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Third-day road log: From Angel Fire to Las Vegas, via Black Lake, Guadalupita, Mora, Rociada and Sapello

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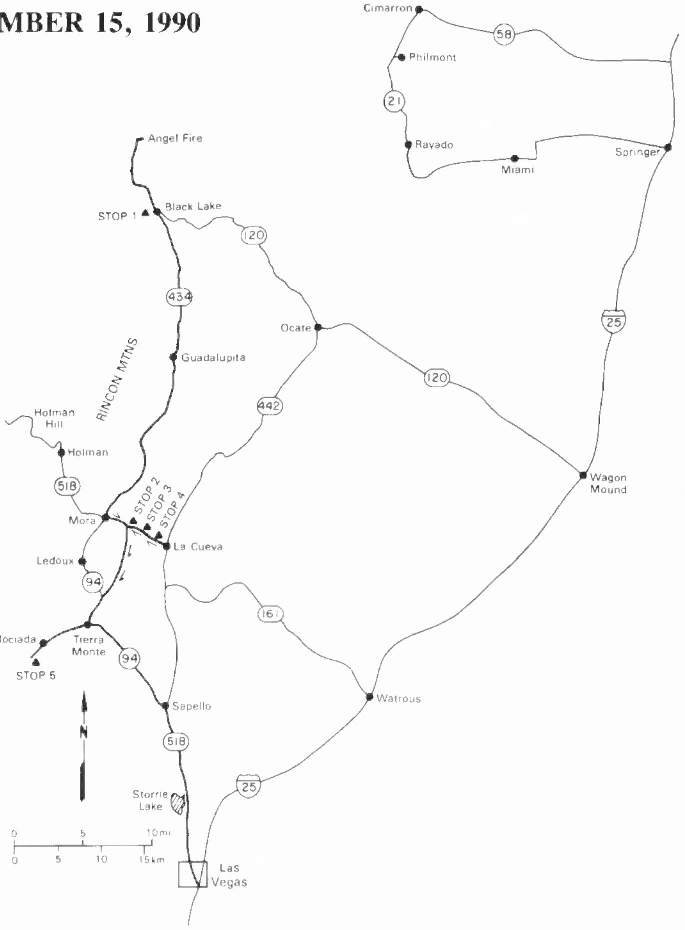
THIRD-DAY ROAD LOG, FROM ANGEL FIRE TO LAS VEGAS, VIA BLACK LAKE, GUADALUPITA, MORA, ROCIADA AND SAPELLO

ELMER H. BALTZ and J. MICHAEL O'NEILL

SATURDAY, SEPTEMBER 15, 1990

Assembly point:	Entrance to Angel Fire Legends Hotel on NM-434.
Departure time:	8:00 a.m.
Distance:	84.4 mi
Stops:	6 (5 plus 1 optional)



SUMMARY

The trip for the third day begins at Angel Fire near the south end of Moreno Valley, proceeds south and ends at Las Vegas. From Angel Fire south, the route is along NM-434 past Black Lake, down the gorge of Coyote Creek (Guadalupita Canyon) to Guadalupita and thence southward to the center of Mora. NM-434 is a paved two-lane road which is locally narrow, has sharp curves, some steep grades and passes through several communities. MODERATE SPEEDS AND CONSIDERABLE CAUTION ARE NECESSARY because of these conditions and because of local traffic.

From Mora the route follows NM-518 (formerly NM-3) east across Mora Valley through the hogbacks in the water gap of Mora River to the small community of La Cueva. From La Cueva the route is retraced back on NM-518 to the west end of Mora River gap. NM-518 has much high-speed traffic and curves where visibility ahead is limited. Therefore CONSIDERABLE CAUTION IS ADVISED in parking and observing outcrops because the shoulders are narrow.

The next segment begins just west of Mora River gap at the intersection of NM-518 and the south-trending unpaved county road just west of the westernmost outcrops of Precambrian rocks. This dirt road is maintained frequently but becomes slick and rutted in wet weather. The route follows this road south past Rito Cabolla, onto paved NM-94, and continues south on NM-94 through the alluvial Las Quebraditas Valley to the intersection with paved NM-105. The route then follows NM-105 south to Pendaries Ranch in the Rociada Valley and returns northward to the intersection with NM-94. Thence it continues southeastward on NM-94 past Manuelitas to Sapello and the intersection with NM-518. The route continues south on NM-518 to Las Vegas where it joins I-25.

SUMMARY OF GEOLOGIC STRUCTURE FOR THIRD DAY

The route of the road log weaves across the southeastern margin of the Laramide Sangre de Cristo uplift from the Moreno Valley south to Sapello and through the southern part of the Laramide Las Vegas basin to Las Vegas (Fig. 3.1). Southwest of Las Vegas the uplift passes into low monoclinal folds that plunge gently southeast and die out in the Great Plains. The Laramide structures are superposed on and across Paleozoic uplifts and across the deep parts of the Pennsylvanian–Early Permian Rowe–Mora basin and its southern shelf areas. Evidence of east-directed Laramide thrusting will be examined, as will evidence for lengthy down-to-the-west Pliocene-Quaternary faults that constitute the easternmost parts of the Rio Grande rift system in this region. Thick deposits of Pennsylvanian-Permian rocks of the Rowe-Mora basin will be examined at Mora River.

Cenozoic deposits of the Moreno Valley are underlain in part by a Laramide syncline (Clark and Read, 1972) between the Sangre de Cristo uplift on the west and the Laramide-upthrust Precambrian basement rocks of the southern Cimarron Mountains on the east. The east side of the Laramide syncline has been dropped, down-to-the-west, along Neogene faults.

The basement blocks of the Cimarron Mountains are Cenozoic-rejuvenated parts of a more extensive Pennsylvanian and Permian and, probably, Triassic uplift, the Cimarron arch (Figs. 3.2, 3.3) (Baltz, 1965), that is present also in the subsurface of the northern part of the Las Vegas basin. Graton (1910) first noted the general absence of Carboniferous rocks near the head of Cimarron Canyon, and later mapping (Wanek et al., 1964; Clark and Read, 1972; Goodknight, 1976) confirmed that thin sections of the Upper Pennsylvanian and Lower Permian Sangre de Cristo Formation and, locally, the Upper Triassic strata lie on the Precambrian.

The Precambrian rocks of the southern Cimarron Mountains are truncated at the south by northwesterly trending faults (Fig. 3.1) called the Los Cabin fault by Wanek et al. (1964) and the Saladon Creek fault by Smith and Colpitts (1980). In the Sangre de Cristo uplift, southwest of a probable extension of this fault

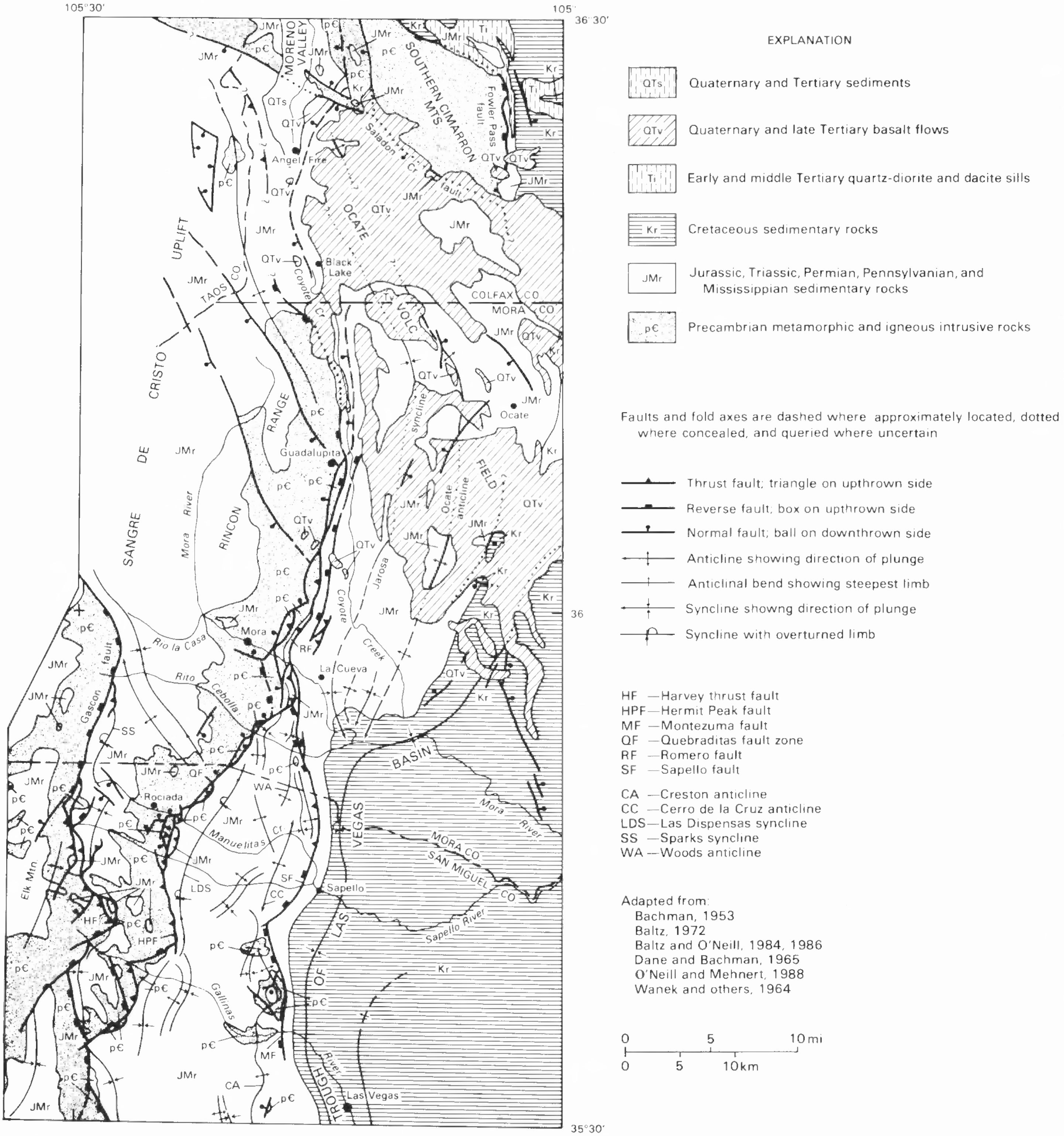


FIGURE 3.1. Principal Cenozoic structural features of the southeastern Sangre de Cristo uplift and western Las Vegas basin.

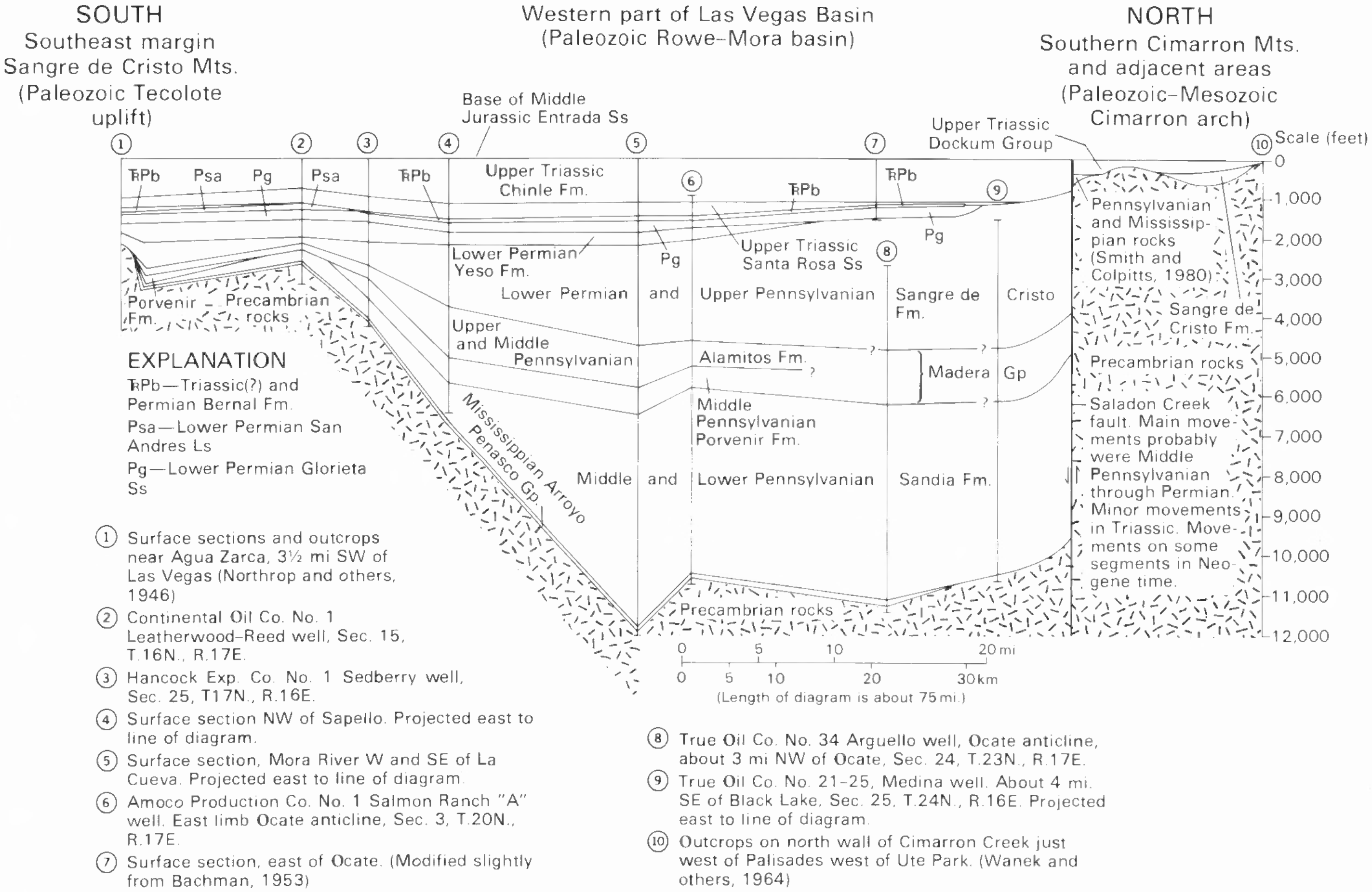


FIGURE 3.2 Correlation diagram of Mississippian through Triassic rocks of the western Las Vegas basin and southern Cimarron Mountains. Line of diagram shown on Figure 3.3.

zone, Lower and Middle Pennsylvanian rocks are more than 6000 ft thick (Sutherland, 1963). In the subsurface of the Las Vegas basin, southwest of the Saladon Creek fault, Pennsylvanian and Lower Permian rocks are on the order of 10,000 ft thick (Fig. 3.2).

South and southeast of the Cimarron Mountains the Laramide structure of the northwestern part of the Las Vegas basin is poorly known because much of it is concealed by the Neogene-Quaternary Ocate volcanic field (O'Neill and Mehnert, 1988). This part of the basin beneath the volcanics is a Laramide south-sloping structural terrace marked by at least one large anticline east and southeast of Angel Fire and, farther south, by the broad, low Ocate anticline and the flanking shallow Jarosa syncline on the west (Bachman, 1953). Well data and seismic profiles suggest that the Ocate anticline is basement-cored, and at least parts are underlain by a west-dipping thrust fault that displaces Precambrian, Mississippian and Lower Pennsylvanian rocks but dies out in overlying rocks on the east limb of the anticline. The structural terrace plunges south and disappears from the Las Vegas basin southeast of Mora (Baltz and O'Neill, 1984).

West and southwest of Angel Fire the main part of the Sangre de Cristo uplift is a broad, gently west-tilted block surfaced by thick Pennsylvanian rocks. This block, extending as far west as Taos, is a Cenozoic-uplifted relic of a deep part of the Rowe-Mora basin. The eastern part of the block is a northwesterly trending, asymmetric, east-verging anticline with a crenulated eastern limb, which the field trip will traverse south of Black Lake. Smith and Colpitts (1980) suggested that west and southwest of Angel Fire, Pennsylvanian rocks of the eastern limb of the anticline are broken by several west-dipping thrusts, but reconnaissance at places farther south suggests that major faults may not be present there. Because the stratigraphy of the Pennsylvanian rocks is poorly known here, the question of faulting is still open, and the structural boundary of the uplift and the Las Vegas basin here is uncertain. To the south the anticline passes into the northerly plunging, basement-cored, east-verging uplift that is now part of the Rincon Range (Fig. 3.1).

The Rincon Range is a northerly trending, locally flat-topped, asymmetric anticline with a faulted, steep eastern limb. Mississippian rocks are exposed at many places on the crest, and Lower Pennsylvanian rocks form the western limb. The anticline is segmented by two major northwest-trending transverse faults that are downthrown to the southwest. The Precambrian quartzites of the range are part of a pre-Mississippian (presumably Precambrian) east-verging anticline with a locally overturned east limb which is well displayed north of Mora. Scanty exposures through basalt flows and colluvium in the canyon of Coyote Creek south of Black Lake and north of Guadalupita suggest that the Precambrian quartzites of the east side of the Rincon Range are faulted against vertical to overturned Lower to Middle Pennsylvanian rocks, marking the boundary of the Sangre de Cristo uplift and the Las Vegas basin. Mapping of this structural zone in the vicinity of Guadalupita (Bachman, 1953) suggests that the faults are west-dipping reverse or thrust

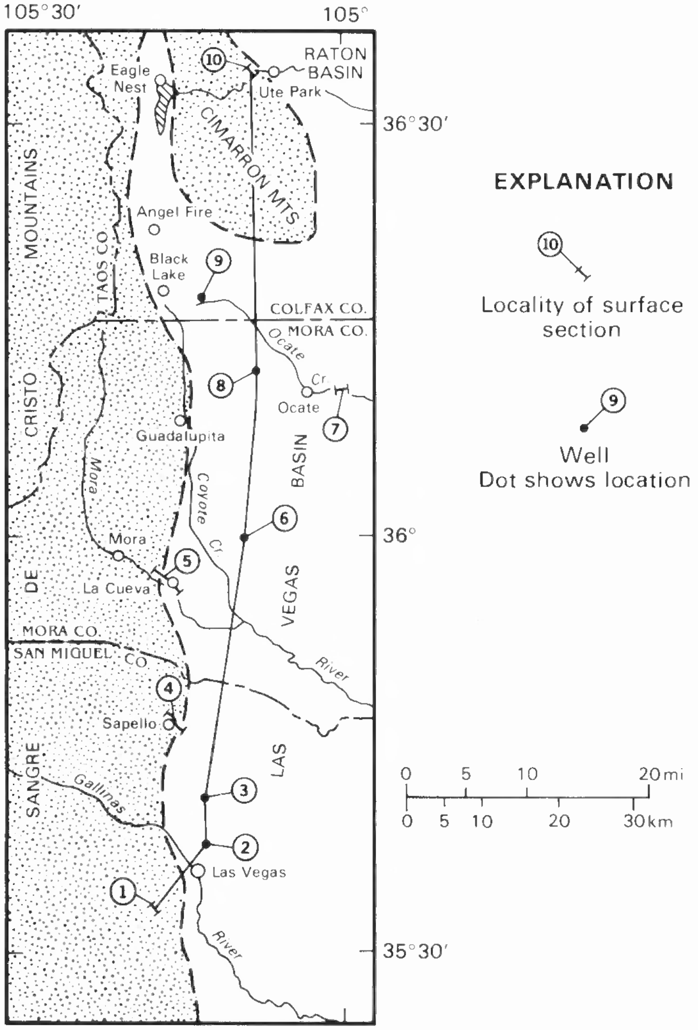


FIGURE 3.3. Map showing line of correlation diagram of Figure 3.2.

faults. This faulted frontal zone of the Sangre de Cristo uplift persists south of Mora River. Several miles northeast of Mora the total Laramide west-east shortening by folding and thrusting may be almost 2 miles (Baltz and O'Neill, 1984, section A–A′).

From Mora south (Fig. 3.1), the easternmost part of the Sangre de Cristo uplift is a series of gently west-tilted, basement-cored blocks surfaced by Pennsylvanian rocks. The western margins of these blocks are synclines with vertical to overturned western limbs. The eastern edges of the blocks are northerly trending, easterly verging, asymmetric anticlines thrust a few thousands of feet across the overturned west limb of the Las Vegas basin on the Sapello and Montezuma faults (Baltz and O'Neill, 1984, 1986). To the south, thrusts die out into folds in the frontal zone northwest of Las Vegas (Baltz, 1972).

A little south of the Mora River the frontal fault zone bifurcates into the eastern zone described above, and an interior zone of southwest-trending, east-vergent Laramide thrusts and superposed Pliocene-Quaternary down-to-the-west normal faults of the Quebraditas fault zone (Fig. 3.1). West of this zone, the general uplift of the Rincon Range continues as a southwest-trending, west- and northwest-tilted, basement-cored block of Pennsylvanian rocks with a syncline and overturned rocks on its western margin. Precambrian metavolcanic and metasedimentary rocks at the east edge of this block are folded into the north-northeast-trending Precambrian El Oro anticline. West of this block, west and southwest of Mora, a major reverse fault, the Gascon fault (Fig. 3.1), lifts Precambrian, Mississippian and Lower Pennsylvanian rocks of the central part of the Sangre de Cristo uplift to altitudes of almost 12,000 ft. By contrast, the top of Precambrian rocks in the Las Vegas basin east of Mora probably is locally 4000 ft or more below sea level (Baltz and O'Neill, 1984). Several thousand feet of this structural relief is of Paleozoic age rather than Laramide, because the area east of Mora is the deep northern part of the Paleozoic Rowe-Mora basin, whereas the area west of the Gascon fault is on the northern margin of the Paleozoic Pecos shelf of the southern part of the Rowe-Mora basin. The extent and nature of the Gascon fault are poorly known but the northern end of the fault bends to the northwest and apparently dies out in the western part of the Sangre de Cristo uplift (Dane and Bachman, 1965). To the south, the Gascon fault seems to die out west of Hermit's Peak, but its displacement is taken up by the east-verging, low-angle Harvey thrust fault (Fig. 3.1) southwest of Rociada.

Northerly trending, down-to-the-west Neogene and Quaternary faults occur near the eastern front of the Sangre de Cristo uplift from north of Eagle Nest south to the vicinity of Sapello. On the eastern side of Moreno Valley, as far south as Eagle Nest Lake, the Eagle Nest fault and its branches displace Cretaceous rocks and Tertiary sills down-to-the-west (Clark and Read, 1972). South of there, the western side of the Precambrian rocks of the southern Cimarron Mountains seems to be a fault line as indicated by outcrops of Triassic, Jurassic and Cretaceous rocks at the eastern edge of the valley (Dane and Bachman, 1965) far below the crest of Precambrian rocks in the Cimarron Mountains.

Between Angel Fire and Black Lake several patches of Pliocene (4.47 ± 0.23 Ma) basalt lie in valleys along the route of the caravan and seem to be downfaulted several hundred feet from similar flows at Agua Fria Peak and the high mesa to the south (O'Neill and Mehnert, 1988). Between Black Lake and Guadalupita, similar-age flows occur in the canyon of Coyote Creek, apparently downfaulted from the Pliocene flows on the mesas east of the canyon (O'Neill and Mehnert, 1988).

South of Guadalupita the route of the field trip is through several broad, north-northeast-trending alluvial valleys that lie west of the Laramide structural front of the Sangre de Cristo uplift. Seismic-refraction profile lines at places in the Mora and Rociada Valleys show that the alluvium generally thickens eastward in these valleys. Short, relatively straight scarp lines at the eastern sides of the valleys (Baltz and O'Neill, 1984, 1986) appear to be down-to-the-west Pliocene-Quaternary faults mainly superposed on Laramide thrust zones. Throws on these young faults are estimated to 600–700 ft locally. The system of young faults dies out at Sapello River.

Mileage

0.0 Starting point is at turnoff to Angel Fire Legends Hotel in Angel Fire on NM-434. **Proceed south (left) on NM-434** through Angel Fire toward Black Lake.

Outcrops at places along the road are near the stratigraphic top of Pennsylvanian mixed marine and nonmarine rocks described as the Alamitos Formation by Smith and Colpitts (1980) and consist of interbedded shale, feldspathic sandstone, pebbly conglomerate, siltstone and some fossiliferous limestone. Colors are predominantly light brown and light gray. On the slopes of Angel Fire ski run at the east, red beds of Pennsylvanian(?) and Lower Permian Sangre de Cristo Formation are part of a large anticline.

Extensive Pliocene(?) and Quaternary pediment deposits of sand, gravel, silt and clay cropping out at 9:00 slope north toward the Moreno Valley and cap wide areas on the flanks of the Sangre de Cristo Mountains to the west and southwest. To the west, on the skyline, are Pennsylvanian sedimentary rocks on a large northwesterly plunging anticline that is the eastern, frontal fold of the Sangre de Cristo uplift in this vicinity. Some of these rocks contain early Desmoinesian fusulinids and have been assigned by Smith and Colpitts (1980) to the Flechado Formation of Morrowan through Desmoinesian age (Sutherland, 1963; Sutherland and Harlow, 1973) and the Magdalena Group by Dane and Bachman (1965). Smith and Colpitts (1980) suggest that several northerly trending, east-yielding Laramide thrusts break the Pennsylvanian rocks on the east limb of the anticline. As seen farther south on the field trip, the frontal anticline rises structurally and, in the Rincon Range, has a core of Precambrian quartzite and metavolcanic rocks.

Pennsylvanian rocks have not been subdivided and mapped in this part of New Mexico. A chart (Fig. 3.4) shows published nomenclature and general correlations

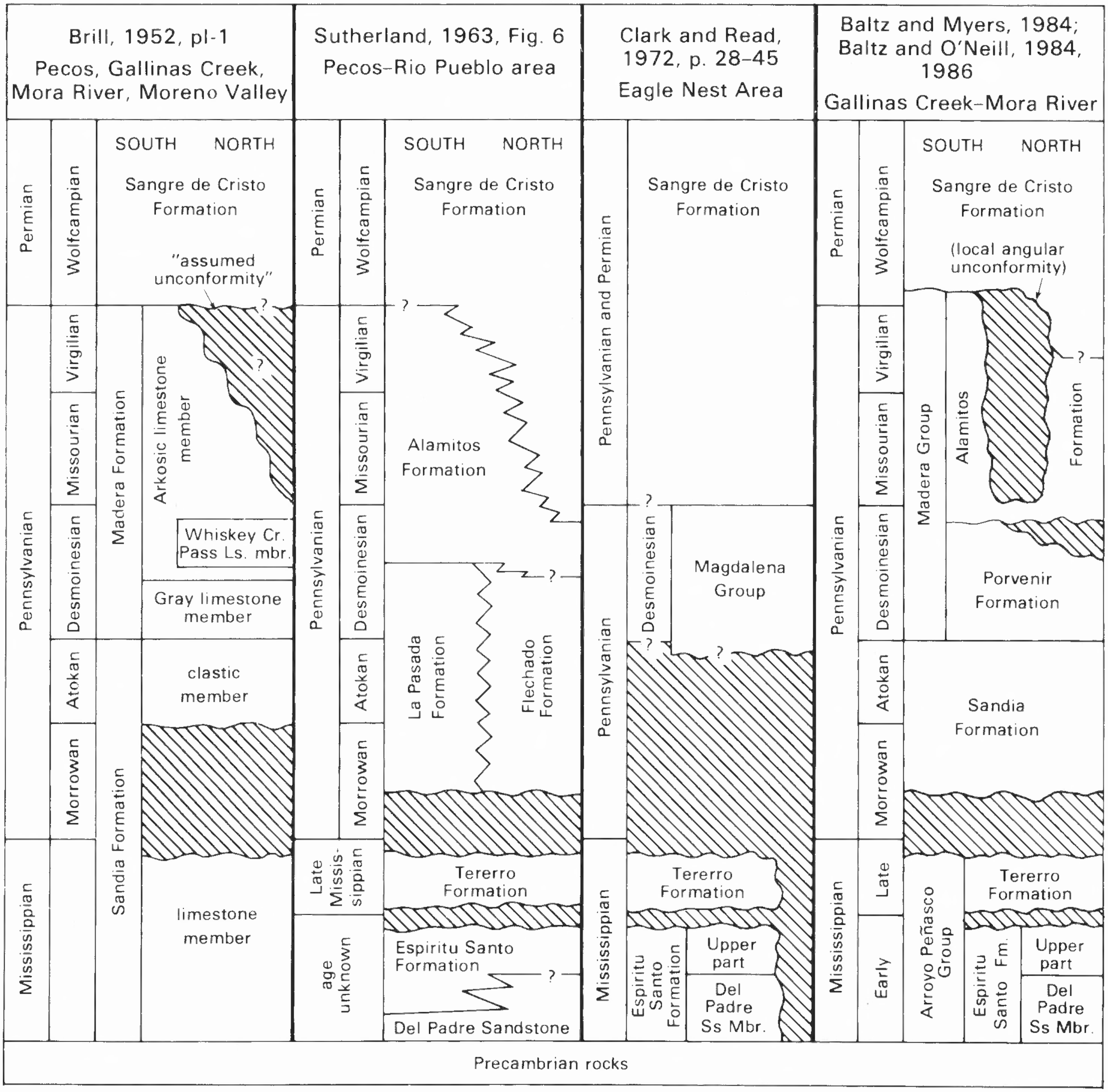


FIGURE 3.4. Nomenclature of Mississippian, Pennsylvanian and Lower Permian rocks of parts of the Sangre de Cristo Mountains.

for parts of the Sangre de Cristo Mountains in New Mexico. Nomenclature and correlations in the log south to Mora follow the usage of Baltz and Myers (1984) but are provisional only.

Continue south through Angel Fire on NM-434. **0.2**

0.2 Mountain at 9:00 is Agua Fria Peak, a major eruptive center in the northern part of the Ocate volcanic field. Agua Fria Peak is a large shield volcano and is the largest of several vents in this area. Most of these vents are topographic highs marked by abundant scoria, highly oxidized basaltic rocks, and locally, orange-yellow-weathering tuff and tuff breccia. Flows from these vents, that were dated between 5 and 4 Ma (O'Neill and Mehnert, 1988), consist mainly of olivine basalt and locally minor andesite and dacite. These flows can be traced more than 30 km to the southeast and cap many of the high mesas that surround the village of Ocate. Tree-covered hills at 3:00 are composed of folded Pennsylvanian Sandia and Porvenir Formations that are cut by reverse faults. **0.4**

0.6 Roadcut exposes upper part of Pennsylvanian sequence (Alamitos Formation). **0.1**

0.7 Hills at 9:00–10:30 contain Permo-Pennsylvanian Sangre de Cristo Formation. **0.3**

1.0 Road on right leads to Angel Fire Country Club. **0.1**

1.1 Sangre de Cristo Formation in outcrops to left consist of trough-crossbedded coarse conglomeratic sandstone, red micaceous sandstone and siltstone and reddish nodular micritic limestone. **0.3**

1.4 The springs on left and at 11:00 are located on the trace of a normal fault that has downdropped Sangre de Cristo Formation on the east. **0.3**

1.7 Green pumphouse on right supplies water to a tank located behind trees above and left on slope. Pumping tests here confirmed the presence of a hydrologic barrier east of the road (normal fault noted at mile 1.4). **0.1**

1.8 Outcrops in roadcuts are near the contact of mixed marine-nonmarine Pennsylvanian rocks and nonmarine rocks of the Sangre de Cristo Formation. **0.1**

1.9 Milepost 32. **0.2**

2.1 Trailer park on left. Upper part of Pennsylvanian sequence is exposed to right across Cieneguilla Creek. **0.3**

2.4 West-dipping Sangre de Cristo Formation in roadcuts on left. **0.2**

2.6 Private lake on right. **0.3**

2.9 Milepost 31. **0.3**

3.2 Outcrops of Sangre de Cristo Formation in roadcut are predominantly yellowish-gray and red shaly siltstone and very fine grained sandstone but contain medium-grained quartzite-pebble sandstone and concretionary limestone zones. **0.1**

3.3 Summit, Black Lake divide. Divide separates the Cieneguilla Creek drainage system of the southern Moreno Valley from the Coyota Creek drainage system. On hill to the west, exposures mainly are west-dipping Pennsylvanian shale and sandstone. **0.1**

3.4 Top of Pennsylvanian partly marine red beds possibly equivalent to Alamitos Formation. Overlying rocks of Sangre de Cristo Formation are shaly red siltstone, some fine- to coarse-grained feldspathic sandstone and some thin ledge-forming beds of arkosic conglomerate containing quartz and granite pebbles. **0.2**

3.6 Road crosses lower contact of steeply dipping, stratigraphically lowest red and purple beds, consisting mainly of very fine grained sandstone, shaly sandstone and olivine-gray-weathering siltstone and a trace of bioclastic, crinoid-columnal limestone. These beds may be equivalent to part of the Alamitos Formation of areas to the south, but paleontologic evidence is not available. **0.1**

3.7 Lowest red beds of Alamitos(?) Formation in roadcut at 9:00. **0.2**

3.9 Milepost 30. **0.3**

4.2 **Intersection** of NM-434 and Forest Service Road 76 (County Road B29). **Continue south** on NM-434. Pennsylvanian rocks on both sides of road dip 70–80°E. Rocks at 9:00 are Pennsylvanian sandy fossiliferous limestone and limy sandstone. Steep dips continue at least 1/4 mile to the west on eastern overturned anticline of the Sangre de Cristo uplift. Rocks in roadcut have general lithologic aspect of the Middle Pennsylvanian (Desmoinesian) Porvenir Formation of areas to the south, but fossil identifications are not available. Limestone beds on Forest Road 76 near the crest of the anticline at the west contain early Desmoinesian fusulinids (*Beedeina* sp.) and, therefore, are age-equivalent to lower part of Porvenir Formation farther south. **0.8**

5.0 To the south, Pennsylvanian rocks become gently east dipping. **0.4**

5.4 Roadcuts at 9:00, for the next 0.3 mi, expose the stratigraphically lowest red shale, greenish shale and nodular limestone of the Alamitos(?) Formation. At places arkosic sandstone forms ledges above these basal beds. Road crosses the postulated trace of a northerly trending down-to-the-west Pliocene-Quaternary fault (O'Neill and Mehnert, 1988). **0.5**

5.9 At 9:00 is small side canyon and ranch buildings. South of here Pennsylvanian rocks in roadcuts and hills begin to dip gently east to northeast. **1.2**

7.1 At 9:00, gently east- and northeast-dipping, fine-grained sandstone, siltstone and shale are possibly equivalent to Porvenir Formation. These are overlain by Pliocene volcanic-flow rocks (O'Neill and Mehnert, 1988) which appear to have been faulted down several hundred feet from equivalent flows on mesas to the east. **0.4**

7.5 Entering community of **Black Lake. 0.6**

8.1 **Junction** of NM-434 and NM-120 at Black Lake. **STOP 1. Pull off on right** near Poor Boy's Country Club. The purpose of this stop is to describe the Ocate volcanic field, Precambrian rocks of Rincon Range, Paleozoic rocks and Cenozoic structure. Black Lake valley at 12:00–3:00 is a nearly closed alluvial basin that has barely been breached at the south by the headwaters of Coyote Creek.

At 12:00–1:30 on the skyline to the southwest are Precambrian quartzites of the northern part of the Rincon Range. These rocks plunge northwest and, at about the saddle on the skyline, pass under rocks probably age-equivalent to the Sandia Formation. The stratigraphically highest Pennsylvanian rocks have Middle Pennsylvanian (Desmoinesian) fusulinids and are age-equivalent to the Porvenir Formation.

The Precambrian and Pennsylvanian rocks on the skyline are approximately at the crest of the eastern-frontal anticline of the Sangre de Cristo uplift. Whether Laramide faulting occurs on the east limb of the anticline at this latitude is not known. The Pennsylvanian rocks dip east, pass beneath the alluvium of Black Lake valley, and crop out in bluffs at 9:00 just east of Black Lake. Gently northeast-dipping sandstones in the bluff at 9:00 are well sorted, highly crossbedded, and contain a few marine fossils. They may be nearshore bar or beach deposits. Stratigraphic position suggests they are Desmoinesian. The total thickness of Pennsylvanian rocks in this area is not known, but the True Oil Company No. 25-25 Medina well several miles southeast of Black Lake penetrated almost 6000 ft of Pennsylvanian rocks below the Sangre de Cristo Formation and bottomed in the Precambrian (Fig. 3.2).

To the south, basalt cropping out at the east edge of the valley is early Pliocene in age (O'Neill and Mehnert, 1988). These rocks cap a broad topographic shelf and are not broken by the Neogene fault to the north which dies out southward in the vicinity of Black Lake.

The high hill on the skyline at 11:00 is Cerro Montoso, a basalt-capped mesa. Olivine basalt from this mesa is dated as 8.34 ± 0.5 Ma. The volcanic rocks that cap this mesa, which reaches an elevation of nearly 10,300 ft, are underlain by well-rounded stream pebbles, cobbles and boulders. The basalts on Cerro Montoso are among the oldest known flows in the volcanic field, and preserve beneath their cover the physiographically highest gravel-covered surfaces in the region. These flows appear to rest on a surface or series of nearly equivalent surfaces that slope gently southeast from a drainage divide, which in this part of the Sangre de Cristo Mountains, was located east of the present divide, probably near the Rincon Range. This paleosurface cuts across diverse rock types and sharp structural breaks, suggesting that late Miocene time was marked principally by erosion and pediplanation.

Pliocene volcanic rocks (map unit Tv2 of O'Neill and Mehnert, 1988) along Coyote Creek from Black Lake south toward the village of Guadalupita consist of olivine basalt flows locally more than 150 ft thick. The distal, southern end of the flows is largely confined to the valley floor. Northward, these flows occupy a much larger area west of the creek but end abruptly against the east wall of the valley. The surface on which these flows lie appears to be relatively flat, rising gently toward Black Lake. Two vents directly south of Black Lake appear to be the main source of these flows. The more northerly and principal vent stands as a rounded, elongate knob capped by strongly oxidized scoria, volcanic breccia and blocky flows. A slightly younger vent directly southeast is circular in plan and dome-shaped in cross section. Basalts everywhere dip away from a central basaltic knob that is capped by minor scoriaceous material. This feature appears to be a basaltic intrusion, satellitic to the main vent, which domed the overlying volcanic rocks and expelled very little basalt as flows. NM-434 passes through the eastern part of this structure.

PRE–COYOTE CREEK LANDSCAPE AND HIGH PLAINS ORIGINS

Paul N. Dolliver

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The headwater divide area of Coyote Creek near Black Lake, New Mexico is an appropriate site to contemplate a late Miocene erosional landscape which supplied fluvial gravel to the southern Great Plains. Five basalt-capped erosion surface remnants on the periphery of the Coyote Creek basin provide sparse but instructive insights into the history of interaction between two physiographic provinces: the Sangre de Cristo Mountains and the Southern High Plains.

Rocky Mountain–Great Plains history is commonly envisioned in the following way. Rapid fault-associated uplift on the Rockies induced extensive downcutting and bedrock corrasion. The resulting alluvium was removed from the mountains by streams which flowed out of deeply incised canyons onto a rapidly aggrading gravelly alluvial plain. Plausible as this scenario seems to be, it does not describe the late Miocene southern Rockies or their role in development of the Southern High Plains.

An alternative view originates with erosion surface remnants high above Coyote Creek. When these surfaces are considered in light of other correlative montane surfaces and the plains sedimentary record, they are the basis for at least two conclusions. First, two major episodes of High Plains (Ogallala) fluvial gravel deposition accompanied late Miocene uplift of a deeply weathered erosional terrain in the southern Rockies. Second, this terrain ceased to be an Ogallala gravel source long before it was fragmented by early Pliocene faulting and drainage incision.

The Coyote Creek area erosional record is unique because of its location and age. Coyote watershed volcanics are part of the Ocate volcanic field, the only volcanic succession that mantles the transition between the Rocky Mountains and the Great Plains (Fig. 3.5a). Late Miocene–early Pliocene age Ocate flows bracket the timing of late Tertiary plains sedimentary events more closely than do other Rocky Mountain erosional landscape successions.

Ocate-volcanic-field flows, for purposes of presenting Ogallala-relevant erosional history, can be divided into two groups according to age and physiographic expression. The oldest flows are late Miocene (8.3–5.7 Ma) age and consist of isolated basalt capping the highest gravel-covered surfaces in the Coyote Creek watershed (O'Neill, 1988) (Fig. 3.5a). Early Pliocene–Pleistocene (5–0.8 Ma) basalts/dacites are more areally extensive and mantle numerous gravelly erosion surfaces. The highest and most widespread of these is the Urraca surface, which rises about 150 m (500 ft) above surrounding lowlands and generally is less than 90 m (300 ft) below late Miocene volcanic remnants. Events pertaining to Ogallala gravel deposition ended before formation of the Urraca surface (Fig. 3.5b).

Geography and lithology link Ocate/Coyote erosional terrain with Ogallala depositional sites 485 km (300 mi) to the southeast. The Coyote Creek watershed is updip (northwest) of two bedrock paleovalleys which contain Ogallala fluvial gravel of Southern Rocky Mountain provenance (Fig. 3.5a). The downdip preserved limits of these Ogallala fluvial systems are exceptionally well exposed in re-entrant canyons along the scarped eastern High Plains margin in the Texas Panhandle. These intensively studied sites yield evidence of two major episodes of late Miocene Ogallala gravel deposition, accompanied and succeeded by eolian sedimentation. Older Ogallala (Couch Formation) gravel is devoid of basalt/dacite. Younger more voluminous Bridwell Formation gravel contains volcanics from both the Ocate and contemporaneous Raton volcanic fields. Ages of both formations are constrained by abundant late Miocene–early Pliocene (Clarendonian-Hemphillian) vertebrate fauna (Winkler, 1985).

Couch Formation gravel originated in part on a pre-volcanic Coyote Creek area landscape. Late Miocene Ocate basalts cap what was once a surface of subdued relief which truncated pre-existing structures and zones of contrasting lithology. Judging from accordance of its widely scattered remnants, this late Miocene erosion surface extended uninterrupted from the central Sangre de Cristo Mountains southeastward onto the future Great Plains. To the north in Colorado, physiographically equivalent terrain is preserved essentially intact over broad areas beneath a mantle of early Oligocene volcanic and volcaniclastic rocks (Epis and Chapin, 1975).

The Colorado equivalent of the late Miocene pre-Coyote landscape originated in the wake of Laramide (late Cretaceous–middle Eocene) tectonism. By late Eocene time, intense weathering under a subtropical-

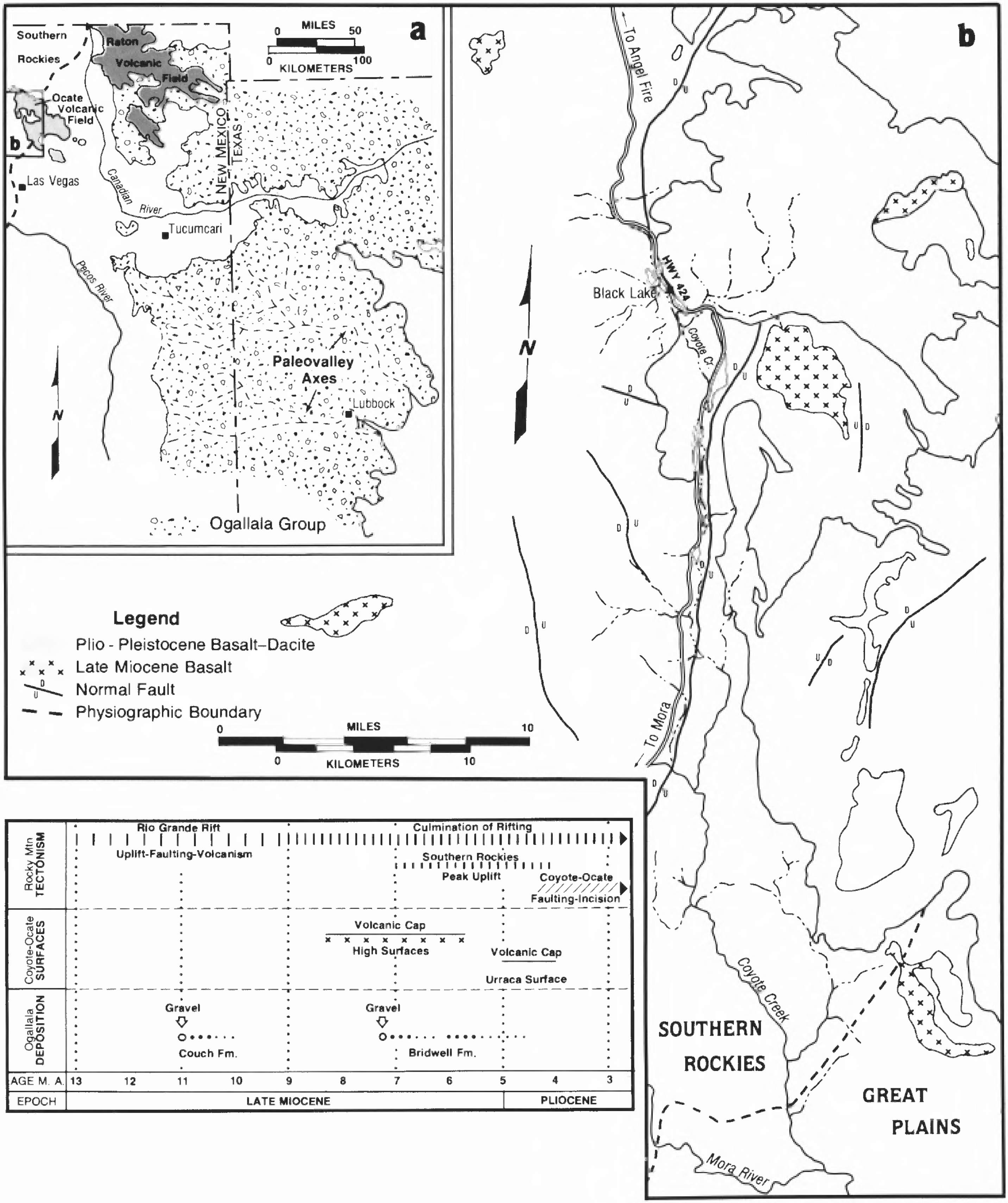


FIGURE 3.5. **a,** Physiographic setting of late Tertiary volcanics and Ogallala Formation on the Southern High Plains. Ogallala paleovalley axes are inferred from Knowles et al., 1984. **b,** Map showing distribution of late Miocene to Pleistocene volcanics and normal faults in the Coyote Creek drainage basin (modified from O'Neill and Mehnert, 1988). Timing of selected tectonic, erosional and depositional events in the Southern Rocky Mountains and Southern High Plains. Ages of tectonic and depositional events are accurate to within about one million years; volcanic cap dates are to within 0.5 million years. Sources: Chapin, 1979; Dolliver and Holliday, 1988; Morgan and Golombek, 1984; O'Neill, 1988; Seager et al., 1984; Winkler, 1985.

subhumid climate had produced a low-relief plain covered by a 10–40+ m deep alluvial covermass (Scott, 1975). Similar conditions undoubtedly existed in northern New Mexico, but they were not interrupted by early Oligocene volcanism. Instead, weathering proceeded for another 25 million years under a progressively drier climate (Leopold and MacGinitie, 1972). With the exception of minor uplift associated with late Oligocene–early Miocene Rio Grande rift extension (Morgan and Golombek, 1984), the deep alluvial pre-Coyote surface remained tectonically stable until late Miocene time.

Couch gravel moved southeastward from the Coyote Creek area under the impulse of upwarping associated with resurgent Rio Grande rifting farther to the west (Fig. 3.5b). The magnitude of vertical movement during the last 10 million years is estimated at 1500–2000 m (5000–6500 ft) (Gable and Hatton, 1983). Roughly half of this uplift may have influenced the late Miocene pre-Coyote Ogallala source terrain (Dolliver, 1984; Osterkamp et al., 1987). The effect of uplift, which was essentially unaccompanied by local faulting, was to mobilize a deeply weathered alluvial covermass and move it plainsward into broad bedrock paleovalleys. This basal valley fill subsequently was blanketed by eolian sediment. Couch deposition ended with widespread pre-Bridwell erosion and stream incision (Winkler, 1985).

Basal Bridwell gravel deposition followed an apparent 2–3 million year hiatus in Ogallala sedimentation. Gravel mobilization occurred early in the culminating stage of Rio Grande rift faulting and Southern Rocky Mountain uplift (Fig. 3.5b). Transport apparently was through the same Ogallala drainage network that had conveyed Couch fluvial sediments. On the plains, this network is incised into underlying Couch sediments and in places even into pre-Couch bedrock. Voluminous Bridwell gravel, including volcanics from both the Ocate and Raton volcanic fields, filled the incised channels.

Bridwell channel aggradation, like basal Couch deposition, accompanied and was succeeded by eolian sediment influx. Much of the High Plains, especially on valley slopes and uplands, was built by episodic eolian accumulation upon a progressively drier and more geomorphically stable landscape (Gustavson and Winkler, 1988).

Paradoxically, Ogallala plains aggradation was waning as the Southern Rocky Mountains approached peak tectonic activity (Fig. 3.5b). The post-Ogallala Urraca surface was cut during continued epeirogenic uplift of the Coyote Creek area. Urraca and the now relict Ogallala source terrain were subsequently fragmented by high-angle normal faulting and drainage incision. The dual templates of early Pliocene fault structure and precursory Laramide structure guided incision, resulting in the Coyote Creek drainage network.

Ogallala sediments contain no evidence of peak Southern Rocky Mountain tectonism and drainage entrenchment. The late Miocene drainage network which supplied Couch and Bridwell gravel to the Southern High Plains had already been disrupted by the combined effects of epeirogenic uplift and evaporite dissolution within the present Canadian and Pecos River basins (Dolliver, 1984; Gustavson and Finley, 1985).

The contemplation we began at Black Lake concludes with this summation. Fluvial construction of the Southern High Plains started with the shedding of gravelly alluvium off a rising, relict, deeply weathered plain that bore little resemblance to the modern Rocky Mountains. Gravel moved into High Plains paleovalleys during two episodes, generally as a valley bottom accompaniment to more widespread and protracted eolian aggradation. The pre-Coyote landscape ceased contributing to High Plains aggradation some two million years before Coyote Creek began excavating the landscape which we now drive through.

Continue south on NM-434 toward Guadalupita and Mora. **0.3**

8.4 **Cattleguard. 0.2**

8.6 Black Lake at 2:00. **0.4**

9.0 Milepost 25. **0.3**

9.3 Crossing Little Coyote Creek. **0.3**

9.6 Crossing Coyote Creek. **0.1**

9.7 Entrance to Black Lake Resorts. **0.3**

10.0 **Cattleguard.** Road continues on Tv2 basalt. Age of sample from near here is 4.47±0.23 Ma. A local eruptive center for this basalt is a hill about 2 mi southwest of here. **0.7**

10.7 **Cattleguard. 0.6**

11.3 Road begins steep, curving descent into Guadalupita Canyon. **REDUCE SPEED AND USE CAUTION.** High mesa at 12:00 is capped by Pliocene Tv2 basalt. Eruptive centers are just beyond view. Road continues on Tv2 basalt which is faulted down from outcrops on high mesa at 12:00. This fault and Paleozoic rocks beneath the basalt are concealed by colluvium on the east wall of Coyote Creek Canyon. **0.5**

11.8 Roadcuts are in basalt lapilli, tuff and scoria. **0.2**

12.0 Milepost 22. **0.6**

12.6 Road passes southward from basalt to pediment gravel and descends to Coyote Creek. Pliocene basalt to west (3:00) lies mainly on Precambrian quartzite of the core of the Rincon Range. **0.3**

12.9 Crossing Little Blue Creek. **Cattleguard. 0.2**

13.1 Bridge across Coyote Creek. **ROAD AHEAD IS NARROW AND SINUOUS. USE CAUTION. 0.5**

13.6 Slumped Pennsylvanian carbonaceous shale and siltstone in roadcut at 9:00. The lithology suggests that these rocks are equivalent to part of the Sandia Formation. Tv2 basalt on west side of canyon. **0.2**

13.8 The east wall of the canyon is blanketed by colluvium and talus of early Pliocene basalt which probably is underlain by Pennsylvanian rocks. At 9:00, Pennsylvanian shale and fine-grained, micaceous sandstone dip 40–50°E. These rocks probably are equivalent to Sandia Formation. A probable Pliocene-Quaternary fault on the east side of the canyon drops basalt from equivalent flows on high mesa to the east. The main Laramide frontal fault zone between Pennsylvanian rocks and Precambrian quartzite of the Rincon Range is concealed by Tv2 basalt on west side of canyon. **0.2**

14.0 Milepost 20. Bridge across Coyote Creek. **0.5**

14.5 Bridge across Coyote Creek. A sample of basalt from near here is dated 4.7±0.3 Ma (O'Neill and Mehnert, 1988). **0.1**

14.6 Bridge across Coyote Creek. From about here south a little more than 2 mi Coyote Creek is incised in Tv2 basalt. Basalt on east side of the creek lies on Pennsylvanian rocks; basalt on west side lies on Precambrian rocks. **0.5**

15.1 **Cattleguard. 0.6**

15.7 **Cattleguard. 0.3**

16.0 Milepost 18. **0.4**

16.4 Sierra Bonita store and campground. **0.4**

16.8 **Cattleguard. 0.3**

17.1 Entrance to Coyote Creek State Park at 9:00 (Fig. 3.6). Continue south on NM-434 toward Guadalupita. Tv2 basalt flows in Coyote Creek valley end about here. Their original southern extent is unknown, but two remnants of Pliocene basalt occur in valleys farther south along the route of the trip. Tv2 basalt capping the mesa east of Coyote Creek continues far to the south. **0.9**

18.0 Milepost 16. **0.2**

18.2 Road is on bouldery Quaternary fans lying on the Precambrian at the west and Pennsylvanian rocks at the east. Wooded ridges at 9:00 are steeply dipping sandstone, conglomerate, gray shale and a little limestone,

FIGURE 3.6. Coyote Creek State Park.

probably all equivalent to the Sandia Formation. The Laramide frontal fault of the Sangre de Cristo uplift is near and just east of this segment of road (Bachman, 1953). **1.4**

19.6 Our Lady of Guadalupe Church at 3:00. View up the valley at 3:00 shows east-dipping Precambrian quartzites of the Rincon Range flattening upward on a Precambrian and, probably, Laramide anticline.

Near the top of the range Mississippian rocks of the Arroyo Peñasco Group lie on an undulating erosional surface, causing variations of 40–50 ft in thickness of the basal Del Padre Sandstone Member of the Espiritu Santo Formation. The total thickness of the Arroyo Peñasco ranges from 50 to 130 ft (Fig. 3.7). The highest part of the Rincon Range is capped by the Lower and Middle Pennsylvanian Sandia Formation which is nearly flat locally, but dips 15–20°W on the west side of the range.

The alluvial valley at 3:00 is at the southeast end of a northwest-trending fault, dropped down to the southwest, that cuts obliquely across the Rincon Range. The age of faulting is unknown; it could be late Paleozoic, Laramide or Neogene. At 10:00, Pliocene Tv2 basalt is the caprock lying on the Lower Permian Glorieta Sandstone of the western part of the Laramide Las Vegas basin just east of the hogback belt. **0.5**

20.1 Milepost 14, Village of **Guadalupita. SLOW. NARROW ROAD AND LOCAL TRAFFIC. 0.9**

21.0 Small settlement. At 9:00 Coyote Creek cuts east through hogbacks of vertical to overturned Pennsylvanian rocks and flows south in the outcrop belt of the Sangre de Cristo Formation (Bachman, 1953). Sedimentary copper and uranium deposits occur in the Sangre de Cristo Formation in that area (Zeller and Baltz, 1954; Tschanz et al., 1958).

The alluvial valleys from here south are underlain by Precambrian rocks which crop out at places on the east side of the valleys and are in fault contact with vertical to overturned Pennsylvanian beds, mainly the Sandia Formation. These faults, that mark the east margin of the Sangre de Cristo uplift, probably are reverse or thrust faults, as required by the geometry of the overturned beds east of the faults. Farther east, Pennsylvanian rocks

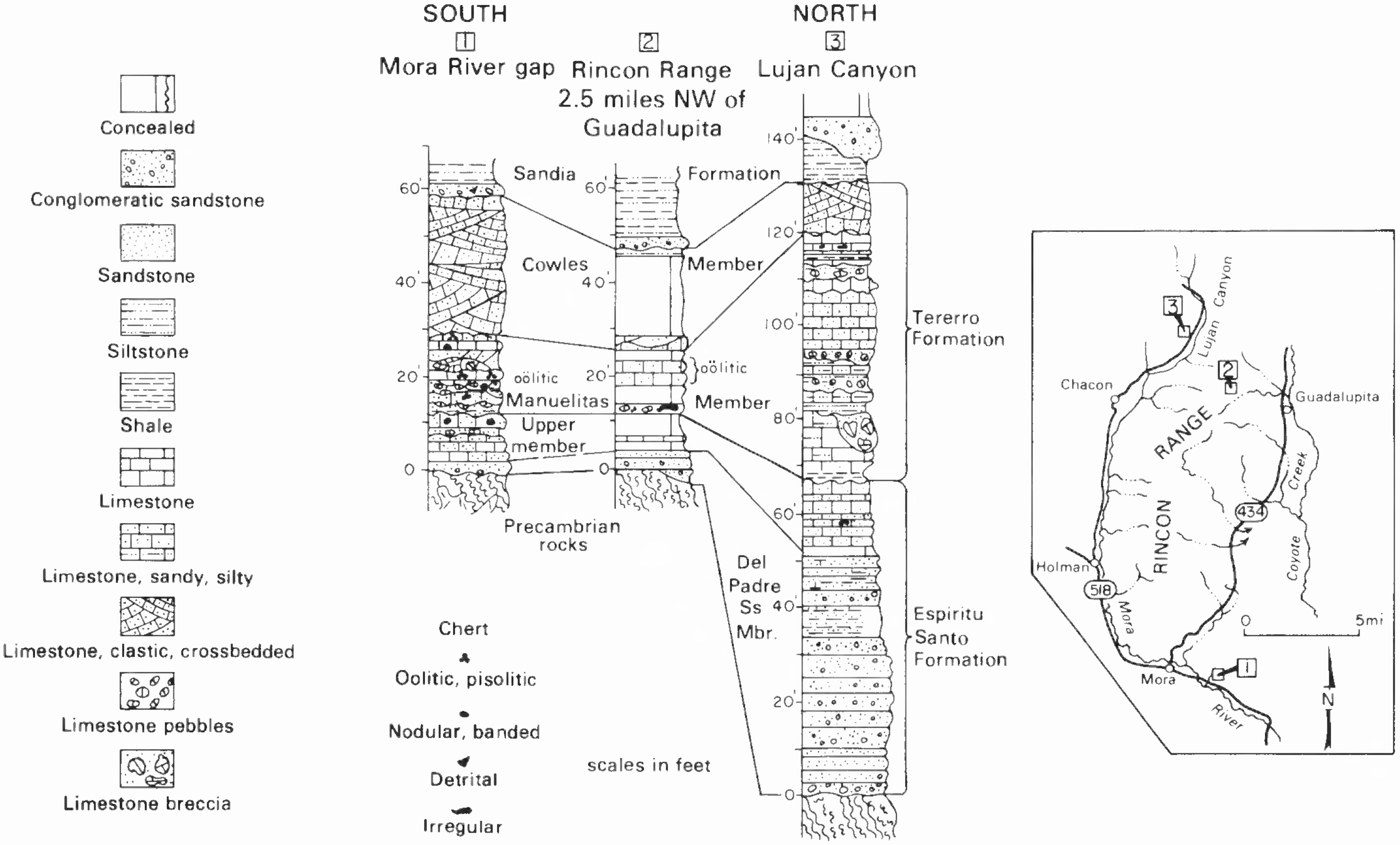


FIGURE 3.7. Sections of Misissippian Arroyo Peñasco Group, Rincon Range and Mora River. Adapted from Baltz (1969, fig. 3).

and the Sangre de Cristo Formation flatten relatively abruptly into the Las Vegas basin.

At 8:00 on the skyline is Cerro Montoso, an eruptive center for Tv2 basalts that cap gently dipping Lower Permian Glorieta Sandstone at the west margin of the Las Vegas basin. Cerro Montoso is a composite volcanic vent that stands more than 600 ft above the surrounding mesa. The cone is composed of alternating layers of scoria, volcanic breccia, and agglomerate and flow-banded andesite. Viscous flows of dacite were emplaced as outward-radiating dikes emanating from the base of the cone during the late stages of eruption. Radiometric age of the basalt at Cerro Montoso is 4.63±0.34 Ma (O'Neill and Mehnert, 1988)

East of Cerro Montosa, olivine basalts, assigned a late Pliocene–early Pleistocene age by O'Neill and Mehnert (1988), have a radiometric age, to the east near Wagon Mound, of 2.2 Ma. These flows are among the most abundant in the volcanic field and were expelled after considerable topographic relief had developed across the region. These flows partly infill the Ocate Valley to the east and cascaded over mesa edges that outlined the valley in latest Pliocene and early Pleistocene time. **2.0**

23.0 Sharp bend to right (west) in road. Road is traversing Quaternary fill on Precambrian rocks. The east-tilted fill probably resulted from Pliocene-Pleistocene down-to-the-west faulting at the east side of the valleys. The probable faults are located near small scarps and are superposed on the Laramide frontal fault zone. **1.1**

24.1 Milepost 10. **0.8**

24.9 View up canyon at 3:00 to top of Rincon Range. Precambrian micaceous quartzites, quartzofeldspathic gneisses and felsites dip east from axis of Precambrian (and Laramide) anticline. **1.2**

26.1 Milepost 8. Ahead, road bends to right (west). Oak-covered hill at roadside (3:00) is basalt lying on Precambrian rocks. The basalt, contaminated with muscovite from the Precambrian, has a radiometric age of 3.89±4.53 Ma (Fig. 3.8). At 8:00 near the east edge of the valley is another patch of Pliocene basalt rising above the alluvium.

At about 8:00, a high-level erosion surface, beveling steeply dipping Pennsylvanian and Permian rocks in the hogbacks, is overlain by nearly horizontal Pliocene basalt flows. The difference in altitude of these basalts and those in the valley to the west is more than 600 ft and demonstrates that young, down-to-the-west faults occur near the east edge of Quaternary deposits of the valley. The faults are not exposed but are marked generally by segments of low fault-line scarps partly masked by late Quaternary fans. The faults generally are in or near the Laramide frontal thrust-fault zone. Displacement of the basaltic rocks also indicates that this valley as well as the present Coyote Creek drainage did not exist in Pliocene time. **0.4**

26.5 View up broad alluvial valley at 3:00 to top of Rincon Range. Mississippian Arroyo Peñasco Group and Lower and Middle Pennsylvanian Sandia Formation cap high part of range. This canyon marks the southeastern part of a northwest-trending fault that cuts obliquely across the Rincon Range and is downthrown to the southwest. As with the fault described at mile 19.6, the time of movement is not known. Road ahead to south traverses local outcrops of Precambrian gneiss and Quaternary bouldery fans derived from Precambrian of Rincon Range. **3.6**

30.1 Milepost 4. **0.3**

30.4 Mouth of Christmas Tree Canyon at 3:00. Continue south on NM-434 which is on a Quaternary boulder fan derived from Precambrian rocks of the Rincon Range. Layered Precambrian metamorphic rocks at 3:00 are

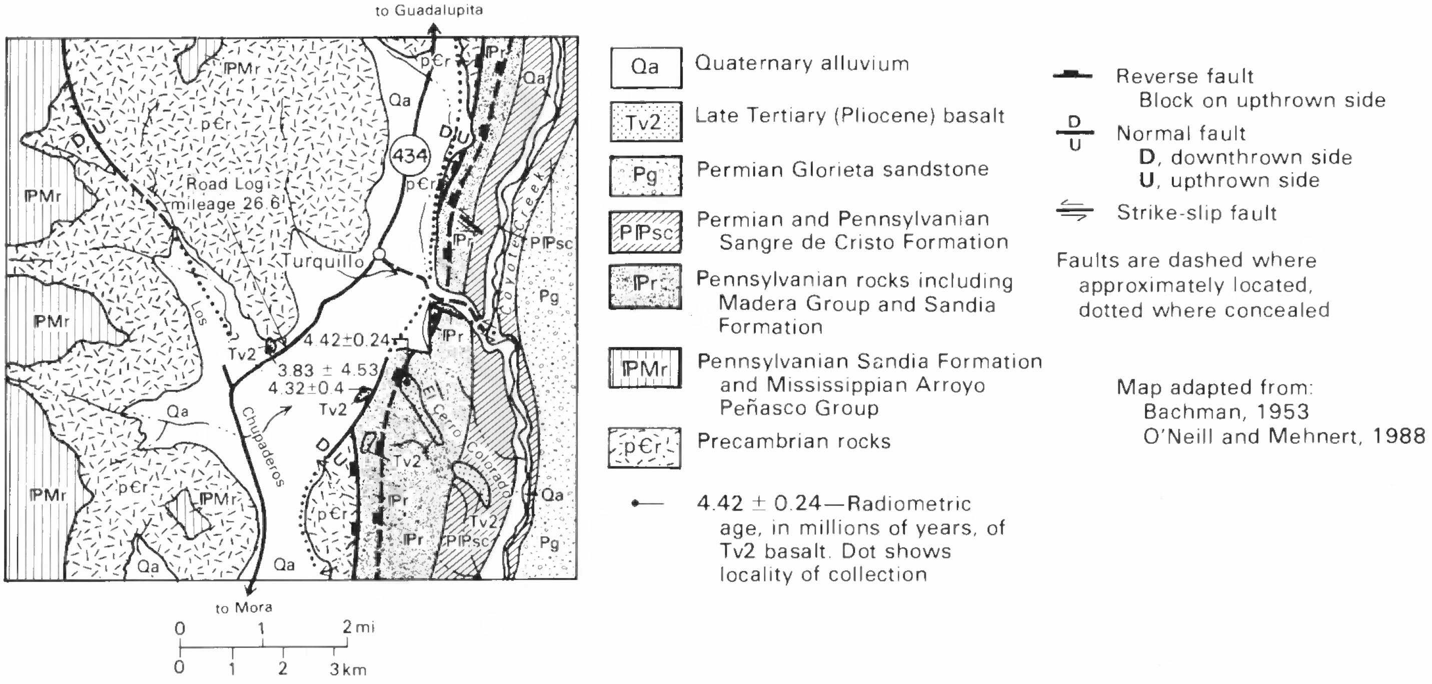


FIGURE 3.8. Geologic map of the Turquillo area near mile 26.1.

nearly horizontal near the crest of the Precambrian Comanche Peak anticline, but are steeply dipping to overturned and west-dipping near NM-434. **1.7**

32.1 Milepost 2. **0.1**

32.2 Road bends to left (east) and passes out of sparse timber cover. View to the south across alluvium-filled Mora Valley. The Mora River is marked by the line of trees and houses of Mora. The river flows on a low fan of Pleistocene and Holocene boulder gravel derived mainly from the Early Proterozoic quartzites of the Hondo Group in the headwaters of Rio la Casa in glaciated parts of the high mountains on the skyline to the southwest (Fig. 3.9). The distal part of the fan is near the east edge of Mora.

Precambrian rocks beneath the Quaternary fill probably are in a Pliocene-Quaternary southeast-tilted half-graben that is a continuation of similar structures to the north. Subtle low scarps in fan deposits near the east side of the valley and near the contact of Quaternary talus and Precambrian rocks of the Romero Hills to the east were interpreted by Baltz and O'Neill (1984) as fault-line scarps largely masked by young slope wash. The displacements are down-to-the-west. The south side of Mora Valley also is bounded by west-northwest-trending down-to-the-north young faults.

Geophysical studies (Mercer and Lappala, 1970) also suggest faulted southern and eastern margins of the valley (Fig. 3.10). The alluvial deposits are at least 320 ft thick near Mora. They are waterlogged, apparently because of subsurface "damming" along a fault, or faults near the west end of Mora River water gap where Quaternary alluvium is only about 30 ft thick. The Romero Hills east of Mora Valley are a northerly trending Precambrian anticline that marks the eastern Laramide margin of the Sangre de Cristo uplift (Fig. 3.11). **1.9**

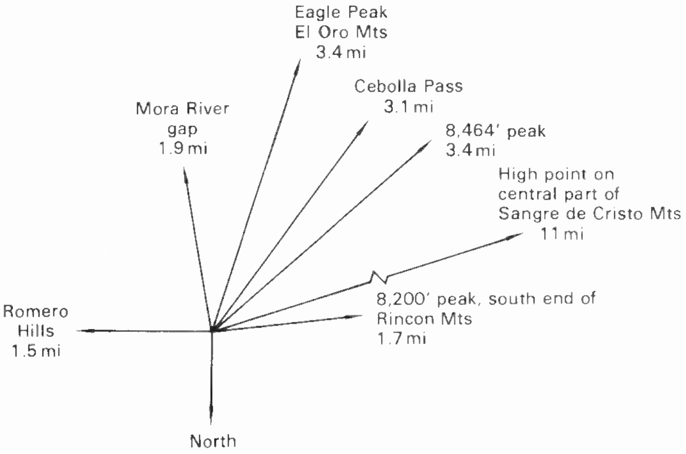


FIGURE 3.9 Panoramic index across Mora Valley southward from near mile 32.9. Explanation for Rosette: Romero Hills—Precambrian rocks at east margin of Sangre de Cristo uplift. West end of Mora River water gap—Precambrian rocks on terrace above Quaternary deposits of Mora Valley. Eagle Peak in El Oro Mountains—the structure of Precambrian rocks is antiformal with a doubly plunging north-northeast-trending axis. Cebolla Pass at west side of El Oro Mountains—cut in Precambrian mica schist, amphibolite and pegmatite on west limb of El Oro anticline. 8464 peak—capped by west-dipping Mississippian Arroyo Peñasco Group and Lower and Middle Pennsylvanian Sandia Formation. High Point (about 12,000 ft) on central part of mountains west of Gascon fault—east face is Early Proterozoic Ortega Formation quartzite which is indented by deep, U-shaped glacial valleys and cirques. Ortega is overlain by patches of Arroyo Peñasco Group and Pennsylvanian rocks. 8200 mountain near south end of Rincon Range—Precambrian quartz-feldspar gneiss, micaceous quartzite and quartz plagioclase gneiss on south-plunging Precambrian Comanche Peak anticline. Highest rocks are west-dipping Arroyo Peñasco Group and Sandia Formation.

34.1 Bridge across Mora River. Stone building at right is the St. Vrain mill (Fig. 3.12), formerly water-powered for grinding wheat and corn raised in the Mora Valley. **0.1**

34.2 **Stop for junction** of NM-434 and NM-518 in Mora. **Turn left** (east) onto NM-518 and traverse eastern part of Mora Valley.

The Mora Valley was frequented by the Spanish in the early 1800's and earlier, but it was dangerous ground visited also by Ute, Apache, Comanche and Kiowa Indians. In 1835, the governor of the Mexican province of New Mexico granted land to 76 settlers who subsequently founded Mora and several nearby communities. The name of the town and the entire grant apparently came from the surname of some of the settlers. The grant comprised much of what is now Mora County.

This area, and other places such as Las Vegas, were colonized partly to protect the borders of the province from Indians and, probably, also because of well-founded fears of incursions of Americans after the 1804 Louisiana Purchase. Military incursions began with the expeditions of Captain Zebulon Pike in 1806 and Major Stephen Long in 1820. After 1821, when the Santa Fe Trail was established, trade with the United States and immigration of American traders and merchants increased rapidly. In 1841, an expedition from the new Republic of Texas attempted, unsuccessfully, to annex Santa Fe.

The military occupation of New Mexico by the United States occurred in 1846. In 1851, Fort Union was established about 16 miles southeast of Mora. The fort did, finally, provide relief from Indian raids and provided employment in the Mora Valley. The fort was the main commissary for other new forts in New Mexico, but it lost importance after the Santa Fe Railroad arrived in 1879, and it was abandoned in 1891. The Mora Valley provided pasturage for Army horses and mules. Lumber for construction at Fort Union and other posts was cut on contract at Mora. The valley was described as "the best wheat-growing area in New Mexico" and the flour was sold to the military. Cerain St. Vrain, a famous mountain man, trader and entrepreneur from St. Louis, by way of northern Colorado (Fort St. Vrain and St. Vrain River) and Taos, settled in Mora and established the water-powered flour mill. St. Vrain died in 1870 and he, various relatives and, presumably, friends were buried on a hill of Precambrian rocks in the valley just south of Mora. Recent proposals to revitalize the economy of Mora include drilling wells to dewater the saturated parts of the valley for agricultural land, and establishing a federal fish hatchery in Mora River gap to the east (Figs. 3.13, 3.14). **1.0**

35.2 At 9:00 in southern Rincon Range, layering in quartz-feldspar gneisses of the Precambrian Comanche Peak anticline (Baltz and O'Neill, 1984) dips steeply east and locally is overturned and dips west. Capping Mississippian and Pennsylvanian rocks dip 10–20°W. East of Mora Valley, on the east flank of Romero Hills, the Paleozoic sedimentary rocks dip 40–70°E. This suggests

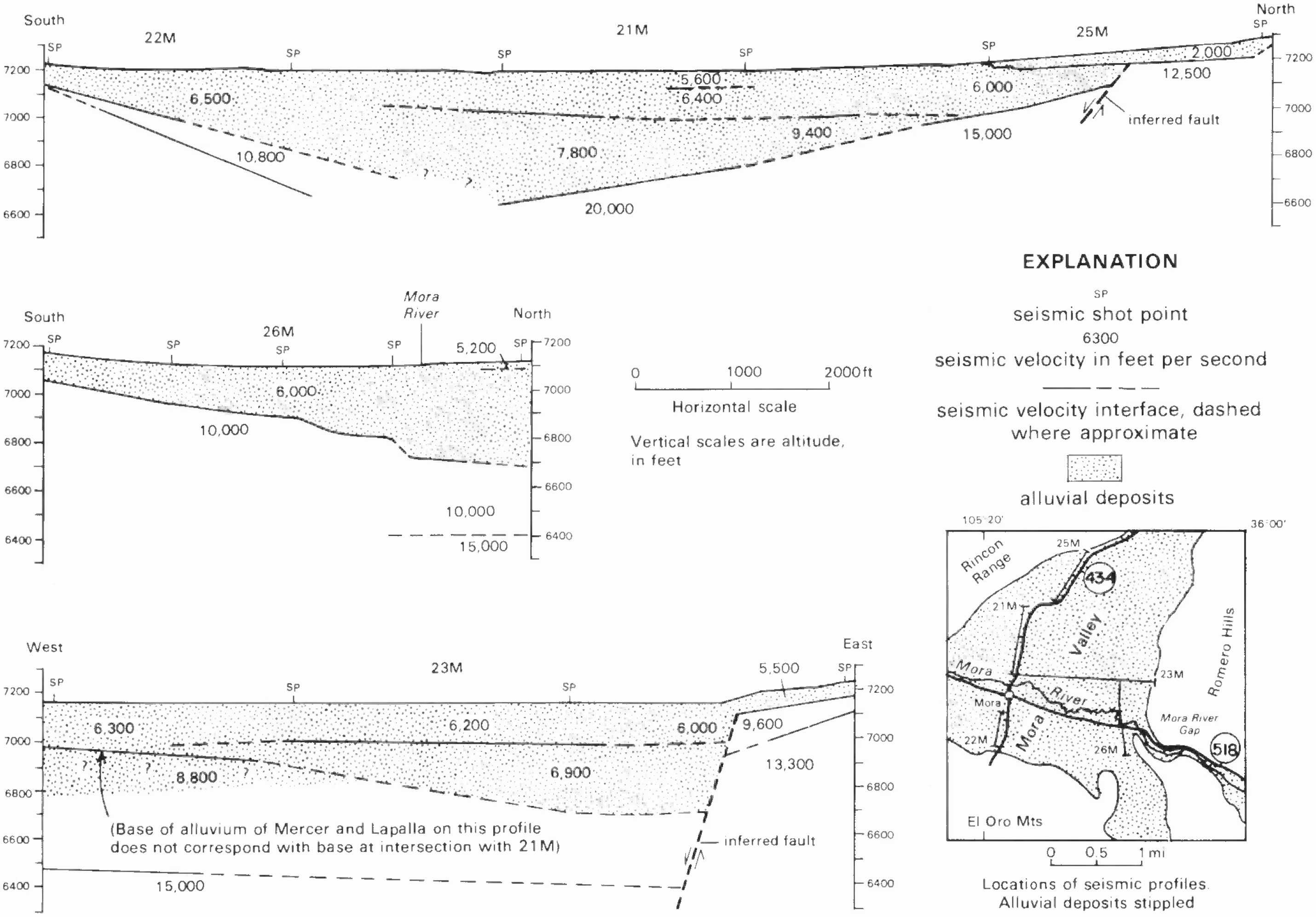


FIGURE 3.10. Seismic-refraction profiles of parts of Mora Valley. Adapted from Mercer and Lappala (1970, figs. 13, 14 and 15). Alluvial deposits lie on Precambrian rocks.

the Mora Valley is a deeply eroded, faulted Laramide anticline, as well as a Pliocene-Quaternary half-graben. At 3:00, mainly concealed down-to-the-north Pliocene-Quaternary faults probably lie beneath Quaternary slope wash near the foot of El Oro Mountains. **0.3**

35.5 Milepost 28. **0.1**

35.6 **STOP 2.** Park on wide shoulder at south side of NM-518 just before roadcut into Precambrian rocks. **BE CAREFUL** at this stop because of narrow shoulders and blind curve on NM-518 which is heavily traveled. Stop is to examine outcrop of amphibolite, gneissic gabbro and pegmatite, all greatly sheared, and to discuss other Precambrian rocks at west end of Mora River gap.

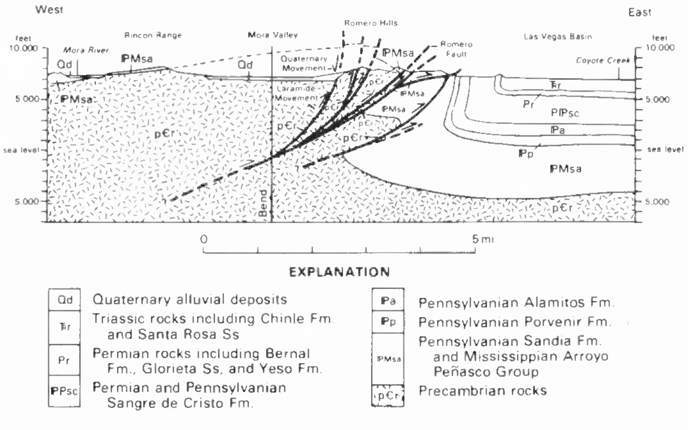


FIGURE 3.11. Cross section from Rincon Range to Las Vegas basin. Line of section is about 1.4 mi north of Mora. Adapted from Baltz and O'Neill (1984, sec. A–A').

Rocks exposed at the west end of the roadcut consist of fine-crystalline, laminated to finely layered amphibolite that locally contains variable amounts of amphibole and probably represents a metasedimentary and metavolcanic rock sequence. These rocks commonly show good linear fabric elements marked by the alignment of prismatic minerals and show abundant, although faint, internal isoclinal folds, best seen at the west end of the exposure. Thin quartzofeldspathic seams in amphibolite are locally isoclinally folded, and foliation cuts directly across fold hinges. Coarsely crystalline, homogeneous layers within this sequence, up to 3 ft in thickness, commonly contain only poorly developed fabric elements and are probably synkinematic gabbroic sills; these rocks are similar to much thicker sills of gneissic gabbro that is gradational into foliated tonalite exposed to the south along the Sapello River.

Amphibolitic rocks in this area are strongly sheared, marked by very finely crystalline, anastomosing shear

FIGURE 3.12. When Cerain St. Vrain moved from Taos to Mora in about 1885 he bought large tracts of land and proceeded to build a flour mill, several sawmills and even a small distillery. The mill, as shown in this view taken in August 1971, was restored by the county and served as a museum. The Hanosh store in Mora was once the St. Vrain hotel. Photo courtesy of Museum of New Mexico. Neg. no. 53360.

zones that locally truncate layering. Shear zones are subparallel to foliation and to axial planes of isoclinal folds.

Quartz-muscovite schist bounds the amphibolite on the east and is characteristic of the micaceous schist of Las Quebraditas (see O'Neill, this volume); schist in this exposure becomes more quartz-rich to the east. Although these rocks dip uniformly west and show well-developed west- to southwest-plunging crenulations, they have also been deformed by northeast-plunging folds and associated axial planar cleavage that verge to the east. These younger folds are unique to this area and probably formed in conjunction with Laramide thrusting of these more easily folded rocks over the Paleozoic cover.

Pegmatites intrude both amphibolite and schist in this area and appear to be of at least two ages. Older pegmatites tend to be thin dikes and sills that appear to have been folded and sheared along with the host rock and are locally boudinaged; the surfaces of these bodies are commonly lineated. The large, thick pegmatites of this area are younger and deformed the host rocks: amphibolite adjacent to these bodies is commonly more coarsely crystalline and much greener due to growth of blue-green hornblende crystals; micaceous schist adjacent to pegmatites commonly shows strong folding that diminishes away from the pegmatite-schist contact.

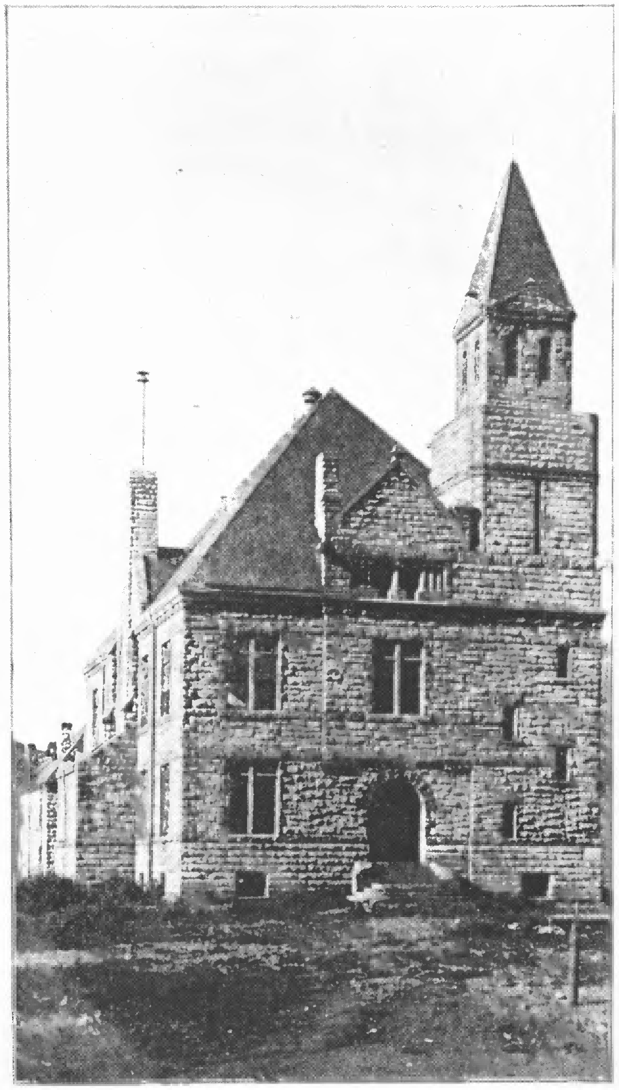


FIGURE 3.13. The Old Mora Courthouse was built in 1889 on land purchased from Cerain St. Vrain for the sum of one dollar. The building was abandoned in about 1939 when a new courthouse was built next door. After a fire in 1960, the building was demolished. Bureau of Immigration Collection. Photo no. 22692. Courtesy New Mexico State Records Center and Archives.

Precambrian rocks of Mora River gap are allochthonous, bounded on the east and west by Laramide reverse and thrust faults. These rocks represent a tectonic sliver that was thrust up and to the northeast. **0.3**

35.9 Bridge across Mora River. Outcrops ahead on both sides of road are quartz-mica schist and interlayered fine-grained quartzite intruded by thick alaskite pegmatite. The schist and quartzite are part of the unit mapped as mica schist and amphibolite of Las Quebraditas by Baltz and O'Neill (1984). **0.6**

36.5 Milepost 27. Outcrops north and south of road are gabbro and amphibolite in the core of a Precambrian anticline in quartz-mica schist. **0.1**

36.6 **STOP 3. Park on right shoulder of road.** The stop to examine structure requires a climb up the hill. The structures here and south of Mora River are shown on Figure

FIGURE 3.14. Street scene in Mora, circa 1916. The town has changed very little in the ensuing 75 years. Collier Collection, album 31989. Courtesy New Mexico State Records Center and Archives.

3.10. At 9:00 the west-dipping Laramide Romero fault, concealed in gully, separates Precambrian gabbro from Mississippian Arroyo Peñasco Group which is overturned and dips 58°NW. The Arroyo Peñasco probably is thrust east against gray shale and sandstone on the west limb of a syncline in the lower part of the Sandia Formation to the east. Upslope, north of the road, the Arroyo Peñasco is overlain by Precambrian rocks and repeated and offset to the east in a fault slice. Near top of hill the gently east-dipping Arroyo Peñasco is repeated again above the main fault (Baltz and O'Neill, 1984).

The Arroyo Peñasco Group, near the top of the hill (Baltz and Read, 1960, p. 1755), is about 60 ft thick. The basal Espiritu Santo Formation is about 12 ft thick. The unconformably overlying Tererro Formation here consists of the Manuelitas and Cowles Members and is about 48 ft thick.

LARAMIDE STRUCTURE AT STOP 3, WESTERN PART OF THE MORA RIVER GAP

Elmer H. Baltz

719 South Lee Court, Lakewood, Colorado 80226

Mora River gap marks a local change from north-northwest to north-northeast in the structural grain of the eastern frontal zone of the Sangre de Cristo uplift (Fig. 3.15). South of Mora River, the eastern uplifted block is a northwest-trending shallow syncline in the lower part of the Sandia Formation. The west limb of the syncline is steeply dipping to overturned, and the Arroyo Peñasco Group and Precambrian rocks are exposed locally on this limb south of the area of Figure 3.15 (Baltz and O'Neill, 1984). The eastern part of the syncline locally is crumpled into sharply folded anticlines and synclines just west of the easterly yielding Guajalote thrust fault whose surface trace is within the Sandia Formation.

East of the Guajalote fault is a plate of north-northwest-trending steeply dipping to overturned, west-dipping rocks of the lower and middle parts of the Sandia Formation that is bounded on the east by the long north-northwest-trending, easterly yielding Sapello reverse fault (Baltz and O'Neill, 1984). Southward, in the hogback belt (south of the area of Fig. 3.15), the Sapello fault cuts across the upper part of the Sandia and throws lower beds of the Sandia against the Middle Pennsylvanian Porvenir Formation.

In the Mora River gap area (Fig. 3.15), the Guajalote and Sapello faults pass northward beneath alluvium in the valley of Mora River, where they may merge (cross section B–B′). North of Mora River this fault zone within the Sandia Formation is not positively identified because of poor exposures and lack of good marker beds in the lower part of the Sandia Formation. About 1800 and 5000 ft north of NM-518, outcrops of overturned and greatly sheared shale of the Sandia may represent the fault zone whose trace is interpreted to be nearly parallel to bedding in the steeply dipping Sandia Formation (Fig. 3.15, cross section A–A′). The fault may die out northward.

Northwest of Mora River and of the projected trace of the Sapello fault, the crumpled anticlinal east limb of the uplifted synclinal block is exposed in roadcuts along NM-518 about 0.3–0.4 mi southeast of Stop 3 of the road log. The axis of the syncline is twisted into a north-northeast trend and has been overriden by Precambrian and Paleozoic rocks above the Romero fault (Fig. 3.15, cross section A–A′).

South of Mora River, in the southwest part of Figure 3.15, a block of the Sandia Formation on the west limb of the synclinal block is twisted into a northeasterly trend and thrust northeast toward the axial part of the syncline (Fig. 3.15, cross section C–C′). The fault is not exposed but is indicated by a nearly 90° divergence of strikes in beds on either side of its mapped trace. This fault in the Sandia extends northward through poor exposures to the south bank of Mora River where it overrides the axis of the synclinal block (Fig. 3.15, cross section B–B′). It may be structurally equivalent to the fault slice beneath the Romero fault north of the river.

The north-northeast-trending Romero fault, from about 1 mi south of Mora River to at least 3 mi north of the river (Baltz and O'Neill, 1984), is the major frontal fault of the Sangre de Cristo uplift. North of Mora River, just west of the fault, the Arroyo Peñasco Group lies in sedimentary contact on Precambrian rocks and is overlain stratigraphically by the lower part of the Sandia Formation. At most places these sedimentary rocks dip east at angles ranging from 25–65°, suggesting that the fault breaks the east limb of a major Laramide anticline whose deeply eroded axial part is in the Mora Valley. North of the area of Figure 3.15 the fault cannot be observed directly because of colluvial cover but is mapped between east-dipping beds of the Sandia and a band of steeply dipping to overturned beds of the Sandia. At places exposures of greatly sheared shale and sandstone probably represent the fault zone.

South of Mora River, at and near the line of cross section C–C′ (Fig. 3.15), the southwestern part of the Romero fault is exposed where Precambrian quartzofeldspathic gneiss is thrown against steeply dipping to overturned beds of the Sandia Formation. Farther south the Sandia Formation, Arroyo Peñasco Group, and Precambrian rocks are repeated twice in imbricate plates beneath the main plate.

North of these outcrops the main trace of the Romero fault and the underlying rocks are offset to the northeast by a right-lateral tear. Steeply dipping slivers of Precambrian, Arroyo Peñasco and Sandia rocks in the erosional window near the west end of the line of cross section B–B′ (Fig. 3.15) are interpreted as imbricate fault slices below the main plate that have been faulted and folded during late stages of movement on the Romero fault and underlying imbricate plates in the Sandia Formation (cross section B–B′). The shortening along the Romero fault and underlying imbrications is 3000–3500 ft, as interpreted on cross section B–B′. However, the amount may be greater or lesser because the thickness of the Sandia Formation in the underlying syncline is unknown and is only estimated from cross sections south of the area of Figure 3.15.

Resume route east on NM-518. **0.1**

36.7 At 9:00 is the approximate axis of a syncline in the lower part of the Sandia Formation. At 3:00 in the bluff south of Mora River the Arroyo Peñasco forms a gray ledge, is overturned, and dips about 40°W. Sandstone ledges at 2:00 are in overturned lower part of Sandia Formation. **0.1**

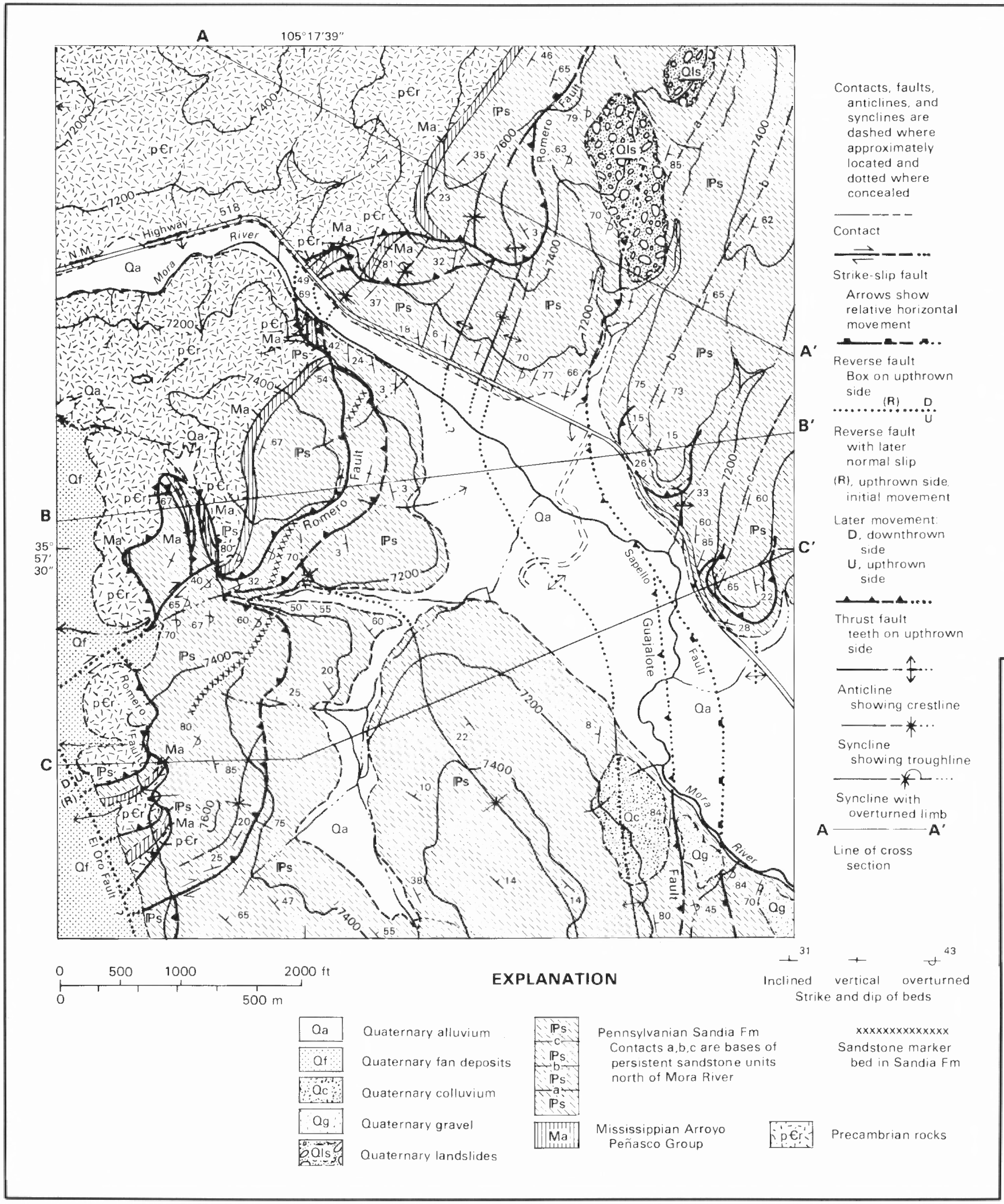
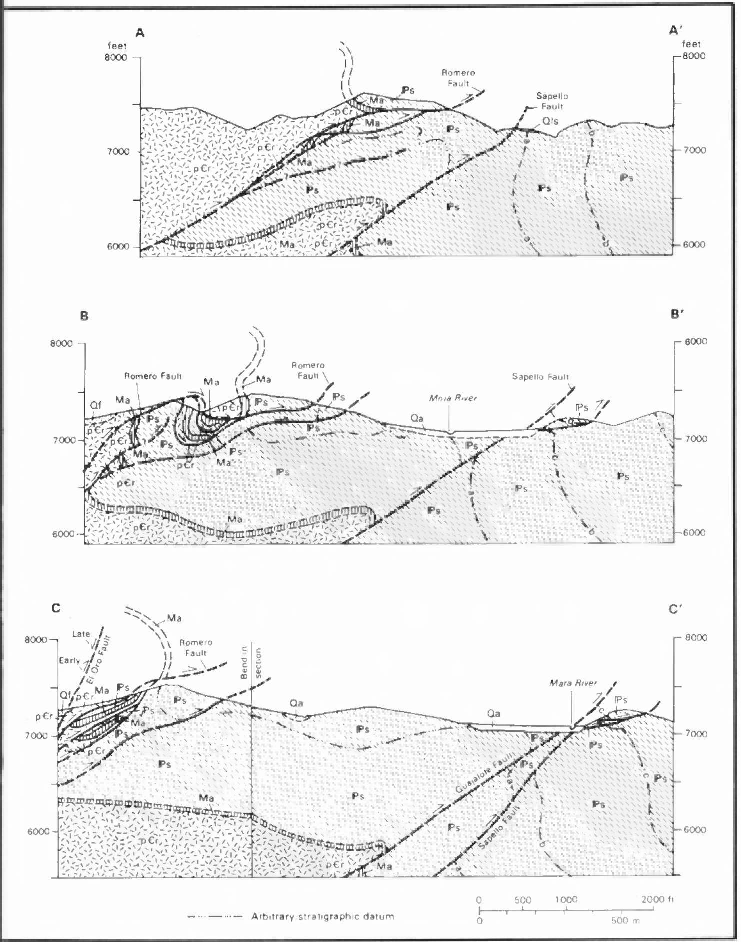


FIGURE 3.15. Geologic map and cross sections of western part of Mora River gap and adjacent area. Mapped by E. H. Baltz, 1976.



36.8 Roadcuts in west-dipping lower part of Sandia Formation. **0.1**

36.9 Outcrops at 9:00 are near crest of an asymmetric anticline. Farther east, the east limb is highly contorted but generally east-dipping beds of lower part of the Sandia. **0.2**

37.1 At 9:00 alluvium in strike valley conceals probable northern part of Guajalote thrust fault. At 2:30 the high hill of beds of the Sandia is the axial part of the same syncline as at mileage 36.7. The east limb is locally crumpled anticline adjacent to the Guajalote fault. At 12:00, sandstone in the bluff north of the highway is underlain by local thrust faults in shale of the Sandia Formation. **0.4**

37.5 **OPTIONAL STOP 4. Park on right** (south shoulder) of highway. **CAREFUL HERE BECAUSE OF HEAVY TRAFFIC.** Stop is to examine outcrop of thick sandstone at 9:00 that lies on gently dipping faults in shale of Sandia Formation. Bedding in the sandstone dips steeply east into the faulted base of the block. Note that the dips become increasingly lower in the eastern part of the block. The depositional environment is not understood. The present structure is interpreted (Fig. 3.15, sec. C–C′) as a splinter of the Sapello fault. Interpretations of this peculiar outcrop are invited.

A composite section of the Sandia Formation is more than 5060 ft thick, with an unknown amount, possibly 600–1000 ft, cut out by the Romero fault. The Sandia was measured 1–1.5 mi north of NM-518 to avoid structural complications near the highway. The lithology of the Sandia is shown in Figure 3.16 and lithologic symbols are explained on Figure 3.17. The lower part contains Morrowan (Early Pennsylvanian) brachiopods. The upper part did not yield identifiable fossils, but farther south it contains late Atokan (Middle Pennsylvanian) fusulinids (Baltz and Myers, 1984, p. B15). At Mora River and elsewhere the overlying Porvenir Formation contains abundant early Desmoinesian (Middle Pennsylvanian) fusulinids. The Amoco No. 1 Salman Ranch A well in the Las Vegas basin several miles east of the front of the mountains (Fig. 3.2) penetrated about 5090 ft of rocks that Baltz correlates with the Sandia, also penetrated the Arroyo Peñasco Group, and bottomed in Precambrian rocks.

At the surface the section (Fig. 3.16) of the Sandia below the "d" sandstone is thick units of gray shale and interbedded thin fossiliferous limestone and thin to thick sandstone. Thin coal beds and carbonaceous shale occur sparingly. The sandstones are quartzose, fine- to very coarse-grained, and there are some pebble conglomerates. Sandstone "c" is the lowest unit in which feldspar is a major constituent (about 10%).

Beginning at about the base of unit "d," the upper 1950 ft of the Sandia contains thick units of gray shale and some interbedded thin fossiliferous limestone, but it also contains fine- to coarse-grained sandstone and pebble conglomerate in units 40–450 ft thick. Many sandstones are highly micaceous. The coarser grained sandstones and conglomerates generally are feldspathic

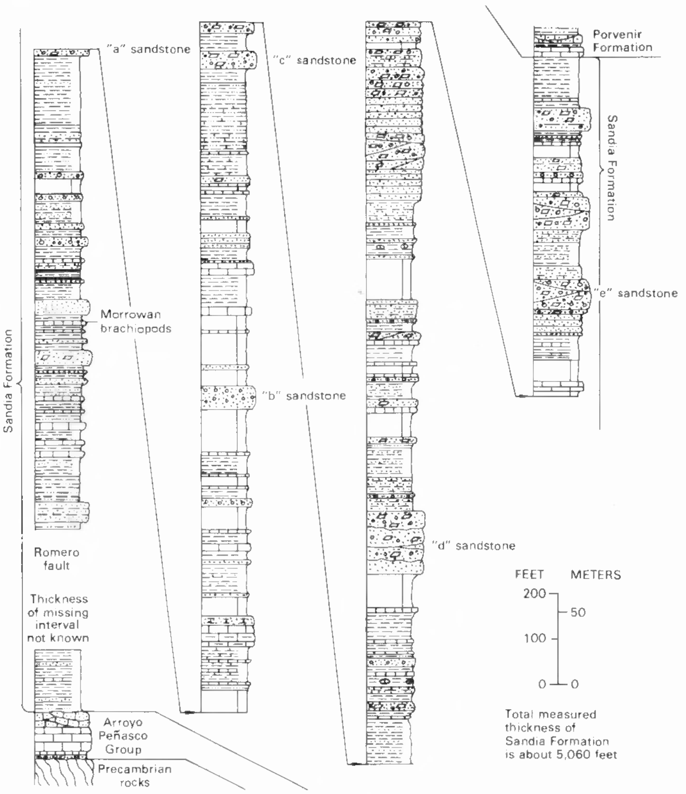


FIGURE 3.16. Composite stratigraphic section of Pennsylvanian Sandia Formation 1.0–1.5 mi north of NM-518 east of Mora. Measured by E. H. Baltz, J. M. O'Neill and M. N. Machette, 1977.

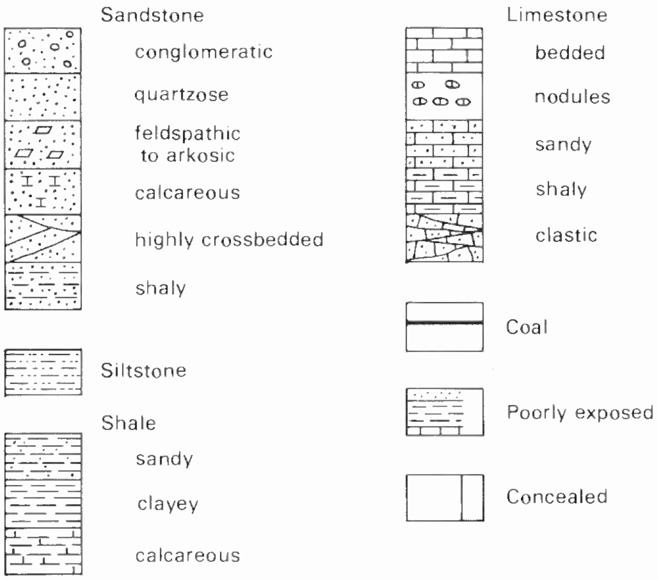


FIGURE 3.17. Explanation of lithologic symbols for stratigraphic sections (Figs. 3.16, 3.18).

to arkosic. Feldspar clasts range from sand size to pebbles, some as much as 1 inch across.

The Sandia, deposited in complex mixed marine and nonmarine environments, includes fan-delta, coastal-plain and offshore shallow-marine deposits of a rapidly subsiding deep part of the Rowe-More basin. The Sandia thins rapidly southward from this area. Less than 6 mi south of Mora River, on the east slopes of Fragoso Ridge south of Rito Cebolla, the Sandia is only 1000 ft thick.

Resume route east on NM-518. **0.4**

37.9 At 9:00 are outcrops of feldspathic to arkosic granule conglomerate and pebbly sandstone near the stratigraphic position of the "e" sandstone of the composite section of the Sandia Formation. **0.1**

38.0 At 9:00 is an alluviated strike valley in the uppermost part of the Sandia Formation. **SLOW FOR STOP AHEAD. 0.1**

38.1 Anticline-syncline pair in Pennsylvanian Porvenir Formation. **0.1**

38.2 **STOP 5. Park on right** (south) shoulder of highway. This stop is to walk through the Porvenir Formation and lower part of the overlying Alamitos Formation.

Rocks exposed at west end of outcrop are just above the base of the Middle Pennsylvanian (Desmoinesian) Porvenir Formation. Basal beds, consisting of interbedded, lenticular, gray limestone and fine-grained sandstone, are exposed on slope of valley just north of outcrop. A stratigraphic section of the Porvenir, measured in these outcrops and on top of bluffs to the east, is shown in Figure 3.18. The Porvenir is mainly shallow marine, but it contains some stream-channel and tidal-flat deposits.

Resume route east on NM-518. **0.1**

38.3 At 9:00 are arkose and green and red shale of basal part of the Alamitos Formation. Arkose here and higher in

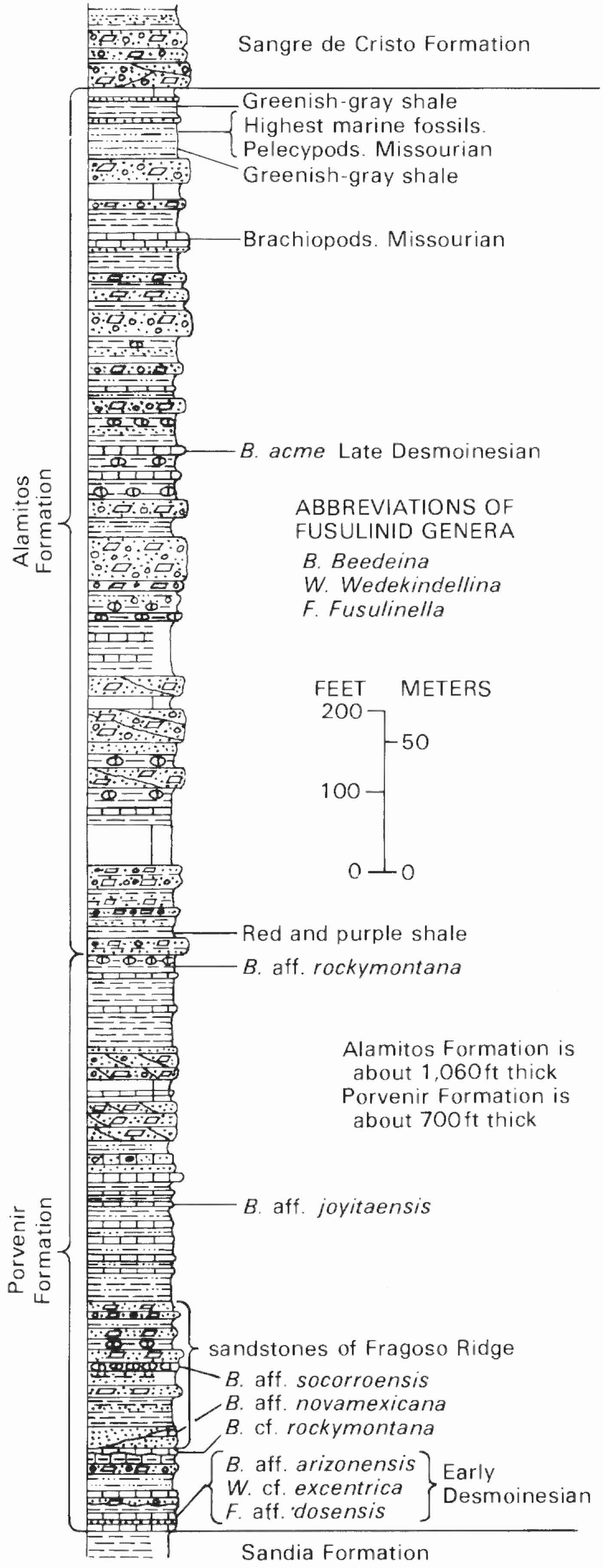


FIGURE 3.18. Stratigraphic section of Pennsylvanian Porvenir and Alamitos Formations exposed along and near NM-518 in Mora River gap east of Mora. Measured by E. H. Baltz and J. M. O'Neill, 1977.

the section contains granules and pebbles, up to 1 inch, of red feldspar and some granules and small pebbles of amphibolite, quartzite and granite. A section of the Alamitos measured in roadcuts and hogbacks to the east is shown in Figure 3.13. The Alamitos contains shallow-marine and nonmarine rocks. The upper contact of the formation is mapped at the top of the highest marine rocks beneath the Sangre de Cristo Formation. The Alamitos here is Middle (uppermost Desmoinesian) and Upper (Missourian) Pennsylvanian. **0.1**

38.4 Thick limestone of Alamitos in roadcuts contains the late Desmoinesian fusulinid *Beedeina acme*. Ahead are more outcrops of red and green shale, some thin limestone and coarse arkose of the Alamitos. **0.05**

38.45 At 9:00, about 600 ft north of highway, quarry exposes brachiopod-bearing Missourian limestone in upper part of Alamitos. **0.05**

38.5 Concealed contact of Alamitos and Sangre de Cristo crosses highway. Highest marine, pelecypod-bearing, grayish-green shale at top of Alamitos is exposed in ranch road in hogbacks at about 9:00. At 10:00–11:00 is east-dipping conglomeratic arkose of the lower part of the Sangre de Cristo. The Sangre de Cristo is 2580 ft thick here. **0.2**

38.7 Greenish shale in roadcut at 9:00 in lower part of Sangre de Cristo contains probable Late Pennsylvanian (Virgilian?) palynomorphs. The slopes, valley and lower part of bluff ahead are on east-dipping, nonmarine Sangre de Cristo Formation. Hogback on skyline is Lower Permian Glorieta Sandstone, underlain by the Lower Permian Yeso Formation which lies on the Sangre de Cristo Formation. **0.4**

39.1 Orangish-red outcrops at 9:00 are Yeso Formation. The Yeso is fine-grained arkosic sandstone and minor amounts of purplish-red siltstone and claystone, all 277 ft thick here. **0.2**

39.3 Hogback of Glorieta Sandstone which is fine- to medium-grained and well sorted. Clasts are well-rounded, slightly frosted quartz. Unit generally is considered marine and is 204 ft thick here. The Lower Permian San Andres Limestone, which overlies the Glorieta in the southern part of the mountains, is absent, having wedged out near Montezuma northwest of Las Vegas. **0.1**

39.4 At 9:00, in strike valley, are poor exposures of red sandstone and shale of the "Bernal Formation." The Bernal is considered to be Permian, though regionally it may be partly Upper Permian and partly Triassic, based on lithologic similarities to rocks of both systems. Bernal is 175 ft thick here. Lucas et al. (this guidebook) assign these rocks to the Moenkopi Formation of Middle Triassic age and suggest that the identification of rocks here as Bernal should be abandoned.

At 9:00–11:00 are east-dipping tan to purplish-red basalt sandstones of the Upper Triassic Santa Rosa Sandstone. Overlying medial beds are shale, thin sandstone and limestone conglomerate; upper unit is limestone-pebble conglomerate and sandstone with interbedded shale. The Santa Rosa is 300 ft thick here. Elsewhere in this guidebook Lucas et al. apply member names to parts of the Santa Rosa. **0.1**

39.5 At 9:00, on hill with stone corrals, is basal part of Upper Triassic Chinle Formation (Bull Canyon Formation of Lucas et al., this guidebook). These rocks are green and red shale, ripple-marked thin sandstone and overlying irregularly bedded stream-channel sandstones. Large adobe building ahead on left is the old La Queva Mill. **0.1**

39.6 **Junction of NM-518 and NM-442. Turn left** (north) onto NM-442 to La Cueva settlement.

The broad valley at the east is a gently folded structural terrace on the west margin of the Las Vegas basin. The valley is surfaced mainly by thin Quaternary deposits lying on the Chinle Formation. Near the base of the high hills southeast of the valley the Middle Jurassic Entrada Sandstone, above the Chinle, forms a light-colored band. The Entrada is overlain by slope-forming Upper Jurassic Morrison Formation, in turn, capped by the Lower Cretaceous Dakota Sandstone on the skyline. See Figure 3.19. About 4 mi south of La Cueva, 10-ft-thick remnants of the Middle Jurassic Todilto Limestone lie on the Entrada and beneath the Morrison just north of Rito Cebolla (Baltz and O'Neill, 1984). Those are the northernmost outcrops of the Todilto currently known in this region.

About 1–2 mi northeast of La Cueva are two large shallow lakes that are supplied with water from the Mora River by the La Cueva canal. The lakes are artificially dammed natural depressions which probably resulted mainly from Quaternary wind deflation, as suggested

Age	Formation	Lithology	Thickness
Early and Early(?) Cretaceous	Dakota Sandstone	Upper part—Sandstone, tan and brown, fine- to medium-grained. Bedding thin and parallel. Contains thin interbeds of gray claystone. About 20 ft thick.	About 170 ft at Mora River 3 mi south of La Cueva
		Middle part—Claystone, gray; contains carbonized-plant fragments. About 11 ft thick.	
		Lower part—Sandstone, light-tan, coarse- to very coarse-grained. Conglomeratic; contains lenses of quartz, chert, and greenish claystone pebbles. Irregular bedding and crossbedding. Contains thin lenses of greenish claystone. About 140 ft thick. Channeled unconformity at base.	
Late Jurassic	Morrison Formation	Upper part—Mainly greenish siltstone and claystone. Near top, contains two 30-ft-thick, gray to tan, fine- to coarse-grained sandstones. Lower part contains thin sandstone beds and jasper-bearing limestone nodules. About 190 ft thick.	About 340 ft in hills SE of La Cueva. Thicker to the south
		Middle part—Sandstones, pinkish-gray to reddish-brown, and mudstones, brownish-red to purplish-red. Sandstones are fine- to medium-grained, subparallel bedded to crossbedded, and 5–25 ft thick. Unit is about 100 ft thick.	
		Lower part—Claystone, red, purple, green, and brown, thin bedded. Contains thin interbeds of limestone, bentonite, and fine-grained white sandstone. Red botryoidal jasper abundant in limestone. About 50 ft thick.	
Middle Jurassic	Entrada Sandstone	Sandstone, buff to light-orange, medium-grained, well-sorted. Upper 15 ft is subparallel bedded. Lower part contains several units whose crossbeds and inclined laminae dip in different directions.	80 ft SE of La Cueva
Late Triassic	Chinle Formation	Upper member—Mudstone and claystone, red, and subordinate thin sandstones and concretionary limestones. Sandstone near base contains limestone pebbles. 450–500 ft thick.	About 1030 ft at Sapello River 11½ mi south of La Cueva
		Middle member—Three sandstone units separated by red mudstones. Upper sandstone is red, fine- to medium-grained, soft. Middle sandstone is brown, medium- to coarse-grained. Basal sandstone is gray-brown and contains limestone pebbles. Unit is 130–150 ft thick.	
		Lower member—Mudstone and claystone, red, and subordinate thin, fine-grained sandstones and concretionary limestone lenses. Near base are ledge-forming, lenticular, stream-channel sandstones. About 450 ft thick.	

FIGURE 3.19. Description of Triassic, Jurassic and Lower Cretaceous rocks exposed southeast of La Cueva. Adapted mainly from Baltz and O'Neill (1984).

LA CUEVA MILL

THIS MILL WAS BUILT IN THE 1870'S BY VICENTE ROMERO.
IN 1851 HE ESTABLISHED THE LA CUEVA RANCH BY PURCHASING
LAND FROM SEVERAL GRANTEES OF THE MORA LAND GRANT WHICH
HAD BEEN CONCEDED BY GOVERNOR ALBINO PEREZ IN 1835.
ACCORDING TO LEGEND VICENTE ROMERO SLEPT IN CAVES WHILE
TENDING HIS SHEEP THUS THE NAME LA CUEVA.
FLOUR WAS GROUND AND ELECTRICITY WAS GENERATED BY THE
MILL UNTIL 1949.

PROPERTY OF WILLIAM SALMAN RANCH

FIGURE 3.20. Sign at La Cueva Mill.

FIGURE 3.21. Waterwheel at La Cueva Mill. Photo by R. M. Colpitts.

by loess-like low deposits on their eastern margins (Baltz and O'Neill, 1984). **0.1**

39.7 Old mill and mercantile building at La Cueva (Figs. 3.20, 3.21). **0.1**

39.8 More adobe ruins on left. **0.1**

39.9 Turn on dirt road to right which leads to old church. **Retrace route south** on NM-442 to junction with NM-518. **0.4**

40.3 **Junction** of NM-442 and NM-518. **Turn right** (west) onto NM-518 and retrace route to west end of Mora River gap. **3.7**

44.0 Bridge across Mora River and westernmost outcrops of Precambrian. **0.3**

44.3 **Junction** of NM-518 and unpaved, unmarked county road leading south. **Turn left** (south) onto county road and cross cattleguard. Most of the route south to Rociada Valley is on Quaternary sediments lying on the Early Proterozoic mica schist and amphibolite of Las Quebraditas (Baltz and O'Neill, 1984, 1986; O'Neill, this guidebook). These rocks are poorly exposed in this part of the Mora Valley. At 1:00–3:00, the high hills are the northeastern part of El Oro Mountains, carved in the core of an elongate, northeast-trending, doubly plunging Precambrian antiform interpreted to be a gneiss dome by Budding and Cepeda (1979) or as an upright, southeast-verging anticline with a migmatitic core by Blatz and O'Neill (1984). On the east flank, foliation and layering are overturned and dip steeply in westerly directions. These rocks consist mainly of quartzofeldspathic gneiss, migmatitic in the lower part, becoming finer grained and more leucocratic upward. The lower part of the section in the core is interlayered with micaceous quartzite whereas the upper part of the sequence contains minor interlayered mica schist. All rocks in this sequence thin to the south. The southward thinning of these rocks is in part tectonic, but may also be due to a Precambrian erosional unconformity between the quartzofeldspathic gneiss and the overlying mica schist and amphibolite.

The Precambrian on the west limb of El Oro anticline is overlain with sharp angular unconformity by the Arroyo Peñasco Group, in turn, overlain by the Sandia Formation. The Paleozoic rocks dip 10–15°W into a Laramide syncline which is a continuation of the west limb of the Rincon Range uplift north of Mora. **0.5**

44.8 Ridge at 2:00 in middleground is thick, highly micaceous, alaskite pegmatite intruded in quartz-mica schist of Las Quebraditas. For several years the mica was mined for use in Christmas tree ornaments. **0.4**

45.2 At 9:00 in gap, Precambrian rocks are exposed on the upper plate of the Romero fault which disappears beneath Quaternary sediments farther south. At 10:00–11:00 the hills are mainly overturned, west-dipping Sandia Formation. The east-dipping to overturned Arroyo Peñasco Group lies on Precambrian rocks just east of the valley edge.

Low, relatively straight scarplets or changes in slope about the tree line on the east edge of the valley probably are Pliocene-Quaternary fault-line scarps marking the concealed down-to-the-west El Oro fault. The displacement here is much less than in the Mora Valley. The west side of the valley is not faulted. The overturned Laramide structures east of the valley suggest the El Oro fault originally was a Laramide reverse fault marking a continuing south-southeast trend of the zone of displacement of the Romero fault. **0.9**

46.1 Crest of drainage divide. The closed drainage basin at 9:00 may be result of wind deflation. Ridges at 3:00 are vertical to overturned orange-tan quartzofeldspar gneiss and interlayered mica schist on east flank of core of El Oro anticline. **1.0**

47.1 Bridge across upper drainage of La Cañada del Guajalote. Hills at 10:00 are quartzofeldspathic gneiss of Rociada overlain by overturned Arroyo Peñasco Group and lower part of the Sandia Formation all thrust east over younger beds of the Sandia. At 11:00, high ridge of quartzofeldspathic gneiss overrides west limb of a syncline in the Sandia. This thrust continues several miles south to near Rito Cebolla where it is offset several thousand feet by three northeast-trending right-lateral wrench faults (Baltz and O'Neill, 1984).

At 10:30 near east edge of valley, a gully in Quaternary sediments exposes El Oro fault which dips about 45°NW. Precambrian rocks of the footwall are polished and striated. Quaternary old fan deposits are in contact with Precambrian, but polishing probably occurred during Laramide thrusting. South of here, Pliocene-Quaternary faulting dies out locally, and Precambrian rocks of the southeast limb of El Oro anticline are exposed across much of the valley. **0.8**

47.9 Bend in road. At 3:00 valley and slopes are underlain by the lower quartz-mica schist unit of Las Quebraditas.

At 11:30–2:00 the hills are underlain by the medial amphibolite unit of Las Quebraditas. Farther southeast, out of view, minor chlorite schist and an upper quartz-mica schist unit are exposed. All these rocks dip steeply northwest on the southeast limb of El Oro anticline and are intruded by long northeast-trending alaskite pegmatites. **0.4**

48.3 Crest of drainage divide. Road descends into valley of Rito Cebolla. Scant outcrops along road are eroded, reddish, Quaternary old fan deposits lying on Precambrian. **0.6**

48.9 Small village. At 2:30 on the distant skyline is Hamilton Mesa in the central part of the mountains. The flat surface approximates the Precambrian-Mississippian contact. The Precambrian is mainly the Early Proterozoic Ortega Formation quartzite which is raised along the north-northeast-trending Gascon fault. Here the vertical separation of top of Precambrian on the fault is about 5000 ft. Some exposures indicate the fault is west-dipping reverse.

Hill at 1:00–2:00 is quartzofeldspathic gneiss and interlayered micaceous quartzite of the lowermost sequence exposed in the core of the El Oro anticline which plunges gently southwest. The Precambrian is overlain nonconformably by the Arroyo Peñasco Group and the Sandia Formation which dip gently west into a Laramide syncline whose west limb is broken by the Gascon fault. **0.3**

49.2 **Junction** with road to North Carmen. **Continue south** toward Rito Cebolla. **0.6**

49.8 Bridge across Rito Cebolla. Outcrops of Precambrian in the valley indicate eroded Quaternary sediments are thin, although young down-to-west normal faults occur at the foot of ridges at the east. The upper (western) part of Cebolla Valley is choked by Quaternary gravels derived from the Ortega Formation in glacial cirques and valleys on the face east of Hamilton Mesa.

At 9:00–11:00 the ridges are Sandia and Porvenir Formations on a south-plunging anticline and syncline. At the east side of the valley locally exposed Proterozoic rocks are in thrust contact with both Pennsylvanian formations in the Quebraditas fault zone which persists south to the Rociada Valley. **0.6**

50.4 Poor exposures in roadcuts are reddish Quaternary old fan deposits containing greatly weathered broken clasts of Proterozoic rocks. Ahead, these deposits lie on pegmatite and amphibolite of Las Quebraditas on the hill in the middle of the valley. **0.3**

50.7 **Junction** of county road and paved NM-94. **Continue south** on NM-94 and enter Las Quebraditas Valley. Poor outcrops in roadcuts are reddish Quaternary old fan deposits and medial fan deposits. **0.3**

51.0 At 9:00, hill is held up by amphibolite and minor quartzite of Las Quebraditas, thrust eastward against Sandia and Porvenir Formations in the SW-trending Quebraditas fault zone which includes both Laramide thrusts and superposed Pliocene-Quaternary down-to-the-west normal faults.

Hills at 1:00–3:00 near road are steeply SE-dipping, lowermost amphibolite and mica schist of Las Quebraditas, all intruded by thick northeast-trending pegmatite sills and dikes. Higher hills are the quartzofeldspathic gneiss core of the El Oro anticline. Precambrian rocks are capped by Arroyo Peñasco and Sandia that dip gently west. **1.4**

52.4 Road bends right near houses. At 9:00 in lower part of hill Precambrian amphibolite and pegmatite are thrust eastward across overturned beds of the Sandia which, in turn, are thrust across overturned lower part of Porvenir (Fig. 3.22). The next exposures of Precambrian rocks in the Quebraditas fault zone are 1.8 mi to the southwest.

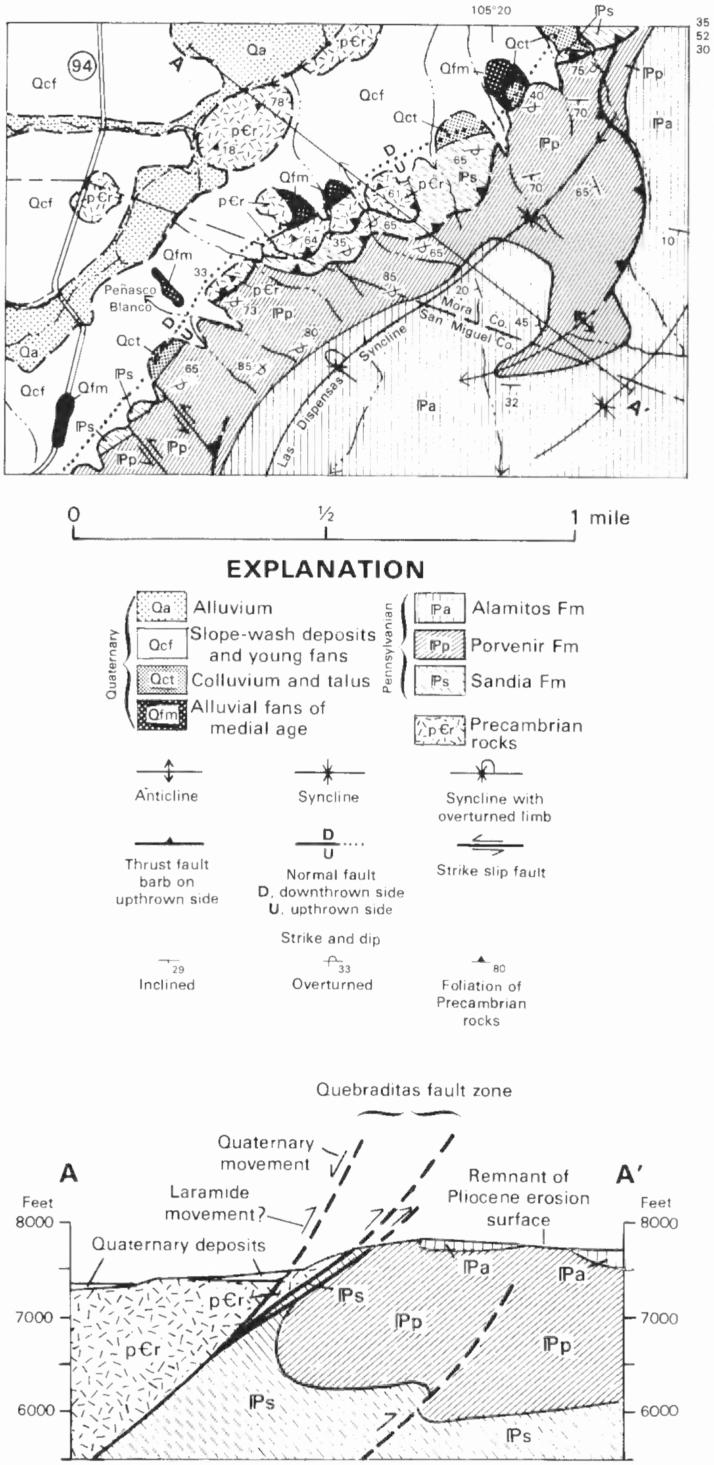


FIGURE 3.22. Map and cross sections of Quebraditas fault zone, east side of Las Quebraditas Valley east of mile 52.4. Adapted from Baltz and O'Neill (1986).

Low hills in Las Quebraditas Valley are outcrops of thick, upper amphibolite of the Quebraditas sequence. At 9:00–1:30 the ridge on the skyline is vertical to overturned beds of the Sandia and Porvenir Formations east of the Quebraditas fault zone. These rocks are beveled by a relatively flat, east-sloping erosion surface on which are a few thin patches of gravel of Precambrian clasts. This surface is part of a formerly widespread Pliocene(?) pediment that is older than the Pliocene-Quaternary faulting in the Quebraditas zone. The western part of the surface lies on Precambrian rocks beneath Quaternary fans in the valley. The young structure is a southeast-tilted half-graben. **0.8**

53.2 **Junction** of NM-94 and NM-105. **Turn sharp right** and continue southwest on NM-105 toward Rociada. Road is on thin Quaternary slope-wash deposits lying on Quaternary medial-fan deposits of the half-graben.

From here southwest for about 3 mi, a nearly straight line of discontinuous low scarplets occurs on bedrock near the tree line at the base of the ridge east of the valley. These may be parts of a fault-line scarp from a late stage of Quaternary down-to-west faulting. The line of scarplets is incised and segmented by small canyons. Young fans from the canyons coalesce at the east edge of the valley and partly bury the scarplets. **0.8**

54.0 At 3:00 the hills are mainly the upper amphibolite of the Las Quebraditas sequence. This dense, dark-gray to black amphibolite is unique in this area in that it is interlayered with dark-gray to purple magnetite-bearing quartzite. These amphibolites are interpreted to have been mafic volcanic flows; the associated magnetite-bearing quartzites may represent poorly developed oxide facies of iron-formation formed by exhalative submarine volcanic activity. Foliation and layering in these rocks dip 30–50°S on the southwest limb of El Oro anticline. The Precambrian rocks are overlain by the Arroyo Peñasco Group; the Sandia Formation caps highest part of hill. The Paleozoic rocks continue to dip gently northwest into a Laramide syncline.

At 2:30 the isolated peak is a remnant of Paleozoic rocks lying on micaceous quartzites and sills of gneissic gabbro in the lower part of the metamorphic rocks of Rociada; these rocks lie above (south of) the Las Quebraditas sequence (see Baltz and O'Neill, 1986; O'Neill, this guidebook). Foliation and layering of Rociada rocks dip 45–60°S. **0.9**

54.9 West end of seismic refraction profile RT3 (Fig. 3.23). East end is at Precambrian fault slice at east edge of valley. **0.8**

GRAVITY AND MAGNETIC ANOMALIES IN THE TAOS–EAGLE NEST–MORA AREA

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Regional gravity and magnetic anomalies in the area targeted by this volume and field trip were discussed by Cordell and Keller (1984). Since that time, we have been able to add a small amount of gravity data in the area. The aeromagnetic survey coverage in the area is good and has not been augmented since it was compiled by Cordell (1984). It consists of survey with east-west flight lines spaced 1 mile apart

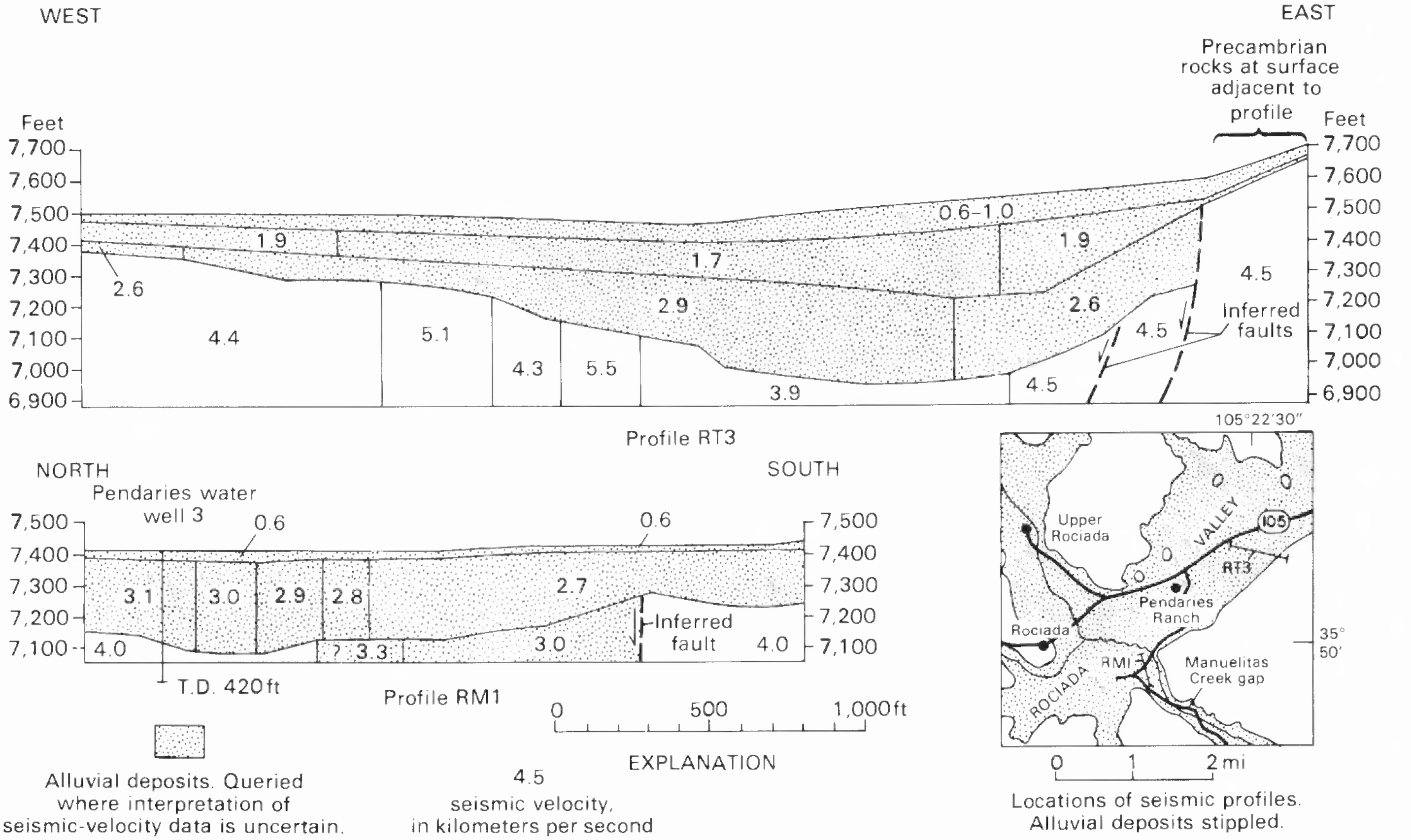


FIGURE 3.23. Seismic refraction profiles in parts of Rociada Valley. Adapted from unpublished profiles by L. W. Pankratz, USGS, 1982. Unpatterned parts are mainly or entirely Precambrian rocks.

flown at various times by the U.S. Geological Survey. The elevation of these surveys varied with the topography, but the survey parameters (see Cordell, 1984) did not vary so much as to produce major artifacts in the data. The purpose of this study is primarily to present more detailed gravity and aeromagnetic maps of the Taos–Eagle Nest–Mora area than were presented in 1984. We will make a few subjective comments, but our main goal is to provide geophysical maps to enhance the geologic discussion of the area. Maps of the entire state of New Mexico were compiled by Cordell (1984) and Keller and Cordell (1984).

The techniques used to process the gravity and aeromagnetic data are routine and are described in Cordell et al. (1982), and Cordell (1984), respectively. A Bouguer anomaly gravity map is presented in Figure 3.24 and a residual total-magnetic intensity map is presented in Figure 3.25. County lines and outlines of Precambrian outcrops are provided to make location of anomalies easier so that individuals familiar with the geology of the area can make their own interpretations.

As noted by Cordell and Keller (1984), the big surprise is the lack of linear gravity highs associated with much of the Precambrian terrane in northern New Mexico. North of Mora the gravity low associated with the Raton basin seems to extend westward beneath Precambrian exposures. The boundary between this basin and the Precambrian exposures is generally thought to be a high-angle reverse fault (e.g., Grose, 1972). Fortuitously located blocks of low density material could certainly produce this gravity low, but low-angle thrusting of the Precambrian over the Raton basin seems to be a real possibility. The thrusting would be Laramide in age but could also result in Precambrian overlying Paleozoic sedimentary rocks in some areas. In fact, none of the Taos–Eagle Nest–Mora area is associated with the expected linear gravity maxima. A magnetic low also occupies this area (Fig. 3.25) but may, at least in part, be due to Precambrian rocks (Quartizites?) with low magnetic susceptibility (Cordell and Keller, 1984). The gravity data suggest that large portions of the Sangre de Cristo could be allochthonous well into Colorado.

Numerous other anomalies are present but beyond the scope of this brief discussion. In particular, the magnetic map (Fig. 3.25) also shows the influence of northeast trends which are probably the result of features within the Precambrian crystalline basement and the western portion of the gravity map is dominated by the north-south-trending features of the Rio Grande rift. Northwest-trending anomalies are prominent farther east in New Mexico (Suleiman and Keller, 1985) and are associated with the southern Oklahoma aulacogen. These are broken up as they cross the Sangre de Cristo Mountains but reappear west of the Rio Grande rift.

55.7 Good view of Rociada Valley ahead. **0.3**

60.0 Entrance to Pendaries village. **Turn left** from NM-105 and follow road through village eastward. **0.3**

60.3 **Cattleguard. Park for STOP 6.** Stop is to discuss Precambrian rocks, Laramide structure and southern termination of Pliocene-Quaternary faulting. Figure 3.26 locates various geographic and geologic features. The geology of the southern part of Rociada Valley is shown on Figure 3.27.

The Rociada Valley and west end of Manuelitas Creek gap are at a change in directions of the Laramide structural grain (Fig. 3.26) from the north-northeast trend of Thunder Ranch fault and, farther south, the north-northwest trend of the Hermit's Peak fault. The Thunder Ranch fault originated as a Laramide thrust breaking the east limb of an asymmetric anticline (section B–B′, Fig. 3.27). The southernmost Pliocene-Quaternary faults are superposed on the thrust and die out to the south at Sapello River. The broad west limb of the Laramide anticline is tilted west into the Beaver Creek syncline whose west limb is overridden by the east-yielding Harvey thrust (Fig. 3.28) about 6 mi southwest of Stop 6.

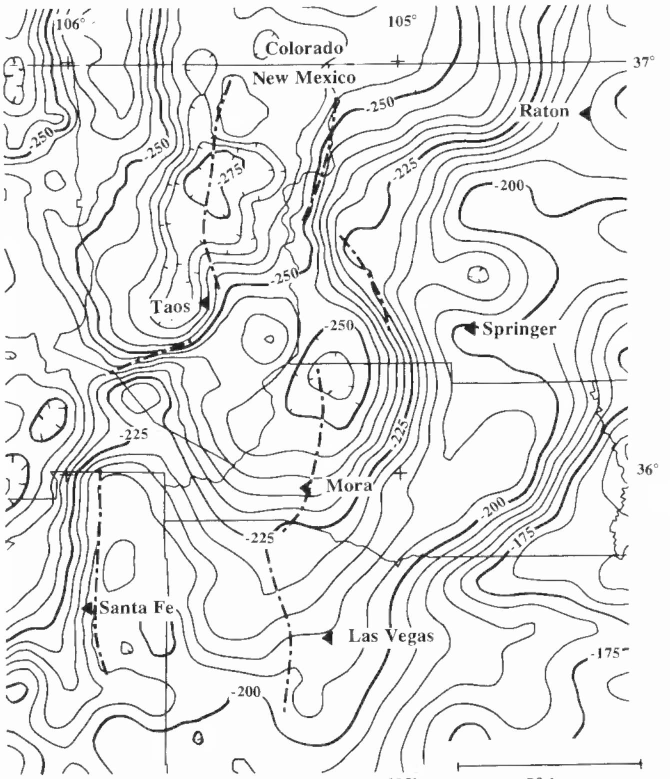


FIGURE 3.24. Bouguer gravity anomaly map. Contour interval—5 milligals. Sea-level datum. Reduction density—2.67 g/cc. The generalized eastern and western limits of Precambrian exposures are shown as dashed lines.

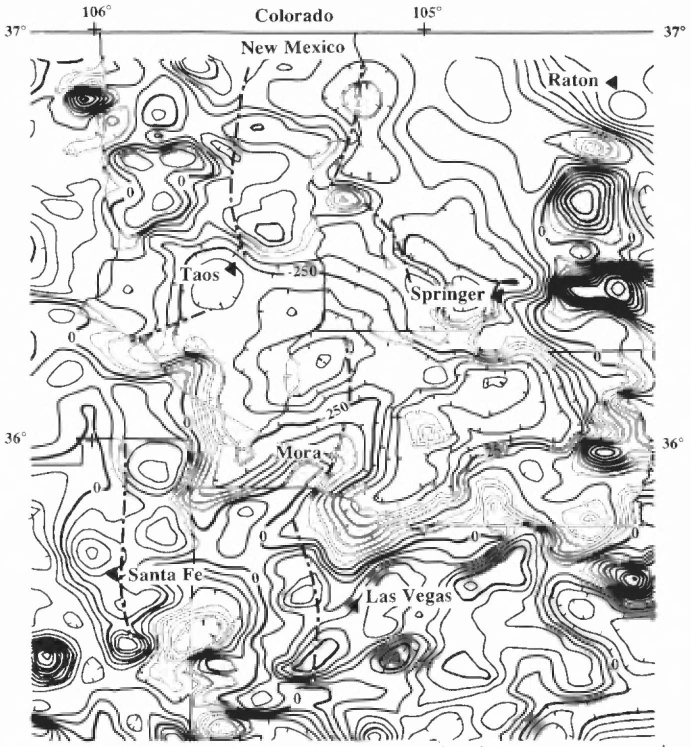


FIGURE 3.25. Residual total-magnetic intensity map. Contour interval—50 gammas. See Cordell (1984) for individual survey boundaries and specifications. The generalized eastern and western limits of Precambrian exposures are shown as dashed lines.

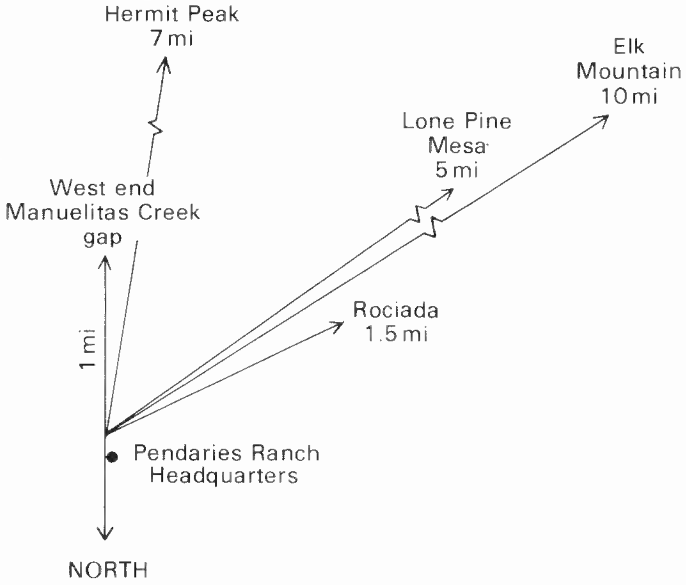


FIGURE 3.26. Panoramic index across Rociada Valley southward from Pendaries Ranch headquarters near Stop 6. Explanation for figure: **Manuelitas Creek gap**—Rociada micaceous quartzite forms bluffs and is overlain by southeast-dipping Arroyo Peñasco Group and Sandia Formation. Type locality of Manuelitas Member of Tererro Formation of Arroyo Peñasco Group (Baltz and Read, 1960). To southeast out of view, on the north wall of the gap, the Arroyo Peñasco is about 95 ft thick, the Sandia is 1030 ft thick, the Porvenir is 1615 ft thick and the Alamitos is 1830 ft thick. **Hermit's Peak**—gneissic rocks of Rociada and granite of Hermit's Peak capped by remnants of west-tilted Arroyo Peñasco Group and Sandia Formation. Gneissic rocks of Rociada that hold up the peak were intruded by postkinematic granite of Hermit's Peak that is extensively exposed on the north-facing slopes. Numerous small granite pegmatites, related to the intrusion and injected into the host rocks, were associated with strong alkali metasomatism that altered the host rocks in an aureole surrounding the granite. The irregular contact formed at this time between metasomatized quartzofeldspathic gneiss and less altered micaceous quartzite cuts across metamorphic compositional and premetamorphic lithologic layering; the contact is present as far north as Rociada and is located in the low ridges directly to the west.

The low, tree-covered, east-trending ridge in the foreground, south of the alluvial valley, is held up by quartzofeldspathic gneiss of Rociada that was complexly intruded by synkinematic mafic to tonalitic rocks. Numerous sills and irregular dikes of gabbro and tonalite are present in these low hills. A small noritic gabbro plug is exposed along the ridge crest just east of the contact of the Precambrian rocks with the overlying Paleozoic sequence. **Lone Pine Mesa**—Precambrian is overlain by Arroyo Peñasco, Sandia and Porvenir rocks, all dipping west into Laramide-age Beaver Creek syncline. West limb of this syncline is broken by the Harvey thrust fault and probable southern part of the Gascon fault. **Elk Mountain**—high central part of mountains. Precambrian is capped by Arroyo Peñasco Group and Pennsylvanian rocks, all lifted along Harvey and Gascon faults.

Concealed probable Pliocene-Quaternary faults at the south side of Rociada Valley (Fig. 3.27) are suggested by offset of Quaternary old fan and medial fan deposits. A water well in the Golf Course graben penetrated almost 300 ft of Quaternary sediments. The central part of the valley is water logged and swampy, probably because of subsurface damming by young faults near the west end of Manuelitas Creek gap, a situation similar to that in the Mora Valley (see Fig. 3.23).

The young faulting is envisioned as having occurred in several stages during which the western part of a widespread late Tertiary pediment surface on Precambrian rocks (now buried in the valley) was tilted southeast as a half-graben. A large remnant of Tertiary or Quaternary bouldery gravel lies on Paleozoic rocks on an eastern remnant of the prefaulting surface north of Manuelitas Creek gap several miles east of Rociada Valley and is as much as 800 ft above the present creek (Baltz and O'Neill, 1986). During each successive stage of faulting the half-graben filled with sediments. After each faulting stage Manuelitas Creek cut downward in the gap to reestablish the drainage to the east.

After Stop 6, **return to NM-105. 0.3**

60.6 **Turn right** (north) onto NM-105. **Retrace route north to junction** of NM-105 and NM-94. **3.0**

63.6 **Junction** of NM-94 and NM-105. **Continue straight** (east) on NM-94. Outcrops are east of Quebraditas fault zone in basal carbonate rocks, shale and sandstone of the Porvenir Formation that are overturned and dip about 70°NW. **0.3**

63.9 Tierra Monte village. Road crosses concealed trace of small thrust that throws overturned Porvenir against east-dipping Alamitos Formation. **0.2**

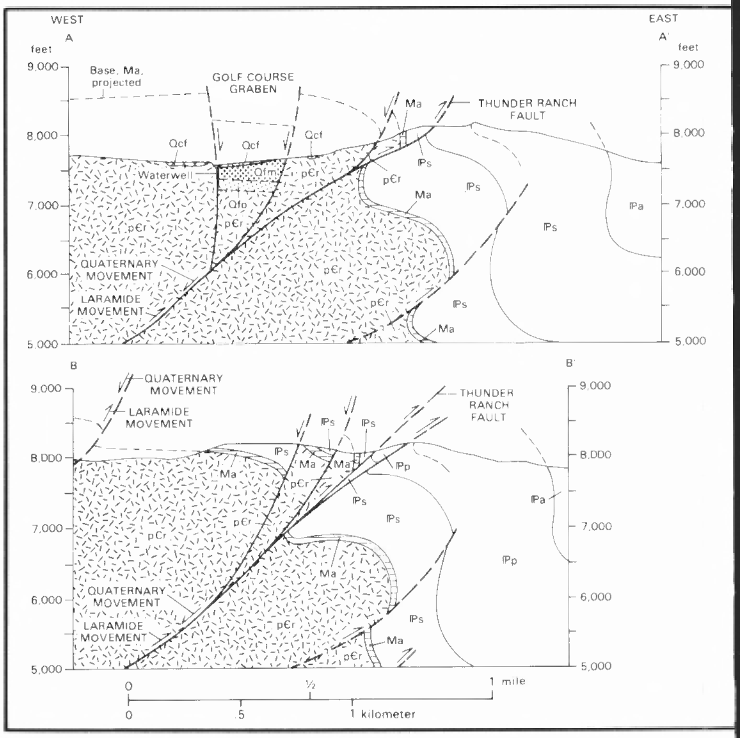
64.1 Approximate trace of SW-plunging Las Dispensas syncline in Alamitos Formation. Ahead are small outcrops of arkose and some limestone of the Alamitos dipping southwest. **0.2**

64.3 Milepost 8. **0.2**

64.5 At 9:00 in ditch is arkose and red shale of the lower part of the Alamitos. **0.4**

64.9 At 9:00 are basal arkoses of the Alamitos dipping west. **0.1**

65.0 At 9:00 is ledge-forming thick sandy limestone in upper part of the Porvenir Formation. This is "a marker zone" that is widespread south of here and at many places contains the lowest late Desmoinesian fusulinid *Beedeina sulphurensis* (Baltz and Myers, 1984). Road ahead is on west-dipping gray shale, quartzose and feldspathic sandstone, and thin limestones of the upper and middle parts of the Porvenir. **0.7**



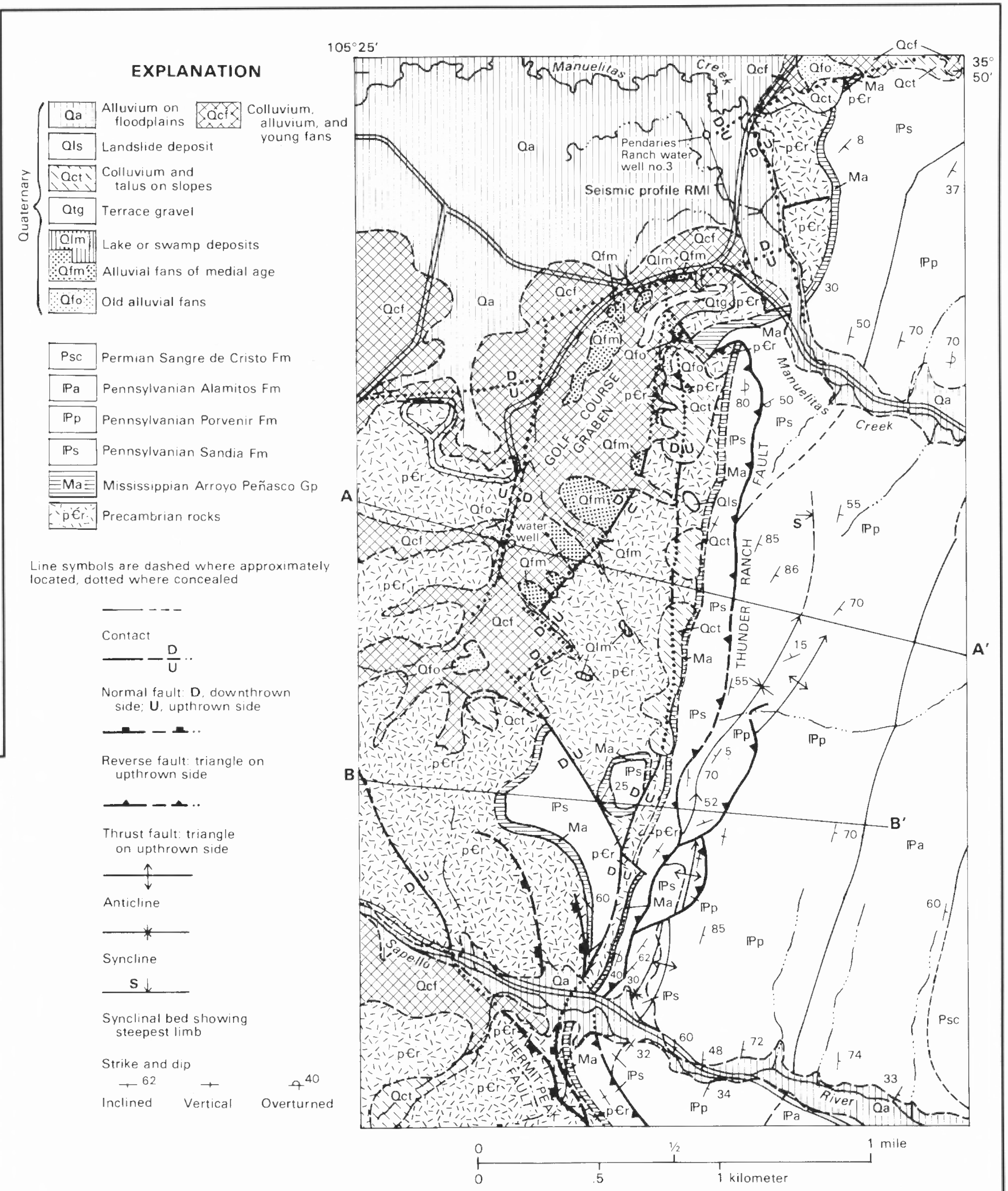


FIGURE 3.27. Geologic map and cross sections of southern part of Rociada Valley and upper Sapello River. Adapted from Baltz and O'Neill (1986).

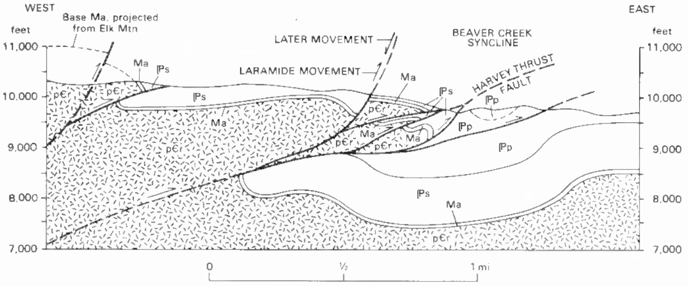


FIGURE 3.28. Cross section of Beaver Creek syncline east of Elk Mountain, about 6 mi southwest of Pendaries Ranch headquarters. Adapted from Baltz and O'Neill (1986, sec. F–F′). Much of the structure down to altitude 8800 ft can be observed on north wall of Hollinger Creek canyon. Western faults may be southern part of the Gascon fault. Symbols explained on Figure 3.27.

65.7 On ridge left (east) of creek are feldspathic sandstones near the middle of the Porvenir. **0.9**

66.6 At 9:00–11:00 the hills east of the valley are held up by a unit informally called the sandstones of Fragoso Ridge by Baltz and Myers (1984). These feldspathic sandstones, in the lower part of the Porvenir, persist to north of Mora River, but wedge out southward into shale as the entire Porvenir changes southward to a mainly carbonate facies south of Sapello River. **0.7**

67.3 Bridge. Drainage on right (south) is Cañon del Horno. A composite reference section of northern sandstone-shale-carbonate facies of the Porvenir (Baltz and Myers, 1984), measured in the ridge south of the canyon and in roadcuts ahead, is shown on Figure 3.29. **0.2**

67.5 Outcrops here and ahead for about 0.2 mi are in feldspathic sandstone and some interbedded shale of the sandstones of Fragoso Ridge.

Rocks dip NW on NW flank of the NE-trending, doubly plunging Cerro de la Cruz anticline which is the eastern frontal fold of the Sangre de Cristo uplift in this area (Baltz and O'Neill, 1986). **0.5**

68.0 At 9:00 the mound in the valley is a greatly recrystallized stromatolitic bioherm at the base of the Porvenir Formation. Other similar bioherms are poorly exposed on the west side of the valley and also to the northeast.

At 11:00–2:00 the crest of Cerro de la Cruz Mountain on the skyline is capped by basal limestone and shale of the Porvenir Formation underlain by conglomeratic sandstone, shale and thin limestone of the Sandia Formation. These rocks are on the dome-like, northeast- and southwest-plunging Cerro de la Cruz anticline. **0.9**

68.9 Bridge across Manuelitas Creek. Outcrops are in the Sandia Formation which is more than 680 ft thick here and the base not exposed. About 4$^1/_2$ mi south along the front of the mountains the Sandia is only 300 ft thick and continues to thin southward. **BE CAUTIOUS AHEAD** AS ROAD PASSES THROUGH MANUELITAS VILLAGE. **0.7**

69.6 **Manuelitas.** Continue ahead on NM-94. **0.1**

69.7 Approximate axis of Cerro de la Cruz anticline. Ahead, beds of Sandia Formation dip east-southeast. At 9:00 the Sandia Formation is exposed north of Manuelitas Creek valley on the northeast-plunging axis of the anticline. Figure 3.30 shows structure of east front of Sangre de Cristo uplift just north of Cerro de la Cruz anticline. **1.2**

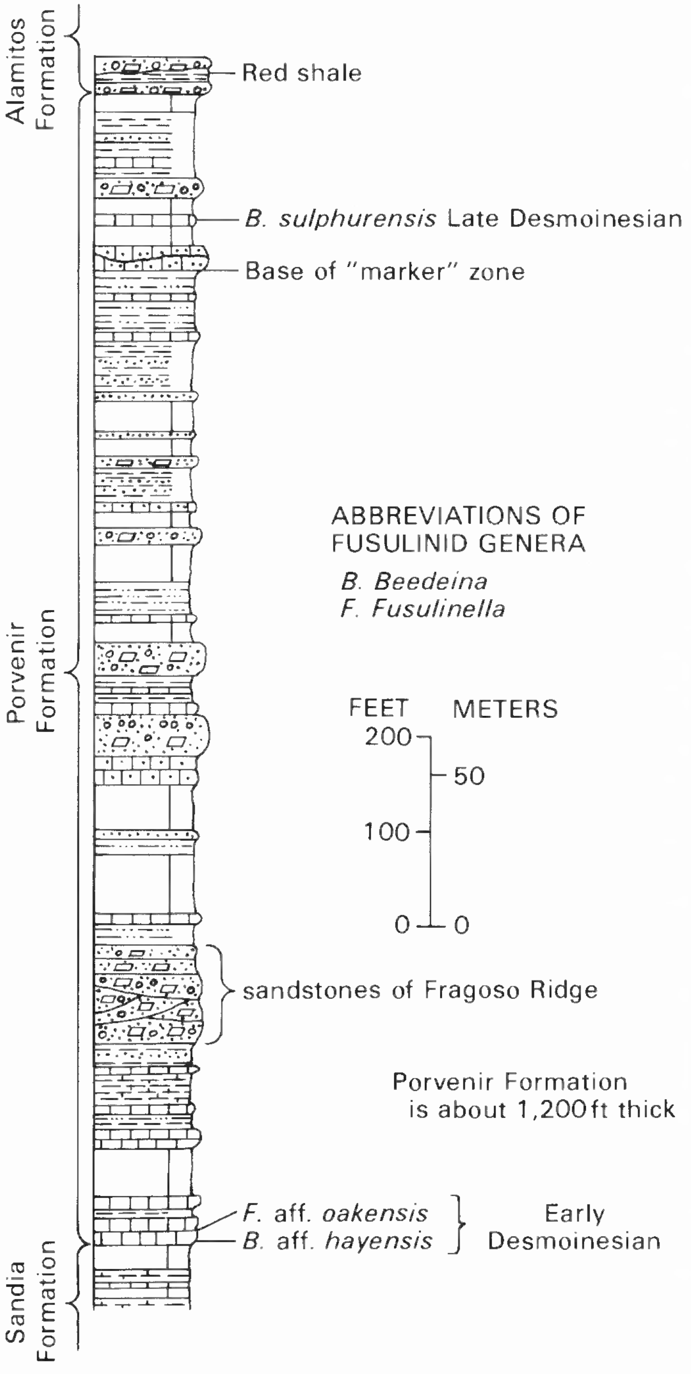


FIGURE 3.29. Composite section of Pennsylvanian Porvenir Formation west side of Canon del Horno and outcrops along and near NM Highway 94 northwest of Manuelitas. Adapted from Baltz and Myers (1984, figs. 7, 9). See Figure 3.17 for explanation of lithologic symbols.

70.9 Concealed approximate contact of steeply east-dipping Sandia and Porvenir Formations on the southeast flank of Cerro de la Cruz anticline. Low, steeply east-dipping, limestone ledges at 9:00 on hillside are a little above the base of the Porvenir and contain early Desmoinesian fusulinids. From there eastward the Porvenir and the overlying Alamitos Formations dip 60–80°E and are overturned and dip steeply west near the west-dipping Sapello fault which breaks the east limb of Cerro de la Cruz anticline.

73.3 At 3:00 in roadcut, platy limestone of upper part of Juana Lopez Member is overlain by gray shale of the Niobrara. **1.0**

74.3 Road is on Quaternary pediment gravel lying on the Niobrara Formation near the trough of the Las Vegas basin. The plains in the distant view to the east are underlain mainly by the Carlile Shale and Greenhorn Limestone on the gently dipping east limb of the Las Vegas basin.

At 8:30–9:00 the large wooded mountain is Turkey Mountain dome whose flanks are carved mainly in the Dakota Sandstone. Rocks as old as the Lower Permian Glorieta Sandstone are exposed in the core (Hayes, 1957). The dome is a result of Tertiary, probably laccolithic, intrusions, as shown by interlayering of thick monzonitic(?) sills and Pennsylvanian rocks in the Union Land and Grazing Co. No. 1 Fort Union well drilled near the center of the dome.

Small hills at the south side of Turkey Mountain are the Maxon Crater whose basaltic flows extend many miles southeast down the canyon of Mora River on the southeast side of the Las Vegas Plateau. The basalt near Maxon Crater is dated at 1.37±0.15 Ma (O'Neill and Mehnert, 1988). **0.6**

74.9 Historical marker reads:

> Hermit's Peak. Elevation 10,212 ft. From 1863 to 1867 this mountain was home of Juan Maria Agostini, an Italian penitent who lived there as a hermit carving crucifixes and religious emblems which he traded for food. Leaving this area, he moved to the Organ Mountains, in southern New Mexico, where he was found murdered in 1869.

0.3

THE FLORA OF THE SANGRE DE CRISTO MOUNTAINS, NEW MEXICO

Paul J. Knight

The flora of the Sangre de Cristo Mountains primarily consists of elements of the Rocky Mountain floristic influence. This floristic region is characterized by four elevational floristic zones which extend from 6000 ft to over 13,000 ft in elevation. These zones are pinyon-juniper woodland (6000–7500 ft in elevation), mixed conifer woodland (7500–9000 ft in elevation), spruce-fir woodland (9000–12,000 ft in elevation) and alpine tundra (12,000–13,000 ft in elevation).

Pinyon-juniper woodland is dominated by small, widely spaced trees, usually interspersed with stands of perennial grasses and scattered shrubs. In some cases, pinyon-juniper woodland takes on a savannah-like composition. The lower portions of pinyon-juniper woodland are dominated by nearly pure stands of one-seed juniper (*Juniperus monosperma*). With increases in elevation, pinyon pine (*Pinus edulis*) becomes more common and eventually dominates the community. In most cases the density of grasses in pinyon-juniper woodland decreases with the increase of pinyon.

The mixed conifer zone is characterized by well-developed forests of timber such as ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga menziesii*), Rocky Mountain juniper (*Juniperus scopulorum*) and white fir (*Abies concolor*). A variety of deciduous trees including Gambel oak (*Quercus gambelii*), aspen (*Populus tremuloides*) and shrubs such as currant (*Ribes*) and mountain mahogany (*Cercocarpus montanus*) are locally common in suitable microhabitats within the mixed conifer zone. The lower portions of mixed conifer woodlands are typically composed of an intermixture of pinyon pine and ponderosa pine. With increasing elevation ponderosa pine dominates. At the mid-range of mixed conifer woodland one finds an admixture of ponderosa pine and Douglas fir. At the upper portions of this floristic zone, dense forests of Douglas fir and white fir can exist.

Spruce-fir woodland is dominated by dense, and often extensive, forests of coniferous trees such as Engelmann spruce (*Picea engelmanni*), subalpine fir (*Abies lasiocarpa*), limber pine (*Pinus flexilis*) and blue spruce (*Picea glauca*). The most common deciduous tree is aspen, which is a fire-succession species dominating large areas that have suffered fire damage in the last 100 years. Depending upon aspect and elevation, species such as Douglas fir and white fir can also grow in spruce-fir woodland. Much of the spruce-fir woodland is dense forests with few subcanopy species.

Alpine-tundra is rare in New Mexico. The best examples are found on Wheeler Peak (elev. 12,161 ft). Alpine-tundra is dominated by grasses, sedges and dwarfed shrubs. This extreme environment discourages all but the hardiest of species. The transition zone from spruce-fir to alpine-tundra is characterized by a reduction of density of spruce and fir trees, and a progressive dwarfing and gnarling of the trees, leaving open meadows of sedges and grasses with scattered, gnarled, shrub-like trees.

In addition to Rocky Mountain influences, the field conference study area includes regions with influences of the Great Basin and Great Plains floras. Along the western base of the Sangre de Cristo Mountains are extensive stands of shrubby species dominated by sagebrush (*Artemisia tridentata*) and saltbrush (*Atriplex canescens*). These species are typical of the Great Basin, where they commonly form expansive stands that continue uninterrupted for hundreds of square miles. The eastern base of the Sangre de Cristo Mountains grades into the Great Plains floristic region. This area is characterized by elements of the short grass and mixed grass associations. It is dominated by buffalo grass (*Buchloe dactyloides*), western wheatgrass (*Agropyron smithii*), little bluestem (*Andropogon scoparius*), blue grama, black grama, three-awn and sideoats grama. The lower portions of the eastern field conference study area will enter into the western edge of this floristic association.

The following is a key to the vegetation associations expected within the study area (Fig. 3.32): **AGHI**—Agricultural areas; **ARAGSP**/*Artemisia tridentata, Hilaria jamesil, Sporobolus airoides, S. cryptandrus, Bouteloua gracillis;* big sagebrush dominates with galleta grass, alkali sacaton, sand dropseed, blue grama and occasional pinyon and juniper trees (association level); **BOAG**—*Bouteloua gracillis* and *Agropyron smithii;* blue grama grass with western wheatgrass; associated species include bottlebrush squirreltail, three-awn, ring muhly, winterfat

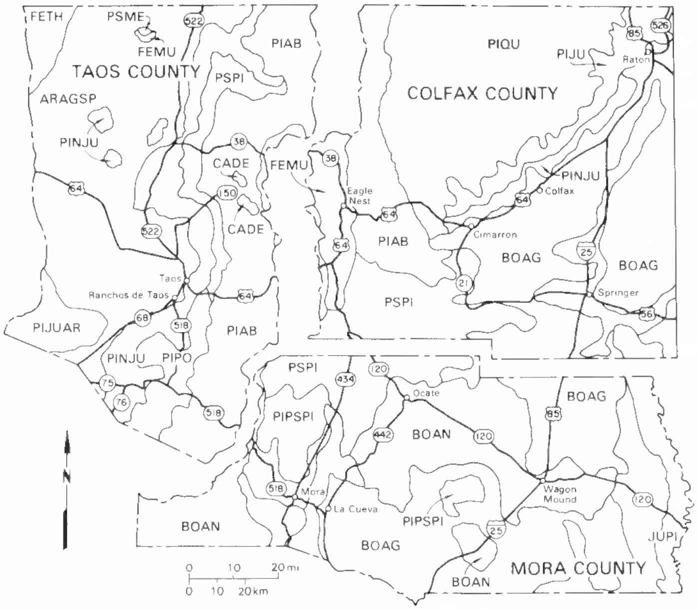


FIGURE 3.32. Map showing vegetation associations in field trip area.

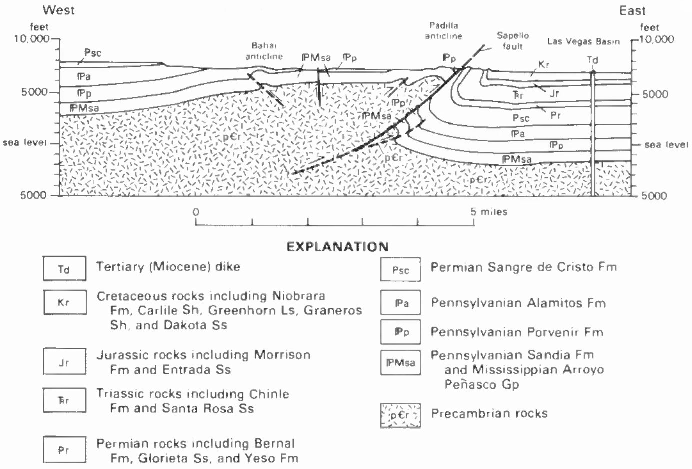


FIGURE 3.30. Cross section of eastern-frontal part of Sangre de Cristo uplift just north of NE-plunging Cerro de la Cruz anticline. Line of section is about 1 mi north of Manuelitas village. Adapted from Baltz and O'Neill (1986, sec. E–E').

On the skyline at 9:00 are overturned west-dipping beds of the Lower Permian Glorieta Sandstone and the Upper Triassic Santa Rosa Sandstone, east of the Sapello fault, on the west limb of the Las Vegas basin **.0.4**

71.3 At 9:00 are low ledges of steeply dipping arkose near the base of the Alamitos Formation. **0.2**

71.5 **Junction** of NM-94 and NM-266 at west end of "Y." **Continue left** (east) on NM-266. Roadcuts at 9:00 are in limestone, gray-green and red shale, and arkose of lower part of the Alamitos Formation. The limestone contains the late Desmoinesian fusulinid *Beedeina sulphurensis*. About 250 ft to the east these beds are thrust to the east along the Sapello fault above slickensided limestone and other rocks of the upper part of the Alamitos that contain Virgilian (Late Pennsylvanian) megafossils. The fault plane, dug out of the roadcut, dips about 40°NW. **0.1**

71.6 Immediately east of "Y" road junction at 9:00 are arkose and red shale of basal part of the (here) Lower Permian Sangre de Cristo Formation. About 300 ft east is nonfossiliferous gray limestone in the lower part of the Sangre de Cristo.

Most of the slopes and alluvial valley of Manuelitas Creek ahead are underlain by the Sangre de Cristo Formation which is overturned and dips west 70–75°. The overlying Permian Yeso Formation and Glorieta Sandstone, and the Permian Bernal Formation are concealed by alluvium, but are exposed in hogbacks to the north. **0.4**

72.0 Bridge across Manuelitas Creek. Confluence of Manuelitas Creek and Sapello River is in valley immediately to south. **0.1**

72.1 At 9:00 ridge of overturned sandstone is the upper part of the Upper Triassic Santa Rosa Sandstone. Green and red shale immediately to the east is the lower part of the Upper Triassic Chinle Formation. **0.1**

72.2 Low ridge in valley at 9:00 is sandstone in the middle member of the Chinle. **0.1**

72.3 **Junction** of NM-266 and NM-518 (old NM-3) at **Sapello.** Thick, light-colored outcrop at 9:00 is the Middle Jurassic Entrada Sandstone. Overlying thin, fine-grained sandstone, red and brown shale, thin limestone, and thin bentonite beds in roadcut are the lower part of the Upper Jurassic Morrison Formation. Between 1 and 2 mi north of here a poorly exposed thin remnant of the Middle Jurassic Todilto Limestone is present between the Entrada and Morrison (Baltz and O'Neill, 1986).

Turn right (south) onto NM-518 toward Las Vegas. Road is on Quaternary terrace gravel overlying Morrison Formation and Dakota Sandstone. **0.2**

72.5 Bridge across Sapello River. At 1:00–2:00 east-dipping Greenhorn Limestone is exposed in roadcut. Road ahead is on mainly concealed lower member of Carlile Shale. Vertical to overturned Lower Cretaceous Dakota Sandstone and older rocks form wooded hogback at 1:00–2:00. Axis of Las Vegas basin is 1½ mi east of here.

From here south to Las Vegas, NM-518 is entirely on shaly Upper Cretaceous rocks or on thin Quaternary deposits that lie on the Cretaceous. Figure 3.31 summarizes the Cretaceous rocks. **0.5**

73.0 Highway crosses the concealed Codell Sandstone Member of the Carlile Shale. The sandstone is fairly well exposed on low hills west of the highway at about 1:00.

The hill at 9:00, just east of the highway, is underlain by the Juana Lopez Member of the Carlile and the superjacent Niobrara Formation and is capped by Quaternary gravel (Baltz and O'Neill, 1986). **0.3**

Formation		Lithology	Thickness	
Niobrara Formation		Shale, medium-gray, containing a few 6-inch- to 1-ft-thick beds of dense gray limestone. Highest part, in trough of Las Vegas Basin, contains brown-weathering, fossiliferous, calcareous siltstone beds. Lower 25 ft is slightly marly shale containing several thin, fossiliferous limestones, all paleontologically equivalent to the Fort Hays Limestone Member of areas to the northeast.	Top eroded everywhere. As much as 500 ft NW of Storrie Lake	
Carlile Shale	Juana Lopez Member	Upper part—Interbedded thin limestone, gray to dark-gray fissile clay shale, and thin bentonite beds. Limestone beds are 1 inch to 1 ft thick, and highly fossiliferous to bioclastic. Shale beds are 1 inch to 3 ft thick. Bentonite beds are tan and ¼–6 inches thick. Unit is about 16 ft thick. Contains *Scaphites whitfieldi* and *Prionocyclus wyomingensis*.	64 ft[1]	About 340 ft
		Lower part—Shale, gray, fissile. Contains a few fossiliferous limestone concretions and 1-inch- to 6-inch-thick beds of dark-gray bioclastic limestone that contain fish scales and shark teeth. Unit is about 48 ft thick. Near base contains *Lopha lugubris* and *Prionocyclus macombi*.		
	Codell Ss Member	Sandstone, light-olive-gray, rusty-brown weathering, fine-grained to silty. Bedding obscure at places because of bioturbation. Contains gray septarian-limestone concretions. Contains *Prionocyclus hyatti* and *Spathites puercoensis*.	30 ft[2]	
	Lower Member	Shale, gray to dark-gray. Upper 30 ft contains a few thin, platy siltstone beds and cobble-size limestone concretions. Lower 7 ft is marly clay shale with a 4-inch-thick bentonite bed at the top.	About 250 ft[3]	
Greenhorn Limestone		Limestone and calcareous shale, interbedded. Limestone beds are sparsely fossiliferous, dense, gray, and ½–4 ft thick; weather bluish-gray. Shales are ½–7½ ft thick.	About 65 ft (1 mi NNE of Sapello)	
Graneros Shale		Shale, dark-gray; contains subordinate amount of thin, platy fine-grained sandstone and siltstone. Calcareous shale and thin bentonite beds occur in upper part. A 1.5-ft-thick bentonite bed occurs at the top.	About 200 ft (N side of Gallinas Creek at Montezuma)	
Dakota Sandstone-Lower and Lower(?) Cretaceous				

[1] Canyon Bonito Arroyo west of NM 518, 1.5 mi north of Storrie Lake dam

[2] ¾ mi NE of Sapello

[3] 1 mi NNE of Sapello

FIGURE 3.31. Description of Upper Cretaceous rocks of southwest part of Las Vegas basin. Fossils identified by S. C. Hook and W. A. Cobban.

and fringed sage (association level); **BOAN**—*Bouteloua* spp. and *Andropogon scoparius;* dominated by various species of grama grass and little bluestem with some western wheatgrass, galleta grass and buffalo grass (association level); **BOJU**—Bouteloua gracillis and *Juniperus monosperma;* dominated by blue grama grass and one-seed juniper, with sideoats grama grass, three-awn grasses and sand dropseed (association level); **BOANJU**—Bouteloua curtipendula, Andropogon scoparius, Juniperus spp.; dominated by sideoats grama grass and little bluestem with some western wheatgrass, galleta grass and buffalo grass (association level); **BRJU**—Brush and *Juniperus* spp.; brushy species are found in codominance with juniper species (series level); **CADE**—*Carez* spp. and *Deschampsia caespitosa;* sedge species, tufted hairgrass and occurrences of iris and pussytoes (association level); **FEMU**—*Festuca arizonica* and *Muhlenbergia montana;* subdominants are Arizona fescue and mountain muhly (association level); **JUPI**—*Juniperus monosperma* and *Pinus edulis;* one-seed juniper and pinyon pine, with galleta grass, indian rice grass and grama grass (series level); **PIAB**—*Picea engelmanni* and *Abies* spp.; Engelmann spruce and fir (association level); **PIJU**—*Pinus ponderosa* and *Juniperus scopulorum:* ponderosa pine dominates and Rocky Mountain juniper is a subdominant; oak species, skunkbush, mountain mahogany, blue grama grass, spike muhly and needlegrass may occur (association level); **PIJUQU**—*Pinus edulis, Juniperus monosperma, Quercus gambelii;* dominated by pinyon pine with juniper a secondary dominant; Gambel oak is common throughout (association level); **PINJU**—*Pinus edulis* and *Juniperus monosperma:* pinyon pine and one-seed juniper with little appreciable woody understory; may include ponderosa pine at higher elevation (series level); **PIJUAR**—*Pinus edulis, Juniperus monosperma, Artemisia tridentata;* dominated by pinyon pine, with one-seed juniper and big sagebrush (association level); **PIQU**—*Pinus ponderosa* and *Quercus gambelii;* dominated by ponderosa pine with the subdominant Gambel oak; other oak species and mountain mahogany are also common (association level); **PIPO**—*Pinus ponderosa;* dominated by ponderosa pine with some Douglas fir and pinyon pine; grassy understory includes Arizona fescue and mountain muhly (association level); **PIPSPI**—*Pinus ponderosa, Pseudotsuga menziesii* and *Pinus edulis;* ponderosa pine with some Douglas fir and pinyon pine. The understory often includes mountain mahogany, serviceberry, bottlebrush, mountain muhly and Arizona fescue (association level); **PSME**—*Pseudotsuga menziesii* and *Pinus ponderosa;* Douglas fir and ponderosa pine (association level); **PSPI**—*Pseudotsuga menziesii* and *Picea engelmanni;* Douglas fir and Englemann spruce (association level); **SPAT**—*Sporobolus airoides* and *Atriplex* spp.; alkali sacaton and saltbush species with occurrences of western wheatgrass, blue grama and rabbitbrush (series level).

75.2 At 3:00 is junction with road to Las Dispensas. Continue south on NM-518. Road is on Quaternary or Tertiary gravel capping Niobrara Formation.

At 2:00–3:00 is the bold east face of Hermit's Peak which is Proterozoic quartzofeldspathic gneiss and granite. The Proterozoic is capped by remnants of the Mississippian Arroyo Peñasco Group and the Lower and Middle Pennsylvanian Sandia Formation that dip west. The Proterozoic rocks are thrust eastward on the Hermit's Peak fault at the east base of the peak (Fig. 3.33). This fault cuts out overturned beds of the Arroyo Peñasco, the Sandia Formation and locally the Porvenir Formation (Baltz, 1972).

The higher parts of the mountains west of Hermit's Peak are Proterozoic rocks capped by Mississippian and Pennsylvanian rocks, all elevated along the east-yielding Harvey thrust fault. **0.8**

76.0 Entrance to Terry Hooper Bonita Ranch at 3:00. NM-518 continues south on veneers of Quaternary pediment gravel lying on the lower part of the Niobrara Formation.

At 1:00–3:00 at the west edge of grassy lowlands, vertical to overturned Dakota Sandstone and older rocks form hogbacks at the west edge of the Las Vegas basin. The basin axis here is near the mountain front. Gravel-capped remnants of the Niobrara in hills at 1:00–1:30 are nearly horizontal a short distance east of the overturned Dakota which dips about 70°W.

At 1:00–3:00 the mountain on the skyline is La Sierrita which is capped by the lower part of the carbonate facies of the Middle Pennsylvanian Porvenir Formation. The underlying Sandia Formation is only 100–250 ft thick and locally truncates the Arroyo Peñasco. Proterozoic quartzofeldspathic gneiss forms a reddish-weathering east face of the mountain. This rock is on the east flank of La Sierrita dome which is a north- and south-plunging Laramide structure whose east limb is broken by the east-yielding Montezuma reverse fault (Fig. 3.33). This north-trending fault locally throws the Precambrian against the middle part of the Upper Triassic Santa Rosa Sandstone. To the north the displacement of the Montezuma fault is taken up by the Sapello fault. To the south the Montezuma fault dies out south of Montezuma on the east limb of the mountain-front Creston anticline. **2.3**

78.3 Road crosses approximate contact of gently west-dipping Niobrara Formation and underlying Juana Lopez Member of Carlile Shale. Small ridges at 9:00 are lowermost Niobrara metamorphosed by a northeast-trending basaltic dike. Several dikes are well exposed northeast of here in Arroyo Pecos near the Carlile-Niobrara contact. **0.6**

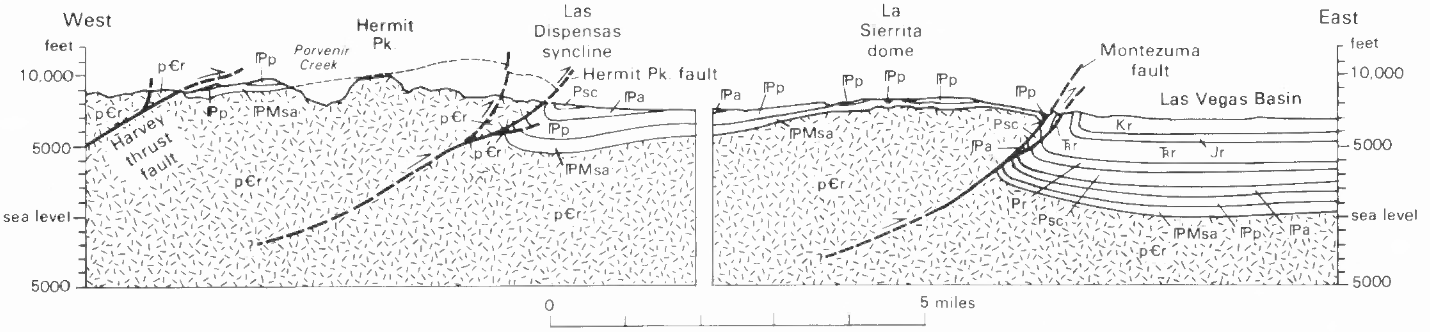


FIGURE 3.33. Cross sections of Hermit's Peak and La Sierrita dome. Line of eastern section is about 0.5 mi southwest of Bonita Ranch. Adapted from Baltz (1972, secs. B–B′ and D–D′). Laramide-age La Sierrita dome is on north end of the Paleozoic Tecolote uplift as shown by westward and northward thickening of Pennsylvanian and Lower Permian rocks. See Figure 3.30 for explanation of symbols.

78.9 Bridge across Canyon Bonito arroyo. Road is on thin alluvium on the lower member of the Carlile Shale. At 3:00 in bluff south of arroyo the Codell Sandstone and Juana Lopez Members of the Carlile are exposed. About $^{1}/_{2}$ mi northwest in the arroyo, a basaltic dike and sills intrude well-exposed upper part of Juana Lopez Member. At 9:00 the lower member of the Carlile and the Codell Sandstone Member are exposed on hills just east of valley. **1.2**

80.1 Vista of High Plains at 9:00–11:00. Much of the plain sloping west from the skyline is underlain by Greenhorn Limestone on the east limb of Las Vegas basin (Northrop et al., 1946). Highest hills on skyline are Carlile Shale capped by Tertiary gravel. This bouldery gravel forms a narrow, sinuous, south-trending mesa, suggesting a former river channel. Clasts are various Precambrian rocks and sedimentary rocks including Glorieta Sandstone and Santa Rosa Sandstone. Some clasts are 1–2 ft across. **0.1**

80.2 North end of Storrie Lake dam. This dam was first envisioned as the Canfield Reservoir for flood storage to irrigate the mesas southeast of Las Vegas and work was begun in 1909. A dam was constructed on Gallinas River at Montezuma at the east edge of the mountains, and a ditch was dug southeastward to divert water to the area of the present lake. The project collapsed financially in 1910. In 1916, R. C. Storrie and Company renewed the work, and by 1922 the dam and distributing canal, 14 mi long, to the mesas southeast of Las Vegas were completed. The proposed irrigated farming was not very successful, but the lake is a major recreational and financial resource for Las Vegas. The total cost of the original project was about $900,000 (Callon, 1962). **0.3**

80.5 South end of Storrie Lake dam. NM-518 to the south is on platy limestone and shale of Juana Lopez Member of Carlile Shale. These rocks dip gently west and, under the western part of the lake, are overlain by the Niobrara Formation in the trough of the Las Vegas basin. From here south to Las Vegas, NM-518 is on the upper part of the Juana Lopez Member.

On the forested skyline at 1:00–3:00 are limestones of the Porvenir Formation on the crest and east limb of the Creston anticline which is the eastern frontal fold of the Sangre de Cristo uplift from Montezuma south. This anticline plunges very gently south-southeast and disappears into the Great Plains more than 15 mi south of Las Vegas. **2.0**

82.5 High hill to the west is Niobrara Formation capped by Tertiary bouldery gravel. **1.0**

83.5 **Intersection** of NM-518 and Legion Drive in northern suburbs of Las Vegas. **Continue south** on NM-518. Road is on thin soil overlying upper platy limestones of Juana Lopez Member of the Carlile Shale which are exposed several blocks west. To the south the Cretaceous rocks rise gently in the southward shallowing Las Vegas basin. Trough of the basin is about 1 mi west of here. **0.9**

84.4 Intersection of NM-518 (7th St.) and NM-329 (Mills Avenue) in north part of Las Vegas. Road is on soil and thin pediment deposits overlying lower member of Carlile Shale. A few blocks to the south many houses are founded on, or have basements in, the Greenhorn Limestone.

PALYNOMORPHIC EVIDENCE OF AGE OF DAKOTA SANDSTONE AT MONTEZUMA, NEW MEXICO

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The Dakota Sandstone at the east front of the Sangre de Cristo Mountains in New Mexico generally, but not everywhere, consists of: (1) a lower massive unit of fluvial pebbly sandstone which constitutes most of the formation; (2) a medial unit of dark-gray carbonaceous siltstone and shale and thin interbeds of sandstone and local lenses of pebbles, all of probable coastal-plain origin; and (3) a thin upper unit of fine- to medium-grained sandstone and some thin shale that probably is a transgressive marine deposit related to the overlying Graneros Shale. This general three-fold division, and the fact that the Dakota extends mainly continuously north to Colorado, have suggested to many investigators that at least the lower and medial parts in New Mexico are age equivalent to the Lower Cretaceous Purgatoire Formation of Colorado. Similarly, the lower part, at least, of the Dakota in New Mexico has been traced southeastward to Tucumcari and probably is equivalent to the Lower Cretaceous Mesa Rica Sandstone of that area. However, paleontologic evidence of age has not been documented for the southern Sangre de Cristo region.

The Dakota is well exposed northwest of Las Vegas in roadcuts and outcrops in the hogback north of Gallinas Creek about 1200 ft east of Montezuma. Four samples of dark-gray carbonaceous silty shale were collected from the medial unit, and one sample was collected from the basal part of the Graneros Shale at these outcrops and submitted to the late Robert H. Tschudy of the U.S. Geological Survey for palynological analysis. The lower three samples from the medial unit of the Dakota and the sample from the Graneros were barren. However, the sample from shale near the top of the medial unit of the Dakota had palynomorphs. This sample was given USGS paleobotany locality number D6385. The analysis, from a written communication (19 May 1982) from R. H. Tschudy to E. H. Baltz, is quoted below:

> The palynomophs were poorly preserved, dark brown in color, broken, and corroded. Furthermore, they exhibited evidence of incipient metamorphism indicated by the impressions of crystals on the walls of the palynomorphs.
>
> The following taxa were identified even though the sample was very poor: *Gleincheniidites* Bisaccate conifer pollen, *Corollina, Taxodiaceaepollenites, Tricolpites* (rough, equatorial view), *Stereisporites, Rugubivesiculites*?, *Lycopodiacidites* cf. *L. canaliculatus, Liliacidites* (reticulate), *Araucariacites* (broken), *Tricolpites* (smooth), *Zlivisporis, Cicatricosisporites, Ischyosporites* cf. *I. disjunctus, Retitricolpites* cf. *R. virgeus Trilobosporites apiverrucatus.*
>
> This limited, poorly preserved assemblage is probably of Albian age. The identified species are all known from the Albian and are not known to extend into the Cenomanian. The presence of tricolpate pollen indicates an age no older than Albian. I was unable to find any tricolporate pollen that would indicate a post-Albian age.

The above analysis probably fixes the age of the medial and lower parts of the Dakota Sandstone at Montezuma as Early Cretaceous. The age of the upper part is not established. The interpretation of Tschudy and regional correlation led Baltz and O'Neill (1984, 1986) to assign the Dakota in the Sapello River–Mora River areas to the Lower and Lower(?) Cretaceous.

End of Third-Day Road Log.