commonly called the Gallup sag. **0.7**

9.4 I-40 roadcut through hogback (Fig. 3-9.4) exposes Gallup Ss which contains a thin coal-bearing unit in upper part. **0.2**

9.6 Crossing hogback developed on Dakota Ss (Fig. 3-9.6a). The slope former between the Dakota and Gallup is the lower part of the Mancos Sh, equivalent for the most part to the Rio Salado Tongue. The structural relief across the hogback is approximately 1700 ft, but what does the basement fault look like? The early investigators didn't worry about faults; they merely assumed a folded basement (Fig. 3-9.6b). **0.6**

10.2 At 10:00 to 11:00 note spires of Church Rock, developed in Morrison Fm (Westwater Canyon Mbr), and Red Rock State Park with the bold cliffs of Entrada Ss. White ss

FIGURE 3-8.3. Aerial view to northeast of the north end of Nutria monocline, from a point above the route near mile 8.3.

FIGURE 3-9.4. Photo of I-40 under construction through hogback at mile 9.4; photograph by O. J. Anderson.

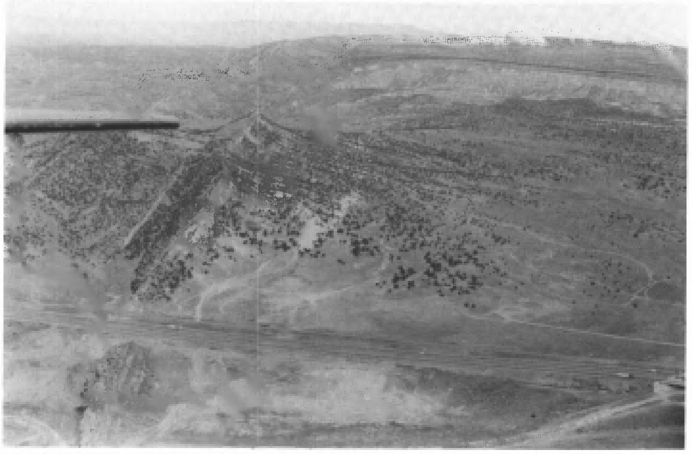


FIGURE 3-9.6a. Aerial view looking north along the hogback on the east side of Gallup, New Mexico. Mile 9.6 is approximately where westbound truck is entering water gap in Dakota Ss hogback at left. The hogback at far left is developed on Gallup Ss with a Mancos Sh valley in between. What does the basement fault look like under this fold, especially here near the corner of the uplift? Photo by O. J. Anderson.

to the north at 8:00–9:00 is the Morrison Fm and Cow Springs Ss. **Stay in right lane.** **0.4**

10.6 Exit 26 off-ramp. **Leave I-40** and loop around to Bus-40 (old US-66). **Prepare for left turn** ahead. **0.3**

10.9 **Stop sign. Turn left** onto Bus-40 westbound. **0.2**

11.1 Hogback to right and left. At about 2:30 just below crest of hogback the basal Dakota in contact with the underlying lighter colored Jurassic can be seen. The mine dump near the crest of the hogback, also about 2:30, was developed in basal Dakota carbonaceous sh and coal that was uraniferous. Mine was called the Hogback (later the Hyde) and was worked between 1952 and 1960. The Jurassic section going south along the hogback is very different from that to the north as both the Todilto and the Morrison pinch out southward. **0.6**

11.7 Crossing hogback through water gap cut by Puerco River. Leopold and Snyder (1951) studied the alluvial fill in the Puerco valley and assigned formation names to two of the units, the Nakaibito and the Gamerco. These names have not come into general use. **0.6**

12.3 Traffic light at Patton Road; continue straight ahead on Bus-40. Stay in left lane. **0.6**

12.9 **Traffic light** at Boardman Road; **turn left** and **proceed south** on Boardman. **0.5**

13.4 Gallup mid-school on right. **0.1**

13.5 Roadcut just ahead in Crevasse Canyon Fm (Dilco Coal Mbr). **0.3**

13.8 Gallup High School on right. **0.7**

14.5 Roadcuts expose carbonaceous shale with thin coals in Dilco Coal Mbr. **0.4**

14.9 At 9:00 in distance reclamation work at Carbon No. 2 strip mine is visible. **0.6**

15.5 **Stop sign.** Gallup Branch of UNM on left. **Continue straight** ahead on Boardman. **0.7**

16.2 **Intersection** with NM-602 at traffic light; **turn left** and **proceed south** on NM-602. **0.7**

16.9 **Turn left** at intersection with dirt road on left ahead for Optional Stop 1. After turn, **wait for escort** to Carbon No. 2 mine. (Gate on this road is kept locked; you must have permission from Carbon Coal before attempting to travel to mine site.) **1.5**

18.4 **OPTIONAL STOP 1.** At this stop a representative of Carbon Coal Co. will discuss the multiple-seam mining operation (Fig. 3-18.4a) that existed here on privately owned land between January 1985 and September 1986. Coal was mined from five beds within a vertical interval of approximately 100 ft in the upper part of the Dilco Coal Mbr of the Crevasse Canyon Fm (Fig. 3-18.4b). The coal was trucked approximately 14 mi to a company rail load-out facility on a Santa Fe spur line near Mentmore. The mine was operated with a work force of about 84 employees and daily production exceeded 3000 tons. The coal was high-volatile C bituminous rank with Btu/

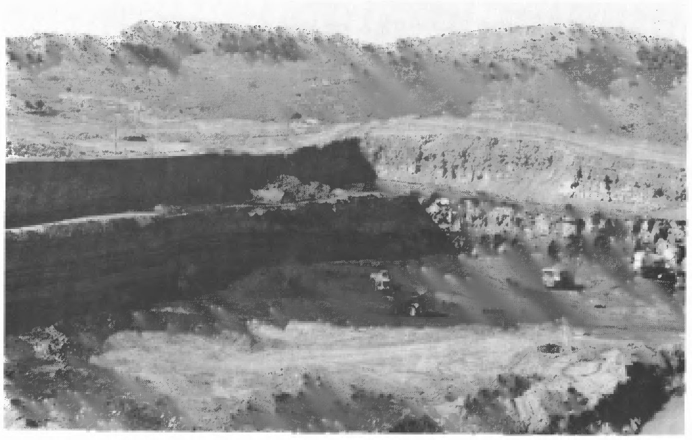


FIGURE 3-18.4a. Strip mining in operation at Carbon No. 2 mine on 24 February 1986. Photo by O. J. Anderson.

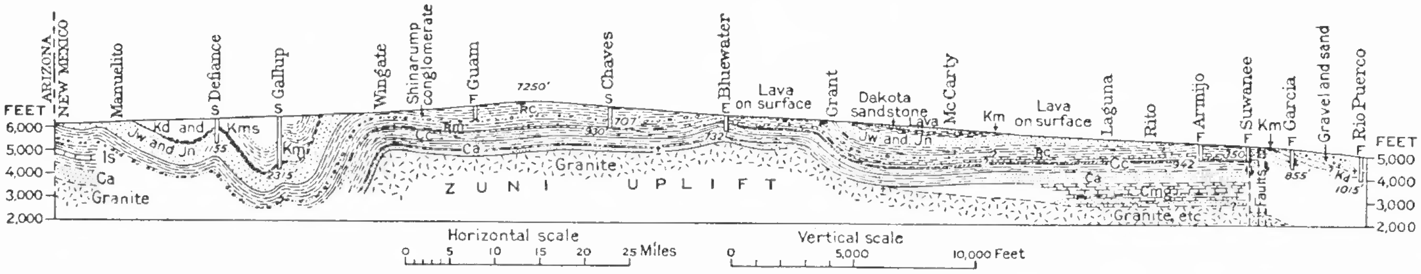


FIGURE 3-9.6b. Section across northwestern New Mexico along Atchison, Topeka & Santa Fe Railway. Exaggeration of dips is caused by great exaggeration of vertical scale. S, successful borings for water; F, borings that failed to obtain good water; E, boring yielding a small supply of water. Cmg, Magdalena Group; Ca, Abo Sandstone; Cc, Chupadera Formation; Trm, Moenkopi Formation; Trc, Chinle Formation; Jw, Wingate Sandstone; Jn, Navajo Formation; Km, Morrison Formation; Kd, Dakota Sandstone; Kmc, Mancos Sh; Kmv, Mesaverde Formation (from Darton, 1928, p. 149).

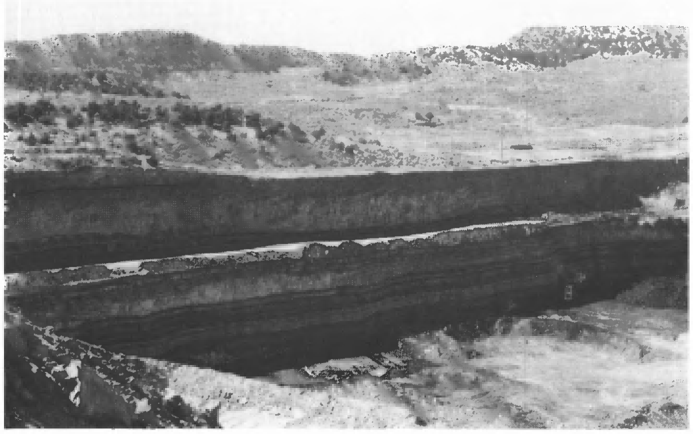


FIGURE 3-18.4b. View of highwall exposing; in descending order, the A (at level of first bench) through E beds. The B is the thickest one in the middle of the highwall below bench. Note thick fluvial channel ss at top of section with low to medium angle crossbed sets dipping to left (east). Photo by O. J. Anderson.

lb values of 9900 to 11000 (in place). The low-sulfur coal was delivered by rail and sold to the Arizona Electric Cooperative, Benson, Arizona, for use in the Apache steam electric generating station. The Apache station was shut down in late 1986 because the cooperative could purchase electricity from the new Palo Verde Nuclear generating station more economically than generating its own. The economics of coal vs. nuclear is a difficult comparison and has to be done on a case-by-case basis. However, the initial impact of a nearby, large, nuclear generating plant was a negative one for New Mexico's steam-coal industry (Anderson and Wolberg, 1987). The following is excerpted from Anderson and Reddy (1986).

The Carbon No. 2 mine is located on the southwest flank of the Gallup anticline in the S$^1/_2$ sec. 35, T15N, R18W, 2 mi south of the city of Gallup. Coal was mined from multiple seams in the upper part of the Dilco Coal Member of the Crevasse Canyon Fm. In descending order the seams are designated A, B, C, D and E. Also present are A′, A″, AB and AB′ seams, but these are either too thin or nonpersistent to be produced, and they are usually spoiled. The B seam, which ranges from 5.5–8 ft thick, is the thickest. The other producing seams range from 1.5 to 5 ft thick; 1.5 ft is the cutoff thickness used in production planning. Total recoverable reserves at a 13:1 maximum stripping ratio are 3.2 million tons.

Overlying the coal-bearing sequence at the pit is a 30-ft-thick, yellowish gray (5Y 8/1), fine-grained, but poorly sorted, quartzose sandstone. The sandstone contains clay galls and numerous stringers of coalified peat fragments, especially in the lower 10 ft. It is a fining-upward crossbedded sequence that is characteristic of an active channel fill in a lower alluvial plain. Crossbedding is of both trough and planar type, medium angle (10–20°) with crossbed dip directions clustering about N80°E, but ranging from N85°E to N25°E.

We found this sandstone to be of significance because it is one of the thickest in the local Crevasse Canyon Fm section and can be taken as the break between the Dilco Coal Mbr and the Bartlett Barren Mbr. Of greater importance, however, is the stratigraphic position of the unit. The base is 293 ft above the top of the Gallup Ss (from drill hole information). Significantly, near the landward pinchout of the Dalton Ss, which occurs along trend of the Nutria monocline 4 mi east of the mine, the base of the massive, upper part of the Dalton is 281 ft above the top of the Gallup Ss (from measured section). These intervals suggest that the units are time equivalents. The 281-ft interval (the Dilco equivalent) thins considerably across the anticlinal axis of the monocline, but this thinning of stratigraphic units upon approach to the monocline from either the gentle northeast side or the abrupt southwest side is further indication of syndepositional tilting rather than tectonic thinning or necking. Although modern erosion has removed this part of the section between the No. 2 mine and the monocline, the inferences and correlations are clear. The anomalously thick fluvial sandstone represents sand backing up onto the lower alluvial plain in response to the approach of the epicontinental sea to within 4 mi of the present mine site.

**Return to NM-602. 1.5**

19.9 **Intersection** with NM-602. **Turn left** and **proceed south. 0.7**

20.6 Crest of hill. Roadcuts are in carbonaceous shales of the Crevasse Canyon. **0.4**

21.0 Highway descends into valley of Bread Springs Wash; note the irregular topography on the nonmarine Crevasse Canyon compared to the even-crested mesas and cuestas that develop on marine sandstones. **2.0**

23.0 Arroyo cutting along modern course of Bread Springs wash visible on right; the 20 to 25 ft of incision probably represents downcutting within the last two hundred years. **0.6**

23.6 Bridge over Bread Springs Wash, a tributary of the Puerco River. **1.2**

24.8 Milepost 23. Note carbonaceous shale abruptly overlain by fluvial channel sandstone in Crevasse Canyon Fm on right side of road. Roadcuts continue in Crevasse Canyon Fm for next 2.0 mi. **0.6**

25.4 **Slow down.** Roadcut on right (Fig. 3-25.4) illustrates repeated episodes of swamp development (black carbonaceous shales and coal) and destruction of vegetation by overbank and crevasse-splay events (the yellow sandstones); continue south. **1.4**

FIGURE 3-25.4. Roadcut in Crevasse Canyon Fm at mile 25.4 illustrates repeated swamp development and overbank-crevasse splay events.

26.8 Milepost 21; leaving valley of Bread Springs Wash. **0.5**

27.3 The reddish to reddish-brown colored alluvium along the road signals the presence of the Bidahochi Fm (Miocene-Pliocene). **0.4**

27.7 The upland surface we are approaching is developed on Bidahochi Fm, which is generally a poorly cemented argillaceous sandstone with localized thin beds of well cemented siliceous sandstone. **0.6**

28.3 Low roadcuts ahead for next 0.7 mi are in Bidahochi. Prepare for right turn. **0.8**

29.1 Skeets Road to right; **turn right,** cross cattleguard and **proceed west.** Note typical development of piñon-juniper forest (*Pinus edulis* and *Juniperus monosperma*) for next several mi. **2.0**

31.1 Crest of hill. Bidahochi Fm is the uppermost unit in view ahead. This area provides some of the best exposures of Bidahochi to be found in the state. **0.3**

31.4 **STOP 2.** Pull over to right hand side of road and carefully walk across to left hand side of road for view of Bidahochi Fm in drainage to south.

At this stop there are approximately 100 ft of Bidahochi Fm exposed resting unconformably on the Crevasse Canyon Fm. Just below road level a 19-in.-thick white rhyolitic ash bed is present (Fig. 3-31.4a). Convoluted beds locally underlie the ash bed and can be seen well here, immediately west of the stop area (Fig. 3-31.4b). These represent soft-sediment deformation; however, any association of this deformation with the ash-fall event is not suggested. Generally, soft-sediment deformation is associated with rapid loading; no evidence of rapid sedimentation is indicated in the overlying section. This ash bed (Fig. 3-31.4c) can be traced throughout the area, albeit with some eastward thinning. The rate of eastward thinning locally is such that one would expect a very nearby source. Since a nearby Pliocene source of ash is not plausible, the source must have been farther upwind, perhaps the Hackberry Mtn area south of Sedona, Arizona, which is part of the upper Verde River volcanic field, 175 mi to the west. The distance is reasonable; however, the onset of tuffaceous volcanism in that area was about 11.5 my ago (McKee and Elston, 1980). That is somewhat older than the Late Miocene to Pliocene age generally accepted for the Bidahochi at this locality (see Love, this guidebook).

FIGURE 3-31.4a. Looking west from Stop 2 at white-ash bed in Bidahochi Fm.

FIGURE 3-31.4b. Convoluted beds in argillaceous, or very poorly sorted, sandstone in Bidahochi Fm are common below ash bed in vicinity of Stop 2.

FIGURE 3-31.4c. White rhyolitic ash bed, 19 in. thick in Bidahochi Fm.

The surface upon which the Bidahochi Fm rests slopes to the west and southwest. This surface was called the Zuni erosion surface by McCann (1938), who calculated a west-southwest gradient of 29 ft/mi. Recent work in this area by Anderson (1989) shows a gradient of 33 ft/mi. As McCann (1938) stated, this would seem to be quite high for a fluvial system that deposited such a fine-grained unit, and perhaps some post-depositional westward tilting of the area is indicated.

**Return to NM-602. 2.3**

33.7 **Intersection** with NM-602 at stop sign. **Turn right** and **proceed south** on 602. **0.5**

34.2 Bread Springs Road to left. This is starting point of Supplemental Road Log 3 (p. 000). Continue straight ahead on 602. **0.2**

34.4 Milepost 18. Joe Milo's Store and trading post on right. Elvis reportedly appeared here in September 1986. **0.3**

34.7 Road continues on Bidahochi Fm. **0.5**

35.2 Crevasse Canyon Fm exposed in bottom of drainage to right. **0.3**

35.5 In roadcut on right side just ahead, white rhyolitic ash bed exposed in Bidahochi. **1.9**

37.4 Milepost 15. Chichiltah-Navajo Memorial Highway to right leads to BIA elementary schools at Chichiltah and Jones Ranch. **0.2**

37.6 Highway descends into valley of Whitewater Arroyo and back into Cretaceous rocks. **1.1**

38.7 Bridge over Whitewater Arroyo. **0.2**

38.9 At approximately 2:30 on north side of Whitewater Arroyo is top of Gallup Ss (Torrivio Mbr). Nearer the highway on south side of arroyo is the basal Crevasse Canyon Fm. **0.3**

39.2 Roadcuts in Bidahochi. **0.7**

39.9 Vanderwagen and Whitewater Trading Post on right. **0.2**

40.1 Crossing Nelson Wash; Torrivio Mbr of Gallup exposed along north side of wash on right. **1.5**

41.6 McKinley County Road 6 to right leads to Kiwanis Park and Cousins Bros. Trading Post. The Bidahochi cover in this area is most unfortunate as it conceals the pinch-out or northward facies change of the Pescado Tongue of the Mancos Sh. With no Pescado present there is no basis for distinguishing a lower Tres Hermanos Fm from an upper Gallup Ss. Thus, to the north and west, the entire regressive sandstone section of late Turonian age is called the Gallup Ss; to the southeast as far as Socorro County, both Tres Hermanos and Gallup Ss are recognized. **1.8**

43.4 McKinley County Road 8 to right; view ahead is valley where Rio Nutria and Rio Pescado meet. At the confluence, the Zuni River begins. **0.3**

43.7 Roadcuts in the Bidahochi are the last we see of this unit. Cretaceous rocks exposed at base of cut on left. As the road descends into the valley, note dip slope on Dakota Ss to right, strike valley developed on Rio Salado Tongue of Mancos ahead, and escarpment on the left capped by the Atarque Mbr of the Tres Hermanos Fm. Dips here are 3–5° ENE. Enter Zuni Indian Reservation. **1.7**

45.4 Milepost 7. Small hill on left is capped by an erosional remnant of Twowells Tongue of Dakota over Whitewater Arroyo Tongue of Mancos. A coil fragment from *Metoicoceras* sp? was found in the yellowish gray to light olive gray fine-grained ss weathering out of top of the hill. **0.1**

45.5 From 9:00 to 11:00, note well-exposed sandstone cliffs of the Atarque Mbr overlain by the carbonaceous Carthage Mbr of Tres Hermanos. **2.1**

47.6 Paved road to right is a short-cut to Zuni Pueblo; continue straight ahead on NM-602 through lower part of Rio Salado Tongue of Mancos. **0.5**

48.1 At 1:00–2:00 note top of Dakota exposed in south bank of arroyo. **0.1**

48.2 Whitewater Arroyo Tongue exposed in roadcuts; at 9:00 the bluff exposes all three members of the Tres Hermanos Fm, the Atarque Mbr, Carthage Mbr and Fite Ranch Ss Mbr which caps the sequence. **0.8**

49.0 **Intersection** with unpaved road; **turn left** and **proceed eastward** to Upper Nutria. **0.1**

49.1 At 9:30 note the Tres Hermanos section above the talus-covered Rio Salado Tongue of Mancos Sh (Fig. 3-49.1). **0.4**

49.5 Prominent mesa at 2:30 is capped by the Gallup Ss, which overlies a 44-ft-thick section of Pescado Tongue of Mancos Sh (Fig. 3-49.5). The stratigraphic relationships of the Gallup–Pescado–Tres Hermanos are described at Stop 3. **0.5**

50.0 Channel of Rio Nutria visible on right. **0.4**

50.4 Near the base of mesa at 9:00 the lower two sandstones are Tres Hermanos overlain by slope-forming Pescado Tongue of Mancos and capped by Gallup Ss. The section is dipping gently eastward, and we will climb through it in the next 5 mi. **1.5**

51.9 Gallup Ss caps mesa at 10:00. **0.5**

52.4 At 9:00–10:00 beyond the small house the Pescado Tongue forms base of slope overlain by the complete Gallup Ss (Fig. 3-52.4). **0.3**

52.7 At 10:00 on the point note the top of the marine Gallup Ss (very light gray crossbedded ss) overlain by the slope-forming carbonaceous Ramah Mbr of the Gallup Ss. **0.2**

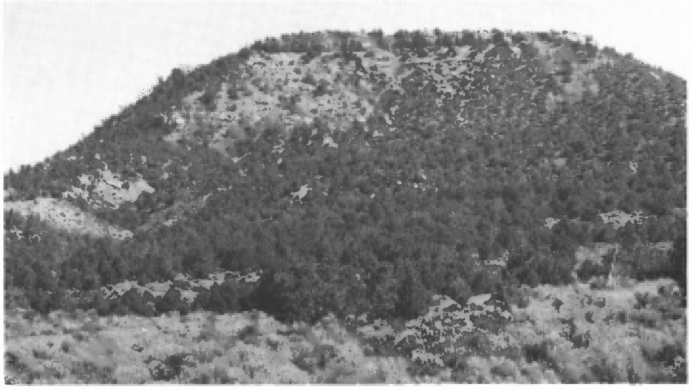


FIGURE 3-49.1. Tres Hermanos sandstones capping mesa on north side of Rio Nutria.

FIGURE 3-49.5. Gallup Ss capping mesa south of mile 49.5. A 44-ft-thick shale section—the Pescado Tongue of the Mancos—underlies the Gallup and separates it from the Fite Ranch Ss Mbr of Tres Hermanos Fm which may be seen as light-colored ledge just below top of mesa on the left side.

FIGURE 3-52.4. View northward at mile 52.4 showing even-bedded marine Gallup Ss near base, overlain by slope-forming Ramah unit and the Torrivio Mbr. The Pescado Tongue is concealed by talus at base of mesa.

52.9 Dam and Nutria Reservoir No. 2 on right. On the left note the grayish-orange weathering marine sandstones of the Gallup, overlain by slope-forming Ramah Mbr, capped by the Torrivio Mbr of Gallup (Fig. 3-52.9), which is commonly red in this area. **0.2**

53.1 Roadcuts on left expose typical fine-grained marine sandstones of Gallup interbedded with lagoonal sandy muds; the section is slightly slumped. **0.6**

53.7 **Cattleguard.** At 11:00 note reddish-brown Torrivio Mbr capping the mesa. **0.1**

53.8 Note top of marine Gallup (lighter colored ss) on left as road bends right. **0.4**

54.2 Road has now ascended into the upper, nonmarine portion of the Gallup. At 1:00 in talus slope under massive Torrivio Mbr is the abandoned and reclaimed School mine. Coal was mined here during the 1920's and earlier for use by the Indian schools at Zuni Pueblo—about a 20-mi haul. Entry was driven northward (Fig. 3-54.2) on a 4.0-ft-thick coal with an in-place Btu value of about 11,000. Coal lies about 75 ft above the top of the marine Gallup and is not paralic; it represents accumulation in a back-swamp, floodbasin environment on a lower alluvial plain. **0.9**

55.1 Charles Maxwell's retirement home on left side of road; note sod roof (Fig. 3-55.1). Road is on Ramah Mbr concealed by thin alluvial cover. **0.3**

FIGURE 3-52.9. Marine Gallup Ss in three distinct sandstone units separated by sandy mudstones and siltstone of lagoonal or bay-fill sequences. Nonmarine part of Gallup overlies the even-bedded, lower marine section.

FIGURE 3-54.2. Entrance to School Mine. Coal bed ranges between 4 and 5 ft thick. Note good roof conditions provided by fluvial channel ss. Entrance was sealed and site reclaimed in 1987. Photo by O. J. Anderson in 1982.

FIGURE 3-55.1. A handyman's special built out of Maxwell's favorite—the Gallup Ss.

55.4 Torrivio Mbr caps small mesa on left. Road makes sharp right and follows earthen embankment. **0.5**

55.9 Cross Rio Nutria. Sandstone to left in arroyo is basal part of Crevasse Canyon Fm; the Gallup has dipped into subsurface at this point. Road forks just ahead, bear right. **0.3**

56.2 After crossing earth dam, road is briefly on dip slope of Torrivio Mbr of Gallup. **0.5**

56.7 Crest of hill reveals panorama of Zuni Mountains on skyline. At 11:30–12:00 in front of the mountains is a segment of the hogback (lighter colored rocks—orange and gray) developed on the Dakota and Gallup Ss in the Nutria monocline. **0.2**

56.9 At 10:00 on the skyline, relatively thick fluvial sandstones at the top of the local Crevasse Canyon section form the drainage divide between Rio Nutria on the south and Whitewater Arroyo to the north. **0.5**

57.4 Road forks, **bear right. 0.3**

57.7 Nutria Reservoir No. 4 on left; no swimming or water skiing. **0.4**

58.1 Cross dam at Reservoir No. 4. **0.4**

58.5 Road bears right onto earthen dam at Reservoir (swamp) No. 3. Very little storage capacity remains in the reservoir due to the high siltation rates. Dams were constructed in 1930's. **0.7**

59.2 **Stop sign** at intersection with paved road; **turn left** and **proceed northeastward** to Upper Nutria. Road is on broad floodplain of Rio Nutria. **2.0**

61.2 Crevasse Canyon Fm in roadcuts and in broken mesa on right. At 11:00 highest point on skyline of Zuni Mtns (elevation 8280 ft) is developed on Permain Glorieta Ss. **0.7**

61.9 At 1:30 note red-orange Gallup Ss forming part of the hogback. **0.7**

62.6 Village of Lower Nutria to left (Fig. 3-62.6). **0.4**

63.0 Pavement ends. At 12:00 the water gap in the Nutria monocline exposes Dakota and Zuni with SW dips up to 80°. At 3:00 in distance note the decreasing dips on each successive block as the southern edge of the monocline is approached. This is probably controlled by discrete basement blocks each having undergone a slightly different amount of crustal shortening. **0.6**

63.6 This point is very close to the synclinal axis of the highly asymmetric Zuni basin. **0.4**

64.0 **Road forks** at wooden bridge; **turn left, do not cross bridge.** Hogback to southeast of road exposes Dakota, Mancos, Tres Hermanos and Gallup. Tres Hermanos does not crop out in hogback to north. **0.7**

64.7 **STOP 3;** Nutria monocline at Nutria water gap (Fig. 3-64.7a). Parking on road to left (Forest Rd 419).

FIGURE 3-62.6. Village of Lower Nutria.

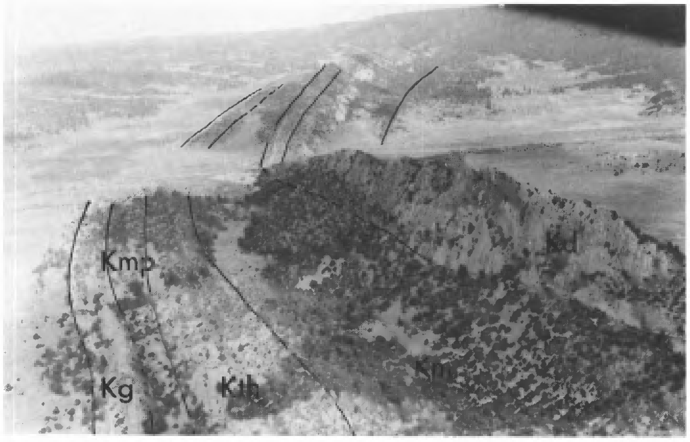


FIGURE 3-64.7a. Aerial view looking northwest at the Nutria water gap from a point just southeast of Stop 3. Nutria monocline changes strike by about 7° at the gap to a more northerly trend.

The Nutria monocline provides excellent outcrops of Permian through Cretaceous rocks. The first part of this stop is at the Dakota Ss hogback on the north side of the Rio Nutria water gap. The second part of the stop, one-half mi to the east across the broad strike valley developed on the Chinle Fm, allows us a look at the Glorieta Ss, the San Andres Ls, the Moenkopi Fm and the Chinle. Figure 3-64.7b is an aerial view showing the two parts of the stop.

The Dakota Ss and Gallup Ss (Upper Cretaceous) together represent fluvial, nearshore and shoreface deposition during the Greenhorn and Carlile cycles of sedimentation (Fig. 3-64.7c). They enclose a southwestward (landward) thinning tongue of Mancos Sh representing offshore, open marine deposition. That shale tongue is approximately 350 ft thick in the area of our stop and immediately to the north, but is not well exposed. The Dakota Ss (Cenomanian) is associated with the transgressive part of the cycle; the Gallup is a regressive shoreface sandstone that prograded out into the Mancos seaway during late Turonian time. At the transgressive maximum the strandline stood as far west as the southwestern corner of present-day Utah and swept a broad arc to the southwestern corner of present-day New Mexico. Much of New Mexico, Colorado and Kansas were far offshore, sediment-starved basins at the time of maximum transgression of the seaway and thus became sites of limestone and calcarenite deposition. This offshore lime facies is called the Greenhorn Formation, the upper member of which, named the Bridge Creek Ls, can be recognized throughout much of western New Mexico. The Bridge Creek Ls beds are present in the section exposed in the hogback on the south side of Rio Nutria, about 28 ft above the Twowells Tongue of the Dakota Ss. This 28-ft-shale interval contrasts with the overlying 290-ft-shale section and indicates that the transgression rates were much higher than regression rates.

Also south of the Rio Nutria the Tres Hermanos Fm can be recognized in outcrop. This unit consists of a regressive-transgressive wedge of sediments generally older than the Gallup Ss. However, shorelines did not uniformly advance and retreat, and this complication produced some unlikely age relationships (see Anderson mini-paper at mile 65.2). The regressive Atarque Ss Mbr and the lower half of the overlying Carthage Mbr represent relatively rapid progradation in a middle Turonian

FIGURE 3-64.7b. Aerial view of broad Chinle Fm strike valley between part 1 and 2 of Stop 3.

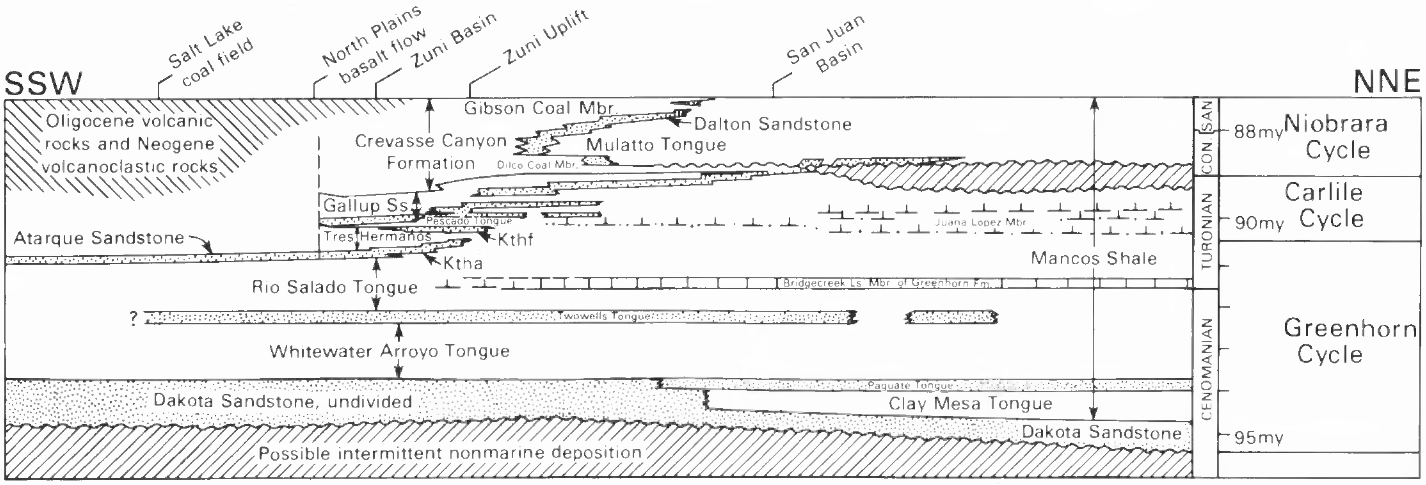


FIGURE 3-64.7c. Late Cretaceous strata and cycles in west-central New Mexico.

depo-center that formed an eastward pointing headland that projected out into the seaway. The northern margin of that headland passed just several miles to the north of here, as the Tres Hermanos Fm is not present north of Grasshopper Springs (3 mi N). The upper part of the Carthage Mbr and the Fite Ranch Mbr represent the onset of a marine transgression that marked the beginning of the Carlile cycle (Fig. 3-64.7c). The Gallup Ss associated with the regressive, later part of the Carlile cycle unfortunately is not well exposed at the stop; like the Tres Hermanos it is well exposed immediately to the south.

In the Dakota Ss before us (Fig. 3-64.7d) there is good exposure of 55 ft of section recording the transition from fluvial/paludal to quiet water lagoonal deposition with a thin paralic coaly zone near the top (Fig. 3-64.7e). Some of the secondary sedimentary features that may be seen in the Dakota at this stop are burrows, root tubes, woody trash, ripple bedding and wave oscillation ripples. The wave ripples trend generally E or SE (Fig. 3-64.7f).

The underlying Jurassic rocks are for the most part eolian ss. At this locality no attempt has been made to

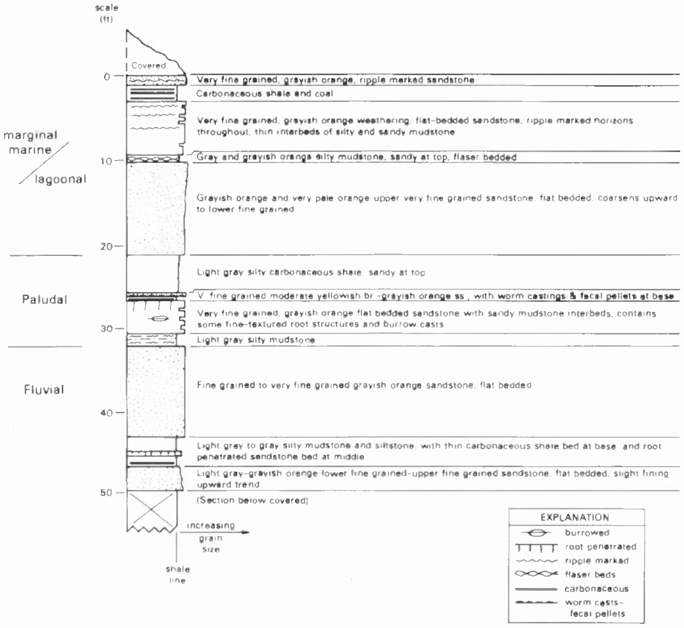


FIGURE 3-64.7e. Measured section of Dakota Ss at outcrop in Rio Nutria water gap in SE$^1/_2$ SW$^1/_4$ sec. 7, T12N, R16W. Approximately 35 ft to K/J below the base of the measured section.

FIGURE 3-64.7d. Looking north at Dakota Ss in hogback at Stop 3, in water gap of Rio Nutria.

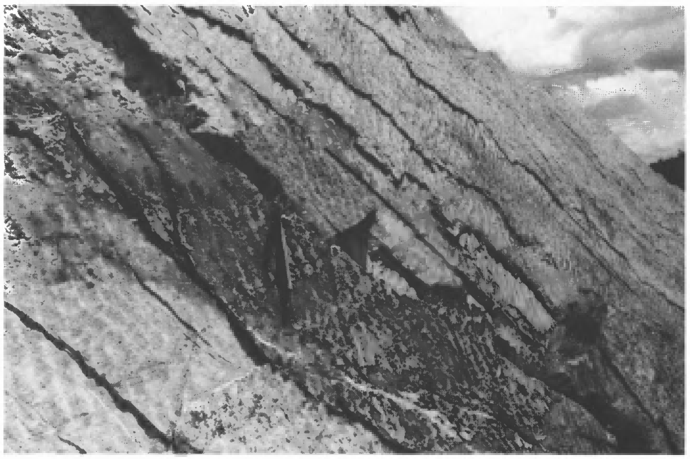


FIGURE 3-64.7f. Wave-oscillation ripple marks on a dip slope developed on marine facies in upper part of Dakota Ss. Note hammer for scale.

differentiate the upper and lower parts of the 700-ft-thick sandstone into Cow Springs and Entrada; we call it Zuni Ss. However, Edmonds (1961) recognized an Entrada, Zuni and Morrison section. His Zuni-Morrison contact was "arbitrary." The Entrada Ss was described as a thin silty sandstone at the base which had a gradational and conformable upper contact with the Zuni. The interesting feature of the Jurassic section here is the 20-ft-thick chert- and quartzite-pebble conglomerate at the base. It forms a mini-hogback, 0.2 mi NE of the stop locality and may be examined on the walk to the second part of the stop. We refer to the facies here informally as the Nutria conglomerate bed of the Zuni Ss. Conglomerates similar to this have been noted in Jurassic Ss at other localities, one being at mile 26.1 of the second-day road log. Another locality is on the Plumansano Basin quadrangle north of Atarque Lake where Anderson (1987) reported a 20-ft conglomerate bed comprising the entire Jurassic section.

At the second part of the stop, across the Chinle valley, an aggregate pit developed near the anticlinal bend of the monocline provides good exposure of the Permian San Andres Limestone (Fig. 3-64.7g). However, the **highwall is somewhat unstable and extreme care must be taken** to avoid injury. Hard hats are recommended for those approaching the base of the cut. Also, remember we are on Zuni Indian Reservation land.

About 75 ft of section is exposed in the pit. The medial 14–15 ft is a distinctive break in the limestone sequence and consists of 3 facies, all lenticular, which are (1) maroon sandy mudstone, (2) white, fine-grained siliceous sandstone—Glorieta type sandstone, and (3) maroon and gray, very fine-grained sandstone. Some type of sediment-starved, shallow-water near-shore basin is indicated by this carbonate-dominated section. Productoid brachiopods, highly recrystallized, are common in the upper part—above the maroon mudstone break. This outcrop is in an area of maximum thickness of the San Andres; in many places on top of the uplift, a karst surface can be recognized at the San Andres/Triassic contact, and the limestone is locally missing (Colpitts et al., this guidebook).

FIGURE 3-64.7g. View to east of aggregate pit developed in San Andres Ls. Near middle is a 15-ft-thick section of mudstone, white Gloreita-type ss and maroon, very fine-grained ss.

In the east-trending Nutria Canyon immediately to the south, the underlying Glorieta Sandstone (Leonardian) is exposed. It is a 200-ft-thick, well cemented, high silica sand characterized locally by thick sets (up to 45 ft) of high-angle crossbeds (Fig. 3-64.7h). The crossbed sets dip almost uniformly to the southwest. The thicker sets are in the lower half of the Glorieta. An eolian origin for this portion of the section is suggested by the thick crossbed sets.

On the south side of the mouth of Nutria Canyon, a 30-ft-thick section of Moenkopi Fm (middle Triassic) is preserved (Fig. 3-64.7i).

FIGURE 3-64.7h. Thick crossbed sets in the Glorieta Ss in Nutria Canyon.

FIGURE 3-64.7i. Thin Moenkopi section on San Andres Ls on south side of Nutria Canyon.

# STRATIGRAPHY OF THE TRIASSIC MOENKOPI FORMATION, WEST-CENTRAL NEW MEXICO

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In west-central New Mexico, Triassic strata we identify as Moenkopi Formation crop out on the northeastern and southwestern flanks of the Zuni Mountains and as erosional remnants on a west-to-northwest-dipping surface of the Permian San Andres Formation on the western limb of the Lucero monocline. In the Lucero uplift, the best preserved sections are those capped with Tertiary basalt. These are found along the central part of the uplift on the divide between Mesa Gallina and Chicken Mountain. Moenkopi strata here were formerly assigned to the Shinarump Conglomerate Member of the Upper Triassic Chinle Formation by Kelley and Wood (1946) and later to the Moenkopi(?) Formation by Stewart et al. (1972). In the Zuni Mountains, these strata have long been recognized as Moenkopi, or Moenkopi(?) Formation (Darton, 1928; Wengerd, 1950; McKee, 1954; Cooley, 1957; Stewart et al., 1972). However, we have established biostratigraphically that these basal Triassic strata were indeed deposited during Moenkopi time (Middle Triassic, Anisian or latest Early Triassic, Scythian). Furthermore, these strata are probable lateral equivalents of the Holbrook Member of the Moenkopi Formation in northeastern Arizona (McKee, 1954) and the Moody Canyon Member in southeastern Utah (Blakey, 1974).

L. F. Ward (1901) named the Moenkopi Formation for strata that crop out at the mouth of Moenkopi Wash in the Little Colorado River Valley near Cameron, Arizona. Darton (1928) first recognized the presence of the Moenkopi Formation in west-central New Mexico, but apparently mistook the Sonsela Sandstone Bed in the Petrified Forest Member of the Chinle Formation for the Shinarump Member of the Chinle. This exaggerated the thickness of the supposed Moenkopi strata by a couple of hundred meters. A year later, Baker and Reeside (1929) stated that the Moenkopi Formation did not occur east of the Zuni Mountains, based on thinning of the Moenkopi from central Arizona eastward toward the Zuni and Defiance uplifts. Kelley and Wood (1946) assigned the basal Triassic strata of the Lucero uplift to the Shinarump Conglomerate based on Baker and Reeside's (1929) work and the opinion of E. D. McKee, who later named two members of the Moenkopi Formation in Arizona (McKee, 1954).

Wengerd (1950, 1959) noted the presence of "questionable Moenkopi sediments" in the Zuni Mountains, in subcrop in the San Juan Basin and on the Lucero uplift. McKee (1954), referring to Wengerd's work, stated that "the facts demonstrate" that no Moenkopi strata crop out east of the northeastern flank of the Zuni Mountains. Cooley (1959) referred these strata in the Zuni Mountains to the Moenkopi(?) Formation and noted lithologic dissimilarity to any Moenkopi sediments in northeastern Arizona. He also noted extensive pre-Moenkopi(?) karst topography and channeling in the top of the Permian San Andres Formation in the Fort Wingate area but did not note any occurrences east of the Zuni Mountains. Stewart et al. (1972) noted the occurrence of Moenkopi(?) Formation in the Zuni Mountains, the Lucero uplift area, the Riley-Puertecito area and east of the Rio Grande on the Sevilleta Grant 26 km northeast of Socorro where it had been included in the Dockum Group by Wilpolt and Wanek (1951).

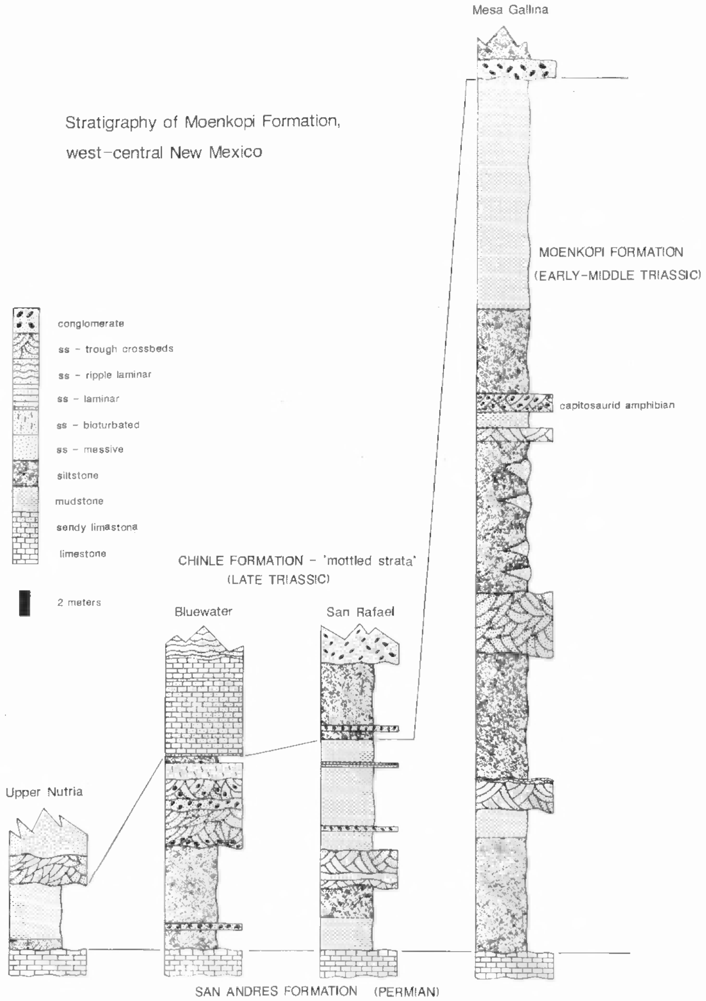

FIGURE 3-64.7j. Selected measured stratigraphic sections of the Moenkopi Formation in west-central New Mexico. Locations of sections are: Upper Nutria—NW¼ SW¼ sec. 8, T12N, R16W, McKinley County; Bluewater—NE¼ NW¼ SE¼ and W½ NE¼ sec. 36, T13N, R12W, Cibola County; San Rafael—SE¼ SW¼ SE¼ sec. 4, T9N, R10W, Cibola County; Mesa Gallina—SE¼ SE¼ NE¼ sec. 10, T5N, R4W, Cibola County.

The Moenkopi Formation of west-central New Mexico consists of interbedded conglomerate and sandstone (20.6%), siltstone (49.6%) and mudstone (29.9%), bounded by profound disconformities. Measured stratigraphic sections show an eastward increase of thickness from 7.1 m at Upper Nutria on the southwestern flank of the Zuni Mountains to 68.3 m on Mesa Gallina in the Lucero uplift, over a distance of about 125 km (Fig. 3-64.7j). Typical Moenkopi Formation lithologies include: grayish red (5R 4/2 and 10R 4/2; rock colors after Goddard et al., 1984), pale red (5R 6/2) and pale reddish brown (10R 5/4) lithic wacke sandstone (lithologic names from Williams et al., 1982) that is trough crossbedded to planar crossbedded; medium gray (N5), grayish red (5R 4/2 and 10R 4/2), moderate brown and pale yellowish brown, matrix- to clast-supported conglomerate that may show pebble imbrication and planar crossbedding; moderate reddish brown (10R 4/6) to dark reddish brown (10R 3/4) siltstone that is generally rippled to laminar, but may be massive; and massive silty mudstone which is dusky red (5R 3/4) to dark reddish brown (10R 3/4) with pale greenish yellow (10Y 8/2) to moderate orange pink (5YR 8/4) mottling.

In the Mesa Gallina area the surface of the underlying Permian San Andres Formation shows extreme paleoweathering and the development of paleotopography on a low-relief surface with abundant goethite pseudomorphs after pyrite forming a crust as much as 1.5 cm thick. Nearby areas such as Riley (Stewart et al., 1972) and the northeastern flank of the Zuni Mountains (Cooley, 1959) may show a karst topography as well as a paleoerosion surface developed in the top of the San Andres.

In the Lucero uplift area, paleotopographic relief is evidenced by the varying thickness of the basal white to yellow mudstones and siltstones of the Moenkopi Formation. On Mesa Gallina these basal sediments are as much as 9 m thick and contain microfossil evidence of a lacustrine origin (Kietzke, 1988). In the outcrops on White Ridge in the Lucero uplift and in the Zuni Mountains, however, they range from 0.8 to 3.7 m in thickness. On the basis of sedimentary structures such as lateral accretion sets, small trough crossbedding and current ripples, these strata are interpreted as having been deposited by fluvial systems (Collinson and Thompson, 1982).

The basal sequence or first phase of Moenkopi deposition is interpreted as the filling in of topographic lows on an erosion surface with ponds or lakes in the lowest spots. As this topography was filled in and leveled off, the dominant mode of sedimentation became small meandering streams, evidenced by abundant small, multistoried or complex, ribbon-type sandstone bodies (after the classification of Friend et al., 1979). The large amount of silt and mud, and the small and isolated nature of the sand bodies, indicate that subsidence rate may have been high with respect to sedimentation rate (Friend et al., 1979; Blakey and Gubitosa, 1984).

Overlying this sequence, the second phase of Moenkopi deposition consists of interbedded mudstones, siltstones and wide sheet-sandstone bodies (Friend et al., 1979; Blakey and Gubitosa, 1984) with coarser basal conglomerates, larger grain size including abundant pebbles in the sands and less evidence for a meandering nature (i.e., not as many lateral-accretion-type deposits and abundant trough and planar crossbeds). These deposits indicate a lower rate of subsidence in relation to sediment supply (Friend et al., 1979). The channels had time to fill up with sediment and were forced to avulse laterally rather than being buried swiftly. This winnowed out the fine-grained overbank deposits, leaving sand instead. These sandstone bodies have a width-to-height ratio greater than 100, which meets the criterion for wide sheet sandstones (Blakey and Gubitosa, 1984).

The third and final phase of deposition is the uppermost portion of the Moenkopi Formation in the Lucero uplift and consists of one sequence that is 25 to 30 m thick. This has a scoured base with a wide sheet conglomerate/sandstone complex that is as much as 5 m thick, followed by 6 to 8 m of rippled siltstone and then by as much as 20 m of massive red mudstone with greenish gray to grayish yellow mottling and a 1.3-m-thick layer of nodular calcrete 13 m above the base. This sequence was deposited during a time of both high subsidence and high sediment supply.

A proximal source area for the Moenkopi to the south and west is suggested by the generally northerly paleoflow in the Lucero uplift, westward thinning and by the lack of textural and mineralogical maturity of the sandstones. This agrees with previous work of Stewart et al. (1972) and others who have postulated a Mogollon highland in southeastern Arizona and southwestern New Mexico. Recently, Bilodeau (1986) has posited the closest source area for Middle Triassic sediments as an island arc system in northwestern Mexico or southeastern California. This would not seem to agree with local evidence, but much more data are needed to settle the question.

Fossil remains are not plentiful in the Moenkopi Formation of New Mexico. The basal conglomerate of the third phase of deposition on Mesa Gallina yielded three partial vertebrae including centra and neural spines and a partial scapula of a non-parasuchian reptile and one partial interclavicle armor plate from an amphibian of the Capitosauroidea. These fossils indicate an Early-Middle Triassic age for the Moenkopi in the Lucero uplift.

Kietzke (1988) identified microfossils from some of the fine-grained units in the Mesa Gallina section. These are ostracodes of the genera *Darwinula*, *Darwinuloides* and possibly *Gerdalia*, charophytic algal remains of the genera *Porochara* (two species) and possibly *Altochara*, and spirorbid polychaete worms of a possible new taxon. These microfauna and flora also suggest an Early to Middle Triassic age for these sediments. The lowest unit on Mesa Gallina produced the great majority of these and probably was deposited in a clear, but saline to mineralized shallow lacustrine environment (Kietzke, 1988).

Thus, the basal Triassic strata formerly assigned to the Shinarump Member of the Chinle Formation or to the Moenkopi(?) Formation in west-central New Mexico are assigned to the Moenkopi Formation and provisionally correlated with the Holbrook and Moody Canyon members of the Moenkopi Formation of Arizona and Utah. Biostratigraphic evidence precludes placing them in the Upper Triassic as the Shinarump Member of the Chinle Formation.

## BASEMENT FAULT MODELS FOR THE NUTRIA MONOCLINE

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The excellent outcrops of Mesozoic and Permian rocks in the Nutria monocline allow construction of cross sections that are accurate with respect to the sedimentary sequence. Not well constrained is the dip and configuration of the basement fault(s) responsible for the monoclinal flexure or drape fold. The Nutria is a typical Colorado Plateau monocline: sinuous, narrow, abrupt, involving Mesozoic and late Paleozoic rocks, gentleness of associated regional dips, and 20 to 70 mi in length (the Nutria is 32 mi long). As Kelley (1955) stated, the monoclines are the dominant structures on the Colorado Plateau.

The cross sections (Fig. 3-64.7k) apply to an area one mi north of our present location. No thrusting is evident at the surface in this area, and structural interpretation becomes a matter of whether or not to fold the granitic basement. Sharp folds in granitic rock are not possible without some internal deformation. It may be penetrative—distributed uniformly throughout the shear zone—or it may be localized along relatively closely spaced imbricate thrusts. The basement is not exposed along the Nutria; however, it does crop out in the very similar structure of Oso Ridge 5 mi to the northeast. The granite in Oso Ridge is somewhat fractured and altered, but no evidence of a granulized zone or fault breccia was found near the upper contact with the Abo Formation. The contact where viewed near mapped springs appeared to be depositional, and no evidence of bedding plane slippage in the overlying sedimentary sequence was noted. The inference is that the basement did not undergo sharp folding there. Perhaps basement faults exist but are more widely spaced than diagrammed (Fig. 3-64.7l), and more diligent work is needed to uncover them.

The Oso Ridge cross sections pass through the Nutria monocline 4 mi north of our present location in an area where thrusting is evident and has cut out most of the Chinle Formation (Fig. 3-64.7l). Thrusting was recognized in this area by Edmonds (1961), who referred to the fault as the Stinking Springs thrust. One of the models in Figure 3-64.7l relies on multiple thrusts and shear planes with minimal folding of the basement. However, only one major thrust cuts the surface. A slight concave upward configuration on the thrust planes could explain why successive and perhaps flatter thrusts develop. The other model illustrates considerably more basement folding and only two major thrust faults. A minimum of two are required to allow for the recumbent fault slice which is needed to solve volume problems beneath the basement overhang. The volume problem arises in monoclines when the sedimentary drape higher in the section dips away from the basement thrust or reverse fault. The triangular area thus created must be filled, and overturned beds in a recumbent fault slice in combination with some basement folding is the logical explanation.

For a discussion of the origin of the forces and complex stress field responisble for the Nutria monocline and Zuni Mountains, see Chamberlin and Anderson (this guidebook).

After stop return to Dakota Ss hogback area at junction with Forest Road 419 and **retrace route back to NM-53.** Road log resumes at mile 64.7.

(64.7) Resume road log from this point (part 1 of Stop 3). **0.5**

65.2 At 12:00 is the largely abandoned village of Upper Nutria; much of the local building stone is the Dakota Ss, and to a lesser extent the Gallup Ss. At 11:00 the near-vertical ribs west of the Dakota Ss hogback are in the Tres Hermanos Fm separated from the overlying Gallup by a relatively thick Pescado Tongue of the Mancos—here 123 ft thick. No fossils were found locally in the Pescado, however, *Inoceramus flaccidus* was collected

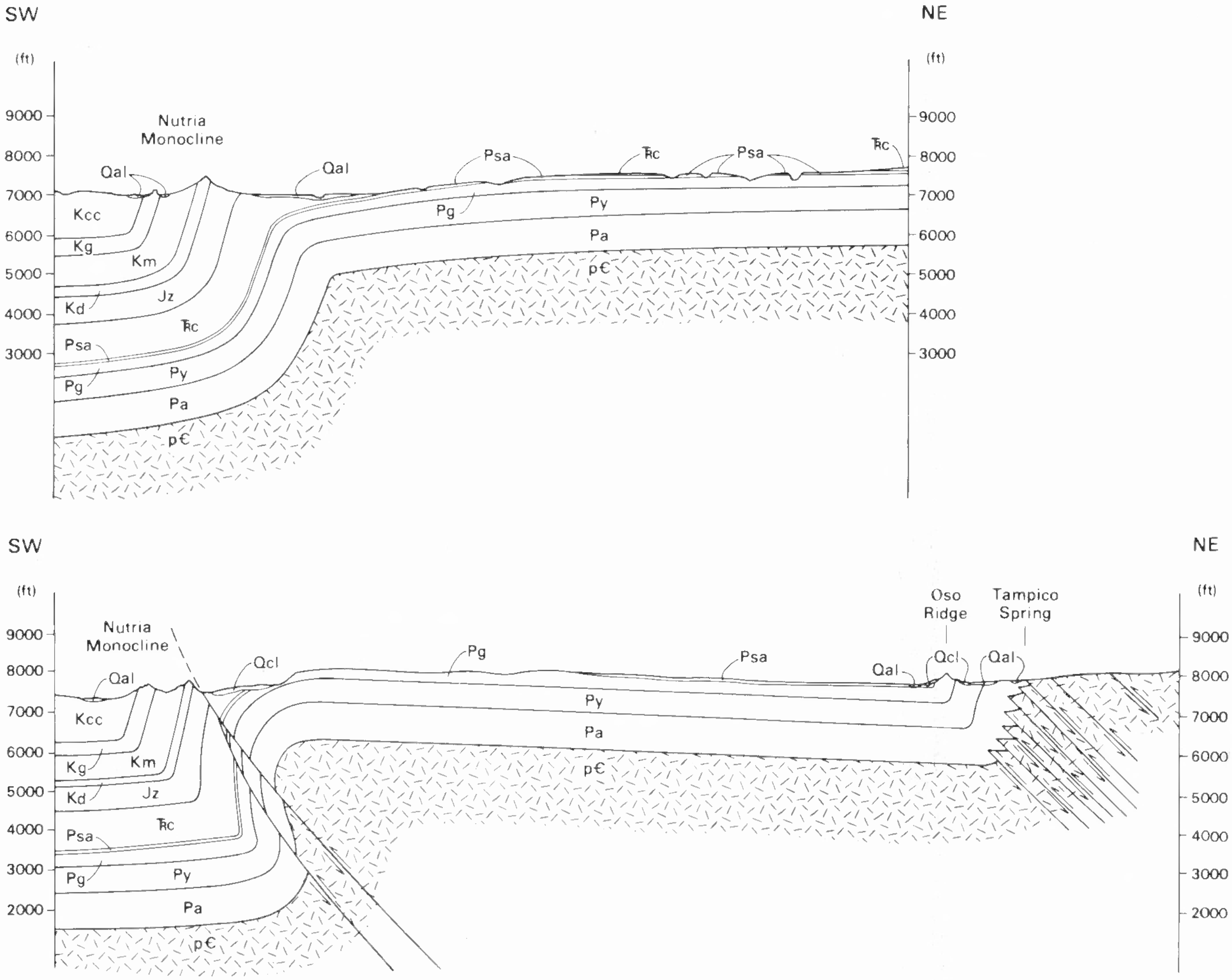

FIGURE 3-64.7k. Cross sections through the Nutria monocline north of Stop 3.

from near the base of the underlying Fite Ranch Mbr of the Tres Hermanos Fm (identification made by William A. Cobban, USGS). *I. flaccidus* is a middle Turonian bivalve (Fig. 3-65.2) that may overlap with the early Late Turonian range of *I. dimidius*. *I. dimidius* was found in the base of the Fite Ranch Mbr several miles to the south in a more landward position (Anderson, 1987). It was also reported in the E-sandstone mbr of the Gallup on the Vanderwagen Quadrangle 15 mi to the west (Anderson, 1989) and in the Pescado Tongue (Hook et al., 1983). The E-sand is therefore in part the temporal equivalent of the Pescado Tongue and perhaps even the Fite Ranch Mbr. **0.2**

## JUXTAPOSITION OF TRANSGRESSION AND PROGRADATION: A MODEST SUPPOSITION

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A stratigraphic problem exists in the late Turonian sediments of the middle part of the Zuni basin (see the foregoing discussion). Biostratigraphic evidence and physical stratigraphy suggest that the Pescado Tongue of the Mancos, and perhaps the Fite Ranch Member of the Tres Hermanos, are contemporaneous with the Gallup Sandstone. The Gallup was prograding, or regressive; the former units are transgressive—deposited during the transgressive part of the cycle (Fig. 3-64.7c). The Gallup in most parts of the basin is significantly younger than the Tres Hermanos; however, this is the area where the two merge (in a landward direction, and should theoretically approach the same age. They are the same age *but* they do not merge. The local stratal relationships and facies changes, namely the 123 ft of Pescado in this area grading into lagoonal mudstones and sandstones within a few mi to the northwest, demonstrate the juxtaposition of transgression (on the south) and progradation (on the north) and that the merging of the Tres Hermanos and Gallup was not synchronous along the shoreline.

Important concepts to keep in mind are: (1) shifting of major fluvial systems; (2) crustal loading and compaction on the coastal plain; and (3) the Gallup Sandstone to the immediate northwest and west shows much more deltaic, lagoonal and tidal influence than the local Gallup section which can be described as shoreface. The inference of this last concept is that a major fluvial system lay a short distance to the west-northwest of here during deposition of the Pescado Tongue. The Pescado was deposited in a local to subregional embayment developing immediately to the southeast of this fluvial system. The embayment developed on the freshly deposited coastal-plain mudstone and carbonaceous sediment of the Tres Hermanos and Moreno Hill formations which was

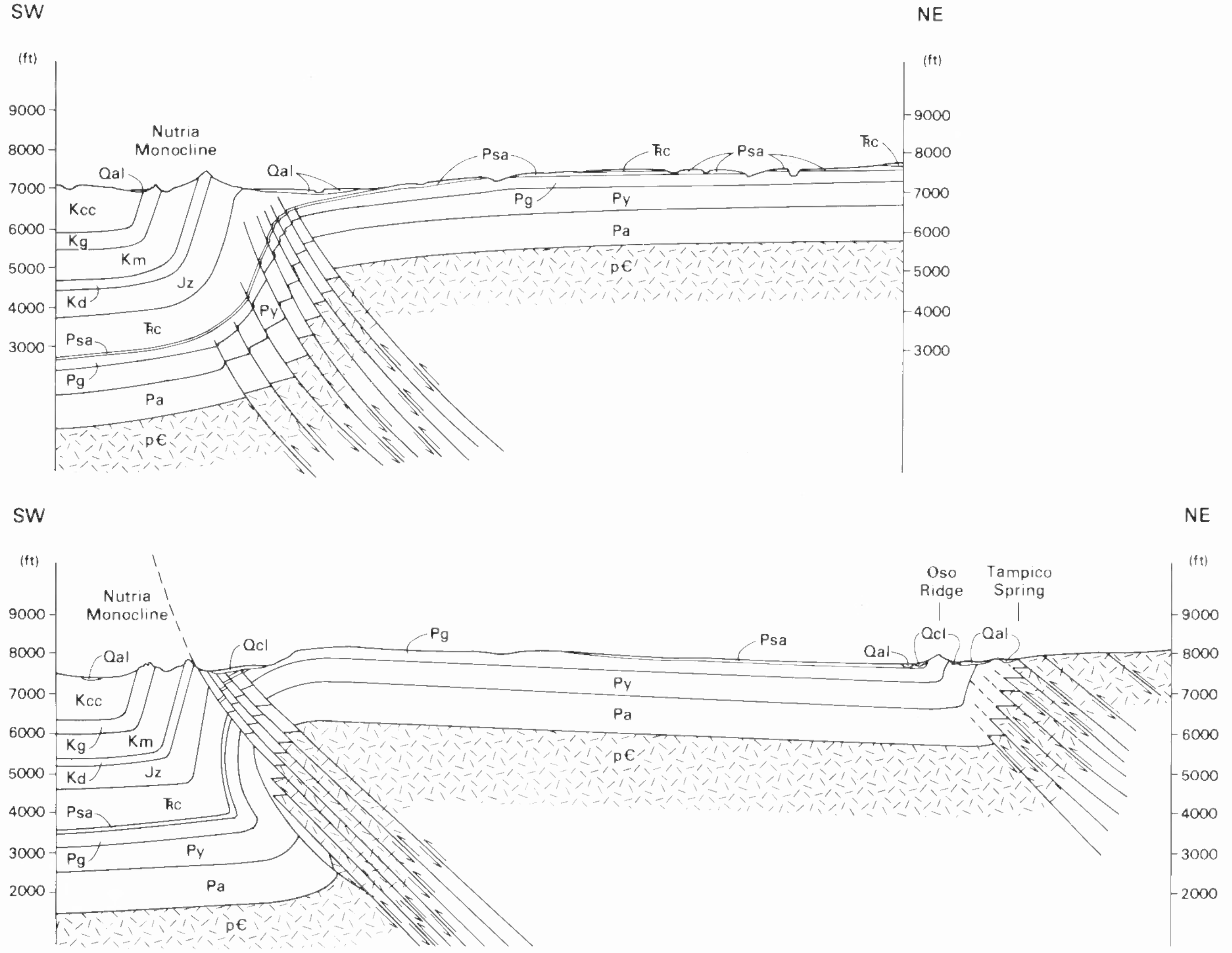

FIGURE 3-64.71. Two models to explain the structure of the Nutria monocline. See text for discussion.

undergoing compaction. Enhancing the compaction was the crustal loading factor, operative exclusively in the area of Tres Hermanos deposition because in that area sediment had replaced water and initiated subsidence. The hypothesis is strengthened considerably by the fact that the Pescado Tongue, and hence the transgression, was limited to the area of Tres Hermanos deposition.

Thus the northwestward shift of a major fluvial system following deposition of the Tres Hermanos set the stage for progradation of the oldest Gallup sandstones in the Vanderwagen, Gallup and Manuelito areas while the encroaching sea, nearing the end of a minor transgression, found a soft spot to the southeast and south. The model allows for the contemporaneity of the Fite Ranch Member, the Pescado Tongue and the oldest recognized Gallup Sandstone. Calling upon strike-slip faulting along a northeast trend (e.g., the compartmental faults discussed on the second-day road log) to juxtapose Cretaceous facies, including the abrupt stratigraphic changes that apparently exist across the Nutria water gap, in no way diminishes the above interpretations. Those interpretations are based upon age-equivalency of strata, not merely their geographical relationships.

65.4 Road to left crosses bridge and leads to upper Nutria; **bear right** and **proceed SW. 0.9**

66.3 Pavement begins. **0.4**

66.7 Lower Nutria on right. **1.9**

68.6 Mesa on skyline at 12:00 is developed on Gallup Ss. **1.6**

70.2 Road to right leads to Nutria lakes; continue straight ahead on pavement. **1.9**

72.1 Roadcut on right exposes carbonaceous shale of the Crevasse Canyon Fm. **1.2**

73.3 Sandstone outcrops on both sides of road are Torrivio Mbr of Gallup. **0.3**

73.6 Roadcuts for next 0.5 mi are in coal-bearing Ramah Mbr of Gallup Ss. **1.3**

74.9 Immediately behind small windmill on right note top of Fite Ranch Mbr of Tres Hermanos. **0.3**

75.2 Sandstone bench just above road level on both sides is formed on top of Fite Ranch Mbr overlain by slope-forming Pescado Tongue of Mancos. **0.4**

75.6 At 9:00 the lower bench-forming unit is the Fite Ranch Ss Mbr, overlain by the Pescado Tongue, and in turn by the light yellow marine Gallup Ss. Section is capped by nonmarine Gallup. Road now descends through Carthage Mbr of Tres Hermanos (Fig. 3-75.6). **0.5**

76.1 Crossbedded sandstone in cut at road level on right is a fluvial unit in lower part of Carthage Mbr of Tres

FIGURE 3-65.2. *Inoceramus flaccidus* collected from base of Fite Ranch Ss Mbr of Tres Hermanos Fm near Upper Nutria (½ natural size). Photo by Robert Burkholder, USGS.

FIGURE 3-75.6. View to east of highway at mile 75.6. Lower bed is top of marine Gallup overlain by generally slope forming Ramah unit, with the Torrivio Mbr capping the section.

Hermanos; however, the thin ss 12 ft above it is burrowed and bioturbated, suggesting marine affinities. **0.5**

76.6 Enter valley of the Rio Pescado. The lower sandstone cliffs to our right were designated as the Pescado Creek reference section for the Tres Hermanos Fm by Hook et al. (1983). **0.4**

77.0 Bridge over Rio Pescado. **0.6**

77.6 **Junction** with NM-53 at **stop sign; turn left** and **proceed E** toward Ramah. **0.2**

77.8 At 10:00, behind red barn is NE-dipping Gallup Ss forming prominent ledge. Fite Ranch Ss Mbr of Tres Hermanos is at valley floor level. **1.0**

78.8 At 9:30, the top of the marine Gallup disappears into the subsurface. The coal-bearing Ramah Mbr overlies it, capped by the reddish-colored, coarse-grained, feldspathic Torrivio Mbr. **1.3**

80.1 At 9:30 to 11:00, mesa exposes the entire nonmarine portion of the Gallup Ss dipping gently NE. The nonmarine Gallup, genetically and lithologically belongs with the Crevasse Canyon Fm. However, where Sears (1925) named the Gallup, the uppermost reddish colored sandstone (the Torrivio Mbr) lies stratigraphically very close to the marine sandstone and was a locally continuous unit. Farther out in the Gallup-Zuni basin the interval between these two sandstones increases significantly, putting the Torrivio Mbr essentially 150 ft up into the nonmarine "Crevasse Canyon part" of the section. The Torrivio Mbr, isolated from the main Gallup, is distinct from other Crevasse Canyon Fm fluvial sandstones only in color and grain size. Where the color is not distinctive it presents a challenge to the field geologist/mapper to find coarse-grained facies within it and correctly identify it as the uppermost Gallup Ss; the feldspathic aspect also helps in the identification. **1.0**

81.1 Cross bridge over Rio Pescado. **0.2**

81.3 Village of **Pescado** (abandoned). **0.5**

81.8 At 10:00–11:00 note the Pescado lobe of the North Plains (El Malpais) basalt in creek bottom. **1.5**

83.3 Small butte at 11:30 is capped by Torrivio Mbr of Gallup. **0.8**

84.1 Leave Zuni Reservation. **1.2**

85.3 Descend into Ramah Valley. **0.3**

85.6 Marine Gallup Ss caps point on left side of road. **0.5**

86.1 Ramah water gap at 10:30 exposes color-banded cliffs of Zuni Ss overlain by darker slope-forming Dakota Ss. **0.5**

86.6 Enter town of **Ramah** (Fig. 3-86.6). Post office on left. A small farming and lumbering community, Ramah was settled in 1874 by Mormons and named for a figure in the Book of Mormon.

A recent article in the "Albuquerque Journal" (22 January 1989) discussed claims that rancher John Miller, who died near Ramah in 1932 or 1933, was William Bonney, aka "Billy the Kid." Photographs of Miller show a striking resemblance to the one authentic photo of "The Kid." Supporters of Miller's identity as Bonney say that Pat Garrett, who claimed to have shot Bonney on 14 July 1881 in Fort Sumner, New Mexico, actually

FIGURE 3-86.6. Downtown Ramah, New Mexico.

shot an Indian companion of "The Kid." They also point to Miller's alleged criminal past and his curious ability to produce large quantities of gold coins from a secret cache as further evidence that he and Bonney were one-and-the-same man. Historians, however, remain skeptical and have added John Miller to a growing list of would-be William Bonneys. **0.8**

87.4 Leave Ramah. Route has crossed a gentle synclinal axis and is now in SW-dipping strata associated with the Zuni uplift. We are on strike of the SE projection of the Nutria monocline, but that structure has, in a series of discrete steps, died out at this point (Fig. 3-87.4). This portion of the Zuni Mountains may have a different uplift history in terms of both style and vergence direction than the portion to the north bounded by the Nutria monocline (see Chamberlin and Anderson, this volume). **0.6**

88.0 At 9:00 low sandstone bench is Dakota Ss. **1.1**

89.1 Forested mesa from 1:00 to 4:00 is capped by Tres Hermanos Fm. Road is following a broad Mancos Sh valley. **0.6**

89.7 Tree-covered surface to left is a dip slope on Dakota Ss. **1.7**

91.4 Lewis Trading Post on left. **1.2**

92.6 Pinnacles of Zuni Ss at 10:00 in water gap are "Los Gigantes"; note crest of Zuni Mountains beyond. **1.6**

94.2 Roadcuts in Twowells Tongue of Dakota. At 11:00 Inscription Rock is in cliffs of Zuni Ss. At 12:00 note cinder cone; at 1:00 N-dipping Dakota Ss defines a local syncline. **0.7**

94.9 Road to right (Indian 125) leads to Pine Hill and Mountainview (headquarters of the Ramah Navajo Agency). **0.3**

95.2 From 9:30–11:30 note SE flank of forested Zuni Mountains; cliffs of Zuni Ss are visible at 9:30 (Fig. 3-95.2). **1.1**

96.3 Milepost 43. At 2:00 note yellow Zuni Ss with white kaolinized zone at top under grayish-orange Dakota Ss. **0.5**

96.8 Enter El Morro National Monument. **0.5**

97.3 Milepost 44; light-colored cliffs of Zuni Ss on right. **0.3**

97.6 At 3:00 is Inscription Rock at base of cliffs. The oldest proven inscription by Spanish conquistadores was that of Don Juan Oñate, 16 April 1605. See NMGS 10th Field Conference Guidebook (1959) for an excellent historical account of El Morro. **0.7**

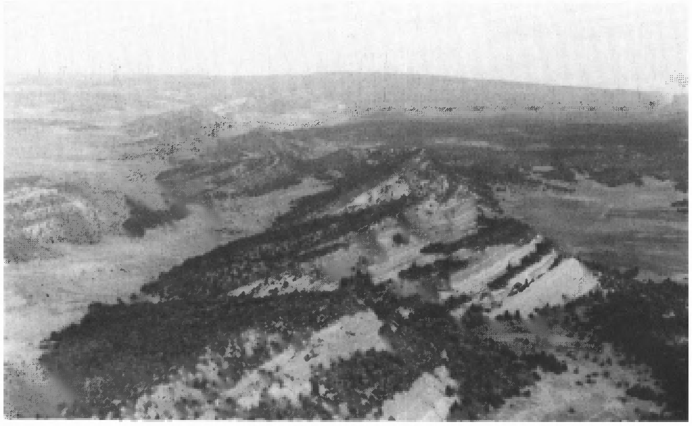
FIGURE 3-87.4. View to north along southern end of Nutria monocline from a point several mi northwest of Ramah. Dips flatten progressively southward on each block separated by water gaps.

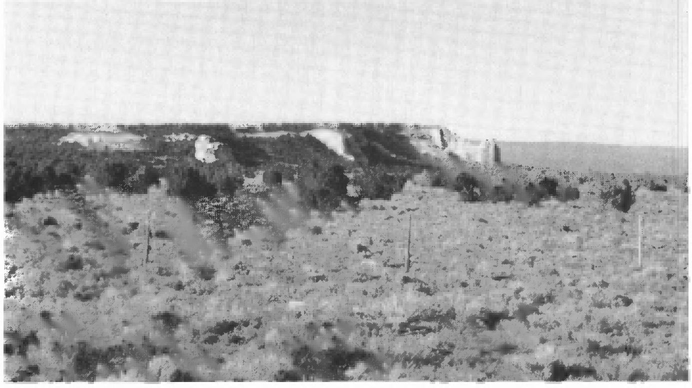
FIGURE 3-95.2. Look northward at light-colored Zuni Ss cliffs capped by Dakota Ss, approximately 2.5 mi west of El Morro National Monument. Zuni Mountains on skyline in background.

98.3 Milepost 45. Road to right to El Morro visitor center; continue straight ahead on NM-53. **0.6**

98.9 Basalt from North Plains flows in roadcut. Note Dakota/Zuni contact near top of mesa at 1:00 to 2:00. **0.4**

99.3 Inscription Rock R.V. park on right. Skyline on left is formed by Zuni Mountains. **1.0**

100.3 Basalt from North Plains lava field in roadcuts. **1.4**

101.7 Cinder cones in the El Malpais and Chain of Craters visible from 12:30 to 3:00. **0.6**

102.3 Milepost 49. Oso Ridge, composed of Glorieta Ss and San Andres Ls forms skyline of Zuni Mountains on the left. **0.5**

102.8 Tinaja Bar and Trading Post on right. **0.9**

103.7 Scar at 11:00 in distance is road-metal quarry in San Andres Ls. **1.2**

104.9 Road to quarry on left. **2.5**

107.4 Red-maroon beds exposed at 10:00 are sandstones of Moenkopi and Chinle fms. **1.5**

108.9 Bandera Crater cinder cone and Cerro Bandera in distance at 12:00. **1.0**

109.9 Oso Crater on skyline at 10:00, source of flows in Agua Fria Creek (to left of highway at mile 116.5). **0.3**

110.2 Small quarry in San Andres Ls on left. **1.7**

111.9 Roadcuts in San Andres Ls. Oso Crater at 9:00. **0.4**

112.3 Milepost 59. Forest Road 50 to left. (This intersection is starting point for Supplemental Road Log 4, which goes through Zuni Canyon.) Continue on NM-53. **0.1**

112.4 San Andres Ls exposed in roadcuts. **0.2**

112.6 Enter El Malpais National Monument. **0.4**

113.0 Road to right is Cibola County 42. Bandera Crater cinder cone at 12:00 to 12:30, Cerro Bandera at 3:00; flows in valley are from Bandera Crater. Continue on NM-53. **0.6**

113.6 San Andres Ls in roadcuts as we cross the Continental Divide, elevation 7882 ft. Bandera Crater on the right. **0.3**

113.9 Cinder pit on left side of road. **0.2**

114.1 **Turn right** at intersection on road to Ice Caves and Bandera Crater, to Optional Stop 4. **0.65**

114.75 **STOP 4 (optional).** Parking area for visitors to Ice Caves and Bandera Crater (Volcano Land). It is about 0.2 mi walk to the ice cave, about 1 mi to the end of trail above

Bandera Crater; the entire circuit is about 1.8 mi (Fig. 3-114.75). Those not interested in walking may browse in the trading post, or just enjoy the pleasant atmosphere.

## BANDERA CRATER

### C. H. Maxwell

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Volcano Land, once known simply as Ice Caves, has been a very pleasant, low-key tourist attraction for decades. The area has been the property of Mr. and Mrs. David Candelaria for more than 40 years, up to the time of this writing, when negotiations were underway toward acquiring the land for inclusion in El Malpais National Monument. The Museum-Trading Post is a cluttered, crowded and altogether delightful place to browse, quite unlike the usual tourist stop.

The reason for the perpetual ice in a lava cave a few tens of feet deep seems an enigma, but the most probable explanation is quite simple. The area is cold in the winter and gets considerable snow; the black lava absorbs lots of heat from the good New Mexico sun, and the snow melts and trickles down into the lava flows. Cold air is heavy and sinks down to fill the lava tubes and freezes any water that trickles in. The summer sun never reaches the ice, the thick lava blanket is good insulation, and the prevailing winds in spring and summer have no access to the ice caves and cannot blow the cold air out as it does in most of the lava tubes. So less ice melts in summer than freezes in winter.

The wide easy trails give access to practically every physical feature of lava eruptions including cinder cones and blankets, bombs, spatter cones (fumaroles), block flows, grooved lava, pahoehoe, aa, ropes, pressure ridges and squeeze-ups, collapse depressions and lava tubes. Bandera Crater is one of the largest of the cinder cones in the region, an ideal example of a breached cone. It is steep sided and symmetrical, 0.6+ mi in diameter and 560 ft high, and has a central depression 750 ft below the rim and 280 ft below the breach on the southwestern side of the cone. Basalt from the cone flowed south and east around the Zuni Mountains and then north to a point about 7.4 mi south of Grants. A large lava tube begins in the flows at the breach and extends to the south and east for 12 mi and possibly continues as far as 18 mi from the crater (Hatheway and Herring, 1970). Ice forms in several other localities in the tube, and in other tubes where air circulation is restricted. An extensive deposit of fine cinders extends north, east and south of the crater, covering older sedimentary rocks and lava flows; bombs are common in and adjacent to the cinder cone.

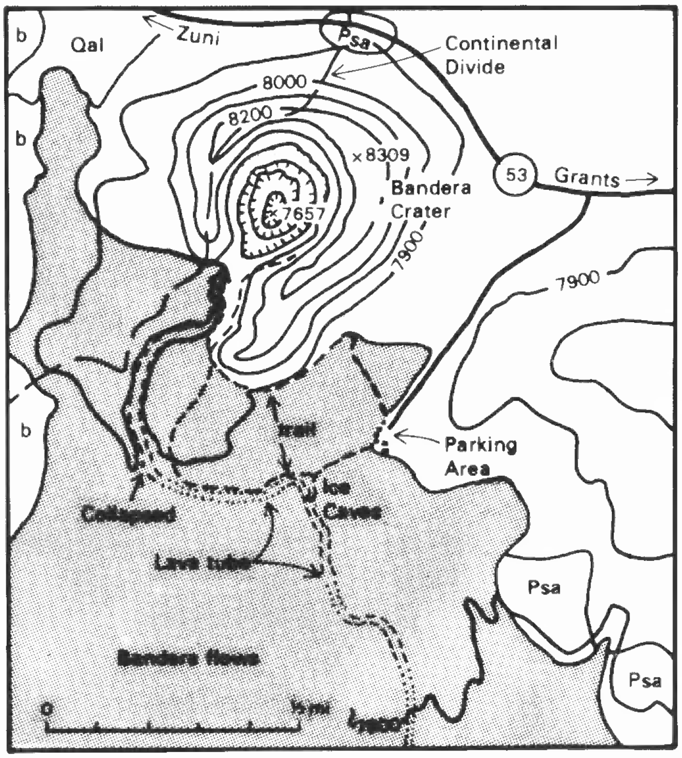

FIGURE 3-114.75. Map of Bandera Crater and Ice Caves area, Stop 4.

Rocks of the Bandera cone and flows are alkali basalts that are typically holocrystalline and microporphyritic with euhedral phenocrysts of olivine, rare clinopyroxene and plagioclase, in a vesicular groundmass of plagioclase ($An_{60}$), pyroxene, opaque minerals and very minor olivine (Laughlin et al., 1972). Ultramafic rock fragments of spinel-bearing dunite and pyroxenite, interpreted to have a mantle origin, are found as cores in bombs that were ejected with the final eruptions from Bandera Crater (Laughlin et al., 1971).

The name Bandera reportedly came from a flagpole and flag mounted on the summit by soldiers, presumably from Old Fort Wingate. However, it is not clear if the flag was on Bandera Crater or on Cerro [de la] Bandera (0.9 mi SW), or both.

After stop **return to NM-53. 0.65**

115.4 **Stop sign** at intersection with NM-53; **turn right** and **proceed eastward. 0.2**

115.6 Road descends into valley of Agua Fria Creek. Look for reddish-orange Yeso Fm draped with cinders in roadcut on left for next 0.3 mi. **0.9**

116.5 Small outcrops of basalt in valley to left are flows from Oso Crater. **0.2**

116.7 Basalt flows from Bandera Crater on right. **1.4**

118.1 Roadcuts expose Quaternary basalt flows from La Tetra volcano resting on Precambrian granite gneiss (Fig. 3-118.1). La Tetra at 3:00; small lava tube exposed in roadcut on right, toward east end. **0.4**

118.5 Ridge on left exposes gneissic granite for the next 0.4 mi. It is fine to coarse grained, locally porphyritic and composed of orthoclase, quartz, oligoclase, hornblende and biotite. **0.8**

119.3 Glorieta Ss caps Cerritos de Jaspe ridge on skyline at 3:00. **0.2**

119.5 Note Abo Fm red beds exposed on ridge at 3:00. **0.1**

119.6 Road to left goes to the 21 Mine. The 21 Mine and the 27 Mine (mile 121.3) were the largest and most productive of the fluorite mines in the Zuni Mountains Fluorspar District (Goddard, 1966). The 21 vein was stoped along a strike length of over 0.3 mi to as deep

FIGURE 3-118.1. Basalt flow drape over Precambrian granite gneiss; person in photo is pointing at contact.

as 380 ft (as of 1955). Orebodies range generally from 15 in. to 6 ft thick. The vein trends variably ENE to E and dips steeply S, with the best ore on the more easterly trending segments. The ore is coarsely crystalline, bright green fluorite, locally brecciated and cemented with fine-grained purple fluorite. Local small areas in the vein have colorless, light to dark blue, purple and amber euhedral crystals. Visitors to the mine area should tread very lightly since some of the stopes are caving to the surface, and many are open to the surface. The fluorite veins in the district are pre-Permian in age, possibly Precambrian. About 4.5 mi north, similar veins terminate at the Precambrian-Abo Fm contact with some evidence of weathering in the vein and no evidence of alteration or mineralization in the overlying Abo. **0.3**

119.9 Gneissic granite on left side of road. **0.5**

120.4 Milepost 66. Granite gneiss in roadcuts; El Calderon volcano at 9:00. **0.2**

120.6 Note basalts from La Tetra volcano exposed along road. **0.7**

121.3 Road on left to housing development and the 27 Mine, up hill behind houses and up canyon to right. The main shaft of the 27 Mine is 700 ft deep, on an orebody 10–15 ft thick and 800–900 ft long (Goddard, 1966). The fluorite veins were discovered about 1908 and started producing in 1937. Major production was in 1941–53, about 224,000 tons. The district has been inactive since 1953. **0.9**

122.2 Leave Cibola National Forest. Cebolleta Mesa at 12:00 in far distance along the route of day 2. **0.5**

122.7 Low ridge on skyline at 2:00 is Little Hole in the Wall, capped by Glorieta Ss. Flows in valley along highway are from La Tetra. **1.5**

124.2 At 9:30, nearly 4 mi away, is flat-topped Gallo Peak, elevation 8664 ft, capped by San Andres Ls. For further discussion of Permian rocks in this area, see Supplemental Road Log 4. Flows along highway are from El Calderon. **0.3**

124.5 Gallo Peak again visible at 9:30 (Fig. 3-124.5). Zuni-Acoma trailhead on right; foot trail goes across El Malpais 6 mi to NM-117. Small ridge 1 mi to south at 3:00 is a steeply eastward-dipping steptoe of Yeso Fm. **0.5**

125.0 Quarry in San Andres Ls on left side of road. **0.5**

125.5 Milepost 71. Leaving El Malpais National Monument. **0.5**

126.0 Ridge on left side of highway exposes San Andres Ls, and high on ridge to north is the Moenkopi Fm (Middle Triassic). Basalt flows to right are from La Tetra volcano. **0.8**

FIGURE 3-124.5. Gallo Peak capped by San Andres Ls, at center of photo.

126.8 At 9:00, note San Andres Ls outcrops in canyon overlain by brick-red Moenkopi Fm. **0.2**

127.0 Basalt flows on right are from El Calderon (or from North Plains?). **0.4**

127.4 Cliffs at 9:00 to 11:00 expose San Andres Ls. **1.0**

128.4 Mt. Taylor at 1:00 in distance; white scar at 12:00 is a perlite mine in a rhyolite dome. See Supplemental Road Log 1. **0.6**

129.0 Orange-red outcrops low in the mesa at 9:30 are beds of Yeso Fm. Loma Montosa to right is San Andres Ls capped by small knobs of Moenkopi Fm. A fault passes between highway and mesa to left. **2.3**

131.3 Highway passes under power lines; the brick-red strata at 10:00–11:00 are Moenkopi Fm overlying San Andres Ls. **1.2**

132.5 Crossing fault with about 600 ft vertical displacement down to the east (Thaden et al., 1967b). **0.2**

132.7 Sandstones of Moenkopi Fm to left of highway. **0.5**

133.2 At 2:00 in distance is a view of the east-dipping Grants monocline, basalt-capped Horace Mesa behind it and Mt. Taylor beyond. **0.9**

134.1 The gentle dip slope from 8:00 to 1:00 is developed on San Andres Ls. The original site of old Fort Wingate is reported to be somewhere on the flats to the right; if so, it was probably a temporary camp. See 1967 NMGS Guidebook (18th) for a history of Fort Wingate. **1.9**

136.0 Enter greater **San Rafael. 0.9**

136.9 San Rafael to left; continue straight ahead on NM-53. Some buildings of Old Fort Wingate still stand in the center of town. **0.7**

137.6 San Andres Ls exposed on left in small cliffs behind San Rafael. **0.3**

137.9 San Rafael Historical Marker on right:

> San Rafael
>
> San Rafael, formerly known as El Gallo, is located at a spring near the Malpais, the great lava flow to the east. The area was visited by members of Vasquez de Coronado's expedition in 1540. In 1862, it was selected as the original site of Fort Wingate, focus of the campaign against the Navajos.

For a discussion of the spring—Ojo del Gallo—see White (this guidebook). **0.4**

137.3 Crossing fault that displaces the Grants monocline about 3 mi to the NE (right lateral), and has about 850 ft vertical displacement down to the east (Thaden et al., 1967a). **1.3**

138.6 Note thin, slabby bedded, gently folded San Andres Ls on left side of highway for next mi. **0.5**

139.1 Small hill above basalt flows at 3:00 is a warm spring mound of calcareous tufa containing numerous casts of reeds and other plant life (Thaden et al., 1967a). Basalt is from volcanic center in the Precambrian core of the Zuni Mountains near Paxton Springs; it flowed 17 mi down Zuni Canyon to this area (Thaden et al., 1967a; Maxwell, 1986). The rock is nepheline normative alkali-olivine basalt; holocrystalline, vesicular, microporphyritic; euhedral olivine phenocrysts, clinopyroxene, and plagioclase in a groundmass of plagioclase, pyroxene and opaque minerals (Laughlin et al., 1972). **0.7**

139.8 Grants city limits. **0.3**

140.1 On-ramp for I-40 east on right. **Turn right** and **proceed east** on I-40 to Albuquerque.

**End of Third-Day Road Log.**