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Third-day road log: From Cuba to La Jara, Regina, Almagre Arroyo, Llaves, Gallina, Arroyo del Agua, Coyote, Youngsville and Abiquiu Dam

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This is one of many related papers that were included in the 1992 NMGS Fall Field Conference Guidebook.

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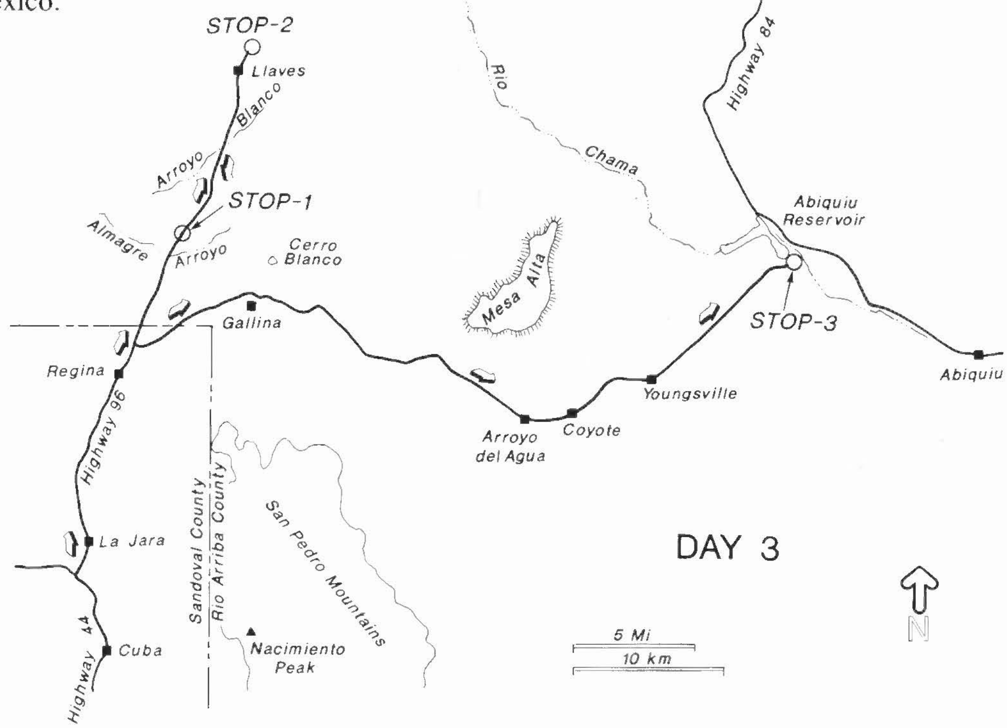
THIRD-DAY ROAD LOG, FROM CUBA TO LA JARA, REGINA, ALMAGRE ARROYO, LLAVES, GALLINA, ARROYO DEL AGUA, COYOTE, YOUNGSVILLE AND ABIQUIU DAM

SPENCER G. LUCAS, ADRIAN P. HUNT, THOMAS E. WILLIAMSON, BARRY S. KUES and VIRGINIA T. McLEMORE

SATURDAY, OCTOBER 3, 1992

Assembly point: Parking lot of Frontier Motel and Cafe, Cuba, New Mexico.
Departure time: 8:00 a.m.
Distance: 74.2 miles
Stops: 3



SUMMARY

The trip for the third day first proceeds north on NM-44 and NM-96 through extensive outcrops of the Eocene San Jose Formation. At Stop 1 we will examine outcrops of the Regina Member of the San Jose Formation and discuss the geology and economic resources of the southeastern San Juan Basin. The trip then proceeds north on NM-96 to near the old Llaves Post Office, where at Stop 2 we will discuss the geology of the type section of the Llaves Member of the San Jose Formation. The trip then reverses its course south on NM-96 to the junction with NM-95, where it then heads east on NM-95. The route passes through hogbacks of the Mesaverde Group that mark the eastern edge of the San Juan Basin and proceeds into a terrane dominated by flat-lying Permian-Cretaceous strata. The trip ends with Stop 3 at Abiquiu dam, where we will discuss engineering geology of the dam and the Upper Triassic stratigraphy of the Chama Basin.

Mileage

0.0 **Turn right** and proceed north on NM-44. **0.1**

0.1 At 3:00 to right, low gray beds are Paleocene Nacimiento Formation in front of Nacimiento uplift. **0.5**

0.6 At 1:00 note Cuba Mesa Member of San Jose Formation above Nacimiento Formation. **0.5**

1.1 Lignites in the Nacimiento Formation on right contain plant fossils. **0.1**

1.2 Road crosses Nacimiento–San Jose contact; we will now drive through 3- to 120-ft-thick sandstones of the Cuba Mesa Member for next 2.2 mi. **0.9**

2.1 Outstanding Cuba Mesa Member crossbedded sandstones on right displays at least three paleochannel cross sections. **0.7**

2.8 Cross San Jose Creek. **0.6**

3.4 Junction with NM-96, **turn right.** View ahead is of Sierra Nacimiento and San Jose Creek valley. **0.4**

3.8 Road passes through narrow gap in Cuba Mesa Member of San Jose Formation outcrop. Note Sierra Nacimiento ahead and to right. **0.1**

3.9 Cross bridge over San Jose Creek. Headward extension of the Rio Puerco drainage, including Rio San Jose, during the Quaternary probably shifted the Continental Divide from east to west in this area (Bryan and McCann, 1936). **0.9**

4.8 Curve in road. Mudstone (pastel green, gray and pink) outcrops at 2:00 are lowest beds of the Regina Member, San Jose Formation. Hills are capped by alluvial deposits on terraces and west-sloping pediments near the Nacimiento Mountains. **0.1**

4.9 Crest hill and enter La Jara. La Jara (population 30), named for the scrub willow, was settled in 1911. From 10:00–12:00, ridges in distance are outcrops of the Regina Member of the San Jose Formation along the Continental Divide. At 2:00, note Quaternary alluvium capping a pediment that slopes away from the Nacimiento Mountains. **0.8**

5.7 Leaving greater La Jara. **0.6**

6.3 Abandoned gas station on left; good view at 2:00 of San Jose Formation outcrops. Intraformational angular unconformities in the San Jose Formation crop out near the Nacimiento fault, 3–5 mi east and southeast of here. **1.6**

7.9 Roadcuts in sheet-like channel sandstone of the Regina Member. These sandstones are lithologically identical to the Cuba Mesa Member but are not mappable into that unit. **1.6**

9.5 Roadcuts are now in Regina Member capped by Quaternary alluvium. **0.6**

10.1 At 12:00, Regina Member variegated mudstones to right of road show typical purple, green, pink, red and brown colors in floodplain facies. **1.4**

11.5 Unpaved road to San Jose trail and 8 mile marker to right. **0.5**

12.0 Entering greater Regina. Regina (population 75) was established in 1911. Logging was the main economic activity until the 1950s, when agriculture became important. The village was named for the capital of Saskatchewan, Canada. **0.3**

12.3 Coonholler Cafe to left. A previous incarnation of this establishment, the Coonholler Bar, was proud of the fact that Glen Campbell made his first musical appearance here, playing with his father's band when only a boy. **0.1**

12.4 NM-305, unpaved road to left, leads to Lindrith. **0.3**

JOHN STRONG NEWBERRY—PIONEER COLORADO PLATEAU GEOLOGIST

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The first scientific mapping of the West was done by the U.S. Army's Corps of Topographic Engineers. The civilian geologists who were appointed to these surveys contributed much to the geologic knowledge of this vast, unexplored region. One of those geologists was John Strong Newberry (Fig. 3.1).

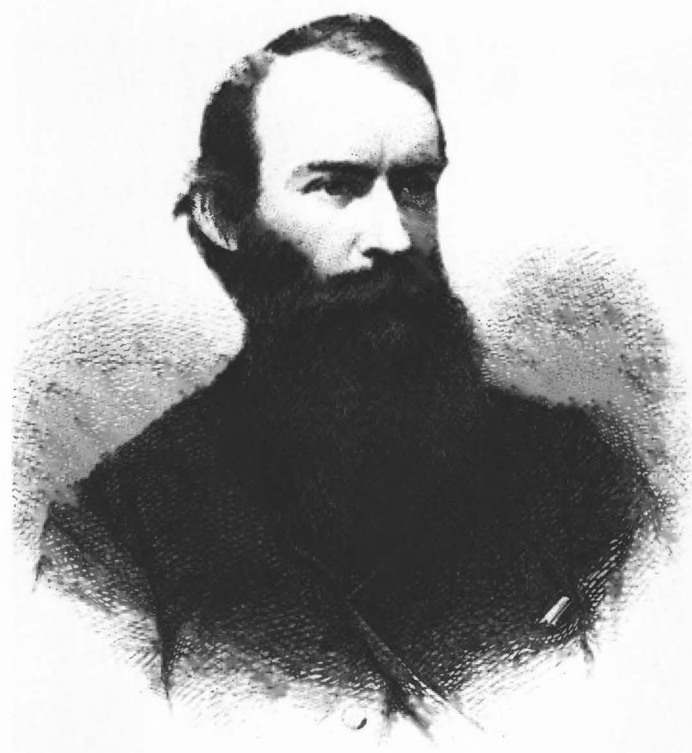

FIGURE 3.1. John Strong Newberry.

Newberry was born in 1822 in Connecticut. He grew up in northeastern Ohio, where his father was a pioneer coal operator near Akron. As a youth he became interested in science and was inspired to take up a scientific career by James Hall, noted New York paleontologist. He graduated from Western Reserve College in 1846 and received his M.D. in 1849. After studying in Europe until 1851, Dr. Newberry set up a medical practice in Cleveland, Ohio. While practicing medicine he worked closely with James Hall, studying geology and paleontology. He willingly set aside his practice to do geological research.

In the spring of 1855, Lt. Robert S. Williamson of the Topographic Engineers was detailed to survey a railroad route between San Francisco, California and settlement in Washington. Newberry was appointed naturalist-surgeon for this survey. During the survey, Lt. Williamson became ill, and he was replaced by Lt. Henry L. Abbott. Newberry studied the volcanoes of the Cascade Range and the effects of erosion, which were contained in his section of Lt. Abbott's report to Congress, published in 1856.

Newberry's work with the Topographic Engineers continued in the fall of 1857, when he joined an expedition to explore the lower Colorado River led by Lt. Joseph C. Ives. This expedition used the 54-ft paddlewheel steamboat, *USS Explorer,* from the mouth of the Colorado River to a point about 20 mi below the present site of Hoover Dam. After the boat could go no further, half of the expedition struck out across northern Arizona. Newberry was the first geologist to observe the Grand Canyon and its tributary canyons, where he compiled a detailed stratigraphic section. He also studied the volcanic features of the San Francisco Peaks and the stratigraphy of the Hopi Mesas. The party reached Fort Defiance, Arizona on 23 May 1858. Some of the expedition continued eastward to Fort Leavenworth under the command of Lt. John Tipton. This gave Newberry a chance to continue his geological observations. Lt. Ives' report, containing Newberry's observations, was not published until 1861. Newberry described the canyons of the Colorado River to the scientific world. He compiled a geologic framework of the plateau country and the Kansas plains that linked his work to that of other geologists such as Hayden, Meek and Marcou.

In June 1859, Capt. John N. Macomb, chief topographical officer in New Mexico, was ordered to lead an expedition northwest from Santa Fe into southeastern Utah Territory in search of a military road. The expedition also was to seek out the confluence of the Green and Grand Rivers that formed the Colorado River. Twenty thousand dollars were appropriated for this San Juan Exploring Expedition. The staff of the expedition consisted of John Newberry, geologist-naturalist; Charles Dimmock, cartographer; and three assistants, Fisher, Vail and Dorsey. Lt. Milton Cogswell and a detachment of the Eighth Infantry provided security against hostile Indians. Also joining the expedition were Albert H. Pfeiffer, a Ute agent, Neponocino Valdez, his interpreter, and guides. Fisher and Vail assisted Capt. Macomb with his astronomical observations, and Dorsey helped Newberry with the collection of natural history specimens.

The expedition left Santa Fe in mid-July, following the Old Spanish Trail into southwestern Colorado, passing by the present settlements of Pagosa Springs, Arboles, Ignacio, Durango, Mancos, Dolores and Dove Creek. While in the area of Dove Creek, Newberry named the surrounding area the Sage Plain, describing it as "an arid expanse," a scene of "dreary monotony," and "orderly and unbroken arrangement of underlying rocks." They entered Utah east of the present site of Monticello in mid-August. It was in this area that Newberry declared the region to be "geologically a basin; topographically a great plateau." Thus, he coined the name Colorado Plateau. As they descended into Dry Valley, via Canon Pintado (now East Canyon), Newberry discovered the remains of a dinosaur, which he partly excavated from rocks now known as the Morrison Formation. This was the first dinosaur discovered in the Rocky Mountain region. In the northern part of Dry Valley, at a water hole along the Old Spanish Trail known as Ojo Verde, the expedition set up a base camp. From the camp, Macomb, Newberry, Dimmock, Cogswell, the three assistants, a helper and an Indian guide proceeded across Hatch Point and descended into Hart Draw (Newberry's Canon Colorado) to look for the legendary confluence of the Green and the Grand Rivers. Recent research by Moab historian F. A. Barnes suggests that after much difficulty they reached a mesa overlooking the Grand River near the mouth of Indian Creek. Here, on 23 August, their Indian guide pointed out the area of the confluence, 8 mi to the southwest.

After Macomb, Newberry and the others rejoined the main party, they proceeded south past the present towns of Monticello and Blanding, following a drainage known as Recapture Creek to the San Juan River. They followed the San Juan River upstream for 13 days until they reached the mouth of Largo Canyon on 15 September. The expedition followed Largo Canyon across the central San Juan Basin to a spring, Ojo del San Jose, near the Nacimiento Mountains. From the spring they followed the valley of the Rio Puerco for 40 mi and then crossed the southern end of the mountains, arriving at Jemez Pueblo in early October. After reaching Santa Fe, Newberry sent all of his specimens (plants, animals, minerals and fossils, including the dinosaur bones) to the Smithsonian Institution. Here, the bones were studied by Joseph Leidy. Later, these bones were referred to *Camarasaurus*.

Capt. Macomb prepared a short interim report in November 1860 and a brief progress report a year later. Newberry's section for the final report was completed in May 1860, but the drafting of the geologic map was not finished. Due to the Civil War, Macomb's final report to the War Department was not published until 1876, and by then the findings of the expedition were largely forgotten.

When the Civil War broke out in 1861, the Topographical Engineers were recalled from the West. Macomb became aide-de-camp to Major General McClellan of the Union Army, and he rose to the rank of colonel. Dr. Newberry joined the Sanitation Commission and was stationed in the West. When the war ended he became professor of geology and paleontology at the Columbia School of Mines in New York. At Columbia, he continued a distinguished career and was appointed State Geologist of Ohio in 1869. Professor Newberry was affiliated with Columbia until his death in 1892.

Newberry's observations with the Topographical Engineers laid the geologic foundation for further investigations on the Colorado Plateau. He called attention to the need for specialized investigations of individual mountain ranges to determine their origin. For example, the pre-Carboniferous rocks he had observed in the Grand Canyon were not present in the Nacimiento Mountains. He believed that the volcanic rocks observed in the San Mateo Mountains (Mt. Taylor) had been deposited at various times, beginning in the Middle Tertiary and continuing into the present epoch. His observations, especially with the Macomb expedition, led him to believe that the Rocky Mountains had undergone several periods of uplift and erosion, but the greatest period of uplift occurred between the close of the Cretaceous and the Miocene, an astute observation for 1859.

12.7 Outcrop (bluff) at 10:00 of Simpson's (1948) type section of the San Jose Formation displays variegated floodplain mudstones and gold-brown channel sandstones of the Regina Member. **0.1**

12.8 At 2:00–2:30, note flatirons of Jurassic strata on front of Sierra Nacimiento. **0.2**

13.0 Leaving greater Regina. **0.6**

13.6 San Pedro Lakes (man-made) on right; light-colored ridge beyond on mountain front is Jurassic? **0.4**

14.0 Spectacular view of Gallina Valley and hogbacks on edge of San Juan Basin ahead as road crests hill. **1.0**

15.0 Rio Arriba County line. **0.6**

15.6 Junction; continue straight. NM-595 to left goes to Lindrith. **1.0**

16.6 Junction with NM-112; **turn left** and proceed north on NM-112. Sandstone capping Regina Member at 9:00 is the "persistent sandstone tongue" of the Llaves Member (see Smith, this volume). **1.4**

18.0 Bridge over Almagre Arroyo; Schmitz monocline at 1:00 in Regina Member, San Jose Formation (Fig. 3.2). Red beds at 2:00 in distance are Permian Cutler Formation. **0.3**

18.3 Forest Road 74 to left goes to Almagre Arroyo, where Cope originally collected many early Eocene vertebrates in 1874 (Simpson, 1950). **0.4**

18.7 **STOP 1** on right side of road. This stop offers a regional view of typical Regina Member strata to the west and northwest, a perspective of the southeastern portion of the San Juan Basin, and a close-up examination of Regina mudrocks (see accompanying minipaper). Cobbles of Precambrian quartzite, granite and metamorphic rocks cap high level pediments and terraces here. These cobbles may have been reworked from the San Jose and other Tertiary strata.

Along the eastern flank of the San Juan Basin, just north of this stop, are the Puerto Chiquito East and Puerto Chiquito West oil fields. Production from the Niobrara interval within the Mancos Shale began in 1960 and has totaled 15,896,329 BO through 1990. Fractures associated with flexures along the otherwise homoclinally dipping strata are crucial for permeability in this unconventional reservoir. Tectonic fractures allow access to low permeability but very oil rich source rocks

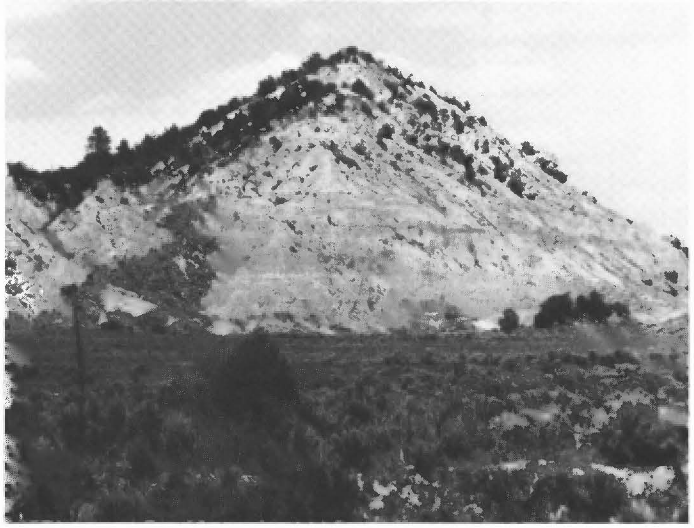

FIGURE 3.2. Steeply dipping beds on left side of hill, the Regina Member of San Jose Formation, are on southeast limb of Schmitz monocline.

in the Niobrara (Gorham et al., 1977). The advent of horizontal drilling technology in the late 1980s and early 1990s has rejuvenated exploration for vertically fractured reservoirs, such as the Niobrara, throughout the Rocky Mountains. A number of horizontal wells have been permitted and completed in the San Juan Basin in 1991, although few data on their success are available.

After stop continue north on NM-112. **0.1**

MUDROCK SEDIMENTOLOGY AND PALEOPEDOLOGY IN THE SAN JOSE FORMATION

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The mudrock-dominated Regina and Tapicitos Members of the San Jose Formation are distinguished by stratigraphic position and color (Baltz, 1967; Smith, this volume). The Regina tends to be drab and varicolored, whereas the Tapicitos is typically brick red. The fine-grained units of the San Jose Formation are visually striking because of their coloring and continuous bedding when observed from a distance. However, close inspection of fresh exposures, polished slabs and thin sections reveals subtle differences in grain size, sedimentary structures, color mottling and trace fossils that resulted from depositional and pedogenic processes on floodplains and diagenetic overprints. The analysis of depositional environments and pedogenesis in ancient overbank sequences has recently been used to refine fluvial depositional models and estimate preservational bias in fluvial strata, among other purposes (Retallack, 1977, 1983; Bown and Kraus, 1981, 1987; Bridge, 1984; Wing, 1984; Kraus, 1987). This article briefly discusses lithologic facies recognized in the mudrocks of the San Jose Formation.

Three mudrock lithofacies recognized by primary sedimentary structures and grain size trends in lithologic sequences occur in all San Jose mudrocks. Evidence of post-depositional modification is similar for both burrowed mudrock lithofacies (Fbssc and Fbsc).

Lithofacies Fbssc is composed of stacked, tabular bodies of fining-upward fine-grained sandstone and mudstone beds and is commonly overlain by thick channel sandstones (Figs. 3.3–3.4). Grain size trends in sequences are similar in the Regina and Tapicitos Members, but mudrocks of the Tapicitos Member contain more silt and less clay than those of the Regina Member. Light-colored, fine-grained sandstones at the bases of fining-upward sequences commonly overlie dark-colored mudrock with abrupt, locally channelized contacts that are interpenetrating due to burrowing. Greater amounts of iron oxy-hydroxides in the finer-grained beds than in interstratified coarser-grained beds explain the distinct color banding (Fig. 3.4). Laminae and cross-laminae are rare and discontinuous on outcrop and occur more commonly in coarser-grained units. Individual beds and lithofacies sequences have been traced laterally for distances up to 1 km. Beds of sandy and muddy units thicken and thin along strike; sandstones become thicker near channel margins.

FIGURE 3.3. Lithofacies Fbssc and Fbsc in Tapicitos Member. Exposed section is equivalent to the upper 10 m of Fig. 3.4C. Measuring staff is 1.75 m long. Location: lat. 36°21′52″, long. 106°59′18″.

Lithofacies Fbssc represents lenticular (splay) and tabular (levee) overbank sedimentation in positions relatively proximal to trunk streams (cf. Hughes and Lewin, 1982). Fining-upward sequences of traction-deposited sand and vertically accreted mud resulted from the waning flows of relatively high-energy overbank events. Thick accumulations of muddy sediment suggest sedimentation on vegetated levees during less extreme, and more frequent, floods. The common occurrence of channelized basal contacts in lithofacies Fbssc suggests that crevassing and splay deposition were major processes in the development of natural levees near trunk channels (Coleman, 1969; Bown and Kraus, 1987). The lack of observable depositional dips in the San Jose overbank deposits is not unusual for ancient fluvial strata, and reflects subtle topography on aggradational surfaces (Bridge, 1984) as well as reduction of depositional dips due to compaction.

Lithofacies Fbsc displays meter-thick beds of intensely bioturbated mudstone with rare stratification and strong blocky structure. The lithofacies is strongly colored in both its matrix and mottles, corresponding to high iron values (Fig. 3.4). Rare beds of shale (lithofacies Fl) are interbedded within bioturbated mudrock (Fig. 3.4, 9.75 m). Lithofacies Fbsc represents accumulation of mud without significant sand in distal positions of floodplain areas. The absence of distinct lithologic breaks in the sequences suggests a lack of significant erosional events.

Lithofacies Fl encompasses thin, distinctive beds of laminated siltstone and shale characterized by the anomalous occurrence of preserved sedimentary structures and carbonized fossil leaves and twigs (Tidwell et al., 1981; Smith and Lucas, 1991). Lenticular beds of this lithofacies fill channel scours in sheet sandstones. Sedimentary structures and fossil-plant fragments indicate that lithofacies Fl was deposited in locally anoxic, probably stratified, lacustrine environments. Large exposures of lithofacies Fl represent lakes; thin beds of shale within lithofacies Fbsc suggest occasional submersion of floodplains by anoxic oxygen-stratified ponds; lenticular bodies represent small ponds in abandoned channels.

Roots, burrows, lack of most primary sedimentary structures and clay illuviation along root pores in mudrock-dominant lithofacies are interpreted to represent pedogenesis of overbank sediment (Fig. 3.5). Blocky structure highlighted by carbonized roots along ped surfaces must have formed during growth of those roots and therefore represents pedogenic cracking (Fig. 3.5). Bioturbation of fine subangular to subrounded granular peds indicates their formation near the former land surface.

The origin of prevalent strong, blocky structure is likely related to the closing of pores, dewatering and post-burial compaction, possibly with some small-scale faulting around peds. Much of the strata contain translocated clay along root pores, but are not generally separable into horizons. Thus, illuvial and other soil processes may have overprinted surface horizons to the point that many of the mudrock units may represent cumulate B horizons. Correspondence of higher dithionite-extractable iron values and stronger colors with finer-grained lithologies suggests that iron oxy-hydroxide species were adsorbed on clays and that much of the color banding is due to primary stratification in overbank environments. The lack of unambiguous field or laboratory evidence for distinct pedogenic horizons in most of the San Jose mudrocks is in accordance with cumulate pedogenesis on aggrading, low-relief overbank environments.

Lenticular, channelized bodies of mudrock-filled scours are relatively common in Regina outcrops (Fig. 3.6). Sandstones line the bases of the scours, which are dominantly filled by lithofacies Fbssc. The mudrock-filled channels apparently represent cut and fills of gully systems, with meters of relief, across levees and/or floodplains (Kraus and Middleton, 1987). The basal sandstones apparently represent the channel along the bottoms of the scours. The sedimentology of mudrocks in these scours has not been studied in detail. The existence of cut-and-fill sequences indicates local episodes of baselevel lowering, possibly along streams tributary to the trunk system.

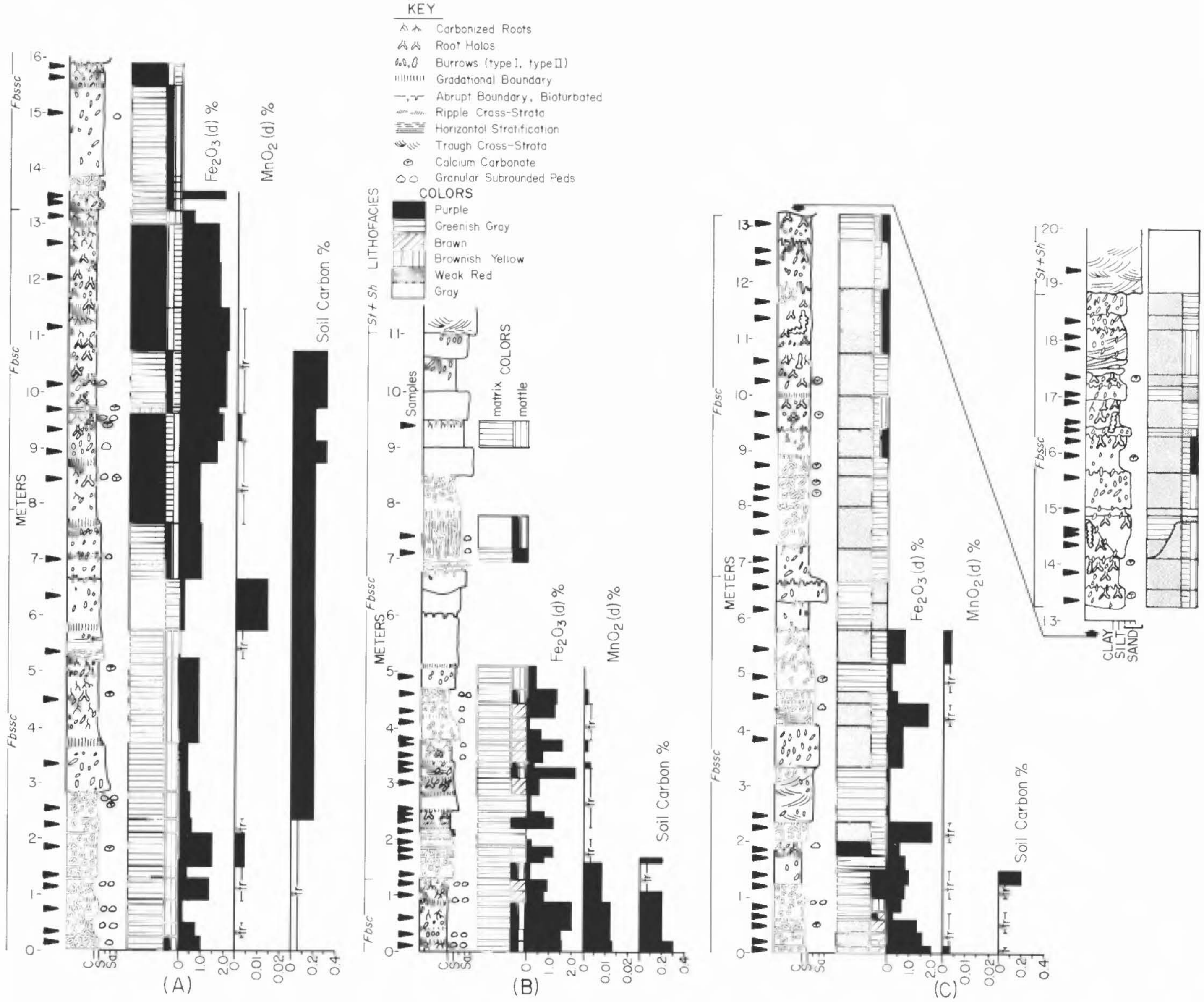


FIGURE 3.4. Stratigraphic sections, colors and geochemistry of lithofacies Fbssc and Fbsc in the Regina Member (A and B) and Tapicitos Member (C). tr = trace. Locations: (A) lat. 36°16′15″, long. 106°55′00″; (B) lat. 36°35′44″, long. 107°22′56″; (C) lat. 36°21′52″, long. 106°59′18″.

Levee and splay sequences indicate overbank events were commonly channelized and produced bodies of fining-upward mudrock (lithofacies Fbssc) that are tabular over distances of up to a few km. Upward increase in bioturbation and rooting of fining-upward sequences indicate the episodic high- and low-energy stacking of weakly developed paleosols in the construction of levees (cf. Bown and Kraus, 1987). Distal-floodplain mudrock sequences (lithofacies Fbsc) were deposited in low-relief regions that received sluggish flood waters. Modern clastic flood-basin environments rarely receive more than a few centimeters of sediment in any flood event (Bridge and Leeder, 1979), suggesting slow, relatively continuous sedimentation and pedogenesis. Laminated mudrocks represent shallow lakes that accumulated plant debris. The rare occurrence of laminated mudrocks suggests either that much of the floodplain was subaerial or that bioturbation destroyed sedimentary structures in most lacustrine or swampy environments, making lacustrine environments difficult to recognize on outcrop.

Evidence for surficial drainage in much of the mudrock supports an interpretation of at least occasional subaerial exposure of much of the floodplain. The association of preserved organic material in much of the Regina, and in a few Tapicitos mudrocks with clay-rich lithologies, suggest that gleyed soil conditions and reduced ground water may have

FIGURE 3.5. Carbonized roots within mudrocks of the Regina Member. Roots (r) both follow fractures (f) within greenish mudrocks (left) and pierce mottled mudrocks where they are associated with halos (h) (right). Sample on right shows a plan view; arrows point to stratigraphic up. The samples on the right and left are from positions 180 cm and 70 cm, respectively, above the base of section A in Fig. 3.4.

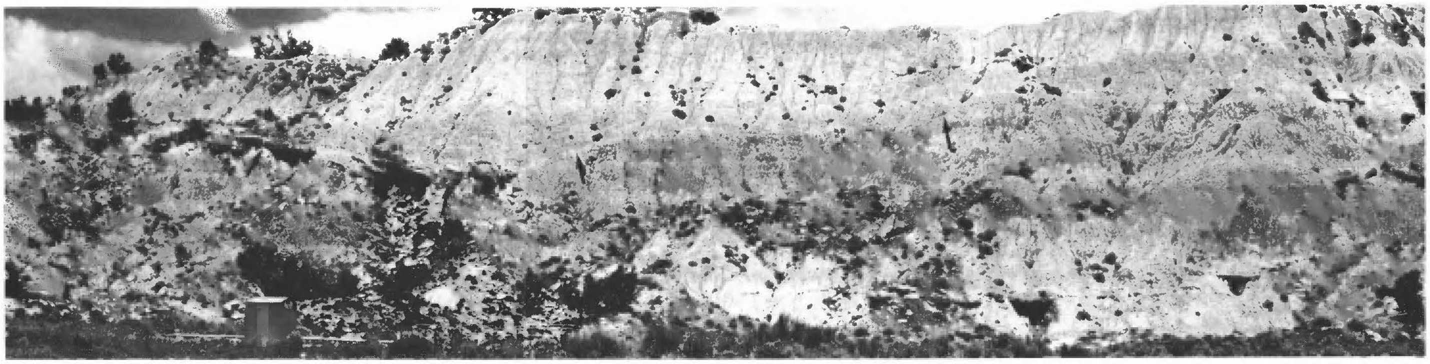


FIGURE 3.6. Photograph of ribbon sandstone at the base of a scour (arrows) that is dominantly filled by mudrock (Regina Member). Exposure is 35 m high.

prevailed in the less permeable deposits. In contrast, the reddish color and lack of organic carbon in much of the Tapicitos Member, and in parts of the Regina Member, are associated with more silt-rich mudrock lithologies (Fig. 3.4). This association suggests that overbank deposits with less clay were better drained and underwent deeper aeration and oxidation prior to burial. Lower ground-water tables prevailed on Tapicitos floodplains than on much of the Regina floodplains. This differing paleohydrology likely led to differing microenvironments for surface fauna and flora. Subtle effects of floodplain paleohydrology on channel hydraulics and resulting sedimentology are expected but unknown.

Vertical facies sequences indicate that channel-belt migration onto distal floodplains (Fbsc) was preceded by deposition on proximal floodplains (Fbssc) (Fig. 3.3; Bridge, 1984; Kraus, 1987). Additional evidence for topography in overbank areas includes ribbon-sandstone channels oriented at an angle to major sheet-sandstone channels, which must have cut through a topographic high (i.e., a levee) to reach a lower local baselevel, such as a main-stem channel or floodplain (Smith and Lucas, 1991).

The association between color and grain size of overbank mudrock (Fig. 3.4) may explain the stratigraphic distribution of the reddish "Largo facies" and drab, varicolored "Almagre facies" of Simpson (1948) and Haskin (1980). The fact that the Regina Member reddens in color upward and northward, toward the Llaves Member (across Simpson's Almagre-Largo facies boundary) is consistent with the reasoning that the unit coarsens in grain size nearer to the channel belts of the Llaves Member. The coarseness of mudrocks in the uppermost unit of the San Jose Formation, the Tapicitos Member, may be due to erosion of increased percentages of Precambrian metamorphic rocks, relative to sedimentary cover, during the last stages of preserved sedimentation in the basin.

18.8 Crest of hill reveals broad panorama ahead of hogbacks along eastern edge of San Juan Basin. **0.9**

19.7 Roadcuts in San Jose Formation. **1.0**

20.7 Crest of hill; broad valley at 10:00 is Arroyo Blanco with type Regina Member to north. Note northward interfingering of Regina Member into Llaves Member to left. **3.0**

23.7 Cross arroyo Blanco; outcrops on ridge to right are Nacimiento Formation. **0.4**

24.1 At highway sign, sandstones on ridges immediately to left are Cuba Mesa Member of San Jose Formation. **0.9**

25.0 Nacimiento Formation exposed in roadcuts. **1.4**

26.4 Small ridge to right is Paleocene Ojo Alamo Sandstone and Cretaceous Fruitland-Kirtland Formations of Baltz (1967). These outcrops are supposed to indicate absence of Cretaceous Pictured Cliffs Sandstone here, which Dane (1946) and Baltz (1967) believed to indicate that the Pictured Cliffs Sandstone was deposited in a restricted northwest-trending embayment of the Late Cretaceous epeiric sea (Fig. 3.7). However, Fassett and Hinds (1971) convincingly argued that these *Ophiomorpha*-bearing strata are a slightly unusual facies of the Pictured Cliffs Sandstone. **0.7**

27.1 Old Llaves Post Office on left. The post office at Llaves (Spanish, keys) dates from 1940. **0.7**

27.8 **STOP 2;** overview of type section of the Llaves Member of the San Jose Formation and Cañoncito de Las Yeguas. Directly west of the stop is the type area of the Llaves Member of the San Jose Formation (Fig. 3.8). Poorly exposed mudrocks and cliff-forming sandstones of the Nacimiento Formation make up the base of the hillside. The Cuba Mesa Member is a distinct, continuous sandstone approximately one-third the way up the slope north of the canyon. The Llaves Member directly overlies the Cuba Mesa Member here, and is laterally replaced by the Regina Member further to the north and west. Paleocurrent measurements indicate that streams depositing both the Cuba Mesa and Llaves Members in this area flowed to the west and southwest (Fig. 3.9). Clast lithologies in conglomerates are dominated by quartzites and other metamorphic rocks, some of which are distinctly similar to the Ortega Quartzite of the Tusas Mountains to the east.

The overall tabular geometry of the Llaves Member in the east-central portion of the San Juan Basin suggests that sand was carried into the basin from a distinct drainage basin. A model combining paleocurrent and clast-lithology data with the position of a likely source area, defined by the folded Ortega Quartzite, is shown in Fig. 3.10). This channel system apparently existed during deposition of the Cuba Mesa Member and was tributary to the major north-south-flowing San Jose channel systems.

After stop retrace route south on NM-112 to NM-~~95.~~ 96 **11.3**

39.1 Stop sign at intersection with NM-~~95,~~ 96 **turn left** and proceed north-northeast on NM-~~95.~~ 96 **0.6**

39.7 Outcrops of Cretaceous Lewis Shale in arroyo on left and in roadcut. **0.6**

40.3 Pass through steeply dipping Cretaceous Mesaverde Group hogback; note coal-bearing strata. Road now passes into Cretaceous Mancos Shale strike valley. **0.7**

41.0 Good view to left of Cretaceous Cliff House Sandstone capping hogback above coaly beds. **0.1**

41.1 Crest of hill, Mancos Shale roadcuts. Jurassic and Triassic red beds ahead at 12:00. **0.6**

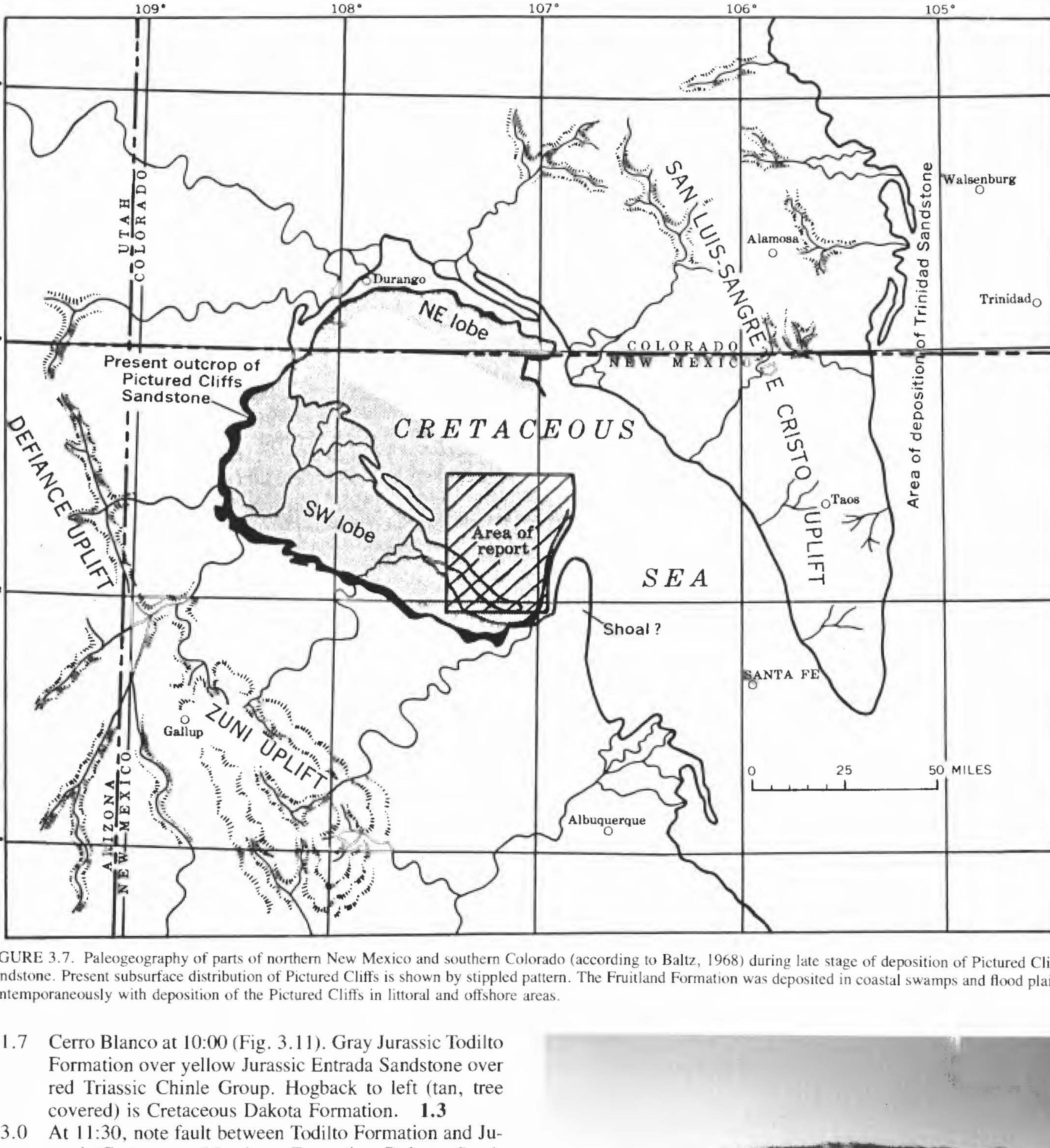


FIGURE 3.7. Paleogeography of parts of northern New Mexico and southern Colorado (according to Baltz, 1968) during late stage of deposition of Pictured Cliffs Sandstone. Present subsurface distribution of Pictured Cliffs is shown by stippled pattern. The Fruitland Formation was deposited in coastal swamps and flood plains contemporaneously with deposition of the Pictured Cliffs in littoral and offshore areas.

41.7 Cerro Blanco at 10:00 (Fig. 3.11). Gray Jurassic Todilto Formation over yellow Jurassic Entrada Sandstone over red Triassic Chinle Group. Hogback to left (tan, tree covered) is Cretaceous Dakota Formation. **1.3**

43.0 At 11:30, note fault between Todilto Formation and Jurassic/Cretaceous Morrison Formation–Dakota Sandstone to west of Cerro Blanco. **0.6**

43.6 Enter greater Gallina (Gallina Plaza). Gallina (population 400) is spread out across the valley of the Rio Capulin, at an elevation of about 7400 ft. The name literally means hen or chicken in Spanish, but more likely refers to the wild turkeys once common in the area. Pearce (1965) noted that it was settled in 1818 by Antonio Ortiz. The post office arrived in 1890, but before World War II Gallina was tiny, a population of only 10 being recorded in the 1930s. The San Pedro Moun-

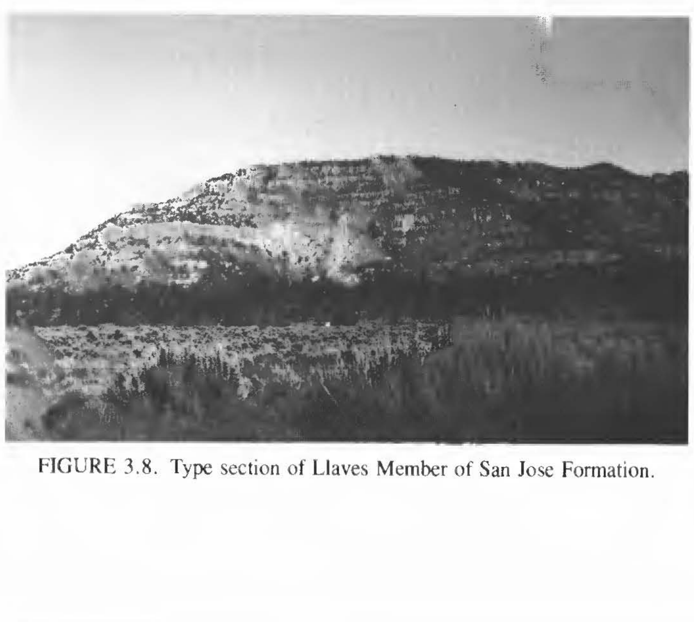


FIGURE 3.8. Type section of Llaves Member of San Jose Formation.

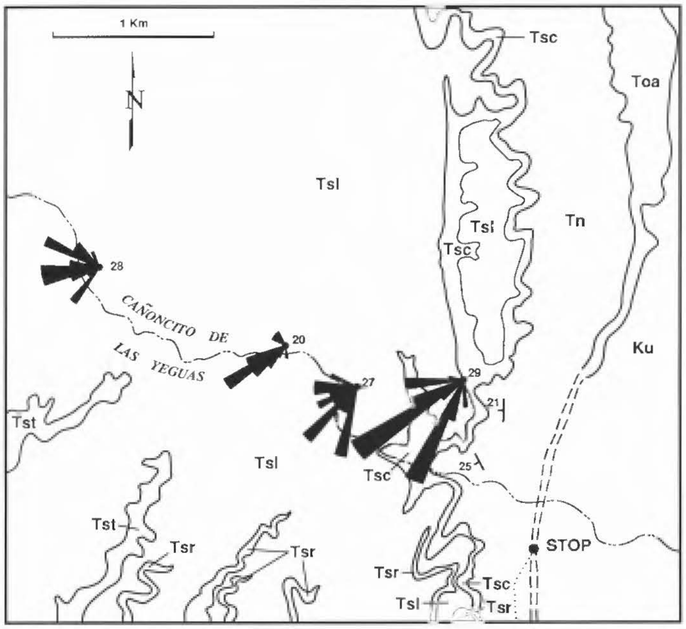


FIGURE 3.9. Large-scale paleocurrent map of Cañon de las Yeguas area.

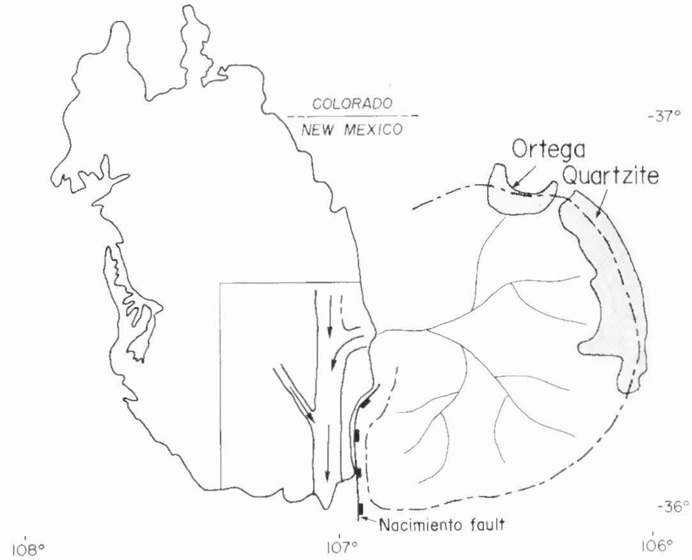


FIGURE 3.10. Paleogeographic map of uplifts east of the San Juan Basin.

tains rise to an elevation of 10,592 ft to the south, while Capulin Peak (9199 ft) marks the northeastern edge of the town, with several high mesas extending into the Chama Wilderness to the north and east.

Red bed or sandstone copper deposits occur in the Gallina area (McLemore and Chenowith, this volume). Two deposits were mined for uranium with 24 tons of ore produced, grading 0.03% U_3O_8. Some copper mines have been produced but no production records are available.

West of Gallina, uranium occurs in the Regina Member of the San Jose Formation. Radiometric anomalies, both surface and subsurface, indicate a potential for roll-type sandstone uranium deposits at shallow depths.

The San Pedro Mountains are a large mass of Proterozoic granitic rocks, primarily pink, weakly porphyritic muscovite-biotite granite and gray tonalite. Metasedimentary terranes are exposed near the heads of La Jara and San Jose Creeks, west of the Rio Gallina (Woodward, 1987). The northern slopes of the San Pedro Mountains consist of Madera and Abo strata, the latter unconformably overlain by Triassic Chinle Group sediments about 1.5 to 2 mi south of Gallina. Capulin Peak and associated mesas consist of Jurassic Entrada, Todilto and Morrison Formation strata overlying the Chinle, and are capped by Dakota Group sandstones. **0.6**

44.2 Good view to left of Todilto Formation over Entrada Formation over Chinle Group along Cerro Blanco ridge; Cope's *Typothorax* locality is to the north through the gap (see Lucas and Hunt, this volume). **0.3**

44.5 Road cuts in Chinle Group red beds of Petrified Forest Formation next 1.0 mi. **1.0**

45.5 Enter Gallina proper. **0.4**

45.9 Gallina post office on right. **0.2**

46.1 View at 11:00 of Mesa Gurule shows Chinle Group–Dakota section (Fig. 3.12). Note buff Entrada Sandstone overlain by Morrison Formation. **0.6**

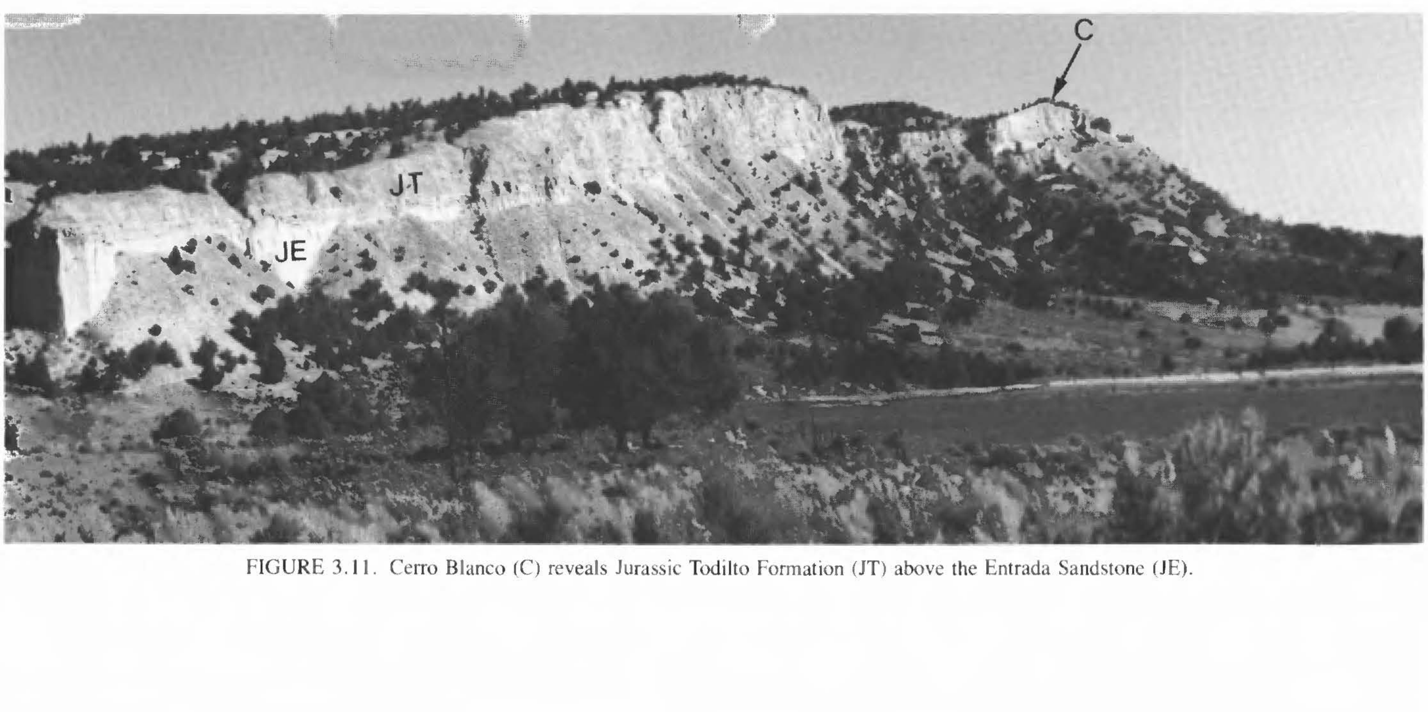


FIGURE 3.11. Cerro Blanco (C) reveals Jurassic Todilto Formation (JT) above the Entrada Sandstone (JE).

FIGURE 3.12. Mesa Gurule near Gallina reveals Chinle Group (TRC) and Entrada (JE), Todilto (JT), Morrison (JM) and Dakota (KD) formations.

46.7 Leave greater Gallina; roadcuts in Chinle Group. Here, Entrada Sandstone sits right on upper part of the Petrified Forest Formation of the Chinle Group. **1.3**

48.0 Note dark Todilto Formation above yellow Entrada Sandstone at 9:00–10:00. Road is on strike valley developed primarily in Chinle Group mudrocks for next 7.7 mi. **2.1**

50.1 Cerro Pedernal is prominent peak at 12:00. **1.4**

51.5 View ahead of Chinle Group–Dakota Formation section on Mesa Alta at 11:00–12:00 begins to come into view; Morrison Formation can be easily divided into lower purple Recapture Member and upper Brushy Basin Member (pastel greens and pinks). **1.2**

52.7 Sandstone on right of road is in Poleo Formation of Chinle Group. **0.4**

53.1 Mesa Montosa at 11:30 is capped with Poleo Formation above red beds of lower Chinle Group and Permian Cutler Formation. Road now begins to descend to Rio Puerco. **0.5**

53.6 Outstanding view of Mesa Alta section of Chinle Group–Dakota Formation at 9:00. **2.1**

55.7 Begin descent to Arroyo del Agua. Cutler Formation ahead. **0.1**

55.8 Roadcuts in Poleo Formation. **0.1**

55.9 Road drops into Salitral Formation. **0.3**

56.2 Road crosses Agua Zarca Formation. Note outstanding Permian red beds (Cutler Formation) on cliff to left and ahead (Fig. 3.13). Road is on Permian for the next 6.5 mi. **1.9**

58.1 Enter Arroyo del Agua. In 1877 David Baldwin discovered Permian fossil bones in what is now the Cutler Formation near Arroyo del Agua (Fig. 3.14). Baldwin was collecting for the Yale paleontologist O. C. Marsh. However, Marsh became dissatisfied with Baldwin, who promptly offered his services to Marsh's great rival, E. D. Cope of Philadelphia. Marsh had not even unpacked Baldwin's finds when Cope announced the discovery of Permian fossils from Texas at a scientific meeting. Marsh left the meeting early, opened Baldwin's packages and wrote a brief and very poor (he mixed a reptile and an amphibian in one genus) paper that he published in the American Journal of Science, which he controlled. Thus, Marsh beat Cope to press in announcing the discovery of Permian vertebrates in North America. Subsequently, many important collections have been made in this area of Permian vertebrates by, among others, the University of Chicago, the University of Michigan, the University of California and the Carnegie Museum of Natural History. **0.2**

FIGURE 3.13. View of Mesa Alta section reveals Permian Cutler Formation (PC) overlain by Agua Zarca (AZ), Salitral (S) and Poleo (P) formations of Chinle Group.

58.3 Cross Rio Puerco and leave Arroyo del Agua. **0.7**

59.0 Permian red beds in roadcuts; note paleosols on left. **0.8**

59.8 Enter Coyote. At 8:00–9:00 note fault up canyon. Coyote (population 100) was settled in 1862, with the post office arriving in 1885. On the detailed Department of the Interior General Land Office map of New Mexico (1882), Coyote and Cañones are the only towns indicated along today's route between Cuba and Abiquiu. **0.3**

60.1 Bluff at 1:00–2:00 exposes Cutler, Agua Zarca, Salitral and Poleo Formations. **0.2**

60.3 Cross Coyote Creek. **0.2**

60.5 Leave Coyote. **0.2**

60.7 Road to right to Coyote Ranger Station. View ahead of bluffs of Jurassic–Cretaceous strata on east side of Chama Valley above Ghost Ranch. Road now is climbing section again onto Triassic rocks. **1.7**

62.4 Road is now on Agua Zarca Formation. **0.3**

62.7 Road intersects Agua Zarca just past local landfill. **0.3**

63.0 Cerro Pedernal at 2:00. At base of canyon below Cerro Pedernal note low yellow cliff of Entrada Sandstone overlain by gray Todilto Formation. **0.3**

63.3 Road now on Poleo Formation. **0.6**

63.9 Entering Youngsville (population 50), a small farming and ranching community established in 1914. **0.2**

64.1 Youngsville post office on right. **0.1**

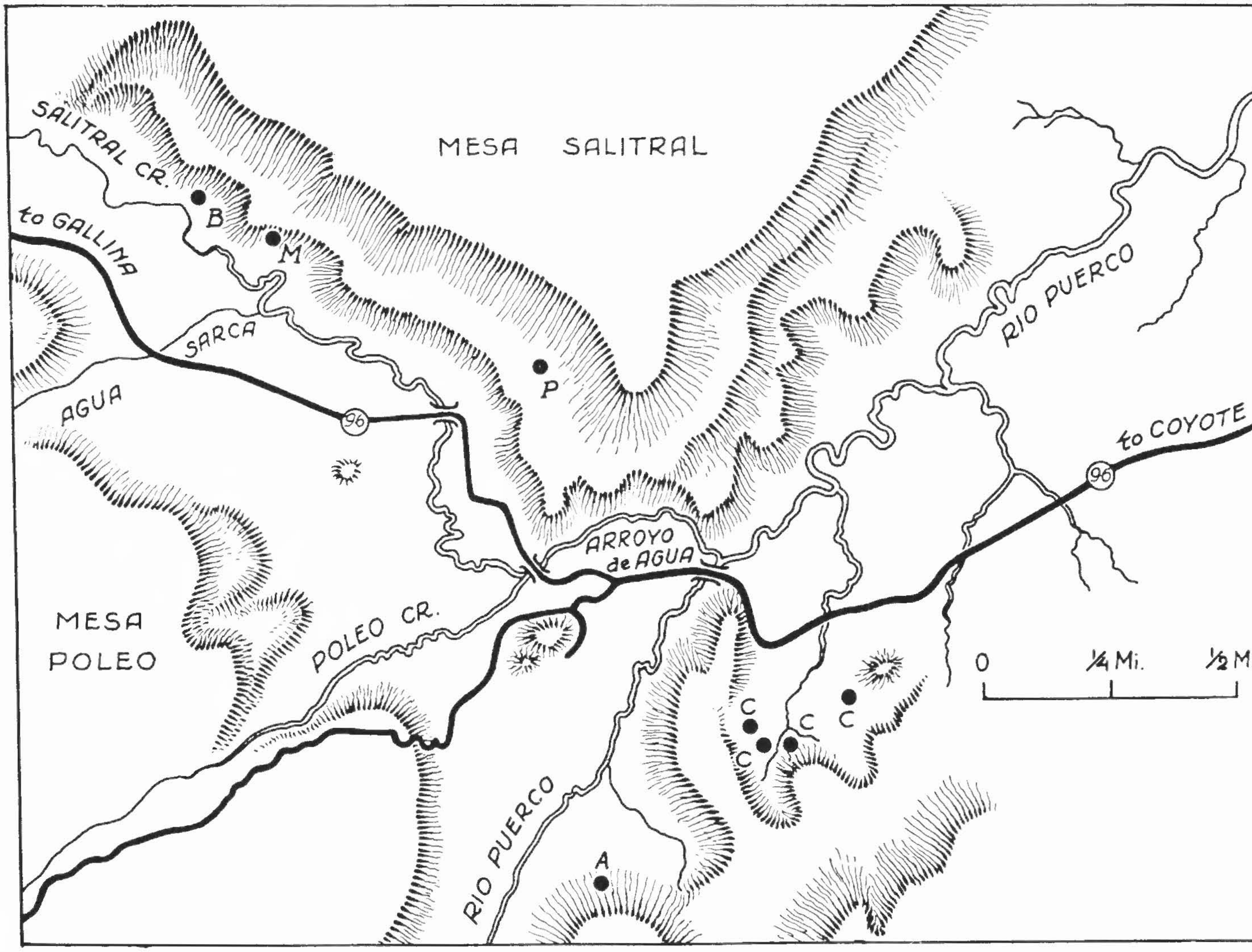


FIGURE 3.14. Vertebrate collecting area near Arroyo de Agua. A, Anderson quarry of the University of California; B, Baldwin bonebed; C, California quarries southeast of Arroyo de Agua; M, Miller bonebed. Except for the California excavations, most fossils have been obtained along the bluff from B to about the point P (from Romer, 1960).

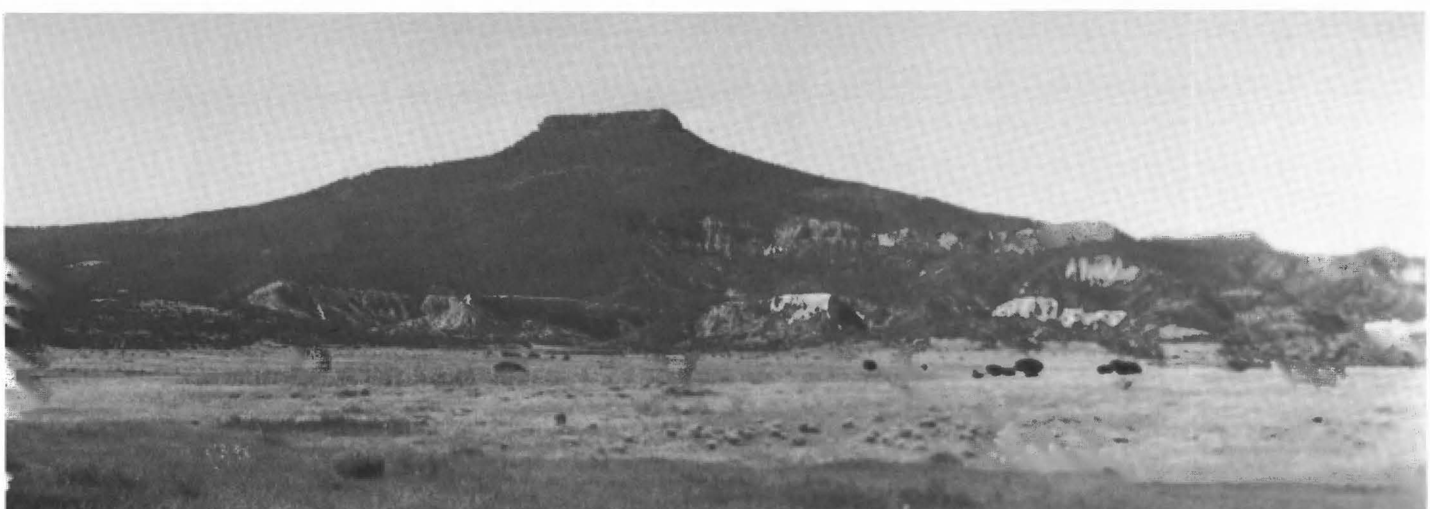


FIGURE 3.15. Cerro Pedernal from near mile 69.9.

64.2 Leaving Youngsville. At 10:00 in distance cliffs of Entrada Sandstone and long Morrison Formation slope are visible above Ghost Ranch. **0.3**

64.5 Road (and roadcuts) on Chinle Group, Petrified Forest Formation. **0.2**

64.7 Cattle guard. **0.8**

65.5 Crest hill and begin descent to Rio Chama Valley; water of Abiquiu Reservoir visible at 11:00 in distance. The long dip slope we drive down is developed on the Poleo Formation. **2.8**

68.3 Cattle guard. **0.7**

69.0 Low roadcuts on right are in Poleo Formation next 0.2 mi. **0.7**

69.7 Cattle guard. **0.1**

69.8 Roadcuts in Poleo Formation. **0.1**

69.9 Mile marker 43; view to 3:30 (Fig. 3.15) of Cerro Pedernal with canyon at base developed in Chinle Group, Entrada Sandstone and Todilto Formation. **0.9**

70.8 Poleo Formation in roadcuts on right; mesa on skyline ahead (to east) is capped by Pliocene Sierra Negra Basalt. **0.3**

71.1 Roadcuts to right are in Salitral Formation mudrocks, overlain by sandstones of the Poleo Formation. **0.2**

71.3 Cattle guard. **0.5**

71.8 Road to right goes to Cañones. Cañones (population 50), 2 mi south of NM-96, is a small village listed as a settlement as early as 1849. Continue straight. **0.1**

71.9 Roadcuts in Poleo Formation. **0.1**

72.0 Bridge over Cañones Creek; good view of Poleo Formation down creek, which is drowned here by waters of Abiquiu Reservoir. **0.2**

72.2 Roadcuts in Petrified Forest Formation next 1.6 mi; note Pliocene Sierra Negra basalt to right and left. **0.8**

73.0 View to left of Abiquiu Reservoir and up Chama basin to Ghost Ranch reveals Triassic–Cretaceous section. **0.5**

73.5 Cattle guard. Roadcuts now in mottled mudstones of Petrified Forest Formation. **0.3**

73.8 Road descends onto Poleo Formation. **0.1**

73.9 Cross Abiquiu dam. View down canyon is of Poleo Formation cliffs above Salitral Formation mudstones. **0.3**

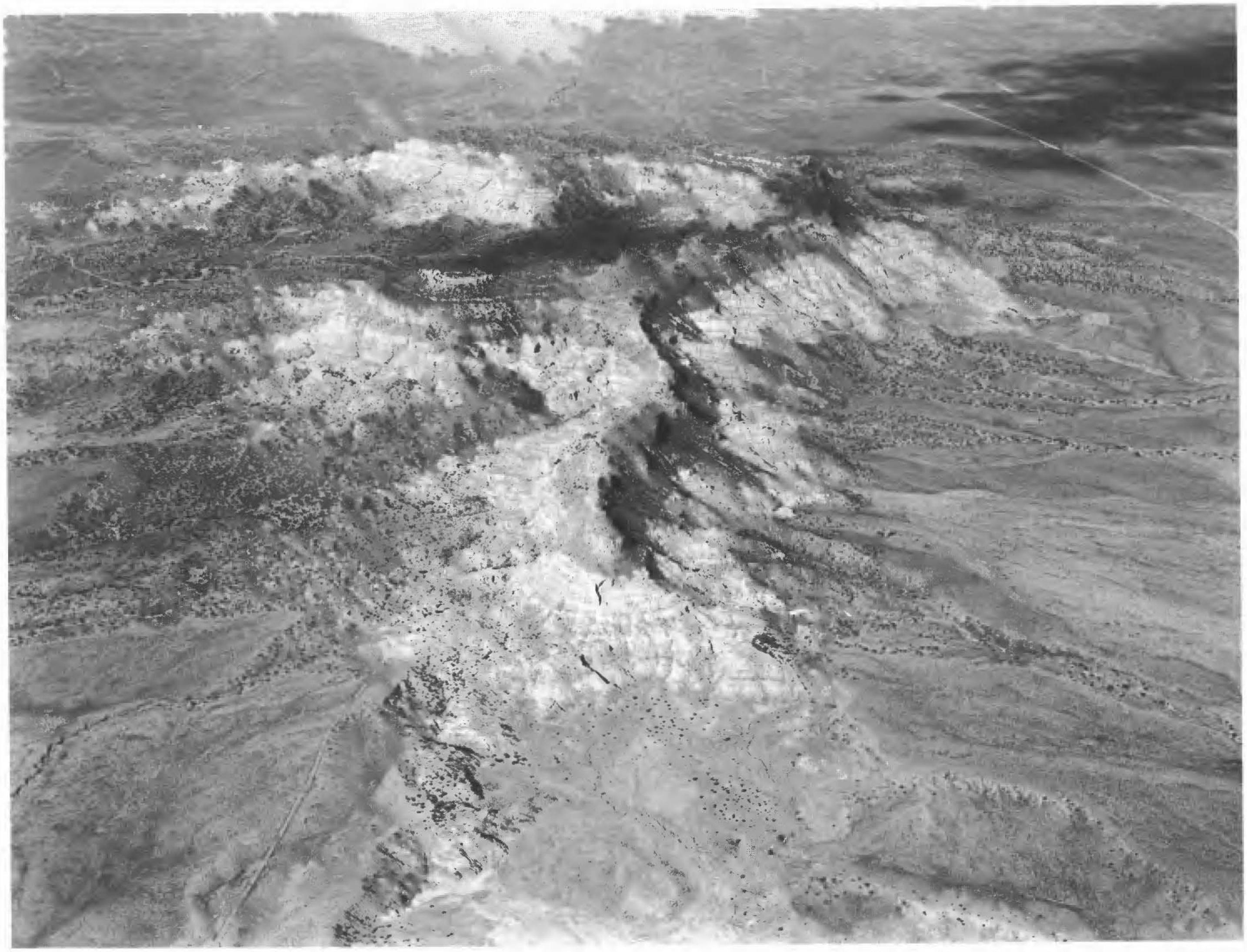
74.2 Across dam pull off to right for **STOP 3** to discuss engineering geology of dam and Triassic strata.

FIGURE 3.16. View downstream from Abiquiu Dam of Permian Cutler Formation (PC) and Triassic Agua Zarca (AZ), Salitral (S) and Poleo (P) formations of Chinle Group.

Below the dam, on the downstream side, the upper portion of the Cutler Formation (Early Permian) is overlain by strata of the Chinle Group (Fig. 3.16). The majority of the Cutler is Early Permian in age, but plant fossils demonstrate that the lower portion in El Cobre Canyon is Middle Pennsylvanian in age (Hunt and Lucas, this volume). In ascending order, the Chinle rocks are (Lucas and Hunt, this volume) Agua Zarca Formation (conglomeratic sandstone), Salitral Formation (siltstone and mudstone), and Poleo Formation (sandstone). The Poleo extends slightly higher than the dam and is in turn overlain by the Petrified Forest Formation, which can be seen on the mainly covered slope to the south of the dam. Elsewhere in the Chama basin, such as across the reservoir at Ghost Ranch, the Petrified Forest is overlain by the Rock Point Formation (Lucas and Hunt, this volume).

Abiquiu dam was completed by the U.S. Army Corps of Engineers in 1963 at a total cost of $20,430,000. The earth dam is 325 ft high and 1540 ft long. The reservoir has a maximum storage capacity of 1,374,000 acre-ft and is used for flood control.

End of Third-Day Road Log.



Aerial view of El Huerfano Mesa from an elevation of approximately 12,000 feet. Strata of the Paleocene Nacimiento Formation lead into the mesa in the left foreground. Cuba Mesa Member of San Jose Formation caps the mesa. NM Highway 44 is visible running from left to right in the upper part of the photograph. Photograph taken the morning of 13 April 1992. Copyright © Paul L. Sealey, 1992.