Second-day road log: From Inn of the Mountain Gods to Hondo, Lincoln, Capitan and return to Inn of the Mountain Gods

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1991, pp. 27-46. https://doi.org/10.56577/FFC-42.27

in:

Geology of the Sierra Blanca, Sacramento, and Capitan Ranges, New Mexico, Barker, J. M.; Kues, B. S.; Austin, G. S.; Lucas, S. G.; [eds.], New Mexico Geological Society 42 nd Annual Fall Field Conference Guidebook, 361 p. https://doi.org/10.56577/FFC-42

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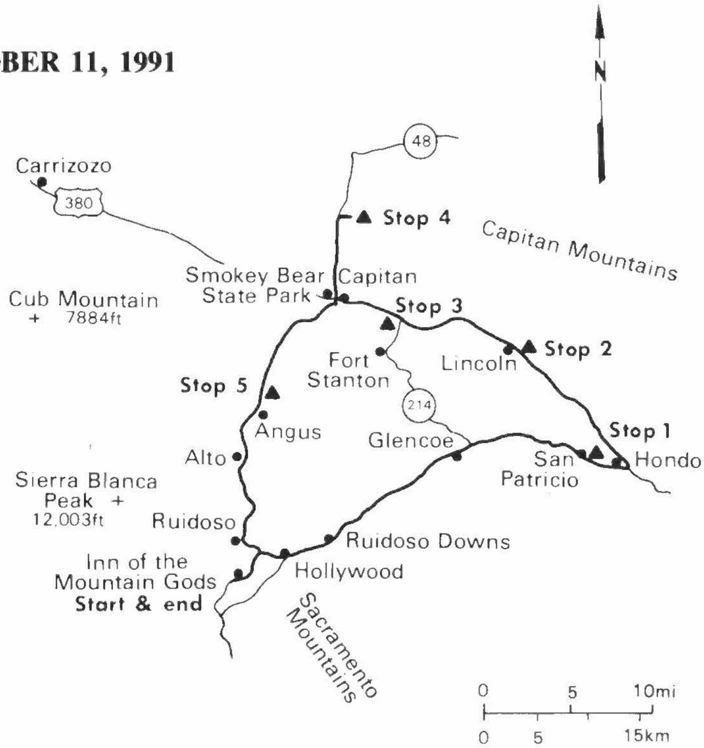
SECOND-DAY ROAD LOG, FROM INN OF THE MOUNTAIN GODS TO HONDO, LINCOLN, CAPITAN AND RETURN TO INN OF THE MOUNTAIN GODS

STEVEN M. CATHER, SPENCER G. LUCAS, VIRGINIA T. McLEMORE and ROBERT M. COLPITTS, JR.

FRIDAY, OCTOBER 11, 1991



Assembly point: Inn of the Mountain Gods, near Ruidoso, New Mexico.
Departure time: 7:45 a.m.
Distance: 92.1 miles
Stops: 5

SUMMARY

The second-day tour consists of a loop that begins and ends at the Inn of the Mountain Gods near Ruidoso. The first part of the route follows US-70 eastward down the Rio Ruidoso valley past good exposures of the Permian Yeso and San Andres Formations, Tertiary intrusives and Quaternary alluvium. The second part of the route then turns northwestward on US-380 at Hondo and continues through Lincoln to Capitan, with a spur route to the Capitan iron mines. The spectacular Lincoln fold belt is well exposed along the route, as are outcrops of Permian, Triassic, Jurassic and Cretaceous strata, and Tertiary intrusive rocks. The third part of the road log follows NM-48 southward between Capitan and Ruidoso, where Upper Cretaceous strata and Tertiary clastic and intrusive rocks are exposed in the eastern part of the Sierra Blanca basin.

Stop 1 is to examine the transition of lithologies between the Yeso and San Andres Formations. At Stop 2 we will examine and discuss the structure of the controversial Lincoln fold belt. Stop 3 provides an overview of the regional tectonics of the Pecos slope, Sierra Blanca basin, and Lincoln County porphyry belt and a discussion of the economic geology of the Capitan area. At Stop 4 we will examine one of the Capitan iron deposits. Stop 5 allows an opportunity to examine the lithology of the Eocene Cub Mountain Formation and the newly proposed, superjacent Sanders Canyon Formation.

This road log draws many data from earlier efforts by Ulvog and Thompson (1964) and Osburn and Arkell (1986). Thin-section descriptions are by S. M. Cather.

PART ONE: RUIDOSO TO HONDO

Mileage

0.0 Inn of the Mountain Gods. Pass under the culvert to stop sign; note Sierra Blanca Peak at 10:00. **Turn right and proceed north** on Carrizo Canyon Road. **0.3**

0.3 Poorly exposed Permian Grayburg Formation in roadcut on right. **0.3**

0.6 Dam of Mescalero Lake at 9:00. Outcrops at far (north) end of dam are Permian Grayburg Formation (red beds) overlain by Cretaceous Dakota Formation (resistant cliff; Fig. 2.1). **0.7**

1.3 Road-metal quarry in fetid limestones and dolomites of Permian San Andres Formation (Rio Bonito Member) at 9:00. San Andres is upfaulted on the east side of the north-striking Carrizo Canyon fault. The San Andres Formation is juxtaposed against Cretaceous Dakota Sandstone, Mancos Shale and Mesaverde Group, and Permian Grayburg Formation west of the fault, which passes through low area west of quarry. **0.3**

1.6 Cattle guard; leaving Mescalero Apache Reservation. **0.1**

1.7 Cliffs of Rio Bonito Member of San Andres Formation in roadcut on left display travertine-cemented collapse and rubble breccias. Dissolution features are common along Carrizo Canyon and result from dissolution along joints and fractures associated with Carrizo Canyon fault. **0.2**

FIGURE 2.1. Outcrops of Permian Grayburg Formation overlain by Cretaceous Dakota Formation.

1.9 Quarry in alluvial gravels in bottom of Carrizo Canyon on right. Carrizo Lodge on left. San Andres Formation at 3:00 displays dissolution features, including collapse breccias and travertine-cemented cave deposits. These deposits are often confused with strata in the Yeso Formation, but are finer grained and consist of crystals of dolomite and calcite cemented with calcite. **0.2**

2.1 San Andres Formation on left. **0.4**

2.5 San Andres Formation on left across creek. San Andres at 10:00 to 11:00 displays cave and collapse breccia. Rounded hills at 9:00 are west of the Carrizo Canyon fault and consist of Cretaceous Mancos Shale and Mesaverde Group. **0.5**

3.0 San Andres Formation in roadcut on left. **0.3**

3.3 Road on left leads west up Grindstone Canyon. Roadcut at 9:00 consists of Cretaceous Mancos Shale (D-Cross Shale?) intruded by Tertiary mafic dikes and sills. Strata are folded and broken near the Carrizo Canyon fault. Hill at 12:00 underlain (in ascending order) by Permian Yeso, San Andres and Grayburg Formations, and Cretaceous Dakota Formation. The trace of the Carrizo Canyon fault runs up arroyo west of hill. Southeast side of the hill is bounded by a northeast-striking normal fault with down-to-the-west displacement. **0.3**

3.6 **Junction** with NM-48 (Sudderth Drive) in Ruidoso. **Turn right. 0.6**

4.2 Stoplight; continue straight. **0.6**

4.8 Stoplight; continue straight. Note igneous rocks on hill at 9:00. **0.5**

5.3 Stoplight at **junction** of US-70 and NM-48 in Ruidoso. **Proceed east on US-70. 1.2**

6.5 Road to Ruidoso Downs racetrack on left. **0.6**

7.1 Beds of Yeso and San Andres Formations across valley at 9:00. **0.4**

7.5 Ruidoso Downs Post Office. **0.4**

7.9 Hale Spring, 0.5 mi south of highway, supplied water to Indian acequias about 900 yrs ago. **0.5**

8.4 Beds of Yeso Formation at 2:00. The Yeso Formation in the Sierra Blanca area is even-bedded, tan, red, yellow, gray and white sandstone, siltstone, dolomite and gypsum as much as 1400 ft thick (Kelley, 1971). It was generally deposited on an arid, marine shelf and in evaporitic lagoons and sabkhas during the Early Permian (Leonardian). **0.1**

8.5 Road narrows to two lanes. **0.2**

8.7 On right, erosional contact between folded sandstone and siltstone of Yeso Formation and Quaternary gravel. Note Quaternary gravels in roadcuts next 1.5 mi. **0.5**

9.2 Slump blocks of San Andres Formation on Yeso Formation across Rio Ruidoso at 9:00. **1.2**

10.4 Quaternary alluvium in right roadcut. **0.4**

10.8 Bridge across Rio Ruidoso. Water-pollution-control project at 8:00. **0.3**

11.1 Roadcuts in folded Yeso Formation with Tertiary porphyritic intrusives (medium gray) next 1.2 mi. In thin section, the intrusive at mile 11.1 shows porphyritic texture with phenocrysts of plagioclase (as much as 1.2 mm in length, largely replaced by calcite) in a groundmass of plagioclase, amphibole, opaque minerals and minor clinopyroxene. This rock is spessartite, a variety of lamprophyre (MacKenzie et al., 1982, p. 133). Beds dip ~45°WNW. **1.1**

12.2 Milepost 268. **0.5**

12.7 Basal San Andres Formation (Rio Bonito Member of Kelley, 1971) in roadcut on left; contact with Yeso Formation is covered. We are on the west limb of a large syncline in which the San Andres will be exposed at road level next 4.1 mi. Compare gentle dip of San Andres here and in hillslope across Rio Ruidoso at 12:00–2:00 to variable, often steep dips seen previously in Yeso Formation.

The San Andres Formation in the Sierra Blanca area consists of four members (Kelley, 1971). In ascending stratigraphic order, these are the Glorieta Sandstone Member (fine-grained, yellow to light-gray sandstone; see Milner, 1978), the Rio Bonito Member (thick-bedded, gray to grayish-brown limestone), the Bonney Canyon Member (thin-bedded, gray to grayish-brown limestone), and the Fourmile Draw Member (evaporitic sequence of dolomite, gypsum, red mudstone and sandstone). The San Andres Formation thickens to the southeast (Fig. 2.2), where it interfingers with basinal facies of the Delaware Basin (Cutoff and Cherry Canyon Formations). The limestones of the San Andres Formation represent deposition by low-angle, aggrading and prograding carbonate banks with ramp profiles of 1–2° during the Late Permian (Guadalupian; Sarg and Lehmann, 1986). **0.5**

13.2 Fox Cave, a walled-in overhang in San Andres Formation on left (Fig. 2.3). **0.1**

13.3 Milepost 269. Roadcut ahead on left is San Andres Formation with thick Tertiary sill. In thin section, sill displays intergranular texture with clinopyroxene, biotite and opaque minerals filling interstices between plagioclase laths. Plagioclase is as much as 1.5 mm in length and shows seritization and vacuolization in cores. According to MacKenzie et al. (1982, p. 133) this rock is kersantite, a variety of lamprophyre. **0.9**

14.2 Milepost 270. Thick sill intrudes San Andres Formation on left; thin sills within San Andres ahead on left. **0.4**

14.6 Roadcuts in San Andres Formation. **0.5**

15.1 Beaver Sand and Gravel Co. quarry in San Andres on left. Crusher operation produces road materials for city of Ruidoso. Quarry was established ca. 1981. **0.1**

15.2 Milepost 271. **0.6**

15.8 Leaving Lincoln National Forest. Exposures of Quater-

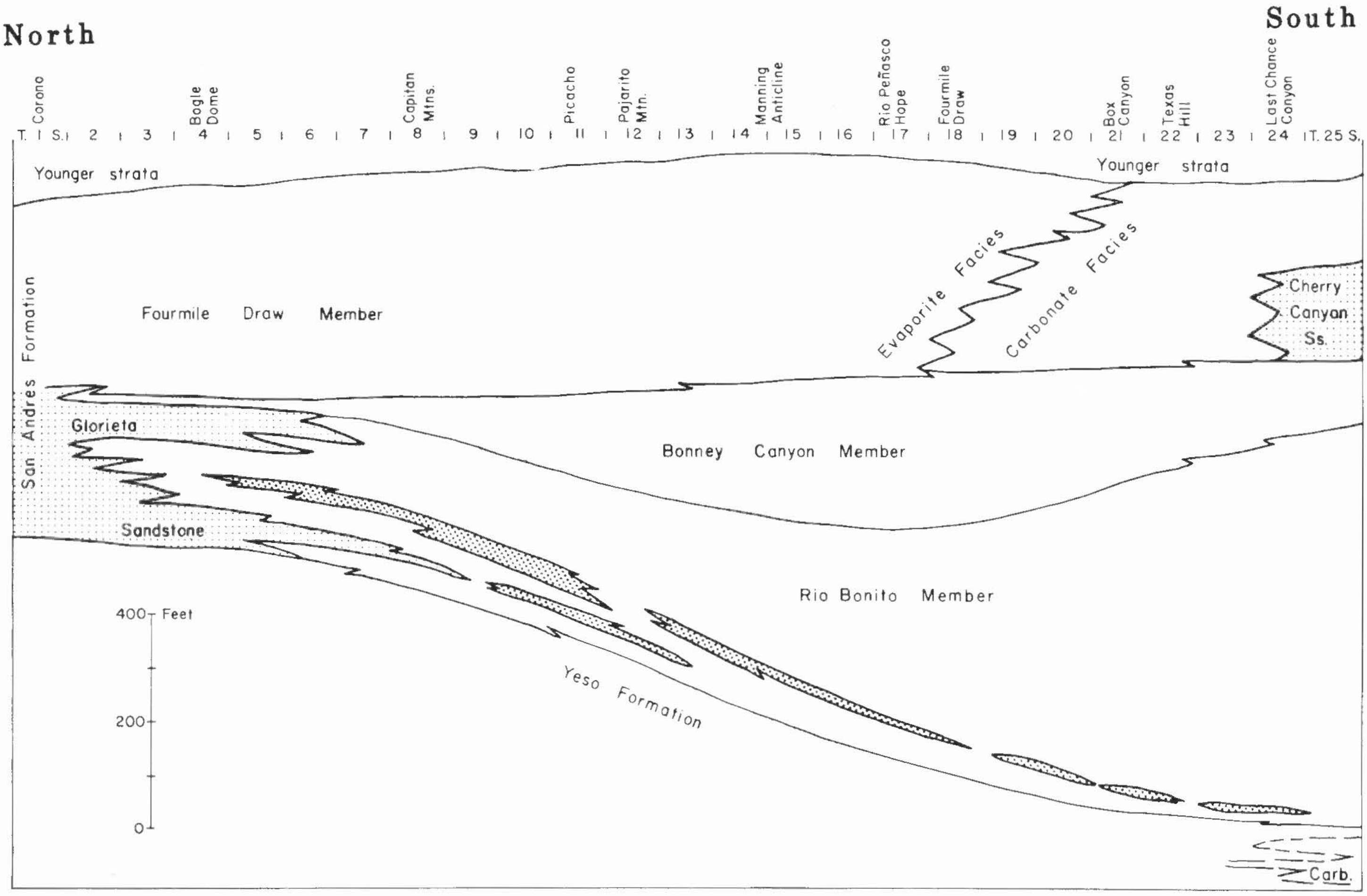


FIGURE 2.2. North-south stratigraphic diagram of members of the San Andres Formation (Kelley, 1971).

nary alluvium and San Andres Formation on left. **0.2**

16.0 Roadcut exposes thick, light-colored sill within San Andres Formation. Tertiary dikes and sills are common throughout the Sierra Blanca basin and eastward to near Tinnie, about 18 mi east of the present location. Tinnie is 4.5 mi east of the intersection of US-70 and US-380. **0.7**

16.7 Contact between Yeso Formation and San Andres Formation on left. Yellow, fine-grained sandstone (lower tongue of Glorieta Sandstone Member of Milner, 1978) is locally the basal unit of San Andres Formation. The Glorieta Sandstone Member intertongues with carbonates of the Rio Bonito Member, and pinches out to the south (Fig. 2.2). The Glorieta is generally given formational rank in areas to the north and northwest (e.g., Lucas et al., 1987; Colpitts, 1989), where it is thicker and includes more fluvial and eolian facies. In Lincoln County, the Glorieta Sandstone consists of one or two sandstone tongues in the lower Rio Bonito Member of the San Andres Formation (Fig. 2.2). These tongues are fine-grained quartzose sandstone as much as 22 m thick. Deposition of these sandstones occurred along north-northeast-trending coastlines in beach-upper shoreface, middle shoreface, lagoonal and tidal channel environments (Milner, 1978). **0.3**

FIGURE 2.3. Fox Cave, a walled-in overhang beneath San Andres Formation.

17.0 Contact between Yeso Formation and San Andres Formation to left. **0.2**

17.2 Official Scenic Marker: "John H. Tunstall Murder Site—In one of the Lincoln County War's earliest violent encounters, John H. Tunstall was shot and killed at a nearby site on February 18, 1878. Tunstall's death set off a series of violent reprisals between his friends, among whom was William 'Billy the Kid' Bonney, and forces of the Murphy/Dolan faction of this tragic conflict. Tunstall, an English businessman, came to New Mexico in 1876." See minipaper by M. H. Austin at Part Two, mile 9.6, of Second-Day Road Log for more on the Lincoln County War.

FIGURE 2.4. The Bonnell Co. sand and gravel operation.

Yeso Formation in roadcut to left; town of Glencoe in valley ahead to right. **0.3**

17.5 Yeso Formation in roadcuts to left, with San Andres Formation on slope above. **0.5**

18.0 Small syncline brings San Andres Formation down to road level. **0.1**

18.1 Yeso Formation to left. **0.5**

18.6 Folded Yeso Formation overlain by Quaternary alluvium to left. **0.1**

18.7 **Junction** with NM-214 on left; **continue straight** over bridge across Devils Canyon Creek. Pleistocene alluvial-fan deposits of Devils Canyon Creek at 10:00–11:00 have been mined since 1972 for sand and gravel by Bonnell Co. (Fig. 2.4). Top of fan deposits hosted a prehistoric Indian village that was excavated in 1956 by archeologists of Texas Technical College. **0.3**

19.0 Glencoe Post Office on left. San Andres forms bluffs to left. **0.3**

19.3 Dissected Pleistocene alluvial-fan deposits on left. **0.4**

19.7 Roadcuts in Quaternary alluvium on left. About 12 mi due south of here is Pajarito Mountain, an exposed remnant of the late Paleozoic Pedernal uplift that was eventually onlapped and buried by the Yeso Formation (Fig. 2.5; Kelley, 1971). Precambrian syenites (Kelley, 1968) exposed at Pajarito Mountain contain significant yttrium and zirconium, mostly in the mineral eudialyte (Sherer, 1990). **0.5**

PAJARITO MOUNTAIN YTTRIUM-ZIRCONIUM DEPOSIT, MESCALERO APACHE INDIAN RESERVATION, OTERO COUNTY, NEW MEXICO

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Pajarito Mountain lies in the northeastern part of the Mescalero Apache Indian Reservation, south of Ruidoso in Otero County (Fig. 2.6) and rises about 183 m above the plateau to an elevation of 2443 m (Fig. 2.7). Crystalline rocks of Proterozoic age were first reported by Kelley (1968), although previous workers (Thompson, 1942, p. 12; Lloyd, 1949, pl. 1) suggested that these rocks were Proterozoic. Motts and Gaul (1960), after detailed mapping and petrographic studies, presented arguments for a Tertiary age of the complex, but subsequent dating by Kelley (1968) and the U.S. Geological Survey (Moore et al., 1988) confirm a Proterozoic age of about 1100–1200 Ma.

The Pajarito Mountain complex consists of an unusual lithologic assemblage for Proterozoic rocks in New Mexico, in that the complex is predominately alkaline. Several varieties of syenite, quartz syenite, alkali granite and gabbro are exposed at Pajarito Mountain and are intruded by pegmatite and gabbroic dikes (Fig. 2.8; Kelley, 1968; Condie and Budding, 1979; Moore et al., 1988; Sherer, 1990). Such rocks, although locally present in some Proterozoic terranes of New Mexico, are not the major lithologies.

Preliminary data by Moore et al. (1988) suggests a complex mineralogic assemblage consisting of essential K-feldspar, plagioclase, and arfvedsonite and accessory riebeckite, quartz, eudialyte, fluorite, monazite, apatite, biotite, rutile(?), sphene, aegirine-augite and zircon. Sherer (1990) reported the occurrence of zirconium silicates, lanthanide minerals and several yttrium-bearing minerals. Selected chemical analyses indicate the Proterozoic rocks are anomalously high in light rare-earth elements (La as high as 1500 ppm, Ce as high as 3910 ppm; McLemore, unpubl. data; Moore et al., 1988), zinc (700 ppm; Moore et al., 1988) and niobium (200 ppm; Moore et al., 1988). No feldspathoids have been observed at Pajarito Mountain (personal field reconnaissance, 1987; Sherer, 1990), although Moore et al. (1988, table 1) reported the presence of nepheline syenite. Detailed petrographic and geochemical work is needed. Some of these commodities may be economically recovered in the future.

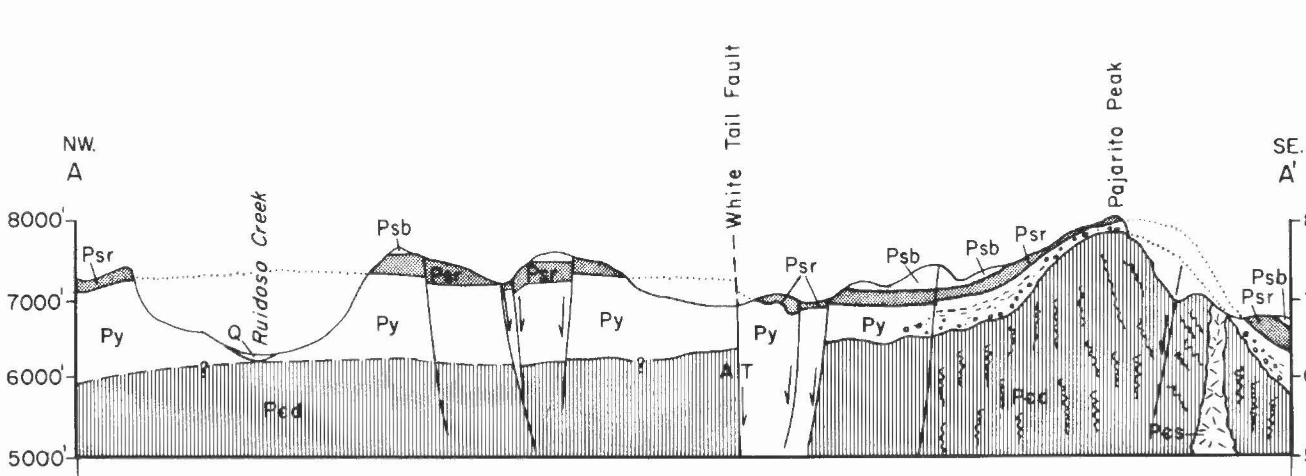

FIGURE 2.5. Northwest-southeast structure section (Kelley, 1971) showing Yeso Formation thinning over Pajarito Mountain and vicinity, a remnant of late Paleozoic Pedernal uplift.

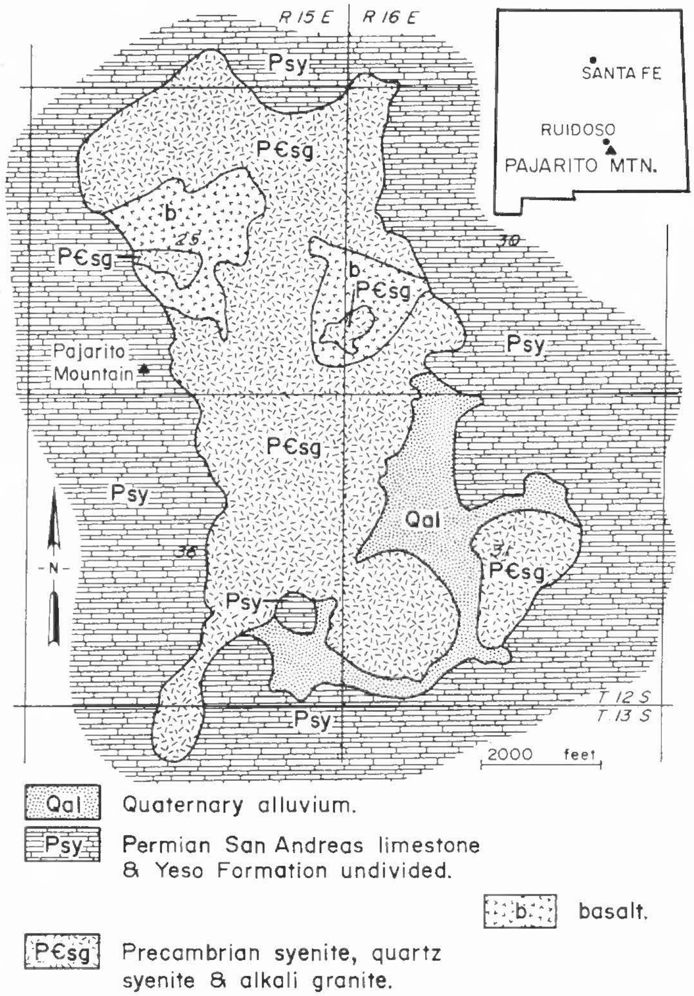

FIGURE 2.6. Geologic map of the Pajarito Mountain alkaline complex, Otero County, New Mexico (Kelley, 1968; Moore et al., 1988; Sherer, 1990).

Molycorp has announced a recoverable resource of 2.7 million tons grading 0.18% Y_2O_3 and 1.2% ZrO_2 in the northern part of Pajarito Mountain (Sherer, 1990). Eudialyte is the major ore mineral and is disseminated in the alkaline rocks at Pajarito. Eudialyte is a zirconium silicate containing yttrium and is generally amenable to heap-leach recovery. Molycorp plans to mine the deposit by open-pit methods and process the ore on site (Sherer, 1990). Currently, Molycorp is preparing environmental impact and development plans. This will be the first deposit in the world to be mined exclusively for yttrium and zirconium, which are typically produced as co-products or by-products of mining other elements (U.S. Bureau of Mines, 1989). However, the development of this resource is dependent upon the ever-changing market and demand for these high-technological products.

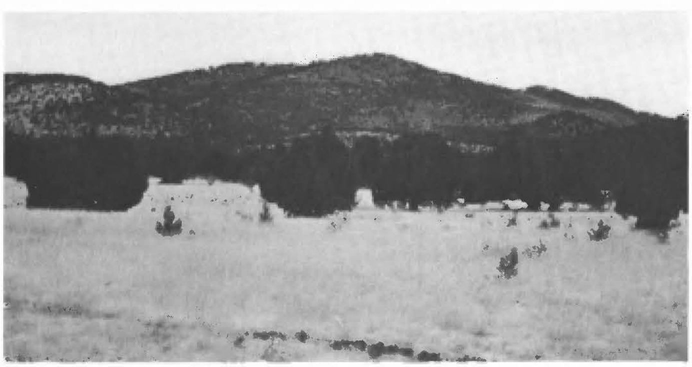

FIGURE 2.7. View of Pajarito Mountain, looking south.

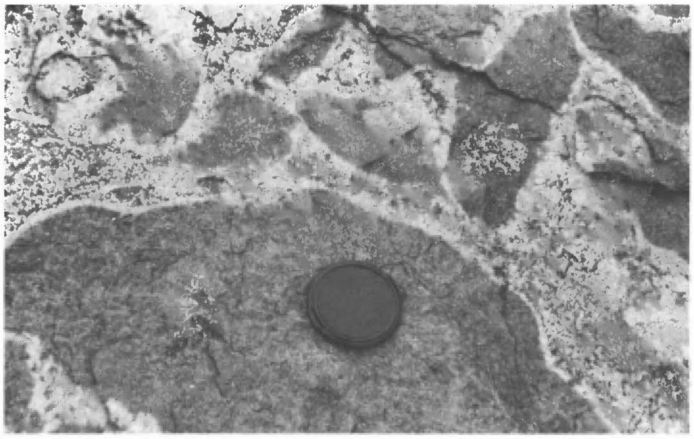

FIGURE 2.8. Gabbro-syenite breccia at the Bare Dome area of the Pajarito alkaline complex.

Yttrium is used in phosphors in color televisions and computer monitors, laser crystals, zirconia electrolytes, superalloys, catalysts and substrates, heating elements, synthetic garnets for microwave and other electronic applications, and ceramics and glass. Orpac, Inc. has introduced an yttrium concrete and yttrium may have potential use in superconducting magnets. Zirconium is used in foundry sands, refractories, ceramics and abrasives (U.S. Bureau of Mines, 1989).

The origin and genesis of the Pajarito Mountain complex is speculative at present, due to the lack of detailed petrographic and geochemical studies. The complex lies in the southern portion of a northeasterly belt of anorogenic, middle Proterozoic, plutonic magmatism that extends across North America (Fig. 2.9; Anderson, 1983; Woolley, 1987). The alkaline plutonic rocks within this belt were probably a result of complex differentiation and fractionation of an upper-mantle or lower-crustal source as indicated by alkaline lithologies and enriched rare-earth elements. Specific details of the genesis require detailed petrographic, geochemical and isotopic studies.

Access to the Pajarito Mountain deposit is restricted and permission must be obtained from the Mescalero Indian Tribe and Molycorp, Inc., before entering the area. Many thanks to Robert Eveleth and George Austin for reviewing an earlier version of this manuscript. Thanks to

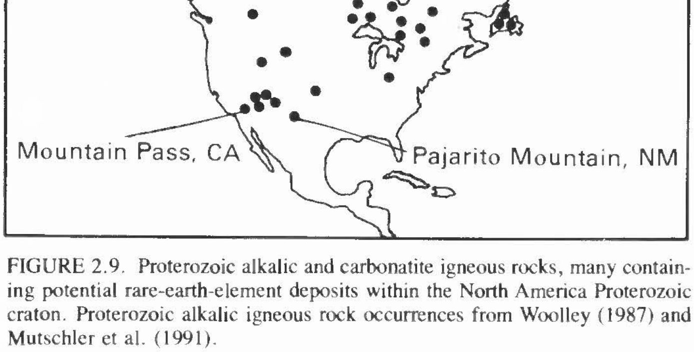

FIGURE 2.9. Proterozoic alkalic and carbonatite igneous rocks, many containing potential rare-earth-element deposits within the North America Proterozoic craton. Proterozoic alkalic igneous rock occurrences from Woolley (1987) and Mutschler et al. (1991).

Theresa Lopez for typing the manuscript. Fig. 2.6 is reprinted from New Mexico Geology (v. 12, p. 21), with permission.

20.2 Milepost 276. Roadcuts in Quaternary alluvium on left next 1.8 mi. **0.6**

20.8 Skyline ridge at 11:00–1:00 is San Andres Formation. **2.0**

22.8 Folded Yeso Formation in roadcuts on left contains dolomite units as much as 2 m thick. **0.1**

22.9 Yeso–San Andres contact on left. **0.4**

23.3 Deformed beds of Yeso Formation on left. **0.6**

23.9 Roadcut in slide block of San Andres Formation. **0.3**

24.2 Milepost 280. Deformed beds of Yeso Formation overlain by Quaternary sand and gravel on left, next 2.0 mi. **0.7**

24.9 Roadcuts in Yeso Formation at left. **0.5**

25.4 Town of San Patricio (home of artist Peter Hurd) in valley to right (Fig. 2.10). Approaching Stop 1 on left. **0.5**

25.9 **Turn left into quarry** to examine exposures of Yeso Formation and San Andres Formation in quarry. **STOP 1.** The purpose of this stop is to examine the transition between the Yeso Formation and the overlying San Andres Formation, both of Permian age (Fig. 2.11). The Yeso at this location consists of a series of sandstone, limestone or dolomite and gypsum cycles that are characteristic of the Torres Member of the Yeso Formation in central New Mexico. The quarry is floored by one of these carbonates and is overlain by a red sandstone followed by a yellowish gray sandstone. A gypsum usually occurs with the yellowish gray sandstone. The cycle is again capped by dolomite or oolitic limestone. One cycle is 9 m thick. Two cycles are exposed here below the San Andres contact. Of prime interest is the lack of the two upper members of the Yeso Formation, the Cañas Gypsum Member and the Joyita Sandstone Member. The Cañas is missing because there was no shoreline salina present. The Joyita Sandstone is missing because there is no Glorieta Sandstone present below the San Andres east of the Pedernal axis. The Joyita Sandstone is directly related to the Glorieta Sandstone, representing a transition from a hypersaline shoreline-sabkha environment to an offshore bar-beach complex.

The contact with the overlying San Andres is sharp and may represent a period of subaerial exposure or erosion. This suggests the San Andres transgression was rapid in this area. Milner (1976) reported a series of evaporitic and non-evaporitic facies for the San Andres. Although evidence for the presence of evaporites is ambiguous, the occurrence of length-slow chalcedony suggests deposition in hypersaline conditions. It seems then, the base of the San Andres is nearly identical to the carbonates found in the underlying Yeso Formation. The primary difference is, of course, stability of the environments in the San Andres. Further work is needed to demonstrate differences and similarities between the Yeso and San Andres carbonate rocks.

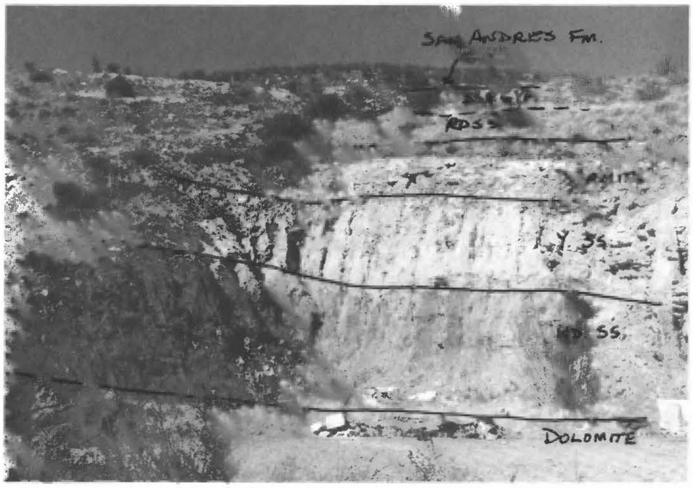

FIGURE 2.11. Yeso (bottom) to San Andres (top) transition at Stop 1.

FIGURE 2.10. The Peter Hurd gallery in San Patricio.

Retrace route and continue east on US-70. 0.5

26.4 Crossing White Tail buckle, one of many northeast-trending, right-lateral strike slip faults in the region (Fig. 2.12). **0.4**

26.8 Roadcut on left in large slump block of San Andres Formation. Block has been displaced at least 70 m. **0.8**

27.6 Deformed Yeso Formation locally overlain by San Andres in roadcuts, next 0.9 mi. **0.5**

28.1 Milepost 284. **0.4**

28.5 Town of Hondo to right. **0.3**

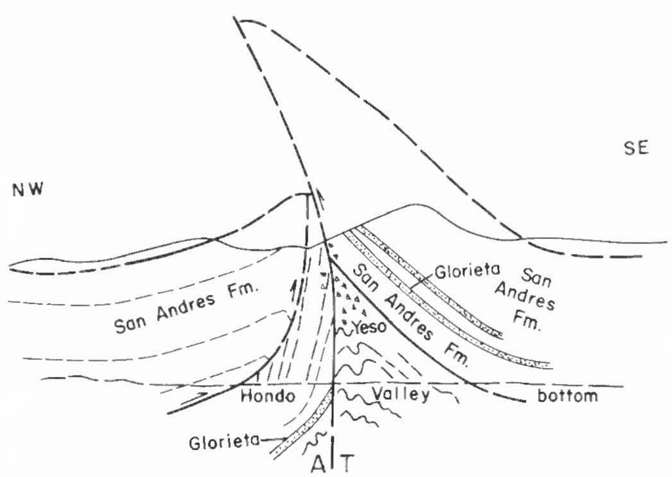

FIGURE 2.12. Structure section through Border Buckle of Hondo Canyon (Kelley, 1971) showing combined compressional and strike-slip deformation that is characteristic of the major buckles on the Pecos Slope.

28.8 Bridge over Rio Bonito, which joins Rio Ruidoso 0.5 mi downstream to form Rio Hondo. **0.2**

29.0 **Junction** of US-70 with US-380.

End of Part One, Second-Day Road Log.

PART TWO: HONDO TO CAPITAN AND CAPITAN IRON MINES

Mileage

0.0 **Junction** of US-70 with US-380. **Proceed west** on US-380. **0.4**

0.4 Poorly exposed Yeso Formation on left, overlain by San Andres Formation. **0.4**

0.8 Quaternary colluvium and alluvium in roadcuts, next 0.4 mi. **0.2**

1.0 Tilted slump block of San Andres Formation at 9:00. **0.6**

1.6 Historical marker on right (Fig. 2.13). "Fritz family cemetery, est. 1882. Fritz family was prominent and influential in history of Lincoln County." Fritz Spring is nearby to north; aquifer is Glorieta Sandstone Member. **0.2**

1.8 Quaternary sand and gravel in roadcuts, next 0.3 mi. **0.6**

2.4 Roadcut in Yeso Formation on right. **0.2**

2.6 Folded Yeso Formation in roadcut on right. **0.3**

2.9 On left, bridge over Rio Bonito to La Feliz Montaña Ranch. **0.3**

3.2 Begin series of roadcuts in Yeso Formation and slump blocks of San Andres Formation, next 0.6 mi. **0.6**

3.8 Contact between Yeso Formation and San Andres Formation in roadcut on right. Yellow sandstone is lower tongue of Glorieta Sandstone Member of San Andres Formation (Milner, 1978). **0.2**

4.0 Milepost 104. **0.4**

4.4 Note subhorizontal bedding and lack of deformation in ledge-forming San Andres Formation at 9:00–12:00. **0.8**

5.2 Entering Lincoln Historic District. Bridge crosses Rio Bonito; roadcut beyond bridge on left exposes Yeso Formation (red, green and gray beds) and Glorieta Sandstone Member (yellow) and Rio Bonito Member (gray) of San Andres Formation. Glorieta Sandstone Member interfingers with carbonates of Rio Bonito Member and pinches out to the south (Kelley, 1971; Milner, 1978). **0.8**

FIGURE 2.13. Grave markers in the Fritz family cemetery.

6.0 Milepost 102. Quaternary colluvium in left roadcut. **0.4**

6.4 Ledges of San Andres Formation across valley to right. **0.4**

6.8 At 2:00, weakly deformed beds of San Andres Formation. **0.5**

7.3 Strongly deformed beds of Yeso Formation underlie gently folded San Andres Formation at 1:00–2:00. **0.7**

8.0 Milepost 100; **STOP 2. Turn right into pasture and park.** Good view of Lincoln folds (Fig. 2.14), with folded Yeso Formation beneath undeformed San Andres Formation. Workers have variously attributed the folding to landsliding, drag folding, regional deformation and forceful igneous intrusion. **Continue west** on US-380. **0.7**

EVALUATION OF BASEMENT CONTROL ON THE FORMATION OF THE NORTHERN TINNIE FOLD BELT, SOUTHEASTERN LINCOLN COUNTY, NEW MEXICO

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The origin and genesis of the Tinnie fold belt, the Lincoln folds, and the associated folds and buckles to the east have long been the subject of widespread speculation and theorizing. Numerous interpretations involving the origin and structure of the Lincoln and Tinnie folds have been presented, including Semmes (1920), Knapp (1933), Panhandle Geological Society (1939), Kelley and Thompson (1964), Craddock (1964) and Foley (1964).

Efforts to investigate basement control on the development of the overlying sedimentary structures have been sparse. Bucher (1956), Dennis and Hall (1978) and Dennis et al. (1985) presented experimental models that simulate the structural and stratigraphic conditions as they occur in the Tinnie folds. These models incorporate lateral (west to east) movement along a decollement surface above a generally undeformed basement. The Sierra Blanca igneous activity may have provided a vertical force on the Yeso Formation, which was converted to horizontal force farther east. Dennis et al. (1986) suggested that this horizontal force provided the dynamics for folding of the relatively soft intercalated evaporites and limestones of the Yeso Formation near Lin-

FIGURE 2.14. Aerial view of Lincoln folds in Yeso Formation near Stop 2. Note subhorizontal dip of overlying San Andres Formation.

coln, as well as the limestones of the overlying San Andres Formation farther east. The folding of the San Andres Formation is spatially coincident with its decreased thickness east of Lincoln.

A necessary element of this fold-genesis model is a disturbance or abutment in the basement surface that impedes lateral movement and sets the location and extent of the observed folding. In an attempt to identify whether such a vertical, basement anomaly actually exists in the Tinnie area, a detailed gravity and magnetic survey was conducted across the Tinnie fold belt extending from US-70 and US-380 to the Capitan Mountains. The following discussion presents the findings of this survey, as well as the major structural features of the Tinnie fold belt north of the latitude of Escondido Creek. More detail concerning the geophysical evaluation of the basement and the geology of the Tinnie folds was presented by Burt (1989).

The Tinnie fold belt of this study occurs north of Tinnie, New Mexico, and is an intensely folded portion of a much larger fold and fault system that is some 50 mi wide, stretching from the Sierra Blanca to east of Roswell. The Tinnie folds involve San Andres Formation limestone and Yeso Formation lithologies, and consist of a series of long, closely spaced, tight to moderately tight anticlines and synclines. The limbs of the folds dip steeply to moderately steeply and are in places overturned. In a section about 4 mi north of Tinnie, a well-developed and exposed fan fold with convergently dipping beds straddles NM-368. Locally, folding is asymmetrical and/or the limbs are separated by broad, flat, or mildly synclinal surfaces which tend to create box-like fold characteristics.

Folding within the Yeso is commonly tighter than in the San Andres, owing mostly to the contrast in competency between the two formations. Wavelengths in the San Andres, measured from anticline crest to crest, average about 1500 ft (Kelley, 1971; Craddock, 1964). In contrast, Yeso fold wavelengths, measured west of the study area, average about 700 ft between adjacent anticline crests (Craddock, 1964). The Yeso is moderately to strongly folded virtually everywhere it is exposed. Exposures of the Yeso are often found in valleys that coincide with breached anticlines.

The primary fold axes of the Tinnie fold belt north of Escondido Creek are shown on Fig. 2.15. The divergence of the folding shown on the figure occurs at about the latitude of Escondido Creek. A total of 16 principally south-plunging anticlines and synclines are present north of Escondido Creek. These folds are separated into two groups by a broad, flat, generally unfolded area of San Andres Formation rocks. Burt (1989) presented a detailed evaluation of the Glorieta Sandstone interval in the northern Tinnie folds, and the relationship of the Tinnie folds north of Escondido Canyon to the main trunk folds south of the creek. Glorieta Sandstone forms the primary marker lithology in this portion of the Tinnie fold belt.

Kelley (1971) characterized the Tinnie folds as an anticlinorium, based on cross sections drawn near US-70 and US-380. This characterization is all but lost farther north in the vicinity of Escondido Creek, where the folding widens and is generally more asymmetrical. A cross section depicting the folds in the Escondido Creek area is shown on Fig. 2.16. There is no surface expression of faulting in the northern Tinnie fold belt, and there is no common fold vergence.

A gravity survey and three magnetic traverses were conducted across the Tinnie fold belt. The gravity survey extended through the town of Tinnie along US-70 and US-380. The three magnetic traverses were located along US-70 and US-380, at the southern base of the Capitan Mountains (on a U.S. Forest Service access road), and at the latitude of the radio tower located about 4 mi north of Tinnie.

Gravity measurements were collected at 40 stations spanning more than 10 mi across the Tinnie folds. Measurements were obtained using a La Coste and Romberg temperature-controlled gravimeter (model G300). Each station was occupied until at least two readings agreed to within 6 µgal. The field data were reduced to simple Bouguer anomaly values in accordance with the procedures described by Dobrin (1976). An average density value of 2.67 gm/cm^3, representing the dense limestone and basement rocks in the field area, was used in the data reduction and modeling. The average density of the lithologies overlying the

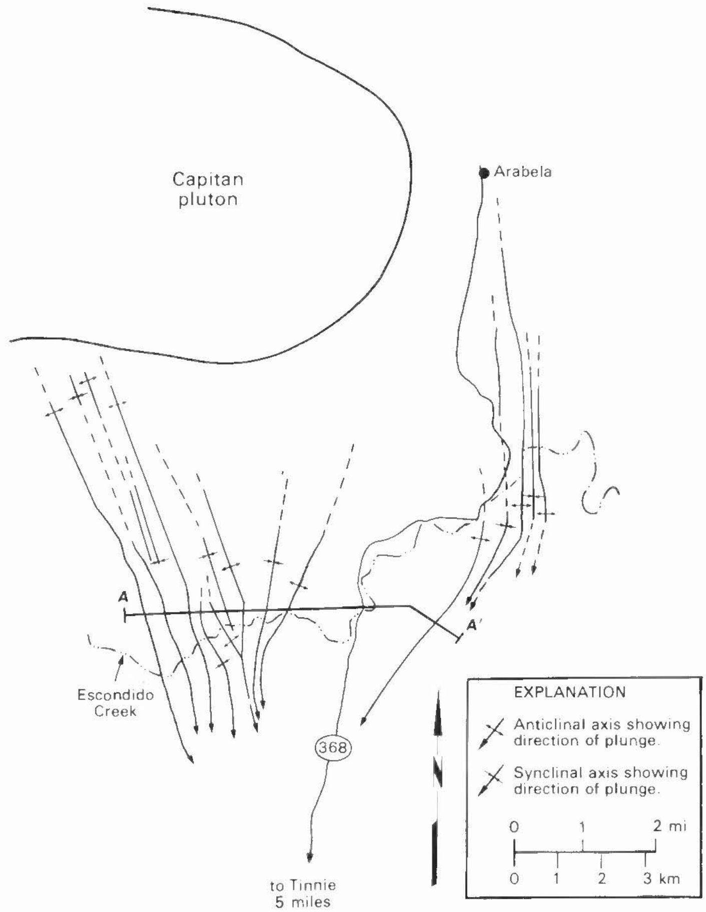

FIGURE 2.15. Map showing primary fold axes of the northern Tinnie fold belt and line of section in Fig. 2.16.

basement was estimated to be 2.47 gm/cm^3. These lithologies include the siltstone, sandstone, thin-bedded dolomite, limestone and gypsum of the Yeso Formation and, to a lesser extent, the underlying sandstone, shale and conglomerates of the Abo and Bursum Formations presumed to exist in this area. The regional gravity gradient through the Tinnie area was removed from the observed Bouguer anomaly values using data obtained from Keller and Cordell (1983). The resulting residual Bouguer anomaly values were used in the evaluation of the basement structure.

The gravity profile was quantitatively modeled using a computer program called GSLAB (Phibbs, 1988). This program calculates the gravity for partially infinite slabs, which are added together to approximate the shape of the structure best fitting the observed anomaly profile. Through multiple iterations using various lithologic and structural geometries, a best-fit solution was obtained representing a reasonable interpretation of the basement configuration that satisfies the observed gravity anomaly data.

Magnetic measurements were collected at 96 stations along the three traverses across the Tinnie folds. Station spacing was maintained at 0.1 mi intervals where possible. Measurements were obtained using a Geometrics Proton Precession hand-held magnetometer with a precision of 5 γ. The instrument was positioned facing north at each station, and measurements were recorded only after three separate readings agreed to within 2–3 γ. The data were reduced by subtracting out magnetic field diurnal variations and instrument drift, and modeled using the formula given by Telford et al. (1976). This model uses horizontal, thin sheets to approximate subsurface structural geometries in a manner similar to that of the GSLAB model. The overburden was given a susceptibility value of zero, and the basement was given a value obtained from Telford et al. (1976) of 0.0003 emu, which is slightly greater than the average value for granite.

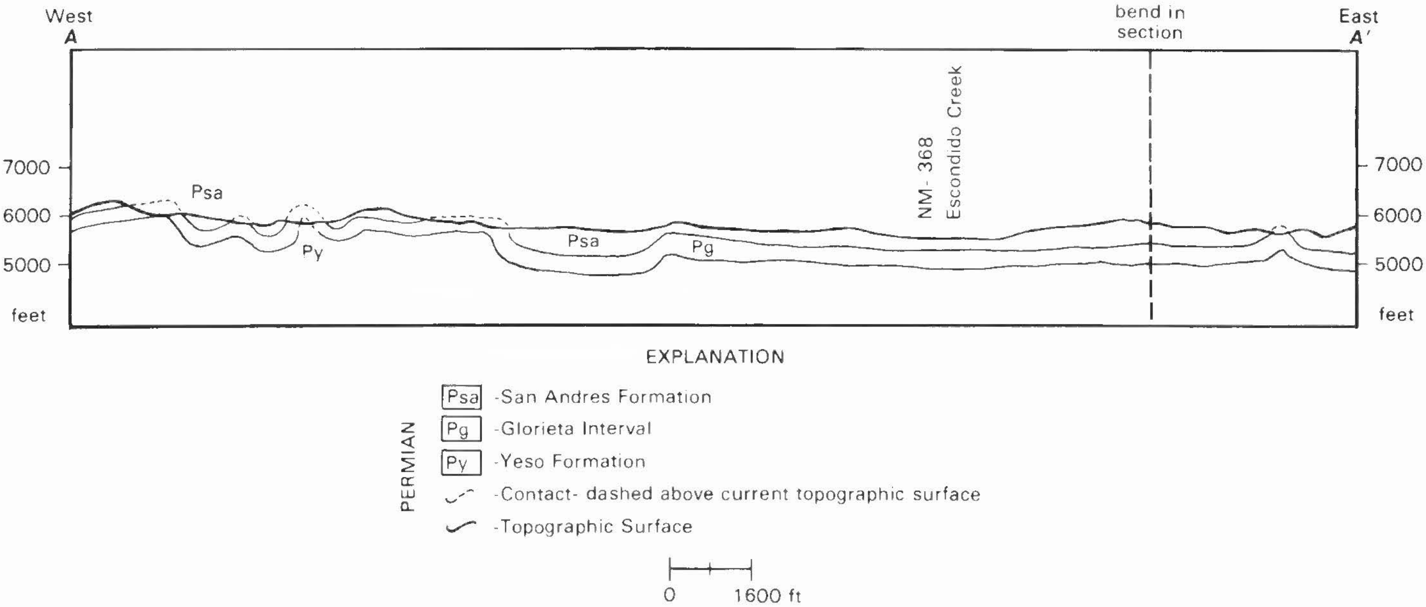

FIGURE 2.16. Cross section of northern Tinnie fold belt. Line of section shown in Fig. 2.15.

A distinct, positive, gravity and magnetic anomaly was observed coincident with the Tinnie fold belt. The gravity anomaly spans a lateral distance of at least 4.5 mi with a magnitude of over 3.5 mgals (Burt, 1989, pl. 5). The modeled structure that most closely matches the signature of the observed gravity profile represents horizontal relief on the basement surface of some 6000 ft. The top of this surface is now at a depth of about 4000 ft below ground. This depth is reasonable in relation to basement depths observed in other parts of the Tinnie fold region. The shape of the basement structure depicted in the model is asymmetrical, with a slope of nearly 70° on the eastern side, a relatively flat upper surface, and a slope of about 45° on the west. The structure is almost 4 mi wide in an east/west direction, and extends from at least Tinnie to the Capitan Mountains. The magnetic anomalies depicted in the three profiles varied in magnitude, but the modeled data are consistent with the basement structure identified by the gravity model, including its asymmetry.

The findings of the gravity and magnetic portion of this study indicate that basement structure control has had a direct influence on the location and extent of folding of the Tinnie fold belt. Interpretation of the gravity and magnetic surveys resulted in complementary models that allow three-dimensional visualization of a linear, roughly north-south-trending uplift of the basement surface directly beneath the surface expression of the Tinnie fold belt. The relationship between this basement structure and the Capitan pluton is as yet unclear. Qualitative interpretation of magnetic survey data suggests that the Capitan pluton uplifted the basement structure during intrusion, or otherwise increased its relief.

In order for this locally uplifted basement surface to have had a significant effect on the origin of the Tinnie fold belt, decollement-style horizontal movement of rocks overlying the basement probably occurred. The basement structure acted as an impediment to eastward flow of overlying pre-Yeso(?), Yeso and San Andres strata, which resulted in the initiation of folding in the Tinnie area. According to this model the Yeso Formation, due to its high evaporite content, acted as the decollement surface and was more tightly and complexly folded than the more competent limestones of the overlying San Andres Formation.

I thank Roswitha Grannell of California State University, Long Beach, for her input and support throughout this study, and the late John G. Dennis, also of CSULB, for developing the working model utilized in this endeavor and for his support during the structural geology evaluation.

8.7 Folded Yeso Formation across valley to right. **0.4**
9.1 Cemetery to right. **0.1**
9.2 Official Scenic Historic Marker: "Lincoln—Spanish-speaking settlers established a town here in the 1850's, after the U.S. Army began to control the Mescalero Apaches. First known as Placitas del Rio Bonito, the name of the community was changed to Lincoln when Lincoln County was created in 1869." **0.4**
9.6 Entering Lincoln, center of the Lincoln County War (1876–1881). **0.1**

THE LINCOLN COUNTY WAR AND THE LEGEND OF BILLY THE KID

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"They all wanted to kill somebody. Every son-of-a-bitch wanted to kill somebody."—J. Evetts Haley (Utley, 1987, p. 65)

The town of Lincoln, with a population of about 400 in the late 1870s, was typical of the Old West. Hostility abounded, fed by the quest for money and power, as well as by the code of the West. The code demanded personal courage, with total disregard for life, and instant response to insult, no matter how trivial. Almost everyone carried a gun and stood ready to shoot it out at the slightest provocation. This readiness was inflamed by the constant availability, and use, of whiskey.

Not that there wasn't ample reason for hostility on the part of the citizens of Lincoln. Fort Stanton had been established 9 mi from Lincoln in 1855. Major Lawrence G. Murphy came to Fort Stanton with the Army. After he was released from service for questionable behavior, he established the only store in the area and was the sole provider for both Fort Stanton and the Mescalero Apache Indian Agency. This monopoly extended to the residents, and Murphy took ruthless advantage of the situation, inflating prices and issuing scrip for services rendered. The scrip ensured the continuing loyalty of people such as the local sheriff. As Murphy's health failed, due at least in part to his heavy drinking, he sold out to James Dolan and John Riley.

When Alexander McSween arrived on the scene, he decided to challenge the Murphy-Dolan-Riley monopoly and built the area's second store. The venture was financed by a wealthy young Englishman named John Henry Tunstall, who had come to the American West determined to make a fortune. The populace in general supported this challenge to the Murphy monopoly.

Hostility built, and on February 18, 1878, Tunstall was either murdered in cold blood, or killed while resisting arrest, depending on which story one believes. The fatal shooting was done by possemen deputized by the local sheriff, William Brady, who was in the Murphy camp at least in part becasue he was paid in their scrip.

Tunstall's shooting was avenged in early March when "The Regulators," McSween supporters, killed two members of the posse, including Sheriff Brady. One of the members of The Regulators, known as Billy Bonney, Kid Antrim, or just The Kid, was insignificant at the time. Later he would become the subject of a multitude of books, stories and movies . . . as Billy the Kid.

Skirmishing between the Murphy and McSween forces escalated. On July 14, 1878, some 60 men assembled at the McSween house. The next day approximately 40 men on the opposing side gathered just down the street at the Wortley Hotel (which was renovated in 1960 and is today an operating hotel), and July 15 is considered the official beginning of the Lincoln County War.

The next two days saw only sporadic fighting and few shots, but many verbal insults. During these days, as well as throughout the preceding months, the citizens of Lincoln had appealed to the soldiers of Fort Stanton for assistance. On the evening of the 18th the soldiers finally arrived, but only to protect women and children.

The actual effect of the army's presence was to get in the way of McSween's supporters; they could not shoot from the house without risking hitting a soldier. Gradually the supporters drifted away, until only McSween, his wife, Susan, and about 14 men were left.

The Murphy forces, seizing their advantage, torched the McSween house on July 19. Alex McSween and two supporters were killed; Alex was reportedly gunned down as he stood outside, silhouetted against the flames and offering to surrender. The others, including Billy Bonney, managed to escape.

McSween's killing marked the end of the Lincoln County War. It had not been a range war or a blood feud, as it is frequently pictured. It was a fight between business competitors, aided by opposing political factors. It was a war with very little real leadership—a war without heroes.

On the other hand, the legend of Billy the Kid was forming. According to one description, "He came to Lincoln County late in October 1877, a few weeks after his eighteenth birthday and thus hardly out of adolescence. He looked his youth—140 pounds, spare, of medium stature, with brown hair, light complexion, and a smooth face betraying the downy beginnings of a beard and mustache. Two squirrel-like front teeth slightly marred his appearance. He rode well and shot well and practiced all the time. With agreeable and winning ways, he made friends easily." (Utley, 1986, p. 21–22)

Billy the Kid's route to the Lincoln County Jail was as convoluted as events leading to the Lincoln County War. It involved Governor Lew Wallace and a trumped-up arrest, followed by a trial in Mesilla. The Governor apparently could not control the trial, as he had promised Billy he would, in return for Billy's testimony in another murder trial.

As a result of the trial, Billy was confined in Lincoln County's newly acquired courthouse . . . the old Murphy-Dolan-Riley store. On April 28, 1881, Billy killed two deputy sheriffs, using a gun that very likely was hidden in the outhouse, and escaped.

By this time, Pat Garrett had arrived on the scene. He lived at Fort Sumner and was elected sheriff in 1880. On July 14, 1881, Sheriff Garrett shot and killed Billy the Kid.

The legend of Billy the Kid lives on, and Billy would probably be pleased, maybe even amused. For example, he is said to have killed one person for each of his 21 years. According to records, however, he didn't wreak anywhere near that much havoc and destruction. He was not a leader, much less a heroic figure, and he played a rather nondescript part in the Lincoln County War.

The Lincoln County War lasted only five days. As wars go, few shots were fired and few people were killed. But from this war and the subsequent events sprang the legend of Billy the Kid. Thus the Lincoln County War became part of the lore of the West, and each year thousands of tourists visit the town of about 75 residents. The visitors wander through the four museums, including the old courthouse from which Billy the Kid made his escape, and during the first weekend of August thrill to the annual reenactment of the escape. It is intriguing to visit Lincoln, and to visualize the events that history and legend say happened there!

9.7 Folded beds of Yeso Formation across the valley at 3:00. **0.5**

10.2 Old Lincoln County Courthouse on left (Fig. 2.17). Pat Garrett arrested William H. (Billy the Kid) Bonney and imprisoned him in an upstairs room in the courthouse. Bonney made a dramatic escape on April 28, 1881, killing deputies Bell and Ollinger in the process. **0.6**

10.8 Folded beds of Yeso Formation at 3:00. **0.3**

11.1 Yeso Formation in roadcut on left. **0.2**

11.3 Bridge; folded Yeso Formation in roadcuts. **0.7**

12.0 Milepost 96. Good view of San Andres–Yeso contact at 2:00. **0.7**

12.7 Quaternary gravels in roadcuts. **0.1**

12.8 Bridge crosses arroyo. **0.8**

13.6 Yeso Formation in roadcut on left. **0.3**

13.9 Road to Salazar Canyon and Baca Camp Site on right. **Continue east on US-380.** We are now crossing the crestal area of the Mescalero arch (Kelley and Thompson, 1964; Kelley, 1971), a broad north-northeast-trending structural culmination that divides the gently east-dipping (average 1°) ramp of the Pecos slope on the east from the faulted, generally west-dipping flank of the Sierra Blanca basin on the west. **0.1**

14.0 Roadcut on left exposes rubbly San Andres Formation and Yeso Formation. Brecciation may be due to proximity to northeast-trending, down-to-the-southeast fault (Kelley, 1971, pl. 1) in valley to right. US-380 parallels this fault, next 2.5 mi. **0.5**

14.5 Yeso Formation in roadcut on left. **0.5**

15.0 Exposures of San Andres Formation across valley at 3:00. **0.5**

15.5 San Andres Formation in roadcut on left. **0.2**

15.7 Bridge over arroyo; Sierra Blanca at 12:00. **0.2**

15.9 Leaving Lincoln Historic District. **0.3**

16.2 Outcrops of gently dipping San Andres Formation across valley to right. **0.3**

FIGURE 2.17. The famous Lincoln County Courthouse, scene of Billy the Kid's last escape.

16.5 Unpaved road on left to Ft. Stanton Cave (also called Government Cave; Hallinger, 1964). Sierra Blanca at 11:00. **0.3**

16.8 Bridge over Rio Bonito. **0.4**

17.2 Bridge crosses arroyo. Approximate contact between San Andres Formation and overlying poorly exposed Permian red siltstones and mudstones. The lower part of the Artesia Group in parts of Lincoln County, the Grayburg and Queen Formations (Tait et al., 1962), has been identified as "Bernal Formation" by some previous workers (Smith and Budding, 1959; Smith, 1964; Weber, 1964; Kelley, 1971). However, as Tait et al. (1962) and Lucas and Hayden (1991) noted, the name Bernal, introduced for a truncated remnant of the lower Artesia Group in north-central New Mexico by Bachman (1953), does not need to be used in southeastern New Mexico where the constituent formations of the Artesia Group can be recognized. Indeed, these authors favored abandoning Bernal Formation altogether, and replacing it with Artesia Formation in north-central New Mexico at the thinned and eroded edge of the outcrop belt of these Upper Permian clastic shelf deposits. **0.3**

17.5 Capitan Mountains on right skyline. The Capitan pluton has recently been dated at 26.5 ± 1.2 Ma (Allen, 1988). **0.5**

18.0 **Junction** with NM-214 on left; **turn left** on to NM-214. Nearby hills at 2:00 are capped by silica-pebble conglomerate (Fig. 2.18) of Upper Triassic Santa Rosa Formation. Official Scenic Marker on right: "Fort Stanton (1855–1896)—Fort Stanton, named for Captain Henry Stanton, was established to control the Mescalero Apaches. It was burned and evacuated by Union troops in 1861, held briefly by the Confederates, and then reoccupied by Colonel Kit Carson for the Union in 1862. Since its abandonment as a military post, it has been used as a hospital." **0.2**

18.2 Junction with dirt road on right. **Turn right and go through gate. 1.2**

19.4 **STOP 3. Park in saddle** and walk up steep dirt road on left to top of hill for overview of tectonics and stratigraphy of Sierra Blanca basin and discussion of economic geology of Capitan Mountains (Figs. 2.19, 2.20). **Retrace route to junction of NM-214 and US-380. 1.4**

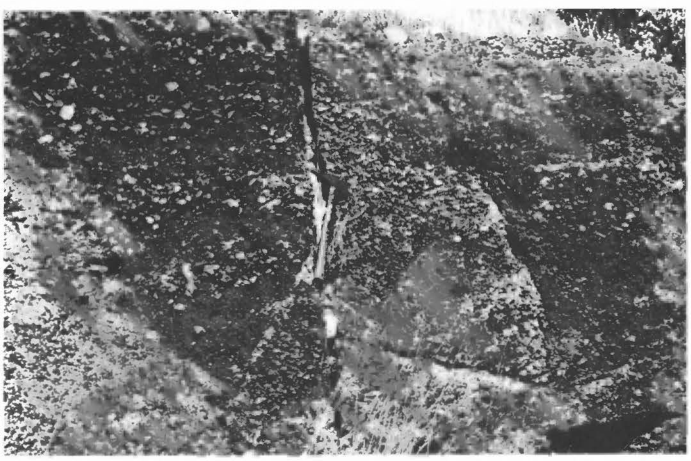

FIGURE 2.18. Silica-pebble conglomerate in Upper Triassic Santa Rosa Formation north of mile 8.0.

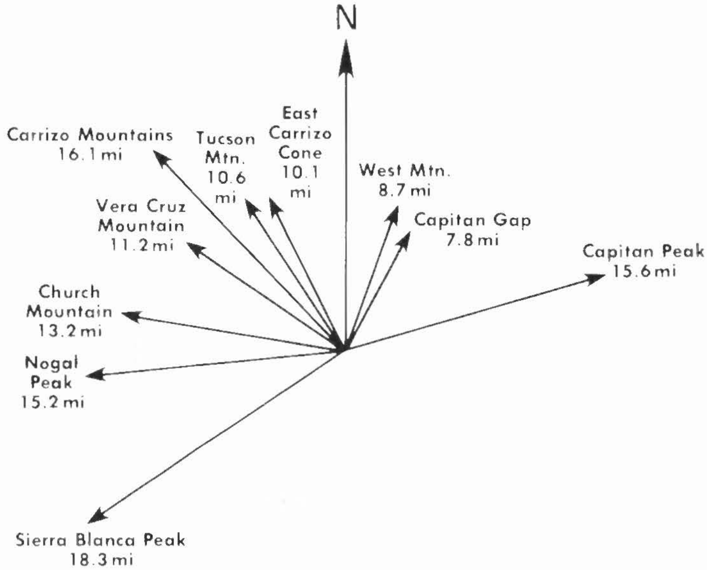

FIGURE 2.19. Panoramic index of principal landforms visible from Stop 3.

TECTONIC OVERVIEW OF THE RUIDOSO REGION

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The Ruidoso region of south-central and southeastern New Mexico contains a variety of tectonic elements of diverse age and origin. At least three episodes of deformation (late Paleozoic, Late Cretaceous–early Tertiary and middle to late Tertiary) have left their imprint on the area during the Phanerozoic, and there is much evidence for reactivation of older basement structures by subsequent tectonism. Despite a long history of geologic investigation in the area, the kinematic history of many structures is incompletely known. The following is a brief synopsis of the major tectonic features of the Ruidoso area (Fig. 2.21).

The Sacramento uplift is a large, east-tilted fault block that forms the prominent escarpment to the east of the Tularosa Basin. Regional dip of bedding in the uplift is about 1° eastward, although structural complications locally abound (Pray, 1961). At least two episodes of pre–Basin-and-Range deformation are indicated. During Late Pennsylvanian–Early Permian (pre-Abo) time, numerous north-trending folds and high-angle, mostly normal, faults formed within the Sacramento uplift (Pray, 1961), contemporaneous with the maximum subsidence in the Orogrande basin to the west. It is perhaps significant that the Sacramento uplift coincides approximately with the southern part of the late Paleozoic Pedernal uplift, and that the structural transition between the Pedernal uplift and the Orogrande basin (Kottlowski, 1960) occupied the same area as the present-day normal faults that divide the Sacramento uplift from the Tularosa Basin.

FIGURE 2.20. Northward view of Capitan Gap from Stop 3.

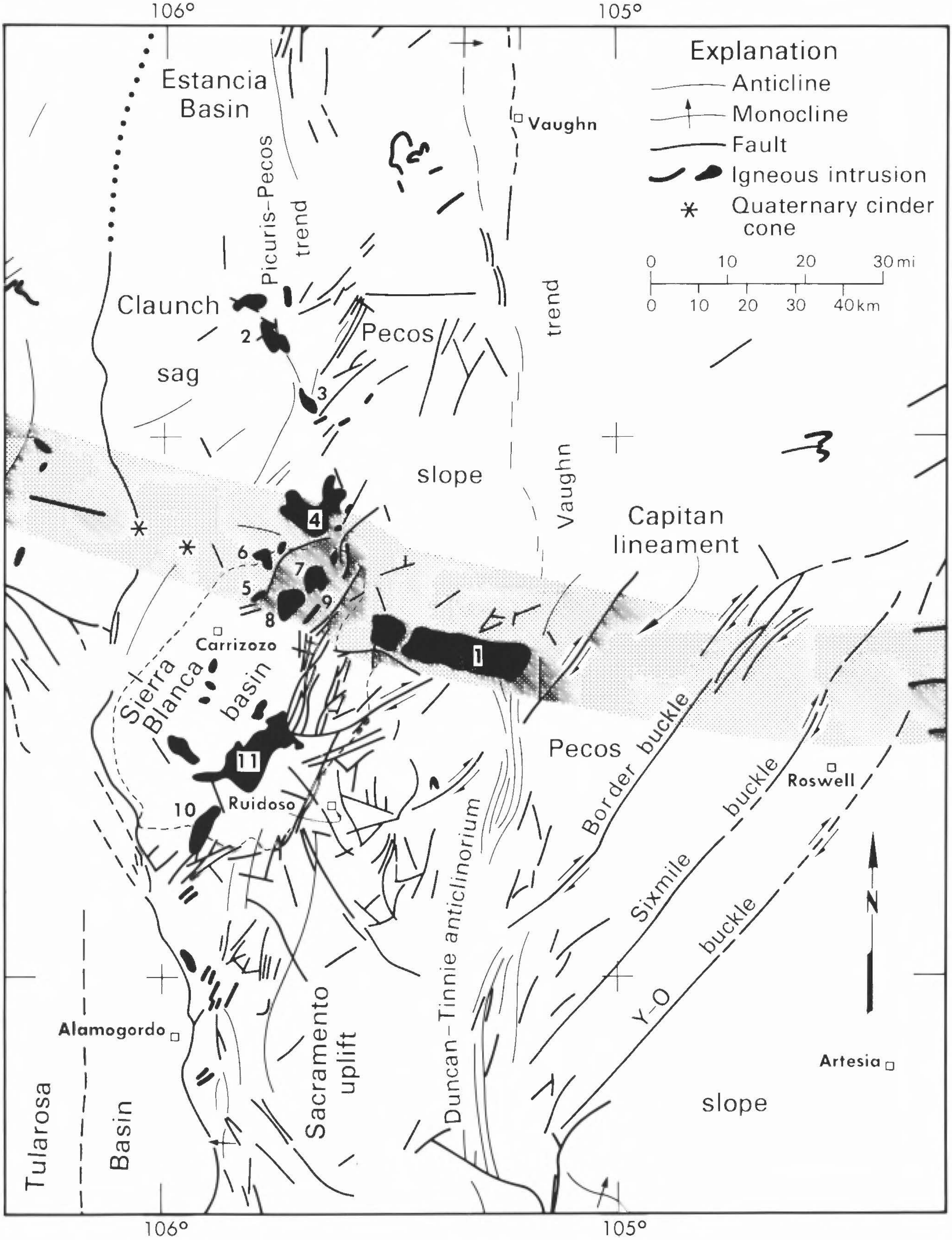

FIGURE 2.21. Tectonic map of the Ruidoso region, modified from Kelley and Thompson (1964), Kelley (1971, 1972), Woodward et al. (1978) and New Mexico Geological Society (1982). Numbered intrusives of Lincoln County porphyry belt are keyed to Table 2.1.

Low-angle thrust faults and associated folds occur locally near the western escarpment of the range (Pray, 1961, p. 131). The faults cut rocks as young as Pennsylvanian and are, in turn, cut by dikes and sills that may be as old as late Eocene (Asquith, 1973). These Laramide(?) thrusts verge eastward and are of distinctly different structural style than faults associated with either late Paleozoic or middle to late Tertiary deformation.

The Tularosa Basin, one of the principal elements of the Rio Grande rift, is a faulted, asymmetrical graben that is bounded on the east by the Sacramento uplift and on the west by the San Andres–Organ–Franklin uplift. The Tularosa Basin consists of two structural sub-basins, a shallow, gently east-tilted half-graben on the eastern side, and a deep western sub-basin (see Lozinsky and Bauer, 1991, this guidebook). Very little is known about the pre-Neogene geology of the western part of the Tularosa Basin, largely because access restrictions have denied exploration on the White Sands Missile Range. The Tularosa Basin is, in large part, spatially coincident with the late Paleozoic Orogrande basin. It is not known, however, if the late Paleozoic basinal strata were uplifted and eroded from the western part of the Tularosa Basin during subsequent Laramide tectonism (Lucas et al., 1989).

The broad area of gently east-dipping strata between the Pecos Valley and Mescalero arch (see below) was termed the Pecos slope by Kelley and Thompson (1964). Although characterized by a gentle homocline that exhibits 0.5-to-1° eastward tilt (Kelley, 1971), the Pecos slope is disrupted locally by folds and faults. The more conspicuous examples of these local structures (Dunken-Tinnie anticlinorium, Lincoln folds and buckles of the Pecos slope) are discussed below.

The Dunken-Tinnie anticlinorium is a discrete structural zone characterized by en echelon folds that overlie a narrow, north-trending block of uplifted Precambrian basement (Bowsher, 1991, this guidebook, fig. 7). Structural relief on the top of the Precambrian is about 1200 m in the southern part of the anticlinorium (Bowsher, 1991) and about 1800 m to the north (Burt, 1988, 1991, this guidebook). The majority of the uplift occurred during late Paleozoic (pre-Abo) time (Bowsher, 1991). Folding and faulting of Permian strata along the anticlinorium appear to have occurred during a subsequent episode of Paleogene tectonic reactivation (Burt, 1988).

The Border, Sixmile and Y-O buckles are long, narrow, faulted folds that are characteristic of the southern part of the Pecos slope. As noted by Kelley (1971), the linearity and the great length of the buckles relative to their small vertical displacements are indicative of a strike-slip origin, and the presence of steeply plunging drag folds, en echelon diagonal folds, and acutely left-branching spur faults argues for right-lateral displacement. Although evidence exists to suggest some late Paleozoic displacement along the Y-O buckle (Havenor, 1968; Kelley, 1971), the timing of the subsequent strike-slip deformation along the buckles is only broadly constrained between the Late Permian and the Neogene.

The Lincoln folds are not depicted in Fig. 2.21 but occur directly south of the Capitan stock near Lincoln, New Mexico. They differ from the buckles of the Pecos slope and the folds of the Dunken-Tinnie anticlinorium in that they are largely restricted to the Yeso Formation and do not involve younger units or the Precambrian basement. The Lincoln folds are disharmonic, show no systematic vergence, and range in trend from northeast to northwest. Theories of their origin are diverse, and include the effects of regional tectonism, plutonism, and both large-scale and local gravity (e.g., Craddock, 1964; Foley, 1964; Yuras, 1976, 1991, this guidebook). Timing of deformation is thought to be early Tertiary by Craddock (1964) and Yuras (1976).

The Mescalero arch is the broad structural divide that separates the Pecos slope from the structurally low areas of the Tularosa Basin, Sierra Blanca basin, and Claunch sag to the west (Kelley and Thompson, 1964; Kelley, 1971). The Mescalero arch coincides with the crestal area of the Sacramento uplift and plunges gently north-northeast, passing about 10 km east of Ruidoso to intersect the midpoint of the Capitan stock. North of the Capitan stock, the Mescalero arch steps west about 16 km and assumes a north-northwest trend (Kelley and Thompson, 1964). The Mescalero arch corresponds approximately to the axis of the late Paleozoic Pedernal uplift (Kelley, 1971).

The Sierra Blanca basin is an asymmetric structural depression of late Laramide age that exhibits a gently dipping western limb and a steeply dipping, faulted eastern limb. The Eocene Cub Mountain Formation constitutes the primary synorogenic basin-fill unit (Lucas et al., 1989; Cather, 1991, this guidebook). Following the cessation of Laramide deformation, the Sierra Blanca basin became a locus of voluminous late Eocene to Miocene volcanism and plutonism (Thompson, 1972; Moore et al., 1991, this guidebook).

The Capitan lineament is a well-defined basement-fracture zone that is manifested by both structural (Red River uplift, Matador arch, Roosevelt uplift; Ewing et al., 1990) and magmatic (Capitan stock, Jones dike, Railroad Mountain and Camino del Diablo dikes; Kelley, 1971) features. The lineament traverses much of north-central and western Texas (Ewing et al., 1990) and appears to terminate westward near Socorro. The lineament has been active at least since the late Paleozoic and has continued to leak magmas until very recently (Broken Back Crater and Little Black Peak basalt centers; Smith, 1964).

A series of north-trending faults and folds appears to be contiguous with the Picuris-Pecos fault (Miller et al., 1963) of northern New Mexico. This Picuris-Pecos trend formed the boundary between the late Paleozoic Pedernal uplift and the Estancia Basin (Kelley, 1972), and also may have influenced subsequent deformation in this region. The Picuris-Pecos trend becomes obscure to the south where it intersects the northern part of the Lincoln County porphyry belt and forms the east boundary of the shallow Claunch sag.

Described by Kelley (1972) as the southern extension of the Colorado Rocky Mountain front, the Vaughn trend consists of north-trending faults and folds that extend southward to the Capitan lineament. The Vaughn trend appears to be contiguous with the Dunken-Tinnie anticlinorium to the south, but structural relief and severity of deformation is much less. The history of deformation along the Vaughn trend is, in most places, poorly constrained (Kelley, 1972).

The Lincoln County porphyry belt consists of at least 11 stocks and laccoliths and innumerable dikes and sills and comprises perhaps the greatest exposed concentration of Tertiary intrusives in New Mexico (Kelley and Thompson, 1964). The intrusive rocks range in age from late Eocene to late Oligocene–early Miocene; age constraints and composition of major intrusives are summarized in Table 2.1.

20.8 **Junction,** NM-214 and US-380. **Turn left (west)** on US-380. The small hill immediately to the east of the junction is composed of the lower part of the Upper Triassic Santa Rosa Formation and is characteristic of the Santa Rosa in this area. Although no contact between the Santa Rosa Formation and Artesia Group is exposed here, topography and nearby contacts (see mile 23.1) indicate that Santa Rosa strata here rest directly on the Artesia Group. This means that the Moenkopi Formation, present between the Santa Rosa and Artesia near Carrizozo (see Day 3 road log and Lucas, 1991, this guidebook), is absent here. The lower Santa Rosa begins with trough-crossbedded limestone-pebble conglomerate and quartzose sandstone (6.7 m), overlain by sandy mudstone and coarse sandstone (16 m), and capped by 3 m of silica-pebble conglomerate that defends the crest of the hill. These lithologies are very reminiscent of some outcrops of the lower, Tecolotito Member of the Santa Rosa Formation in the Santa Rosa–Fort Sumner areas of De Baca and Guadalupe counties to the north (Lucas and Hunt, 1987). **0.1**

20.9 Exposures of red-orange Grayburg Formation in low rounded hills in middle distance at 3:00. **0.6**

TABLE 2.1 Lithologies and ages of principal intrusives of Lincoln County porphyry belt (modified from Lucas et al., 1991, table 1). Locations of intrusive centers are shown in Fig. 2.21.

Intrusive Center	Dominant Lithology	Age (Ma)
1. Capitan pluton	granite to alkali granite	26.5
2. Gallinas Mountains	andesite, latite, trachyte, microsyenite, rhyolite, syenite to syenogabbro	?
3. Tecolote Hills	syenite to syenogabbro	?
4. Jicarilla Mountains	syenite to syenogabbro to monzonite	37.3-38.2
5. Baxter Mountain	syenogabbro to syenite, lamprophyre dikes	35.2-29.8
6. Lone Mountain	quartz syenite to alkali granite	?
7. Patos Mountain	rhyolite, syenite, monzonite	?
8. Carrizo Mountain	quartz syenite to alkali granite	?
9. Vera Cruz Mountain	trachyte	?
10. Black Mountain	gabbro to syenite	37.5-36.3
11. Sierra Blanca complex	rhyolite to granite, lamprophyre dikes	37.3-25.8

21.5 Milepost 86. Smokey Bear story on sign at right. Exposure of Santa Rosa Formation sandstone and conglomerate across valley at 3:00. **0.4**

SMOKEY BEAR HISTORICAL STATE PARK

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In May 1950, a raging forest fire in the Lincoln National Forest was blackening approximately 17,000 ac of the Capitan Mountains. As fire fighters brought the blaze under control, a small black bear cub was found clinging to the remains of a charred tree. First aid was administered to the badly burned bear cub, and he was sent to Santa Fe for further treatment. Although the fire fighters didn't realize it then, a national symbol was born. The story of the bear cub was told in newspapers and on radio throughout the country. The cub, named Smokey Bear, went to the National Zoo in Washington, D.C., and became the living symbol for fire prevention. Through many successful campaigns, Smokey was responsible for reducing the number of man-made forest fires, resulting in savings estimated at $27 billion during the past 40 years (Young, 1984).

Actually, the idea of a Smokey Bear representing the national symbol for forest fire prevention originated in 1944 when Japanese fire balloons coming in from the Pacific threatened to ignite the forests on the West Coast (Young, 1984; Morrison, 1989). Most of the nation's fire fighters had gone off to war and the Japanese fire balloons emphasized the need to do something to prevent forest fires across the nation. A War Advertising Committee was established which created Smokey Bear as a picture of a bear wearing a ranger's uniform and carrying a shovel, saying "Remember—only YOU can prevent forest fires." Smokey was named after "Smokey Joe" Martin, who was the Assistant Chief of the New York City Fire Department from 1919 to 1930 (Young, 1984). The advertising campaign worked and when the bear cub was found in the Capitan Mountains, the victim of a forest fire, it was only natural to name it Smokey and continue the fire prevention campaign.

Smokey Bear is a national hero; he has appeared in numerous parades, in cartoons, on television and on fire prevention posters throughout America. Other countries have adopted the idea of a bear to symbolize fire prevention (Young, 1984). Smokey receives so much mail that he has his own zip code (20252) and each letter is answered and signed with a pawprint. The Smokey Bear Act of 1952 protects Smokey Bear and provides that only the USDA Forest Service can license Smokey Bear products (Morrison, 1989). A portion of the sale of these products goes for fire prevention programs. A U.S. postage stamp was issued on August 13, 1984 at Capitan, commemorating Smokey Bear.

Smokey died on November 9, 1976, from natural causes, and his body is buried at the Smokey Bear Historical State Park, in the center of Capitan. A new bear cub, also a victim of a forest fire in the Capitan Mountains, was moved to the National Zoo to carry on as Smokey II.

Smokey Bear Historical State Park is the smallest of New Mexico's state parks and consists of only three acres at an elevation of 6500 ft. The Capitan Mountains rise to over 10,000 ft behind the small town (Fig. 2.22). Nearly 18,000 people visit the park each year. A visitor's center, completed in 1979, houses extensive exhibits commemorating Smokey Bear and the Forest Service's fire prevention program. In the small theater, visitors are able to view a movie depicting Smokey's life and fire prevention. A talking Smokey reminds everyone "Only YOU can prevent forest fires." A nearby city-owned museum and gift shop is built of logs and contains additional exhibits. The day-use park has restrooms and picnic tables but no overnight camping facilities; two RV parks are nearby in Capitan. A nature trail winds through exhibits of plants native to New Mexico and passes Smokey's grave near the duck pond.

The state park is in the center of Capitan, which was founded in 1884 when Seaborn T. Gray homesteaded and built a small store. A post office was established in 1894. The EP&NE Railroad built a spur into Gray and changed the name to Capitan, after the surrounding mountains (Pearce, 1965). The town was incorporated in 1941. In 1950, residents took pride in being the birthplace of Smokey Bear and erected signs at each end of town on US-380 proclaiming Capitan the home of Smokey Bear. The log museum, now next to the state museum, was built in the early 1950s. The Forest Service gave special permission to the town to build the Smokey Bear Motel and Cafe, which is still in operation. For the efforts of the townspeople, the first Presidential Smokey Oscar for conservation was awarded to Capitan in 1958.

21.9 Roadcuts in Santa Rosa Formation. Exposure of Santa Rosa Formation on low hill at 3:00, with Capitan Gap on skyline. **0.9**

22.8 Rodeo Bar on right. Oil test No. 1 Pearson (TD 1005 ft) was drilled in the field on left side of the road; see Havenor (1964) for details. **0.3**

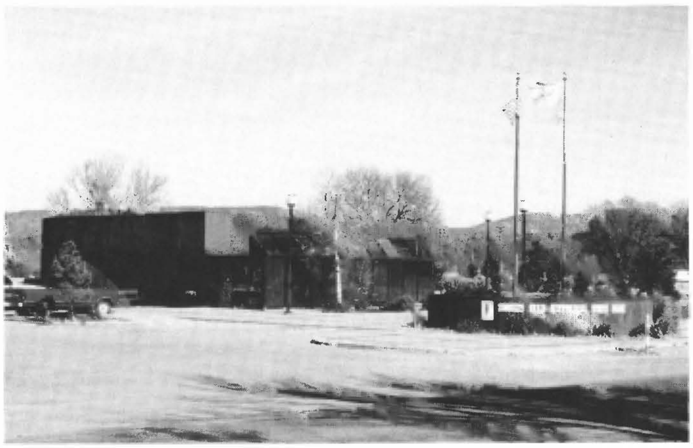

FIGURE 2.22. Smokey Bear Historical State Park, with the Capitan Mountains forming the skyline.

23.1 Road to Capitan Gap on right. Dakota Sandstone caps ridges at 10:00–3:00. At Gyp Spring Creek (NW1/4 NW1/4 sec. 6, T9S, R15E), about 2 mi north-northeast of here, laminar and fine-grained, gypsiferous sandstones and green shales of the Artesia Group are overlain by limestone- and silica-pebble conglomerates and quartzose, trough-crossbedded sandstones of the Santa Rosa Formation. This appears to be the best-exposed Permo-Triassic boundary contact on the eastern flank of the Sierra Blanca basin. **0.5**

23.6 Triassic on left in roadcuts next 0.5 mi; Dakota Sandstone caps ridges at 9:00–3:00. Triassic is the San Pedro Arroyo Formation (formerly Chinle Formation or Dockum Group; see Lucas, 1991, this guidebook). **0.6**

24.2 Contact between San Pedro Arroyo Formation and Jurassic Morrison Formation on left. **0.1**

SOUTHEASTERNMOST OUTCROPS OF THE MORRISON FORMATION, CAPITAN, LINCOLN COUNTY, NEW MEXICO

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The nonmarine Morrison Formation, of Late Jurassic–Early Cretaceous age, has an enormous outcrop area that encompasses most of the Rocky Mountain region of the western United States (Fig. 2.23). In New Mexico, extensive outcrops of the Morrison occur in the northern half of the state. Recently, Hunt and Lucas (1987) and Hayden et al. (1990) identified outcrops of the Morrison Formation in Socorro County, as much as 55 mi (92 km) south of the traditionally recognized southern limit of Morrison outcrops (Dane and Bachman, 1965). Here, I describe briefly the recently identified southeasternmost outcrop of the Morrison Formation, in the roadcut of NM Highway 380 at Capitan, Lincoln County (Fig. 2.23). This outcrop is 60 mi (100 km) east of the Socorro County outcrops and about 90 mi (150 km) south of the southernmost Morrison Formation outcrops in Guadalupe County, east-central New Mexico (Lucas et al., 1985).

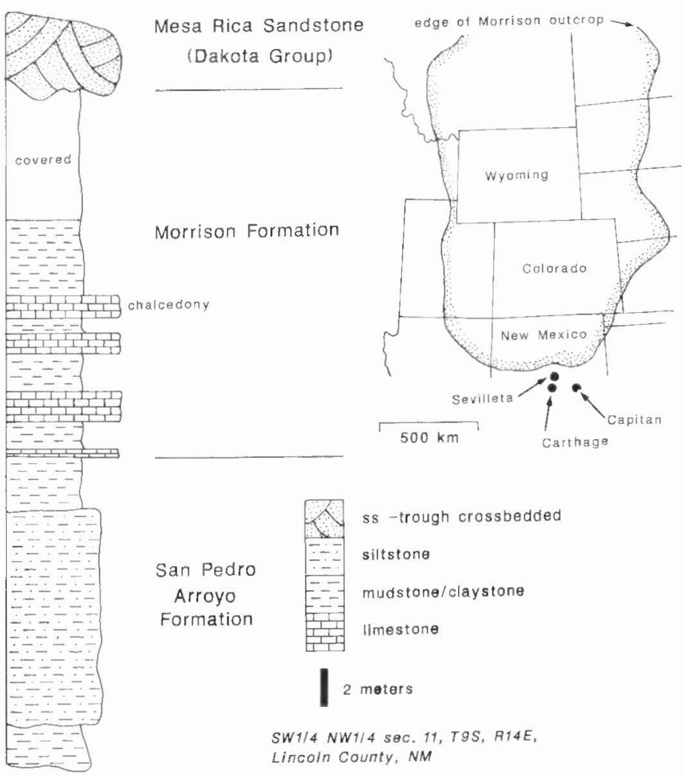

FIGURE 2.23. Measured stratigraphic section of the Morrison Formation at Capitan, and map showing the long-recognized limit of Morrison Formation outcrops in the Western Interior and the location of the recently identified Morrison outcrops in Socorro County (Sevilleta, Carthage) and at Capitan.

Strata at Capitan identified as Morrison Formation were previously considered weathered beds at the top of the Upper Triassic "Chinle Formation" (Kelley, 1971). However, the Morrison strata at Capitan are quite different from underlying Upper Triassic red beds of the San Pedro Arroyo Formation (Lucas, 1991, this guidebook), which are mostly grayish red and reddish brown, bentonitic, calcareous mudstones and muddy siltstones. In contrast, the 19.5 m of Morrison strata are dominated by variegated grayish green, greenish gray and grayish red-purple, non-calcareous siltstone and bentonitic claystone (80%) split by resistant ledges of grayish green and yellowish green limestone (20%). These limestones have textures ranging from nodular to pisolitic, and the uppermost limestone ledge is riddled with veins and nodules of chalcedony. The Lower Cretaceous Mesa Rica Sandstone (Dakota Group), a dark yellowish orange, trough-crossbedded quartzarenite, overlies the Morrison Formation at Capitan.

The strata at Capitan I identify as Morrison Formation resemble no portion of the Upper Triassic section exposed elsewhere in Lincoln County (Lucas, 1991, this guidebook). They neither show evidence of deep weathering nor resemble Lower Cretaceous marine strata to the east or north. Particularly significant is the presence of beds of nodular limestone and chalcedony, a characteristic of the Morrison Formation to the north. Identification of these strata as Morrison Formation thus is based on stratigraphic position and lithologic similarity.

The Capitan Morrison strata closely resemble the strata identified in Socorro County as Morrison by Hunt and Lucas (1987) and Hayden et al. (1990), but they are thicker. It seems most reasonable to view the outcrop at Capitan as a thin, truncated remnant of the upper part of the Morrison Formation (Brushy Basin Member) that was deposited near the extreme southern edge of the Morrison depositional basin. Whether or not more southerly outcrops of the Morrison Formation exist will have to be shown by additional fieldwork.

24.3 Dakota Sandstone in roadcuts; beds dip southwest about 23° into the Sierra Blanca basin. Valley ahead is cut in Mancos Shale, where Cobban (1986) described ammonites and bivalves of the middle and upper Cenomanian *Acanthoceras amphibolum* and *Calycoceras canitaurinum* zones from the bed of Salado Creek. **0.5**

24.8 Official Historic Marker: "Capitan (population 762; elevation 6,350 ft)—Many incidents of the Lincoln County War, 1876–1879, occurred in the area around Capitan. The promoters Charles B. and John A. Eddy platted the townsite in 1900 after building a spur of the El Paso and Northeastern Railroad from Carrizozo in order to open the Salado coal fields. The mines were abandoned in 1901." **0.4**

25.2 **Junction** with NM-48 on left. **Turn right** and proceed north on NM-246. **0.1**

25.3 Bridge over Salado Creek. **0.3**

25.6 Road ahead follows valley cut on Upper Cretaceous Mancos Shale. Dakota Sandstone forms dip slope on right; ridge on left is held up by Gallup Sandstone and Crevasse Canyon Formation. **0.3**

25.9 Thin dikes form ridge near road on left. **0.3**

26.2 Small quarry pit on right in limestone lens in Mancos Shale. **0.1**

26.3 Northeast-trending dike near road on right. **0.1**

26.4 Eastward protrusion of Gallup Sandstone into valley at

12:00 marks axis of gentle, west-plunging syncline. **0.7**

27.1 Milepost 2. Capitan Mountains 1:00–3:00; Capitan Gap at 2:00. **1.3**

28.4 Watergap exposes Dakota Sandstone along Gyp Spring Canyon at 2:30 (Fig. 2.24). **0.5**

28.9 Crossing approximate trace of west-trending Capitan fault (Kelley and Thompson, 1964; Kelley, 1971). Ahead on upthrown (north) side of fault, west-dipping San Andres Formation is exposed on timbered slopes at 12:00. Santa Rosa, Chinle, Dakota, Mancos and Mesaverde exposures at 11:00 to 10:00. Tucson Mountain on skyline at 10:00. Three miles west of here Western Ranchers No. 1 Beecher was drilled to a depth of 1342 ft (Havenor, 1964). **0.2**

29.1 Milepost 4. **0.2**

29.3 Entering Lincoln National Forest; junction with ranch road on right. Continue straight on NM-246. **0.1**

29.4 San Andres Formation exposed in roadcuts, next 0.8 mi. **0.8**

30.2 Milepost 5. **0.2**

30.4 Road crosses culvert over arroyo. **0.2**

30.6 San Andres Formation outcrops in roadcuts, next 0.3 mi. **0.3**

30.9 **Turn right** on dirt road. **0.1**

31.0 Roadcuts ahead on San Andres Formation. **0.7**

31.7 Road forks; **bear right. 0.1**

31.8 Road forks twice; **keep to left. 0.1**

31.9 Entering open pit iron mine (Fig. 2.25). **Be alert. 0.1**

32.0 **STOP 4. Park on floor of open pit** for discussion of the Capitan iron deposits. **Following discussion, retrace route to Capitan. 6.9**

NOTES ON THE SMOKEY MINE, CAPITAN IRON DEPOSITS, LINCOLN COUNTY, NEW MEXICO

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Iron deposits, predominantly magnetite replacing or disseminated in limestone, are common in central New Mexico. These deposits extend from the east end of Capitan Mountain nearly to Bingham, and from

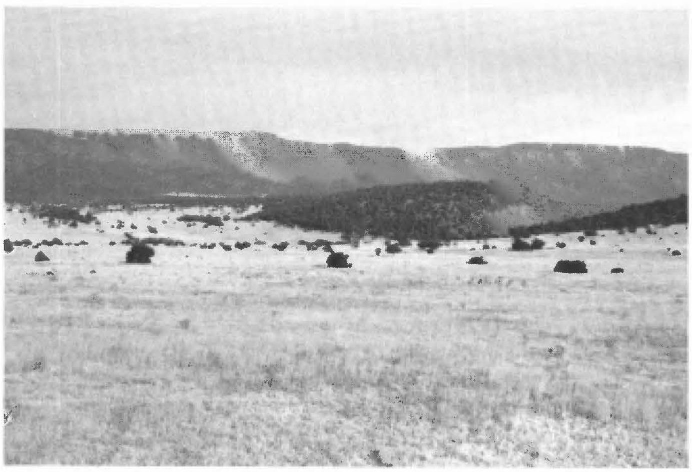

FIGURE 2.24. View northeastward of watergap of Gyp Spring Canyon cut through Dakota Sandstone. Capitan Mountains on skyline.

FIGURE 2.25. Looking east toward open-pit iron mine at Stop 4.

Carrizozo to the north end of the Gallinas Mountains. They are associated with small plug-like or laccolithic intrusives that are commonly syenitic in composition or at least are somewhat silica-poor. The bodies are small, pod-like, or lenticular, and have been exploited in several places. The associations with the intrusives are not always direct and there may be several modes of formation for the bodies.

The iron deposits were probably discovered when the Spaniards entered the area looking for gold, silver and copper. The discovery of gold in the Jicarilla district and at White Oaks sparked a flurry of mining around the turn of the century. The iron deposits were claimed during this time and some shipments were made to El Paso prior to World War I. During World War I and up to 1921 approximately 35,000 tons of iron ore were produced. Interest in Lincoln County iron ores was revived during World War II, but the small size of the individual deposits and the excessive shipping charges to the nearest consumers combined to limit the production. A little over 16,000 tons were shipped during 1942 and 1943, but wartime conditions made the mining unprofitable. The total production from Lincoln County to 1957 amounted to 59,725 tons, produced from scattered deposits on Lone Mountain north of Carrizozo, and from deposits in the Jicarilla and Gallinas Mountains. When the Tijeras Canyon cement plant was built during the early 1960s, demand for magnetite as a constituent in special cements sparked new activity, and production in both Lincoln and Socorro counties was stimulated.

The Capitan deposit has been known since the turn of the century, but for many years had only cursory development, even though some of the claims covering it had been patented. Kelley (1949) examined many of the iron deposits during World War II and recommended that Capitan be explored by the U.S. Bureau of Mines because it seemed to be the largest of the known occurrences. Accordingly, a drilling and sampling program was begun during the spring of 1944. The first phase of the drilling was done with wagon drills and 9-m steel. Considerable difficulty was encountered in drilling some of the vuggy zones in the ore and the final results were limited to approximately 5.5 m of total depth. During 1947–48 seven churn drill holes were sunk on the property to depths ranging from 60 to 120 m; all bottomed in aplite of the Capitan intrusive. The results of the exploration indicated more than 1,000,000 tons of iron ore at depths of less than 18 m below the surface averaging 45.64% iron (Kelley, 1949, p. 148). The main deposit lies mostly in sections 10 and 15, T8S, R14E, just west of the common corner of sections 10, 11, 14 and 15. Since the deposit was taken over in 1975 by H. D. Larue and sons, between 200,000 and 250,000 tons ore have been produced from a pit approximately 450 m long and 335 m wide (Fig. 2.26). Current annual production varies from less than 10,000 to more than 15,000 tons depending upon local demand.

Rocks in the pit and surrounding the mine are limestone, shale and sandstone of the Permian San Andres Formation, with thin alluvial

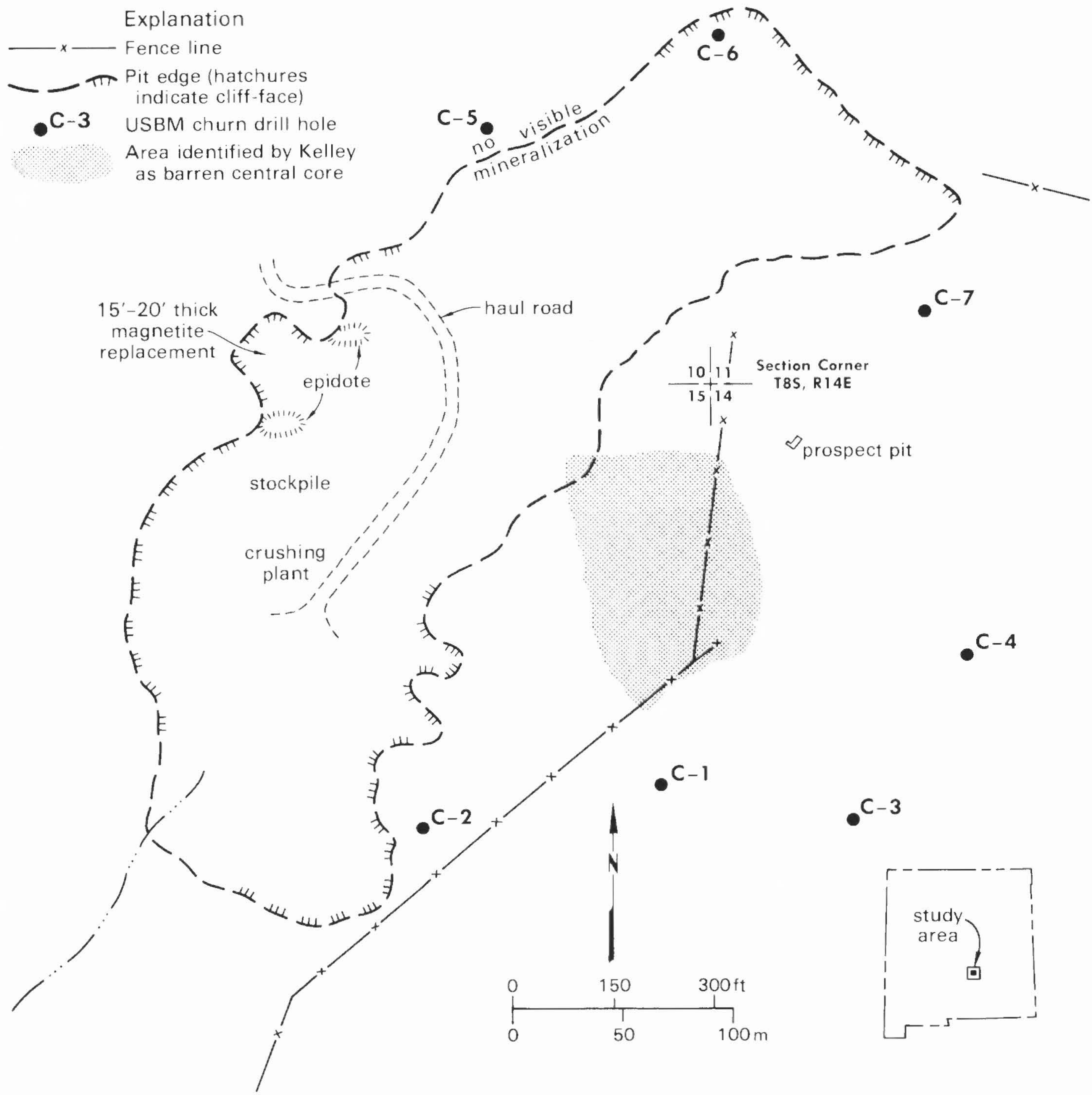

FIGURE 2.26. Brunton and pace traverse sketch map of the Smokey mine open pit, Capitan iron deposits, Lincoln County, New Mexico.

cover in some of the arroyos. A thickness of approximately 300 m of San Andres is exposed to the northwest of the property where it is overlain by sandstone of the Triassic Santa Rosa Formation. Between the mine and the town of Capitan to the south, the San Andres Formation is faulted against sandstone of the Upper Cretaceous Dakota Group (Kelley, 1949). Mining has exposed strongly brecciated zones along the northern and southeastern margins of the pit.

The principal iron mineral is magnetite but both primary and secondary hematite and minor amounts of goethite and limonite also occur. Magnetite fills fractures, replaces limestone, both massively and as disseminated grains, often following apparent bedding structures, and is also found in some of the interbedded shales and sandstones. It is not clear why some limestone beds are completely replaced and others are barren of magnetite. The principal gangue mineral is calcite, with lesser amounts of quartz and clay minerals from the interbedded sandstone and shale. Parts of the beds are silicified and locally calcium and magnesium silicates have completely replaced the original layers. Much of the silication follows the same pattern as the magnetite, in some places completely replacing limestone, and in others following bedding structures as well as coating fractures. The silicates are more prominent in the sandstones and shales. In the center of the roughly elliptical deposit, the San Andres beds have not been replaced by magnetite, and epidote only partially replaces the rocks. There is a rough mineralogic zoning with epidote, phlogopite and tremolite at the center, surrounded by a zone of phlogopite and tremolite without epidote, and the whole surrounded by a zone of tremolite only, grading outward into limestone that does not exhibit recrystallization. Although Kelley (1949) did not mention it, this can be interpreted as temperature zoning, even though the intrusive contact is not apparently related to this central barren area.

Drilling has indicated that the Capitan aplitic intrusive underlies the deposit at depths ranging from 60 to 120 m, but there do not appear to be any sill-like bodies or dikes of the intrusive cutting the deposit. Kelley (1952) believed that the mineralization was introduced from fluids associated with the cooling and crystallization of the Capitan intrusive. He interpreted the deposit as a mineralized sinkhole or collapse zone which had formed prior to the intrusion of the Capitan aplite. Recent mining has not exposed evidence to contradict such an interpretation. Brecciated portions of the deposit are preserved by the magnetite replacement, indicating the pre-ore nature of the breccia. This hypothesis is geologically reasonable since the broad area of San Andres limestone north of Capitan Mountain is pockmarked with numerous sinkholes, which have been forming nearly continuously since the end of Paleozoic time.

The presence of silicates suggestive of contact metamorphism has been noted in many of the iron deposits of Lincoln and Socorro counties, although evidence of the requisite high temperatures has not been recognized. Gibbons (1981) and Jenkins (1985) suggested that the magnetite developed at the Jones Camp deposit to the west, in Socorro County, was derived from the intrusive itself by alteration of ferromagnesian minerals such as hornblende and biotite. Some transfer of Fe was documented by these workers for the Jones Camp dike.

Tests conducted by the U.S. Bureau of Mines (Soule, 1949) indicated that simple magnetic concentration could increase the grade of magnetite ore from the 35%–50% range to over 60% iron with better than 90% recovery. The present plant, visible in the bottom of the pit, uses a coarse crushing circuit followed by screening to a 10 to 20 mesh minimum and then passes the crushed material over a magnetic head pulley on the conveyer belt to separate the magnetite from the remainder of the rock. The concentrate is stockpiled and shipped as magnetite-rich material to the Tijeras Canyon cement plant to make high density cement. The tailings are used locally as road metal and as a source of sand and gravel for driveways and parking lot covering.

The ore would be an excellent feed for a mini-steel mill because it is higher grade than the average iron ore and is very low in sulfur, phosphorus, titania and alumina. Analyses of composite samples by the U.S. Bureau of Mines are given in Table 2.2.

The principal difficulty with the Capitan deposit is its minimal size and its known depth limitation. However, similar deposits might be available locally around the edge of the Capitan intrusive.

TABLE 2.2 Analyses of selected Capitan composite samples. All analyses in percent.

Drill Hole Number	Fe	S	P	TiO_2	CaO	Al_2O_3	SiO_2	Mn	Zn
1	42.88	0.025	0.042	0.07	18.24	0.10	3.74	0.29	0.007
49	47.72	0.022	0.049	0.08	15.28	0.38	1.84	0.37	0.008
75	58.78	0.018	0.040	0.08	6.76	0.53	4.92	0.40	0.011
98	56.36	0.076	0.045	0.12	3.97	0.56	5.90	0.28	0.008

38.9 **Junction,** NM-246 and US-380.
End of Part Two, Second-Day Road Log.

PART THREE: CAPITAN TO RUIDOSO

Mileage

0.0 **Junction,** NM-246, NM-48 and US-380 in Capitan. **Go south on NM-48. 0.2**

0.2 Sharp bend to right. **1.1**

1.3 Roadcut on right exposes sandstone of Upper Cretaceous Crevasse Canyon Formation. Cretaceous coal-bearing strata in the Sierra Blanca basin, long termed Mesaverde Formation (or Group), pertain to the Crevasse Canyon Formation of Coniacian-Santonian age. The Crevasse Canyon here is as much as 244 m of sandstone, siltstone, claystone and coal that represent coastal-plain deposition during and following the R-2 (Gallup) regression of the Western Interior seaway (Molenaar, 1983; Arkell, 1986). Although the Crevasse Canyon Formation is the youngest Cretaceous unit in Lincoln County, younger parts of the Crevasse Canyon crop out beneath the Eocene Cub Mountain Formation in the western part of the Sierra Blanca basin (Bodine, 1956; Kelley, 1971; Cather, 1991, this guidebook). **0.1**

1.4 Gallup Sandstone caps long ridge at 9:00. The Gallup Sandstone in Lincoln County is about 50 m of white-to-gray, quartzose sandstone that represents a variety of coastal marine depositional environments (Arkell, 1986). It was deposited during the Coniacian R-2 regression of the seaway and interfingers with underlying marine shelf sediments (D-Cross Tongue of Mancos Shale) and overlying coastal-plain sediments (Crevasse Canyon Formation) associated with that regression. Valley to right contains trace of Magado Creek fault of Bodine (1956), which juxtaposes Mancos Shale (on east) with Crevasse Canyon Formation. **0.4**

1.8 Mudstone of Crevasse Canyon Formation in roadcut on right. **0.4**

2.2 Sandstone and mudstone of Crevasse Canyon Formation in roadcuts at top of hill. **0.6**

2.8 Crevasse Canyon Formation sandstone and mudstone intruded by porphyritic dikes in roadcuts on left, next 0.2 mi. **0.2**

3.0 Approximate location of contact (covered) between Crevasse Canyon Formation and Eocene Cub Mountain Formation. Where exposed near the type area of the Cub Mountain Formation, this contact is disconformable (Weber, 1964; Lucas et al., 1989). **0.2**

3.2 Milepost 19. Roadcut on left exposes yellow, locally pebbly, medium-to-coarse-grained sandstone of basal Cub Mountain Formation (Fig. 2.27). A pebble lag deposit consisting mostly of well-rounded quartzite (~75%), felsic volcanics (~15%) and chert (~10%), with rare silicified wood, occurs at the top of the roadcut. Pebble imbrications are not well developed here, but suggest east-northeast transport. **0.5**

3.7 Yellow sandstone and characteristic red mudstone of Cub Mountain Formation on left in roadcut. **0.3**

4.0 Sierra Blanca Vista sign. Roadcuts are in intrusive rocks within Cub Mountain Formation(?). **0.3**

4.3 Sierra Blanca at 1:00; vista turnout and Smokey Bear story on right. **0.5**

4.8 Lavas and intrusives of Sierra Blanca Volcanics of Thompson (1966, 1972) in roadcuts. Lavas are mostly brecciated (autobrecciated?) and locally vesicular, with

FIGURE 2.27. Basal pebbly sandstone of Cub Mountain Formation exposed at mile 3.2.

conspicuous phenocrysts of clinopyroxene. A thin section from a lava in this roadcut shows porphyritic texture with phenocrysts of plagioclase and clinopyroxene. Clinopyroxene phenocrysts commonly exhibit sector zoning and are as much as 1.2 mm in length. Groundmass is brown, devitrified glass. **0.4**

5.2 Milepost 17. Cub Mountain Formation sandstone and mudstone in roadcut on left. **0.3**

5.5 Debris-flow deposits in Sierra Blanca Volcanics on right in roadcuts next 0.3 mi (Fig. 2.28). These deposits display poor sorting, nearly random clast orientation, matrix support and absence of internal stratification. Clasts are as much as 2 m in length, and are lithologically similar to the lavas seen at mile 4.8. **0.7**

6.2 Milepost 16. Lavas of Sierra Blanca Volcanics in roadcut, next 0.5 mi. A thin section from the roadcut at mile 6.2 shows seriate texture with plagioclase, clinopyroxene, altered amphibole, opaque minerals and minor orthopyroxene. Clinopyroxene is as much as 1.8 mm in length. **0.6**

6.8 Debris-flow deposits and dike of Sierra Blanca Volcanics in left roadcut. **0.4**

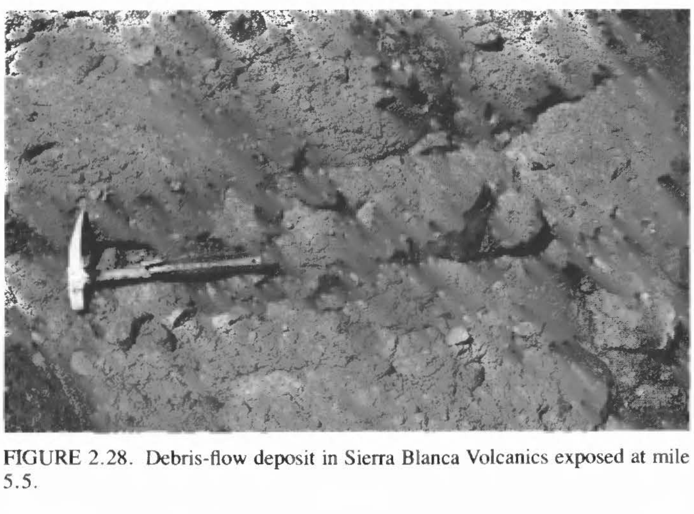

FIGURE 2.28. Debris-flow deposit in Sierra Blanca Volcanics exposed at mile 5.5.

7.2 Milepost 15. Debris-flow deposits and intrusives of Sierra Blanca Volcanics in roadcuts on left. **0.4**

7.6 Roadcuts at top of hill expose lavas of Sierra Blanca Volcanics with fracture-filling calcareous tufa(?) at south end of east roadcut. Tufa deposits are numerous in the field-conference area (Kelley, 1971). **0.3**

7.9 Roadcuts expose lava flows and volcaniclastic sandstone, conglomerate and mudstone beds that dip about 12° northwest. These roadcuts may show the interfingering of fine-grained, distally derived, upper part of volcaniclastic Sanders Canyon Formation (formerly upper part of Cub Mountain Formation and perhaps a distal equivalent of Rubio Peak or Palm Park Formations; see Cather, 1991, this guidebook) with the basal part of the locally derived Sierra Blanca Volcanics. Such interfingering also occurs in the western and northern parts of the Sierra Blanca basin. Pebble imbrications from conglomerates of Sierra Blanca Volcanics indicate paleoflow was toward the southeast. **0.3**

8.2 Milepost 14. Volcaniclastic sandstone and mudstone of Sanders Canyon Formation in roadcuts on right. In thin section, a very fine-grained sandstone from this roadcut consists of about 25% volcanogenic detritus (plagioclase, aphanitic groundmass) and 75% quartz, chert, orthoclase and microcline. Cements are clay and calcite. **0.4**

8.6 Roadcut on right exposes volcaniclastic mudstone and sandstone of Sanders Canyon Formation. Beds dip ~13° to the south. A thin section from a fine-grained sandstone in this roadcut shows about 70% volcanogenic grains (plagioclase, biotite, amphibole and aphanitic groundmass) and about 30% non-volcanic detritus (dominantly quartz and chert). **0.3**

8.9 Volcaniclastic sandstone and mudstone of Sanders Canyon Formation in right roadcut. A thin section from a medium-grained sandstone in this roadcut shows about 70% volcanogenic detritus (plagioclase, aphanitic groundmass, biotite, altered amphibole) and about 30% quartz, chert and granite/gneiss fragments. The sample contains much detrital matrix and calcite cement. **0.2**

9.1 **STOP 5. Pull off on shoulder at base of hill** to examine Eocene Cub Mountain Formation, Sanders Canyon Formation and Tertiary porphyritic dikes. **Beware of traffic.** These roadcuts illustrate the contrasting lithologies of the Cub Mountain Formation and Sanders Canyon Formation. The west roadcut and the northern half of the east roadcut expose purplish gray to reddish gray volcaniclastic sandstone and mudstone of the Sanders Canyon Formation (Fig. 2.29). Thin-section analysis of sandstone from the Sanders Canyon Formation shows the presence of large amounts of volcanogenic detritus (see thin-section descriptions in Cather, 1991, this guidebook, and above, miles 8.2, 8.6 and 8.9). Imbricated clay clasts in sandstone units in the west roadcut suggest paleoflow was northeasterly.

The southern half of the east roadcut at this stop exposes deformed and intruded red mudstone and yellow-gray sandstone of the Cub Mountain Formation. A thin section from a medium sandstone here contains almost exclusively non-volcanic detritus (quartz, chert, orthoclase, microcline, muscovite, granitic and metamorphic rock fragments) with only a few percent pla-

FIGURE 2.29. Fluvial mudstone and sandstone of Sanders Canyon Formation at Stop 5.

FIGURE 2.30. Mon Jeau Lookout, elevation 9641 ft.

gioclase. The Cub Mountain in this roadcut has been faulted up against the Sanders Canyon Formation. Faulting may be related to pervasive down-to-the-west faulting along the east margin of the Sierra Blanca basin (Kelley, 1971) or to down-to-the-north faulting along the east- to northeast-trending Bonito fault, which follows the valley directly south of this stop.

The proposed Cub Mountain/Sanders Canyon terminology (Cather, 1991, this guidebook) is similar to existing formation-rank nomenclature for homotaxial Paleogene sequences elsewhere in New Mexico (El Rito–Blanco Basin/Conejos, Galisteo/Espinaso, Baca/Spears, Love Ranch–Palm Park/Rubio Peak). Indeed, the Cub Mountain/Sanders Canyon rocks may be the distal equivalents of the Love Ranch–Palm Peak/Rubio Peak sequence to the southwest (Lucas et al., 1989; Cather, 1991, this guidebook). **0.1**

9.2 **Junction** with NM-37 on right; **continue south** on NM-48. Bridge over Rio Bonito. **0.1**

9.3 Crossing Rio Bonito fault of Kelley (1971), which trends east to northeast, is down to the northwest, and, as do many of the northeast-trending faults in the region, exhibits evidence for right-lateral displacement. **0.3**

9.6 Roadcuts on left, next 1.5 mi, expose sandstone and mudstone (commonly carbonaceous) of Upper Cretaceous Crevasse Canyon Formation that have been intruded by Tertiary porphyritic dikes and sills. **1.6**

11.2 Milepost 11. **0.3**

11.5 Roadcut on right exposes sandstone of Crevasse Canyon Formation and Tertiary intrusives. **0.2**

11.7 **Junction** on left with road to Sierra Blanca Regional Airport. **Continue south** on NM-48. **0.3**

12.0 Sandstone and mudstone of Crevasse Canyon Formation and Tertiary intrusives in roadcut on right. **0.9**

12.9 Junction with Fort Stanton Road on left; Crevasse Canyon Formation sandstone and mudstone and Tertiary intrusives in roadcut on left. **0.4**

13.3 Junction with NM-532 to Sierra Blanca and Mon Jeau Lookout on right. Roadcuts on left expose sandstone (Cub Mountain Formation?) and intrusives. **0.1**

13.4 Entering town of Alto. Official Scenic Historic Marker (Fig. 2.30): "Mon Jeau Lookout (twelve miles)—Elevation 10,000 ft offers one of the most scenic views in the southwest. Used by Forest Rangers during the fire season. Observation deck open to visitors at all times. Parking space at bottom of lookout tower." **0.3**

13.7 Gently dipping pebbly sandstone of Cub Mountain Formation and Tertiary intrusives in roadcuts on right. **0.2**

13.9 Gavilan Canyon Road on left. **0.3**

14.2 Milepost 8. Porphyritic intrusive rocks in roadcut on right. **0.2**

14.4 Roadcuts expose drab-colored sandstones and mudstones of Crevasse Canyon Formation juxtaposed against fault slivers of red mudstone of Cub Mountain Formation. Numerous porphyritic intrusions are present. **0.3**

14.7 Lavas and breccias of Sierra Blanca Volcanics in roadcut on right. **0.2**

14.9 Spheroidally weathering lavas, debris-flow deposits, and intrusive rocks of Sierra Blanca Volcanics in roadcuts, next 0.4 mi. **1.8**

16.7 Buildings faced with native stone on right and left. **0.7**

17.4 Road to Cedar Creek recreational area on right. **0.1**

17.5 Entrance to Smokey Bear Ranger Station, Lincoln National Forest, on right. **0.7**

18.2 Milepost 4. Variegated sandstone and mudstone of Cub Mountain Formation in right roadcut. **0.6**

18.8 Stoplight. **Turn left** on Sudderth Drive and continue east through downtown Ruidoso. **0.7**

19.5 Stoplight; continue straight. **0.8**

20.3 **Turn right** at Inn of the Mountain Gods signs. **0.2**

20.5 **Turn right** on Carrizo Road; this is mile 3.3 on Part One, Second-Day Road Log. **0.2**

20.7 San Andres Formation in roadcut on right. **1.1**

21.8 Quarry on left; Carrizo Lodge on right. **0.2**

22.0 Cliffs of San Andres Formation on left. **0.1**

22.1 Entering Mescalero Apache Reservation. **0.7**

22.8 Road-metal quarry in San Andres Formation at 3:00. **0.3**

23.1 Dam at 3:00. **0.9**

24.0 Poorly exposed Grayburg Formation in roadcut on left. **0.1**

24.1 **Turn left** into entrance of Inn of the Mountain Gods. **0.1**

24.2 Inn of the Mountain Gods.

End of Second-Day Road Log.