New Mexico Geological Society

Downloaded from: https://nmgs.nmt.edu/publications/guidebooks/43

First-day road log: From Cuba to La Ventana, San Luis, Cabezon, Mesa Portales, Mesa de Cuba and return to Cuba

Spencer G. Lucas, Thomas E. Williamson, Larry N. Smith, Wright-Dunbar, Robyn, Hallett, Bruce, Barry S. Kues, Gretchen Hoffman, Adrian P. Hunt, David W. Love, Virginia T. McLemore, and R. F. Hadley

1992, pp. 1-32. https://doi.org/10.56577/FFC-43.1

in:

San Juan Basin IV, Lucas, S. G.; Kues, B. S.; Williamson, T. E.; Hunt, A. P.; [eds.], New Mexico Geological Society 43rd Annual Fall Field Conference Guidebook, 411 p. https://doi.org/10.56577/FFC-43

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

Annual NMGS Fall Field Conference Guidebooks

Every fall since 1950, the New Mexico Geological Society (NMGS) has held an annual Fall Field Conference that explores some region of New Mexico (or surrounding states). Always well attended, these conferences provide a guidebook to participants. Besides detailed road logs, the guidebooks contain many well written, edited, and peer-reviewed geoscience papers. These books have set the national standard for geologic guidebooks and are an essential geologic reference for anyone working in or around New Mexico.

Free Downloads

NMGS has decided to make peer-reviewed papers from our Fall Field Conference guidebooks available for free download. This is in keeping with our mission of promoting interest, research, and cooperation regarding geology in New Mexico. However, guidebook sales represent a significant proportion of our operating budget. Therefore, only *research papers* are available for download. *Road logs*, *mini-papers*, and other selected content are available only in print for recent guidebooks.

Copyright Information

Publications of the New Mexico Geological Society, printed and electronic, are protected by the copyright laws of the United States. No material from the NMGS website, or printed and electronic publications, may be reprinted or redistributed without NMGS permission. Contact us for permission to reprint portions of any of our publications.

One printed copy of any materials from the NMGS website or our print and electronic publications may be made for individual use without our permission. Teachers and students may make unlimited copies for educational use. Any other use of these materials requires explicit permission.

FIRST-DAY ROAD LOG, FROM CUBA TO LA VENTANA, SAN LUIS, CABEZON, MESA PORTALES, MESA DE CUBA AND RETURN TO CUBA

SPENCER G. LUCAS, THOMAS E. WILLIAMSON, LARRY N. SMITH, ROBYN WRIGHT-DUNBAR, BRUCE HALLETT, BARRY S. KUES, GRETCHEN HOFFMAN, ADRIAN P. HUNT, DAVID W. LOVE, VIRGINIA T. McLEMORE AND R. F. HADLEY

THURSDAY, OCTOBER 1, 1992

Assembly point:	Parking lot of Cuba Cafe, Cuba, New Mexico.
Departure time:	7:45 a.m.
Distance:	95.9 mi
Stops:	5

SUMMARY

Today's route begins by driving south from Cuba toward the eastern edge of the San Juan Basin. In so doing, we descend from the Paleocene strata on which Cuba is built to Upper Cretaceous nonmarine and marine strata at the La Ventana rest stop on NM Highway 44 (Stop 1). Here, we examine the Point Lookout delta and discuss coal and uranium resources in the La Ventana area.

From Stop 1 the route continues south and then southwest to Stop 2 near San Luis, where we investigate the parasequence stacking in Point Lookout shoreface sandstones. Stop 3, for lunch, is at Cerro Chafo, a partially dissected remnant of a tuff ring just southwest of Cabezon Peak. Here, we will examine the igneous geology of Cerro Chafo and discuss the Rio Puerco necks. We also will examine the El Vado Sandstone Member of the Mancos Shale. The next segment of today's route retraces to north of La Ventana and then proceeds west to Mesa Portales. Here, at Stop 4, the discussion focuses on younger Cretaceous rocks (Pictured Cliffs Sandstone and Fruitland/Kirtland Formations) as well as the Cretaceous-Tertiary boundary.

From Mesa Portales, the route proceeds west and then turns sharply northeast to Stop 5 at Mesa de Cuba. This stop is at the type section of the Paleocene Nacimiento Formation and focuses on silcretes, Paleocene stratigraphy and the Paleocene-Eocene boundary.

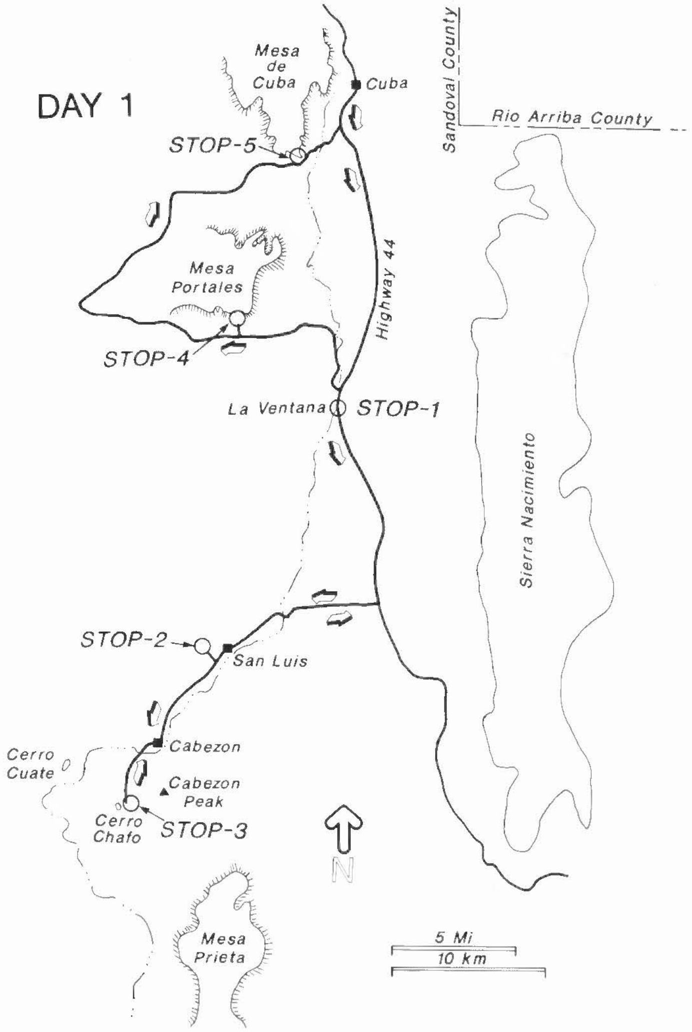
Mileage

0.0 **Turn right** and proceed south on NM-44 to leave Cuba. **0.1**

01 Leave Cuba. NM-197 to right goes to Crownpoint and Gallup. Mesa de Cuba at 1:00–5:00 exposes Paleocene Nacimiento Formation overlain by the lower Eocene/Paleocene Cuba Mesa Member of the San Jose Formation. **0.6**

0.7 Roadcuts are in Paleocene Ojo Alamo Sandstone for next 0.6 mi. **0.6**

1.3 At crest of hill, view at 12:00 is of Ojo Alamo Sandstone capping Mesa Portales in distance. **0.6**



1.9 Steep arroyo banks to right are those of the mighty Rio Puerco. **0.3**

2.2 Note Ojo Alamo Sandstone at 10:00 with houses built on it; skyline to east is Nacimiento Mountains. **0.4**

2.6 Cross bridge over tributary to Rio Puerco. **0.6**

3.2 Ojo Alamo Sandstone in gully on right. Now it can be seen on the right that a complete section of Nacimiento Formation is exposed on the southern and southeastern flanks of Mesa de Cuba. This is the type section of the Nacimiento Formation, which we will examine at Stop 5.

Bryan and McCann (1936), without benefit of detailed topographic maps, interpreted several levels of depositional/erosional surfaces along the upper Rio Puerco. The highest suspected surface includes the crest of the Nacimiento Mountains and slopes west, hypothetically from the mountains across the current Continental Divide into the San Juan Basin. A second, lower hypothetical surface in this area was thought to connect with the ancestral Chacra drainage and join the Ortiz surface farther south (level of Mesa Prieta). After the Rio Puerco drainage was established, the La Jara and Rito Leche piedmont slopes and stream terraces were developed 50–60 and 23–26 m above modern drainages. Lower terraces were found 10 and 3 m above modern valley floors. Stream captures have adjusted the drainage area of the upper Rio Puerco with respect to drainages to the north, west and east.

Although no systematic work has been done on the erosional history of this area since Bryan and McCann, many of their observations can be duplicated along the field trip routes. La Jara, Rito Leche and lower terrace surfaces can be seen between here and the first stop as numerous terrace and piedmont remnants on both sides of the Rio Puerco. The large landslide masses masking the slopes of Cuba Mesa appear to grade to the Rito Leche level.

Chalcedony deposits along the crest of the Nacimiento Mountains may correlate with the Pedernal Member (mid-Miocene calcium-carbonate-soil horizons replaced by silica) of the Abiquiu Formation (Vazzana and Ingersoll, 1981). Chert cobbles reworked from these deposits are found west of the Continental Divide in the Chaco drainage (Love, 1980) and in deposits in the Albuquerque basin downstream from the Rio Chacra as well as in all terrace levels along the Rio Puerco. **0.4**

3.6 Bluff and roadcut to left expose the Ojo Alamo Sandstone; we are driving down the section onto Cretaceous rocks. **0.9**

4.5 At curve in road, view at 2:00 is of the Cretaceous Kirtland-Fruitland Formation badlands under the Ojo Alamo Sandstone on the flank of Mesa Portales. Isolated pyramidal butte at 1:00 is Marion Butte (Fig. 1.1), at which there is a buried palm-stump (*Palmoxylon*) field in the Fruitland Formation (Tidwell et al., 1981). **0.4**

4.9 At 9:00, note double sandstone of the Ojo Alamo Sandstone above the Kirtland Formation. There has been some disagreement over which formation the lower sandstone should be placed in (e.g., Fassett and Hinds, 1971; Smith, this volume). The Rio Puerco in this area is a coarse-sand-bedded braided stream. It appears to be aggrading fairly rapidly. **0.8**

5.7 Curve in road. Cutbank of Rio Puerco on right; Mesa Portales at 1:00–3:00 exposes Cretaceous Pictured Cliff Sandstone (brown at base) overlain by undivided Fruitland-Kirtland Formations overlain by Ojo Alamo Sandstone. Road surface here is on low rolling topography developed in the Cretaceous Lewis Shale for the next 3–4 mi. **3.2**

8.9 The Rio Puerco recently cut through its meander bend to the right. **0.3**

9.2 Curve in road at railing. Cliff House Sandstone appears on right at 3:00. Roadcut on left is in the La Ventana Tongue of the Cliff House Sandstone. The La Ventana Tongue sandstones also are exposed in the cliffs across the Rio Puerco at 3:00, underlain by Lewis Shale in the slope (Fig. 1.2). The La Ventana Tongue of the Cliff House Sandstone is thin here, indicating a relatively rapid transgressive movement of the shoreline at this location. **0.9**

10.1 Road to right crosses Rio Puerco and accesses Mesa Portales. **0.8**

10.9 Bridge over major tributary of Rio Puerco. The lowermost sandstone at 3:00 across the Rio Puerco is the La Ventana Tongue of the Cliff House Sandstone, underlain by the upper Menefee Formation, a soft, slope-forming, coal-bearing sequence. **0.5**

11.4 County road to left follows strike valley in Menefee Formation and leads to Argonics Inc. Clod Buster No. 1 humate mine in the upper Menefee Formation (Fig. 1.3). The Clod Buster has been in operation since 1965, mining organic mudstone, rich in humic acid. Production is at 100 tons/day, mainly removed by front-end loaders. Humate is used as a soil additive either as a solid or in a liquid-extract form (Siemers and Wadell, 1977). **0.9**

12.3 Outcrops to left in the La Ventana Tongue of the Cliff House Sandstone. The total thickness has increased significantly from the last mention of this unit in the road log at mile 10.9. Old Highway 44 to left is washed out about 1 mi to the north at Arroyo de los Pinos. **0.4**

12.7 At 3:00, upper Menefee Formation is well exposed. Note pink-red baked shale beds ("clinker"). Road to

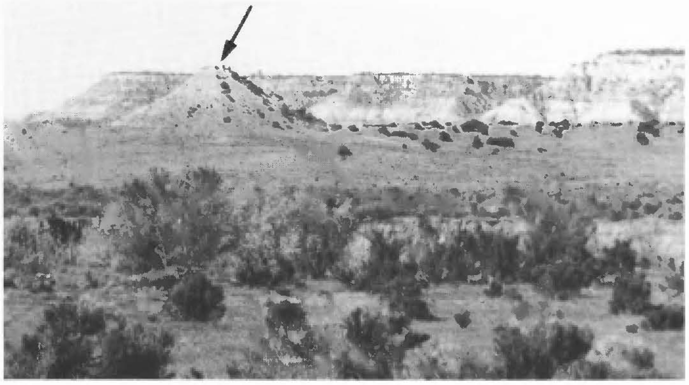


FIGURE 1.1. Marion Butte (arrow) in front of Mesa Portales from mile 4.5.

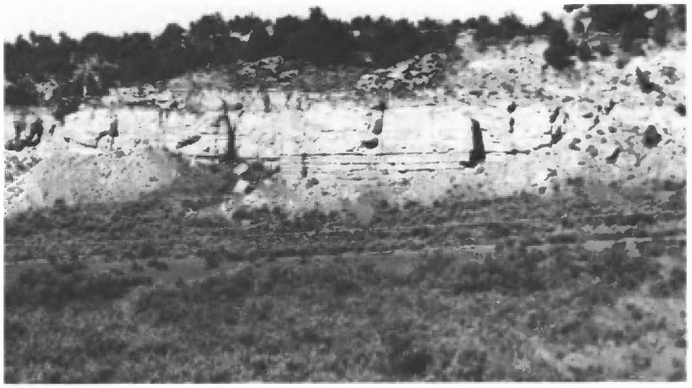


FIGURE 1.2. La Ventana Tongue of Cliff House Sandstone near mile 9.2.

right crosses Rio Puerco, first view of Cabezon at 1:00 in distance. Bluff at 2:00 is La Ventana Tongue of Cliff House Sandstone.

The La Ventana Tongue is a thick sequence of stacked, barrier-beach sandstones in the southern San Juan Basin deposited along a northwest-trending strand line. The sandstones can be quite thick and interfinger with the coal-bearing nonmarine deposits of the upper Menefee Formation to the south-southwest and with marine Lewis Shale to the northeast. In this part of the basin, several thick coals were developed in a paludal facies behind the back-barrier sandstones. The balance between subsidence and sediment supply was such that there was a large buildup of barrier sandstones during a series of shoreline oscillations, allowing significant coal development. **0.8**

13.5 Note stream-terrace levels on both sides of Rio Puerco. **0.3**

13.8 **STOP 1. Pull off to the left** to La Ventana rest area to discuss the coal-mining history of La Ventana, the Point Lookout delta (see minipaper by Wright-Dunbar), the type section of the La Ventana Tongue of Cliff House Sandstone and thrust faulting in Cretaceous strata (see minipaper by Stewart and Hibbard). Note ranch to west, all that remains of coal-mining town of La Ventana (Fig. 1.4).

La Ventana (Spanish, window) now consists of a single dwelling and a few abandoned buildings, but thrived briefly as a coal-mining town in the 1920s and early 1930s. The earliest settlers were ranchers who arrived in the 1870s. Rankin (1944) noted that in 1924, La Ventana contained only a single house, but the following year coal was being mined, and there was a store, several houses and a post office. A group of 11 individuals, mostly from Albuquerque, became interested in the La Ventana area because of the impending railroad and the good coal outcrops. The outcome of this and F. S. Donnell's work to find coal was the San Juan Coal and Coke Company mine permitted in 1923. Five other mines, the Wilkins, Sandoval, Anderson, Sackett, Kistler, and White Ash, were opened in the La Ventana area between 1923 and 1930.

Prospecting and initial development of the coal mines occurred in 1925 to 1927, and the San Juan Coal and Coke Company built a railroad north from San Ysidro

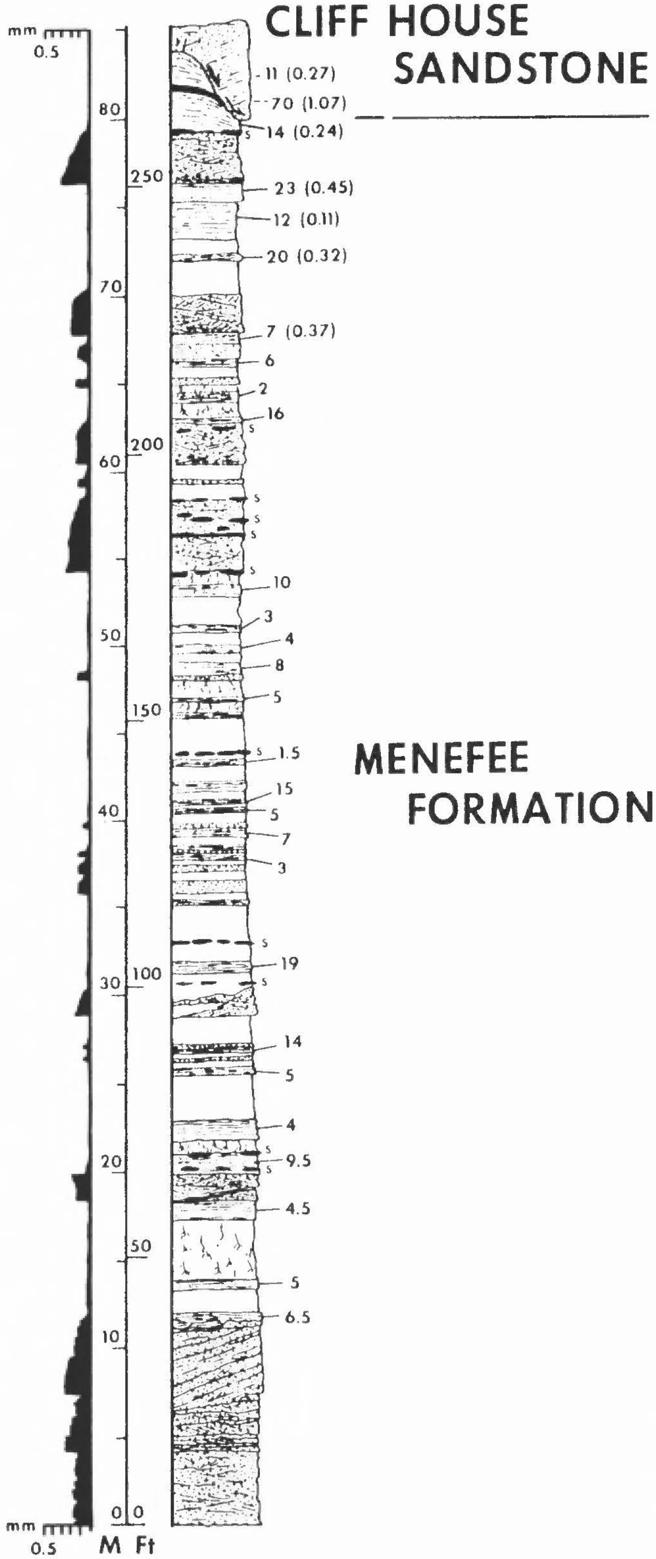


FIGURE 1.3. Measured section (Kme-2) of upper part of Menefee Formation near Clod Buster mine. Large penecontemporaneous sandstone slump blocks of the Cliff House Sandstone (La Ventana Tongue) overlie the Menefee here. Humic acid content (weight percent) of most humate (dashed pattern) and weathered coal (black seam near top) beds are indicated along the right side of the column. Sulfur content (weight percent) for a few beds is noted in parentheses. Other symbols include: S, for siderite nodules and concretions; root marks, for in-situ root tubes; stipple pattern, sandstone; and nonpatterned area, barren mudstone. Approximate grain size (determined with a field visual comparison strip) is indicated by the left column (from Siemers and Wadell, 1977).

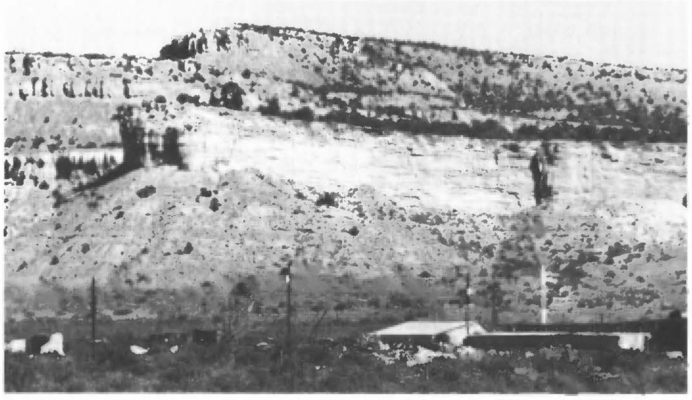


FIGURE 1.4. View of remnants of La Ventana with Cliff House Sandstone cliff underlain by Menefee Formation in background.

to a point about 5 mi north of La Ventana. This line, known successively as the Cuba Extension, Santa Fe Northern, and Santa Fe, San Juan and Northern Railroad, was originally projected to reach Cuba (with its prospective sandstone copper mine), but that segment was never built (Myrick, 1970). This railroad did provide easy transportation of coal from the La Ventana mines to its connection with the Santa Fe Northwestern Railroad at San Ysidro, and thence to the Atchison, Topeka and Santa Fe main line at Bernalillo. Spur lines were constructed to the San Juan and Anderson mines in 1931. Another spur was built to the White Ash tipple. Records show that about 15 to 25 rail cars of coal per week were delivered from La Ventana between 1928 and 1930. In 1930, La Ventana was at its height, boasting the 16-room El Nido Hotel, general merchandise stores, restaurants, a school, and a population of 150 (Sherman and Sherman, 1975).

These operations were short-lived due to the railroad's economic problems and large storms that washed out parts of the line and kept it mostly idle in 1931 and 1932. The Depression prevented permanent repairs from being made, and La Ventana withered and died, with the post office closing in 1932. The rails were finally removed in 1940–1941. After the railroad failed, coal production greatly decreased. There was another spurt of coal mining activity in this area in the late 1930s. About this time (1937), the abandoned San Juan mine caught fire but was under control by 1939. The fire became reactivated when the Peacock mine tunneled into the San Juan mine. It wasn't until 1951, when the U.S. Bureau of Mines completed a fire-control project, that the fire was completely under control (Nickelson, 1988, p. 173, 174, 191).

Coal mined in the La Ventana area was obtained chiefly from several thin beds in the Cleary Member of the Menefee Formation; minor amounts came from a bed at the top of the Allison Member, just beneath the La Ventana Tongue of the Cliff House Sandstone. A short distance below the La Ventana Tongue, this coal is fairly thick (8–10 ft) and is often referred to as the Padilla seam, after one of the miners that worked it. The upper 1–2 ft of the seam is reported to be shaly and of poor quality. The coal northwest of La Ventana is also upper Menefee, but because of its distance from the Nacimiento uplift, the dip of the beds is not as great. The San Juan Coal and Coke Company's Cleary mine, about a mile west-northwest of La Ventana, was the largest mine in the area. During the four years of major production (1928–1931), about 58,500 tons of coal were extracted by underground methods from this mine (Dane, 1936; Shomaker, 1971). Rope haulage was used, with a boiler, hoist, tipple, dump and screens on the surface. The tipple discharged to a spur track that crossed the Rio Puerco by bridge and linked to the main rail line at La Ventana.

The coal was deposited during a major stillstand in an overall transgressive sequence inland from the major back-barrier-sandstone buildup of the La Ventana Tongue of the Cliff House Sandstone. Massive sandstones east of the rest stop, and behind La Ventana store, on the west side of the road, are in the La Ventana Tongue of the Cliff House Sandstone. The lowermost sandstone behind the La Ventana store is the lowermost in the La Ventana Tongue sequence, and the center part of the valley is in the upper Menefee Formation. To the west a series of soft, silty, shaly, coal-bearing units, with occasional burn (clinkers), intertongues with massive, tan sandstones. This series represents the alternating and stacked sequence between the nonmarine Menefee and the barrier-beach sequences of the La Ventana Tongue. This unit is 900 ft thick at this locality (Woodward and Schumacher, 1973). The entire La Ventana–Menefee sequence viewed here intertongues with the Lewis Shale to the north and essentially disappears in the subsurface approximately 30 mi northwest of this point, near Mesa Portales.

Uranium mineralization also occurs in the Menefee Formation on North Butte and South Butte in the La Ventana area (McLemore and Chenoweth, this volume). At these localities uranium mineralization occurs below the La Ventana Tongue. The U.S. Geological Survey (Bachman et al., 1959) indicated that a resource of 132,000 tons of coal and carbonaceous shale grading 0.10% uranium is present.

Uranium was produced at the Butler Brothers deposit in this area in the Dakota Sandstone (McLemore and Chenoweth, this volume). A total of 23 tons of ore grading 0.63% U_3O_8 were mined from a carbonaceous shale or peat bed at the base of the Dakota Sandstone.

After the stop, turn left onto NM-44 and continue south. Road is on Mancos Shale now. **1.9**

THE POINT LOOKOUT DELTA AT LA VENTANA, NEW MEXICO

Robyn Wright-Dunbar

Department of Geology and Geophysics, Rice University, P.O. Box 1892,
Houston, Texas 77251-1892

INTRODUCTION

The Mesaverde Group in the southeastern San Juan Basin contains the basal marine Point Lookout Sandstone, the overlying dominantly nonmarine Menefee Formation, and the uppermost marine La Ventana Tongue of the Cliff House Sandstone. The classic intertonguing of these and related formations (Sears et al., 1941; Molenaar, 1983) reflects temporal changes in the delicate balance of sediment supply, sea level and subsidence in the Western Interior seaway.

As noted originally by Hollenshead and Pritchard (1961), and expanded upon by Palmer and Scott (1984) and Wright (1984, 1986), La Ventana and Point Lookout sandstones in the southeastern San Juan Basin display an internal cyclicity in which higher-order (<100,000 yr) transgressive-regressive couplets form the fundamental stratigraphic units of the migrating shorelines. Wright (1986) subdivided the Point Lookout into seven "time slices," using high-frequency transgressive mudrocks as markers, and mapped multiple Point Lookout shoreline trends in this portion of the basin. Each shoreline trend made a seaward bend in the vicinity of La Ventana (Fig. 1.5), suggesting the presence of a dip-aligned sedimentary package in that area. The observed shoreline irregularity is consistent with previous interpretations that the Point Lookout at La Ventana is (at least partially) deltaic in origin (Siemers et al., 1975; Fuchs-Parker, 1977; Wright, 1984, 1986).

The purpose of this field trip stop is to view these deltaic lithofacies in the Point Lookout within the framework of the high-frequency constituent cycles. Although delta deposits appear to be a relatively unusual

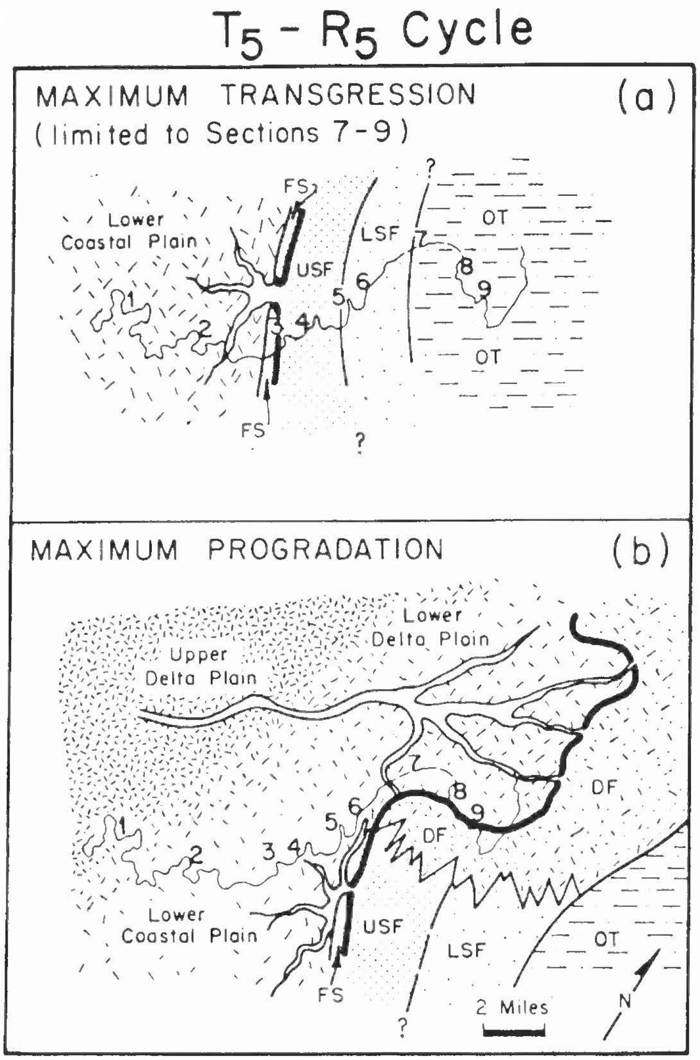


FIGURE 1.5. Paleogeographic maps of the Point Lookout strandline in the southeastern San Juan Basin during the T–R_5 depositional cycle. Numbered locations are measured outcrop sections (#8 is La Ventana, New Mexico). Symbols: FS = foreshore; USF = upper shoreface; LSF = lower shoreface; OT = offshore transition; DF = delta front. From Wright (1986) with permission of the Geological Society of America.

component of the Point Lookout on a basinwide scale, they form a very different reservoir type and also may be systematically related to coal accumulation in the overlying Menefee.

MEASURED SECTION

The basal Point Lookout Sandstone at La Ventana (Fig. 1.6) consists of two coarsening-upward, very fine-grained sandstones (unit 1, 4) with intervening mudrock (units 2, 3). Sandstone sedimentary structures are dominated by 20–40 cm lamina sets of swaly to gently hummocky beds and undulatory parallel laminations. Tool marks in a gutter cast at the base of unit 4 are oriented along a S-SW trend. The sandstones are slope formers except where orange, calcite-cemented concretions form resistant ledges. Shell fragments and siderite nodule lags line gentle scour surfaces within the sandstones and are most visible within resistant concretion ledges.

Disseminated organic debris, including mm-scale wood fragments, is present along some sandstone laminae and throughout the mudrock unit. Sandstones are well-sorted sublitharenites (Shetiwy, 1978; Wright, 1984) with common accessory glauconite. Marine bioturbation is limited to rare *Thalassinoides* and thin *Ophiomorpha* burrows in hummocky sandstone and *Chondrites* in mudrock units.

Unit 5 is a slope-forming, partially covered sandstone at this location, although laterally adjacent exposures reveal a thin (< 2 m) basal siltstone and overlying fine-grained, swaly-bedded sandstone at this stratigraphic interval. Gradationally overlying the covered interval are tabular-bedded, parallel-laminated, organic-rich sandstones of units 6–8, which locally contain current ripple stratification and shallow scour-and-fill structures. A gentle eastward dip (<6°) can be demonstrated for some of the tabular bedsets. Abundant detrital organic debris lines lamina surfaces and shallow scours, and increases in the upper meter of unit 8 to an in situ rooted coal horizon (unit 9) 10–70 cm in thickness. Shallow (<1 m) channels are present locally beneath this rooted coal. Sandstones of unit 5–8 are more poorly sorted than underlying units, with a coarsening-upward range of grain sizes from 125 to 250 microns.

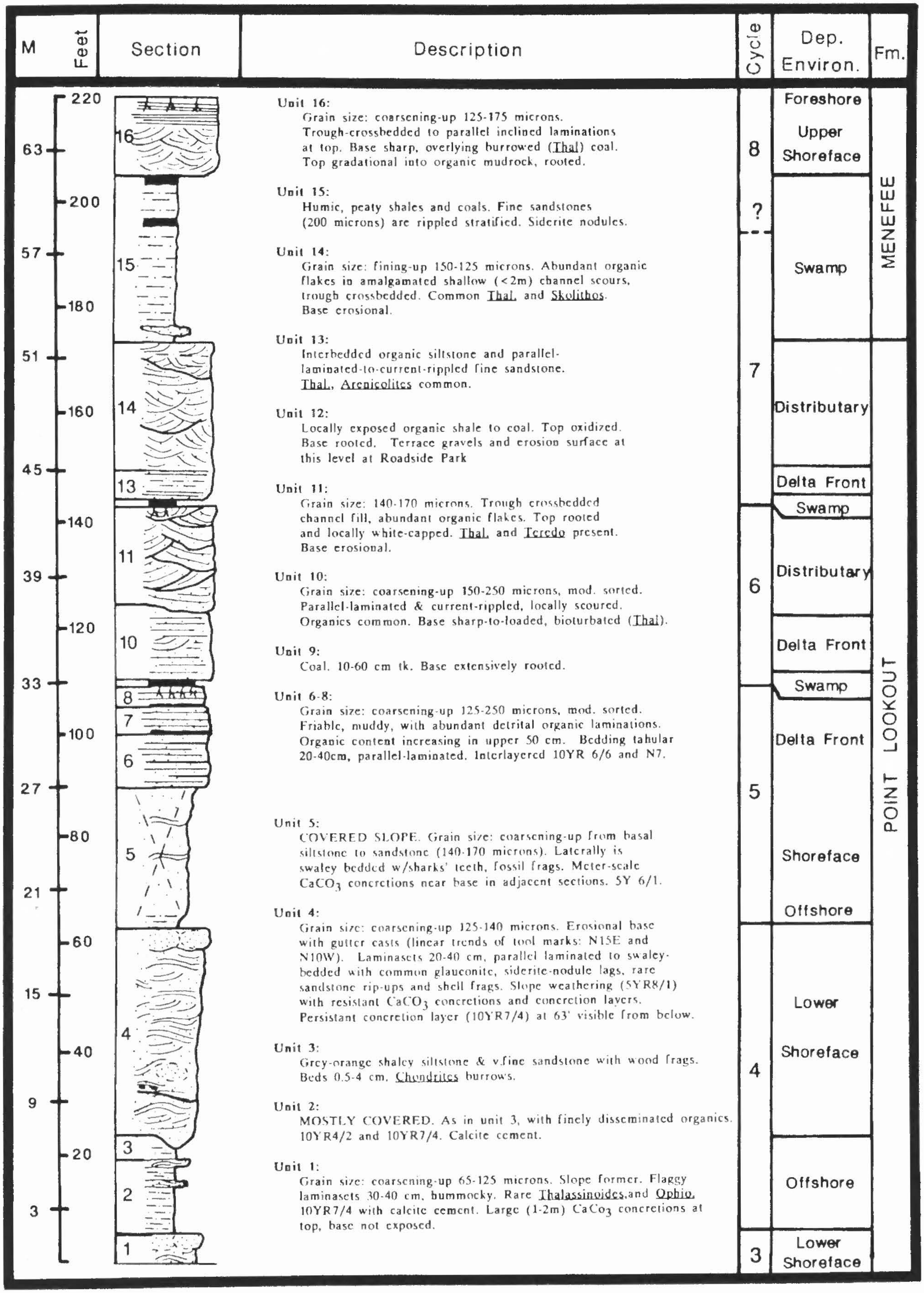
Two remaining sandstone packages (units 10–11 and 13–14) complete the vertical Point Lookout section in the La Ventana area (note that an erosion surface and terrace gravels interrupt this section immediately above the Roadside Park). Each package has a basal parallel-laminated and current-rippled sandstone that overlies either a rooted coal (unit 9) or coaly organic shale (unit 12). *Thalassinoides* burrows are common at the interface between coal and overlying sandstone. Channel scours with trough-cross-stratified fill (units 11 and 14) cut into underlying parallel-laminated facies, and locally eroded completely through, so that units 14 and 11 may be superimposed. Paleocurrent directions are dominantly to the SE, with a systematic NW reversal in small-scale troughs at the top of unit 14. Fine-grained organic material is common to abundant along cross-laminae within these channel units. *Thalassinoides*, *Skolithos* and *Arenicolites* burrows and *Teredo*-bored logs are sparsely present throughout these sandstones. Median grain size falls within the range of 175–250 microns and shows a slight fining trend toward the top of unit 14.

Unit 15 contains the stratigraphically lowest thick organic shales in the section and therefore marks the base of the Menefee Formation at La Ventana. The unit is composed of thinly interbedded, ripple-laminated, fine-grained sandstones, siltstones and organic silty shales. Marine fossils appear to be absent except at the top of the unit, where unit 16 lies in sharp contact. Unit 16 is a bioturbated (*Thalassinoides*), trough-crossbedded sandstone that is capped by parallel laminations.

The stratigraphic interval at La Ventana reflects deposition under two distinct coastal regimes. The older, represented by units 1–4, is that of storm-influenced inner shelf and lower shoreface. Transition from the Mancos Shale to swaly-to-hummocky-bedded and amalgamated Point Lookout sandstones reflects shoaling and increasing influence of combined-flow shelf currents produced during major storms (Harms et al., 1982; Swift et al., 1983). The presence of marine bioturbation and the local occurrence of marine fossil lags, shark teeth and glauconite also support a marine inner shelf to shoreface interpretation. Wright (1986) suggested these sandstones were distal shoreface deposits directly associated with beaches to the west-southwest, and inferred that a seaward shoreline bend occurred at La Ventana. An alternative interpretation by Siemers et al. (1975) placed these in an offshore bar environment. Both interpretations are plausible, with the distinction lying in physical landward correlation into mainland beach deposits.

The two coarsening-upward cycles ("parasequences" of van Wagoner et al., 1987) present in these basal units (R_1 and T–R_4) have been correlated into the measured section from Point Lookout beach deposits to the southwest (Wright, 1986). Wright (1988) and Wright and Hayden (1988) recently documented the existence of both transgressive mudrocks and sandstones at this scale in equivalent strata to the southwest, although these cycles were previously thought to lack transgressive deposits (Wright, 1986). Based on these recent findings, units 2 and 3 are here reinterpreted as part of a transgressive mudrock that is sharply downlapped by the overlying regressive shoreface package (unit 4).

An entirely different depositional setting is manifested in the upper Point Lookout cliffs (units 5–14) at La Ventana. As originally postulated by Siemers et al. (1975) and Fuchs-Parker (1977), these sandstones best fit a deltaic depositional model. Unlike units 1–4, the upper sandstones at La Ventana are tabular-bedded and dominantly parallel-laminated (units 6–8, 10 and 13) with abundant detrital organic matter and



Unit 16:
Grain size: coarsening-up 125-175 microns. Trough-crossbedded to parallel inclined laminations at top. Base sharp, overlying burrowed (Thal) coal. Top gradational into organic mudrock, rooted.

Unit 15:
Humic, peaty shales and coals. Fine sandstones (200 microns) are rippled stratified. Siderite nodules.

Unit 14:
Grain size: fining-up 150-125 microns. Abundant organic flakes in amalgamated shallow (<2m) channel scours, trough crossbedded. Common Thal. and Skolithos. Base erosional.

Unit 13:
Interbedded organic siltstone and parallel-laminated-to-current-rippled fine sandstone. Thal., Arenicolites common.

Unit 12:
Locally exposed organic shale to coal. Top oxidized. Base rooted. Terrace gravels and erosion surface at this level at Roadside Park

Unit 11:
Grain size: 140-170 microns. Trough crossbedded channel fill, abundant organic flakes. Top rooted and locally white-capped. Thal. and Teredo present. Base erosional.

Unit 10:
Grain size: coarsening-up 150-250 microns, mod. sorted. Parallel-laminated & current-rippled, locally scoured. Organics common. Base sharp-to-loaded, bioturbated (Thal).

Unit 9:
Coal. 10-60 cm tk. Base extensively rooted.

Unit 6-8:
Grain size: coarsening-up 125-250 microns, mod. sorted. Friable, muddy, with abundant detrital organic laminations. Organic content increasing in upper 50 cm. Bedding tabular 20-40cm, parallel-laminated. Interlayered 10YR 6/6 and N7.

Unit 5:
COVERED SLOPE. Grain size: coarsening-up from basal siltstone to sandstone (140-170 microns). Laterally is swaley bedded w/sharks' teeth, fossil frags. Meter-scale $CaCO_3$ concretions near base in adjacent sections. 5Y 6/1.

Unit 4:
Grain size: coarsening-up 125-140 microns. Erosional base with gutter casts (linear trends of tool marks: N15E and N10W). Laminasets 20-40 cm, parallel laminated to swaley-bedded with common glauconite, siderite-nodule lags, rare sandstone rip-ups and shell frags. Slope weathering (5YR8/1) with resistant $CaCO_3$ concretions and concretion layers. Persistant concretion layer (10YR7/4) at 63' visible from below.

Unit 3:
Grey-orange shaley siltstone & v.fine sandstone with wood frags. Beds 0.5-4 cm. Chondrites burrows.

Unit 2:
MOSTLY COVERED. As in unit 3, with finely disseminated organics. 10YR4/2 and 10YR7/4. Calcite cement.

Unit 1:
Grain size: coarsening-up 65-125 microns. Slope former. Flaggy laminasets 30-40 cm, hummocky. Rare Thalassinoides,and Ophio. 10YR7/4 with calcite cement. Large (1-2m) $CaCo_3$ concretions at top, base not exposed.

FIGURE 1.6. Point Lookout measured section at La Ventana.

only rare marine bioturbation. These are distributary mouth bar and delta-front facies with superimposed, tide-influenced distributary channels (units 11 and 14). Although much organic matter is clearly detrital, coaly units 9 and 12 are extensively rooted, suggesting in situ development of peat swamps between delta-lobe depositional events.

Cycles T–R_5, T–R_6 and (possibly) T–R_7 occur within deltaic units that are each capped by coal or organic shale. Although no clear transgressive deposits have yet been identified for these cycles, the transition from active distributaries to capping coals may reflect decreasing gradients and aggradation of organic material in low-lying swamps during transgression. Continued submergence and marine inundation allowed the influx of marine burrowing organisms and produced sufficient accommodation space to encourage renewed distributary discharge and to accumulate sands of the next younger delta front. These cycles may be auto-cyclic, in that they were driven purely by fluvial processes similar to the proposed abandonment phases of the Mississippi Delta (Frazier, 1967), or there may be a true fluvial runoff cycle driven by climatic changes (precipitation) in the source area. This question remains to be answered as more quantitative study of individual cycle geometry and lateral extent is accomplished.

LA VENTANA COAL FIELD

From the Roadside Park, one can see the tipple site of the underground San Juan and Peacock coal mines to the west of the La Ventana townsite. Active during the 1920s and 1930s, these are part of the La Ventana coal field in the Menefee Formation, the history and coal resources of which have been described in detail by Shomaker et al. (1971) and Nickelson (1988). According to these authors, large tonnages of 10,500-BTU low-sulfur coal remain in the field, but are unlikely prospects for strip-mining due to excessive dips and overburden. Underground mining in the area was frustrated by railway washouts, reduced coal sales in the 1920s and fire which burned in the San Juan mine from the late 1930s to at least the late 1940s. At the time the fire started, the San Juan mine had produced 57,332 tons of coal with the following typical analysis (from Nickelson, 1988): moisture, 15.8%; volatile matter, 34.5%; fixed carbon, 43.8%; ash, 0.9%; sulfur, 0.6%; BTU, 10,900.

Coal deposits of the La Ventana field accumulated in close association with a marine deltaic depocenter that existed from Point Lookout through La Ventana Tongue time. The fact that the La Ventana area was a site of deltaic deposition throughout its marine history (Siemers et al., 1975; Fuchs-Parker, 1977; Palmer and Scott, 1984; Wright, 1986) suggests there may be a link between the deltas and minable coal deposits. It further causes one to speculate on the possibility of structural control of the fluvial system.

Both the Point Lookout Sandstone and La Ventana Tongue increase in stratigraphic thickness across the area. This is much more pronounced for the La Ventana, but is also visible in Point Lookout isopachs (Shetiwy, 1978; Wright, 1986). This increase results from increased vertical stacking of high-frequency strandline and deltaic cycles. As Ryer (1977, 1981, 1983) documented, there is a tendency for enhanced coal development to occur immediately landward of such vertical cycle buildups (equivalent to "benches" of Hollenshead and Pritchard, 1961). No systematic study of the potential correlation between cycle buildups, deltaic deposits and coal accumulation in the southeastern San Juan Basin has been made. However, it seems likely that detailed mapping of high-frequency cycles may provide clues to local deltaic depocenters and, possibly, a link to coal accumulation patterns in the Menefee.

SUMMARY

Deltaic deposits at La Ventana represent a relatively uncommon lithofacies of the Point Lookout Sandstone that is characterized by greatly increased organic matter and moderately sorted sandstones within both delta-front and distributary-channel deposits. These lithologies are distinct from the cleaner shoreface sandstones that appear to dominate Point Lookout reservoirs. Recognition of high-frequency constituent cycles is critical to proper interpretation of Point Lookout shoreline trends and reservoir types and may allow prediction of vertical reservoir heterogeneity resulting from the presence of transgressive mudrocks. Future research also may support the assertion that a direct link exists between these local deltaic depocenters, vertical strandline buildups and coal accumulation in the Menefee.

LATE CRETACEOUS THRUST FAULTING AT THE EASTERN EDGE OF THE SAN JUAN BASIN, NEW MEXICO

Kevin G. Stewart[1] and James P. Hibbard[2]

[1]Department of Geology, University of North Carolina,
Chapel Hill, North Carolina 27599-3315;
[2]Department of MEAS, North Carolina State University,
Raleigh, North Carolina 27695-8208

Structural studies of Laramide-type uplifts have generally focused on the kinematics and geometry of the faults within the Precambrian crystalline basement (e.g., Brown, 1988). Deformation of the sedimentary cover has generally been viewed only as a response to the loading imparted by the movement of the Precambrian basement. Very little is known about how the cover rocks respond to the first episodes of shortening that ultimately produce the uplifts. At the eastern margin of the San Juan Basin, significant low-angle thrusting of the sediment cover occurred before—and possibly during—the first stage in the formation of the Laramide Nacimiento uplift.

Previous workers (Baltz, 1967; Woodward, 1987) have noted that the Nacimiento uplift involved at least two broad phases of Laramide deformation: folding of strata along the eastern margin of the San Juan Basin, followed by the main uplift involving overturned, west vergent folding of basin strata adjacent to the uplift, and formation of the mountain flank thrust between Precambrian crystalline basement and cover. The initial folding episode is represented as an en-echelon array of broad, north-northwest-plunging folds along the east side of the basin.

Our recent mapping southeast of Cuba, in the east-central part of the San Pablo 7.5′ quadrangle (Fig. 1.7) has revealed a low-angle thrust fault within the upper part of the Late Cretaceous Mesaverde Group that may have preceded the first stage of deformation mentioned above. We have informally termed this fault the San Pablo thrust. The thrust is best exposed on the western limb of a syncline adjacent to the San Pablo anticline (Baltz, 1967) at the localities marked 1 and 2 on Fig. 1.7. The thrust is bedding-parallel and has placed a thin sliver of organic-rich shales and coal of upper Menefee Formation, together with the La Ventana Tongue of the Cliff House Sandstone, on top of autochthonous La Ventana Tongue strata (Fig. 1.8). The thickness of the fault zone in this area is about 3–4 m.

The San Pablo thrust exhibits a variety of minor structures concentrated in the sliver of Menefee Formation at the bottom of the thrust sheet. The thrust zone contains minor folds, cleavage, lineations, shear bands and transposition of layering. The folds are dominantly tight to isoclinal and recumbent, with axial planes that are roughly parallel to bedding (Fig. 1.9). The largest folds have amplitudes greater than 2 m. Most of the folds plunge gently to the north-northwest, but hinge directions are variable in some of the more noncylindrical folds. In general, the folds are asymmetric and verge toward the west.

In many places the folds are sandwiched between zones of finely laminated (mm scale), planar alternations of sandstone and black, organic-rich shale and siltstone. In the region near locality 1 on Fig. 1.7, this layering results from the transposition of thicker sand and shale layers into zones of high shear strain. In thin section, it appears that the dominant deformation mechanisms in these zones have been cataclasis and particulate flow.

An axial planar cleavage parallel to the walls of the shear zone is also common in the parts of the thrust zone containing macroscopic folds. In many places this cleavage cuts higher order folds within the larger folds and is similar in appearance to a "spaced" crenulation cleavage. Locally, a very rough elongation lineation defined by plant fragments is found in the plane of the cleavage, and trends approximately east-northeast. Shear bands in some places cut cleavage in the

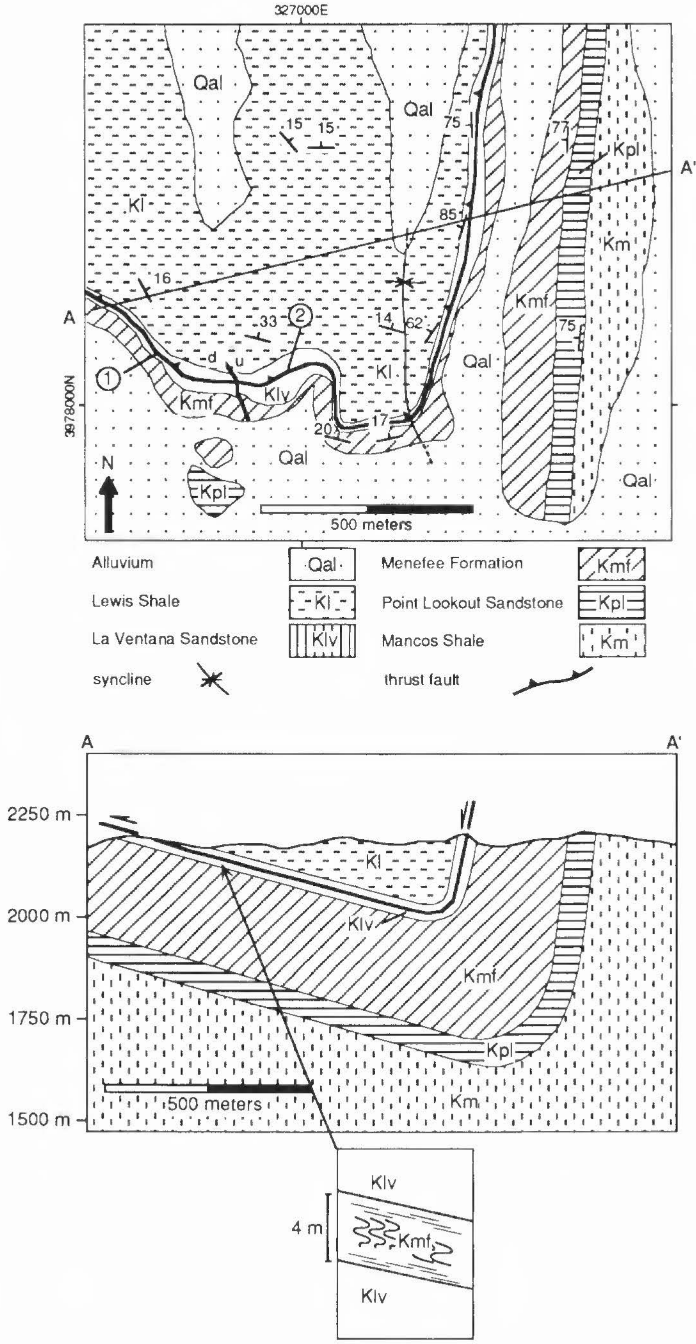


FIGURE 1.7. Geologic map and cross section in east-central part of San Pablo quadrangle.

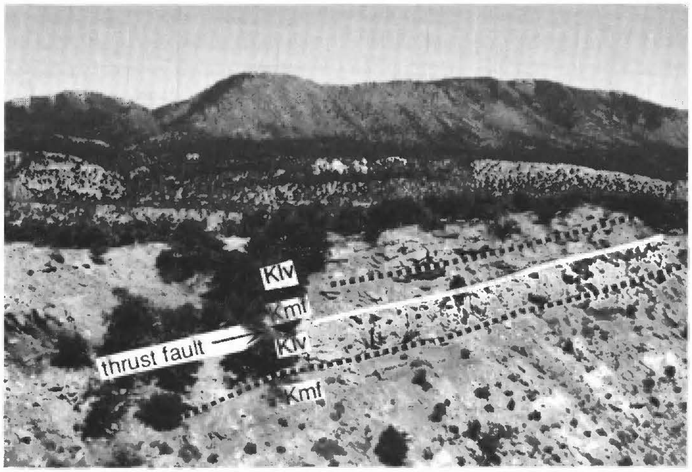


FIGURE 1.8. Thrust that places a thin sliver of Menefee Formation and La Ventana Tongue on top of autochthonous La Ventana Tongue of Cliff House Sandstone.

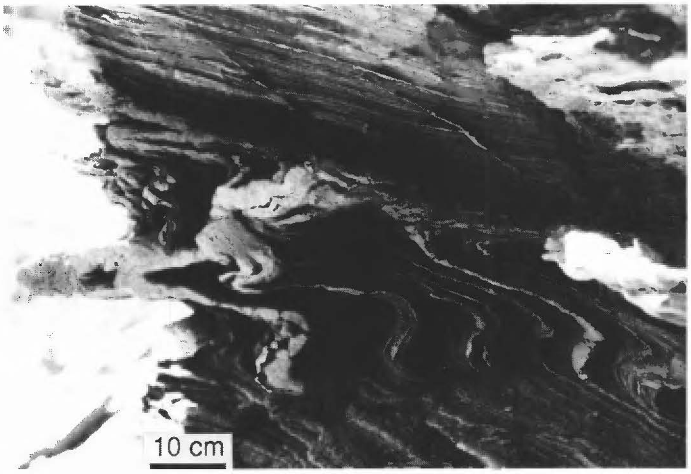


FIGURE 1.9. Fold in Menefee Formation at bottom of thrust sheet.

fault zone. A preliminary analysis of the geometry of the shear bands combined with the fold asymmetry suggests a roughly top-to-the-west transport direction, which is consistent with the sense of movement on the Nacimiento fault to the east (Baltz, 1967).

At this point in our study, we have only a minimum estimate of the total displacement on the San Pablo thrust. We have traced the fault from the area shown in Fig. 1.7 along a series of outcrops to the west for a map distance of about 2 km. If the La Ventana Tongue of the Cliff House Sandstone is doubled over this entire distance, the thrust has a minimum slip of 2 km. Given that the contact between the Menefee Formation and the La Ventana Tongue of the Cliff House Sandstone has been reported as gradational or interfingering in this area (Baltz, 1967), we cannot completely rule out the possibly that we are just seeing a sheared interval between two separate sandstone lenses that have not been doubled by thrusting. We feel, however, that the extent of the shear zone and the intensity of deformation within the zone support the hypothesis that there has been significant displacement on the fault. More mapping and field work is required to resolve these problems.

The timing of the movement on the thrust can be constrained using both stratigraphic and structural evidence. The thrust postdates deposition of the middle Late Cretaceous Menefee Formation and La Ventana Tongue of the Cliff House Sandstone. The San Pablo thrust appears to have been folded by the San Pablo anticline, one of a series of low amplitude, en-echelon folds that formed during the Late Cretaceous and Paleocene in the San Juan Basin (Baltz, 1967; Woodward, 1987). The thrust also must predate the main episode of uplift of the Nacimiento block (Paleocene-Eocene) because it can be traced through the steep eastern limb of the footwall syncline (Fig. 1.7) produced by movement on the Nacimiento fault.

At this early stage in our study, fundamental questions remain regarding the geometry and origin of the San Pablo thrust. In addition to those discussed earlier, we are particularly interested in how this thrust relates to the Nacimiento fault. One possibility is that the San Pablo thrust roots into the Nacimiento fault. If so, the Nacimiento fault has accommodated at least 2 km of shortening. Another possibility is that the sedimentary cover shortened more or less independently of the Precambrian crystalline basement. In either case, the geometry, kinematics and timing of the San Pablo thrust suggest that it is related to the Nacimiento fault and probably formed as an early response to the compression that ultimately led to the formation of the Nacimiento uplift. To our knowledge, this early thrust fault is the first to be reported from a Laramide-type uplift, although the existence of such features has been predicted by mechanical studies (e.g., Spang and Evans, 1988). Future work in this area should provide a more complete picture of the early evolution of Laramide structures.

15.7 Crest of hill, road on right, Cabezon at 2:00 in front of Mt. Taylor volcanic field. Leaving Rio Puerco drainage to Salado drainage; note low drainage divide. The Rio Salado has captured streams of the southern Nacimientos and moved the divide west to low-relief ridges of Mancos Shale. **0.7**

16.4 Roadcuts in Mancos Shale overlain by inset alluvial-fan gravels. **0.9**

17.3 Crest of hill; from 8:00 to 11:00 on the skyline are the Nacimiento Mountains, which are upthrust several thousand ft along a major north-south fault system (Woodward, 1987). **2.1**

19.4 From 1:00 to 2:00 note Cabezon and smaller but abundant volcanic necks in the Rio Puerco volcanic field (see Hallett, this volume) and basalt-capped Mesa Prieta. **1.7**

21.1 Lookout tower on Pajarito Peak to the southeast on the skyline. **0.3**

21.4 Old road leading to right to Cabezon is now blocked; road to left to Holy Ghost Spring and type section of Semilla Sandstone Member of Mancos Shale. Dane et al. (1968) introduced the term Semilla Sandstone as a member of the Mancos Shale. The Semilla is present along the eastern edge of the San Juan Basin and in the Hagan basin of north-central New Mexico, where it represents several offshore shallow-marine sandbars (Fig. 1.10; LaFon, 1981; Fleming, 1989).

Holy Ghost Spring was once part of one of the largest land grants in New Mexico, the Ojo del Espiritu Santo. The grant covered more than 175 mi^2, extending west to the Rio Puerco and east to the Nacimiento Mountains. It was originally awarded by the Spanish crown in 1815 to the de Baca family, descendants of Cabeza de Baca, the earliest Spaniard to have passed through New Mexico. Tradition holds that the name came from the vision of an early traveler, who rushed into his camp one night shouting "El Espiritu Santo!" The others of his party leaving the camp spotted two ghost-like spirals rising from the ground in a nearby canyon and believed them to be a manifestation of the Holy Ghost. Following the "ghosts," they discovered the spring and named it after the apparitions. In 1934, the estate of the de Baca family was sold to the U.S. government, which turned it over to the Jemez Indians as part of a land settlement (Chilton et al., 1984). **0.9**

22.3 **Turn right** on new, unpaved road to San Luis and Cabezon. **0.1**

22.4 Good view of Cabezon and Rio Puerco volcanic necks from 9:30 to 10:30, with Mt. Taylor on skyline beyond Cabezon. Mesa Prieta forms skyline from 9:30–10:00. Road is on lower Mancos Shale. **0.1**

22.5 Outcrops of Mancos Shale in new roadcuts. Note gentle westward dip of strata into San Juan Basin. **1.1**

23.6 Roadcuts are in Mancos Shale. **1.0**

24.6 Crest of hill. Panoramic view to the south, southwest and the west. At 9:00 is Mesa Prieta; its basalt cap has been dated at 2.2 Ma (Armstrong et al., 1976). At 9:30 are the volcanic necks in the Rio Puerco volcanic field, and at 10:00 is Cabezon Peak. Mt. Taylor on skyline at 10:00–10:30. Basalt-capped Mesa Chivato forms apron of volcanic flow surrounding Mt. Taylor. The fissure vents, collapse craters, maars and trachyte domes here are the greatest concentration of volcanic vents in New Mexico. Volcanism on Mesa Chivato occurred from about 3.2 to 1.5 Ma (Bachman and Mehnert, 1978; Crumpler, 1982).

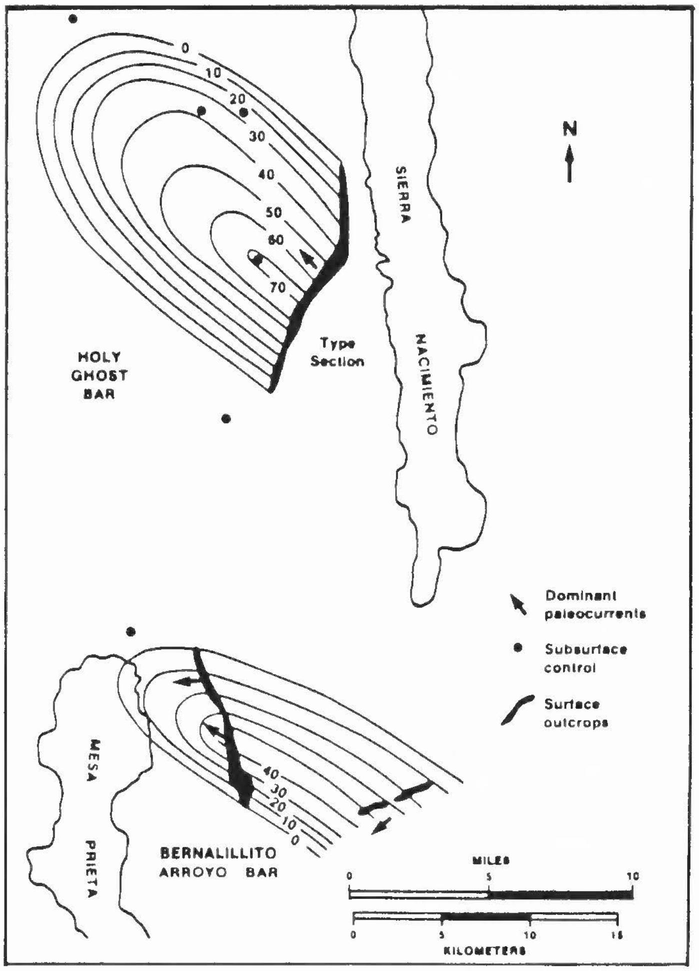


FIGURE 1.10. Isopach of the Semilla Sandstone on the eastern side of the San Juan Basin. Contour interval is 10 ft (from Fleming, 1989).

The transition zone between the Mancos Shale and the Point Lookout Sandstone is visible in cliffs from 11:00–1:00. Cliffs are capped by the Point Lookout Sandstone, and the lower part of the slope is Mancos Shale. From 1:00–2:30 the massive La Ventana sandstones represent the culmination of the buildup between the nonmarine formations to the south and the marine units to the north. The massive sandstone visible in the upper part of the mesa at 2:00 on skyline is near the southernmost extent of the La Ventana Sandstone on this flank of the San Juan Basin. To the left of the slightly arched mesa are three small areas where burn material is visible, giving them their reddish tint. These are Cerro Colorado and Dead Man's Peak, formed within the Menefee Formation. Here, the massive sandstones of the La Ventana are generally absent. **0.7**

25.3 Cattle guard; enter Bureau of Land Management Wildlife Study Area. **0.8**

26.1 Crest of ridge; BLM "Ridge Road" (BLM road 1113) to left; continue straight; Cabezon at 1:00, village of San Luis in valley at 2:00–2:30. Return to Rio Puerco drainage. Note low drainage divide. **0.6**

26.7 Cattle guard. **0.1**

26.8 Bridge over Rio Puerco. Here, the Rio Puerco cuts about 30 ft through the soft claystones and shales of the Mancos. **0.4**

27.2 Road to right to Gaddis Ranch; continue on main road. **0.1**

27.3 Cattle guard. **0.3**

27.6 Enter greater San Luis. San Luis is the northernmost of four abandoned or nearly deserted towns that occupied the middle Rio Puerco valley; the others being Cabezon, Guadalupe and Casa Salazar. Early American exploring parties crossed and recrossed the Rio Puerco in the late 1840s and 1850s but found no permanent inhabitants. Several villages had appeared in the mid-1700s as the Rio Puerco valley was being parceled into nine large land grants (1753–1769), but all were abandoned by 1774 because of constant raids by the Navajos. Indeed, the Indian danger was still present during the initial phases of American occupation. Lieutenant J. W. Abert, returning to Albuquerque after traveling to Acoma in October 1846, very nearly encountered an Indian raiding party. He reported (Abert, 1848, p. 60) that "a large body of Indians, rushing down from the mountains where they had secreted themselves during the night, devastated the whole valley, killing all the human kind they met, and sweeping off the flocks and herds of the Mexicans. No less than 5,000 sheep were carried off within 20 miles of the great city of Albuquerque."

By the 1860s, the Navajos had been defeated and confined to reservations, and people began to settle again in the Rio Puerco valley. The four middle Rio Puerco towns all date from 1870 to 1872. Typically, they were built on the floodplains of the river (Fig. 1.11), on or close to the locations of the 18th century villages. The settlers constructed irrigation ditches, dug by hand or with scoops pulled by draft animals, and built rudimentary dams to divert the flood waters. Agricultural fields were planted between the diversion channels and the river so irrigation water would flow by gravity across the fields and drain into the river. Crops were grown along the river between the towns from a distance of more than 25 mi. These included beans, chili, corn, wheat, alfalfa, oats and vegetables, together with a few apple, pear, plum and cherry orchards. Cattle, sheep, goats and horses were grazed in the surrounding areas farther from the river. Native grasses were cut annually and sold in Albuquerque as "wild hay."

The middle Rio Puerco towns were reasonably successful into the early 20th century. However, beginning in the 1880s, overgrazing and depletion of plant cover, and the accelerated erosion and arroyo entrenchment that resulted, began to alter the landscape and the productivity of the farmland (Fig. 1.11). Lowering of the water table, deepening of the river and arroyo channels and silting of the irrigation ditches became increasingly severe. Devastating flash floods, alternating with periods of drought, contributed to the problems. To the south, in the lower valley, the channel width of the Rio Puerco increased from 75 ft in 1880 to 790 ft in 1939. At La Ventana, to the north, the channel was only 8 ft deep in the 1870s, but was more than 50 ft deep in the 1950s (Widdison, 1958).

Deepening of the Rio Puerco channel made it more difficult to build and maintain diversion dams. Only in the 1930s were government support and engineering expertise available to the dwindling numbers of farmers; the last dam to be built, in 1936 near San Luis, was washed out in 1951 by a large flood. By that time, decades of decreasing productivity and crop yields too small to provide a living had caused nearly every family in the valley to drift away, and most of the towns had been abandoned. Only two families remained in San Luis by the end of the 1950s. Here and there along the Puerco the remains of the irrigation ditches and dams may still be seen, together with the ruins of the towns—testimony to the difficulty of farming in a deteriorating environment, along a mostly dry, but unpredictable, river. During the last few years the population of San Luis has increased and the church has a new, bas-relief facade. Widdison (1958) studied the historical geography of the middle Rio Puerco Valley, and this account is taken from his work. **0.3**

27.9 High Chaparral bar on left. **0.5**

28.4 Small Mancos Shale knob is exposed here. The Point Lookout Sandstone and underlying Mancos Shale form the prominent cliffs located in Mesa San Luis at 3:00. Note at this location that the Point Lookout shoreface sandstones have been removed by a large (presumably tidal) channel, which occupied a total width of approximately 400 m and had a maximum scour depth of 15 m. Channel fill is distinguished from surrounding amalgamated shoreface deposits by a sharp, erosional base and by interbedded shales and lenticular sandstones. Channel cross section is nearly northwest-southeast (roughly parallel to paleoshoreline in this area), suggesting that this may have been a large, shore-parallel tidal creek, rather than an inlet as first suggested by Wright (1986). Because of outcrop inaccessibility, detailed sedimentology and paleocurrent characteristics of this channel are unknown. Note that the channel base can be traced upward and toward the east (right) into a thinly bedded sandstone that caps the mesa. A similar, thin-bedded cap is present throughout most of this area and consists of small, stacked tidal-channel deposits. **1.3**

29.7 Enter ecclesiastical district and school area of San Luis; note Point Lookout Sandstone cyclicity to right (Fig. 1.12). The transition zone at the base of the Point Lookout Sandstone is clearly visible in the cliff to the right of the road for several miles. This transitional unit has been a point of contention, for there are those who would place the base of the Point Lookout Sandstone at the lowest sandstone. Others would place the top of the Mancos Shale at the uppermost shale unit. To the left at 9:00 is the church at San Luis–Iglesia de San Luis Gonzaga de Amarante—1917. **0.5**

30.2 Cattle guard; immediately after cattle guard, **turn right** on dirt road up Arroyo Balcon. **0.8**

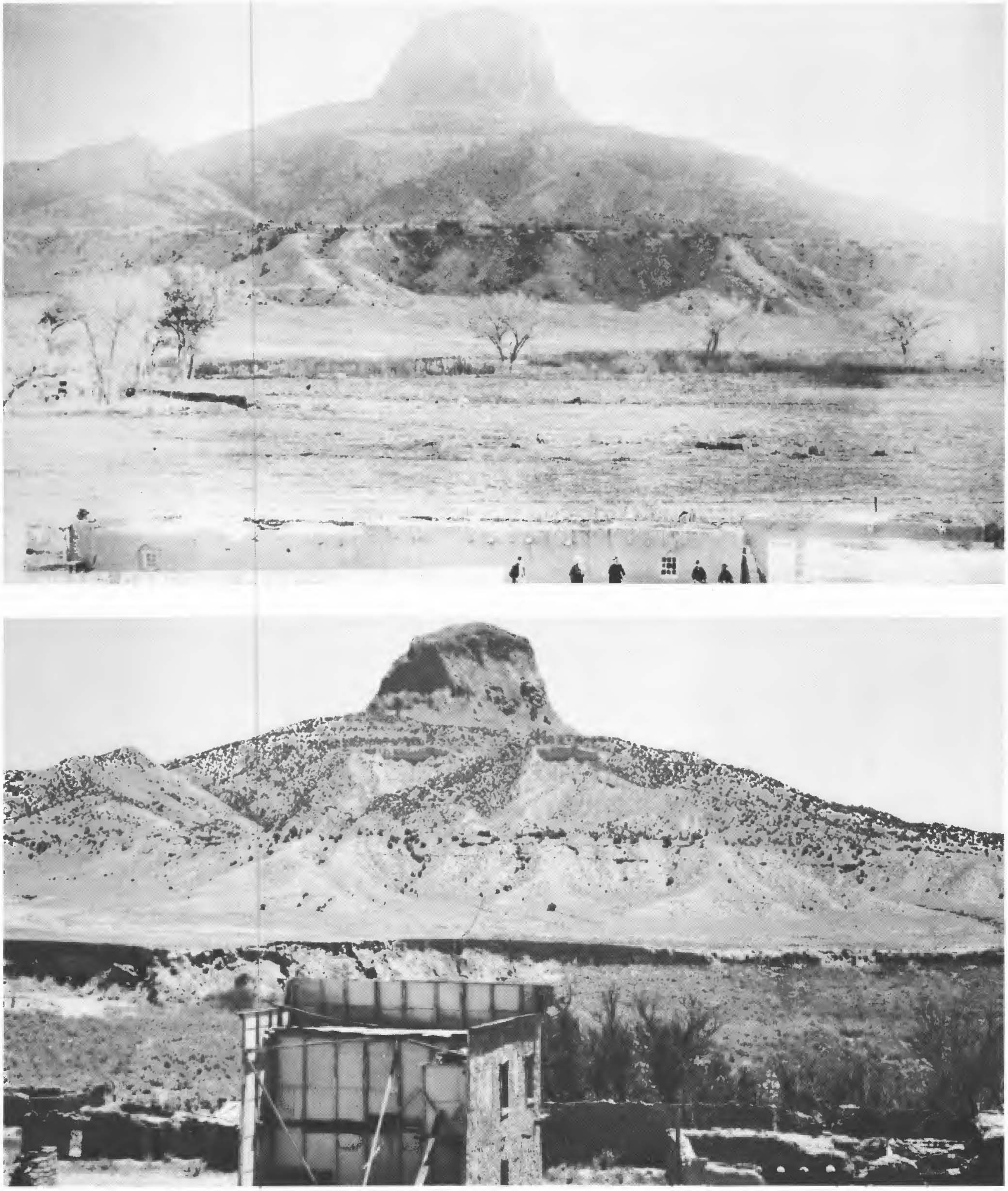


FIGURE 1.11. A, The Rio Puerco and Cabezon Peak as seen in the winter of 1884 from the town of Cabezon, Sandoval County, New Mexico (SE$^{1}/_{4}$ sec. 12, T16N, R3W). View is to the south. The Rio Puerco flows in a shallow, unincised channel marked by cottonwood trees. Cattle and burros graze in the fields bordering the channel. A high water table is indicated by the presence of the cottonwood trees, and the shallow channel is suitable for the practice of flood-irrigation agriculture. Photograph No. 36, Cabezon Peak, by E. A. Bass, Socorro, New Mexico (Library of Congress, Prints and Photographs Division, Lot No. 3268). B, Duplicate of Bass photograph No. 36, taken June 13, 1977 at 1412 hours mountain daylight time by H. E. Malde, U.S. Geological Survey, Denver, Colorado. View is S1°E. The Rio Puerco has changed dramatically in the 93 years since the Bass photograph, and, as a consequence, the way of life in the Cabezon area has changed just as dramatically. The Rio Puerco now flows in a deeply incised arroyo 15 m deep. There has been downcutting of the stream and lowering of the water table, restricting the opportunities for flood irrigation. The fields no longer exist and the town of Cabezon has been abandoned except for occasional use as a movie set. The reasons for the downcutting of the Rio Puerco have long been debated, but whatever the cause the history of the Rio Puerco illustrates well the fragile nature of the New Mexico landscape (Malde photograph No. 985 in U.S. Geological Survey Photo Library, Denver, Colorado).

FIGURE 1.12. Point Lookout Sandstone forms the prominent cliff overlying gray Mancos Shale at Mesa San Luis. Note dissection of massive, amalgamated shoreface sandstones by large tidal channel (arrow defines right margin) filled with lenticular sandstones and thin shales. Transgressive shales T_2 and T_3 lie within the upper Mancos.

31.0 Gate. Several coarsening-upward cycles, or parasequences, are stacked vertically at this location and are separated from one another by marine flooding surfaces (Fig. 1.13). Individual parasequences range from minor silt-clay (tan-gray color) changes in the Mancos Shale to amalgamated Point Lookout shoreface sandstones separated by thin mudrocks or bedding breaks. Especially prominent in outcrop is flooding surface T_2 ("marker shale," Fig. 1.14), which can be correlated paleo-landward (southwest) over 3.6 mi from this location. This surface marks the base of a parasequence that generally coarsens upward from shelf shale to transition zone and lower shoreface storm-deposited sandstones and shales. Mudrocks immediately overlying the flooding surface fine upward, however, and are interpreted to have been deposited during the transgressive, rather than regressive, phase of the cycle (see accompanying minipaper). Using the "marker shale" as a guide, flooding surface T_2 is traceable along the road into Arroyo Balcon. **0.4**

SHORELINE CYCLICITY AND THE TRANSGRESSIVE RECORD: A MODEL BASED ON POINT LOOKOUT SANDSTONE EXPOSURES AT SAN LUIS, NEW MEXICO

Robyn Wright-Dunbar

Department of Geology and Geophysics, Rice University, P.O. Box 1892, Houston, Texas 77251-1892

Point Lookout outcrops along NM-279 display the striking lithologic alternation of marine sandstone and shale that typifies cyclic shoreface sandstones throughout the Western Interior. These hierarchically arranged cyclic deposits ("parasequences" of van Wagoner et al., 1988) form the fundamental building blocks of the regressive Point Lookout strandplain system and provide the basis for high resolution intraformational correlation and paleogeographic reconstruction.

Shoreface parasequences in the San Luis area were first described (Wright, 1986) as progradational units separated from one another by marine flooding surfaces. Consistent with accepted models (van Wagoner et al., 1988), these parasequences were thought to preserve only regressive deposits. Transgression, marked by the intervening marine flooding surfaces, involved local production of lag, but left no depositional record. This interpretation was significantly modifed (Wright and Hayden, 1988; Wright, 1989) by the recognition that thin, fining-upward marine shales directly overlie many of the flooding surfaces at San Luis (Fig. 1.15). The preservation of this previously unrecognized mudrock facies strongly suggests that a transgressive depositional ramp (sensu Everts, 1987) developed during shoreline retrogradation. With rising baselevel, sand supply to the shoreface would have been reduced by fluvial channel aggradation and establishment of bays, lagoons and channeled estuaries (Devine, 1991). A thin, mud-rich "default" facies contemporaneously accumulated on the inner shelf and onlapped the underlying shoreface (T_2, Fig. 1.15). Following renewed coastal progradation and re-release of sand into open marine environments, younger prograding shoreface deposits downlapped onto the mud ramp.

Thus, these thin mudrocks became intercalated within the regressive Point Lookout stratigraphic record as genetically distinct transgressive deposits that preserve upward-deepening. A significant consequence of this relationship is the local production of a sharp-based sandstone where amalgamated shoreface deposits downlap the transgressive maximum flooding surface (Fig. 1.15, Section 5). In contrast to Plint's (1988) model, which invokes baselevel fall to produce sharp-based sandstone, the transgressive depositional ramp model yields a similar result that may repeat in successive parasequences. The two mechanisms can be readily distinguished with sufficient lateral control; sharp-based sandstones are a local product of shoreface downlap in the ramp model but are more widespread in a downdip direction following baselevel fall.

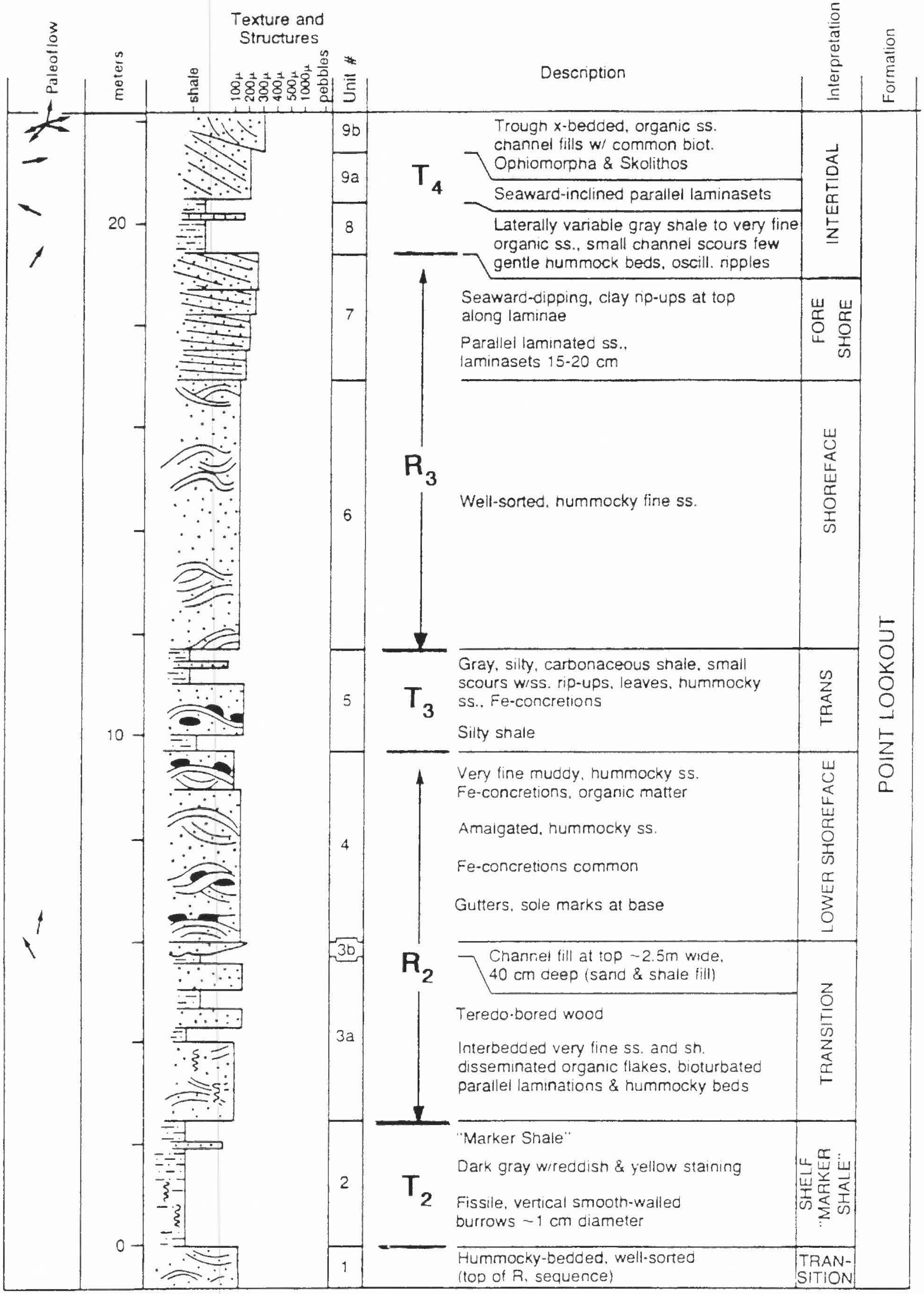


FIGURE 1.13. Arroyo Balcon measured section and interpretation (modified from Wright and Hayden, 1988).

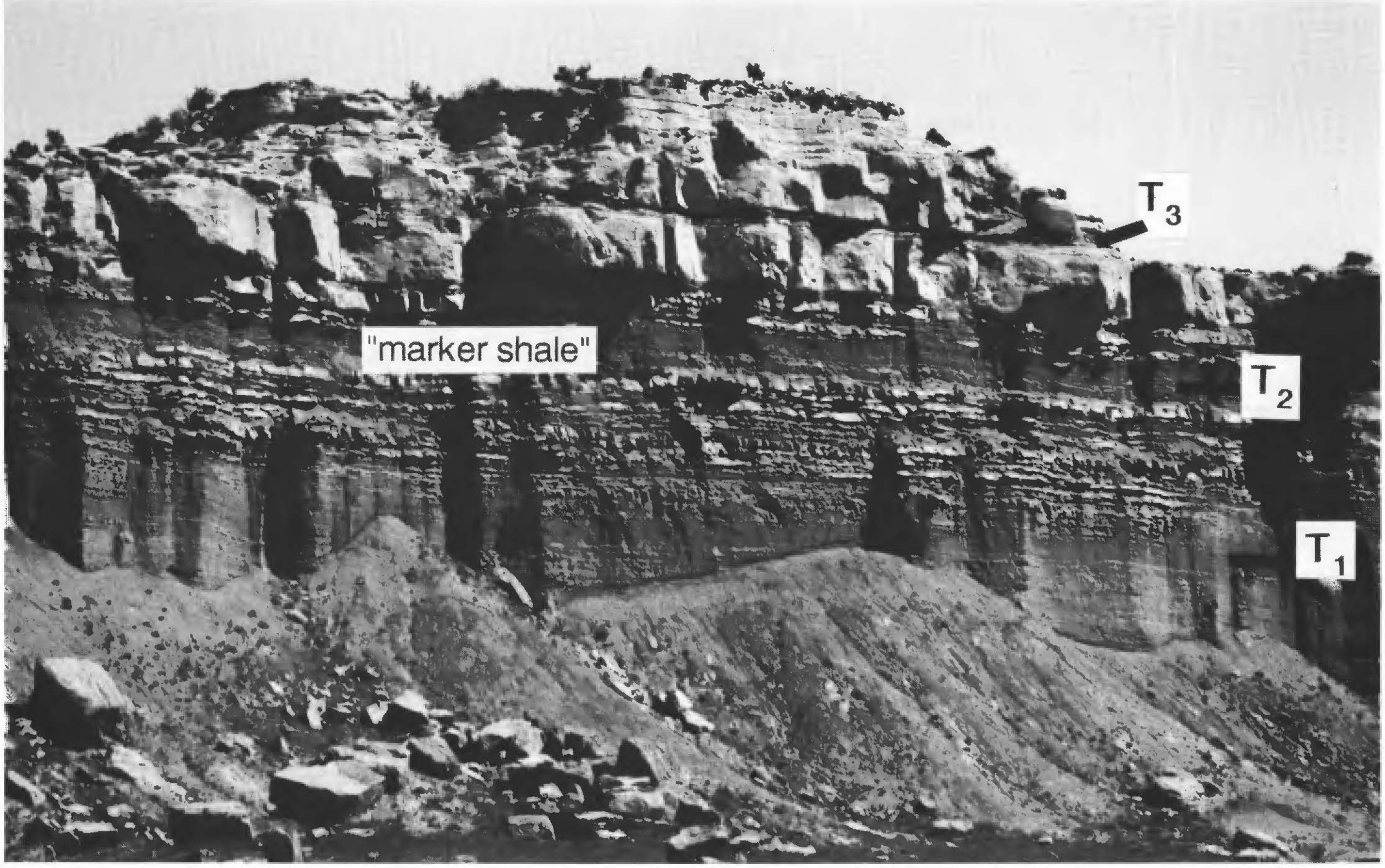


FIGURE 1.14. Point Lookout Sandstone at Bosque Grande Mesa overlies gray Mancos Shale. Here the transgressive "marker shale" T_2 is clearly visible beneath the sandstone cliff. Transgressive shale T_3 has thinned landward into a double shale break separating massive shoreface sandstones.

However, they may appear very similar in individual vertical section, well log or core. While Plint's (1988) model describes an important and viable mechanism for the production of sharp-based sandstones, the transgressive ramp model better predicts the succession of sharp-based sandstones systematically repeated at parasequence scale near San Luis.

A variety of mechanisms may explain the development (or lack) of transgressive ramp deposits at parasequence scale. Evorte (1987) argued that the relative gradients of the pre- and syn-transgression shoreface-ramp surface are critical. Other important factors may include external sediment supply to the shelf, rate/magnitude of the baselevel rise, or position within a parasequence hierarchy. Regardless of the driving process, recent research has made it clear that transgressive phase shelf deposits are a major part of the Point Lookout record throughout the San Juan Basin (Devine, 1980, 1991; Katzman, 1991; Katzman and Wright-Dunbar, this volume).

31.4 **Pull off** on flat area (**STOP 2**) before descending into Arroyo Balcon. Point Lookout Sandstone sequence stratigraphy will be discussed. Looking eastward up the valley, transgressive shale breaks T_2 and T_3 are distinctly visible. "Marker shale" T_2 lies at the base of the cliff exposure and is best seen midway up the valley on the left, where it sits at the valley floor. This same unit is in slope cover at exposures across the arroyo from the vehicles. Transgression T_3 forms a thin marine shale that produces the prominent step separating the lower two sandstones. A third sandstone step near the cliff top is produced by a fine-grained unit that may be a landward equivalent of surface T_4.

These exposures offer an excellent opportunity to examine typical shoreface and inner-shelf storm deposits of the Point Lookout Sandstone (Figs. 1.13, 1.16). Above the T_2 transgressive shale (unit 2), R_2 regressive phase deposits coarsen upward from offshore transition storm sandstones and shales (unit 3) to amalgamated, hummocky cross-stratified lower shoreface sandstones (unit 4). These storm-dominated sandstones are erosionally based, lenticular and filled by hummock-to-parallel laminated very fine-grained sandstone. Watch for small channels and gutters within upper portions of the transition zone. Channels, gutters and sole marks are oriented N-NW to N-NE with respect to the NW-SE-trending local shoreline. Organic material and *Teredo*-bored wood are common within the offshore deposits, possibly suggesting proximity to a fluvial source. Katzman (1991) noted, however, that transgressive phase shelf deposits may contain increasing organic material due to erosion of the coastal plain during barrier retrogradation.

Transgressive surface T_3 caps R_2 shoreface sandstones with a thin, double shale break (unit 5), also interpreted to be a transgressive phase deposit. Within this silty shale interval are leaves, finely disseminated organic fragments, and lenticular very fine-grained sandstones with shale rip-up clasts along the base. Vertically above the shale break are regressive, hummocky-to-swaly, cross-stratified, amalagamated lower shoreface sandstones and swaly-to-parallel-laminated upper shoreface and fore-

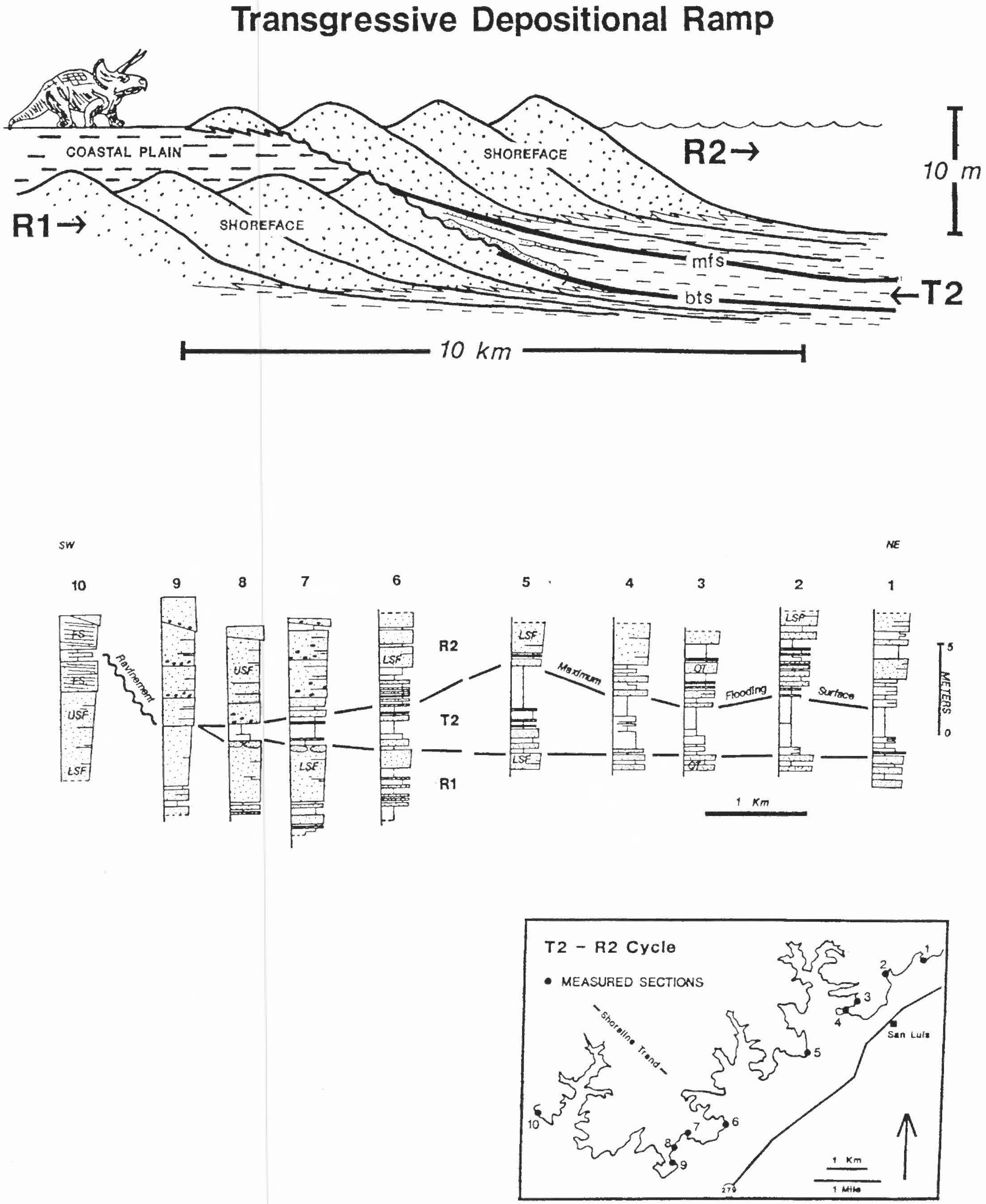


FIGURE 1.15. Schematic model and cross sections showing thin transgressive depositional ramp T_2 developed between regressive shoreface deposits R_1 and R_2 at San Luis, New Mexico. Transgressive deposits fine upward from basal sandstones (stippled) to silt and clay-rich mudrocks (unpatterned) at the maximum flooding level. Landward is to the southwest.

FIGURE 1.16. Point Lookout Sandstone at Stop 2.

shore deposits (units 6–7). Trace fossils found locally include *Thalassinoides* and *Ophiomorpha*.

The uppermost sandstone at this section is separated from strata below by a highly variable muddy sandstone and shale interval (unit 8). Unlike transgressive marine shales below, this unit ranges laterally from gray shale with oscillation ripples to channelized, carbonaceous sandstone with rare hummocky cross-stratification. Locally overlying this fine-grained unit is a 2-m-thick, fine-grained sandstone with seaward-dipping planar laminations (unit 9a). Associated medium-grained, channel-fill deposits (unit 9b) are densely burrowed by *Ophiomorpha* and *Skolithos*, display bidirectional SW-ENE crossbedding, and are laterally equivalent to organic-rich Menefee Formation mudstones. Unit 8 is interpreted as a back-barrier flooding facies of limited extent that was associated with the T_4 marine transgression. Overlying crossbedded sandstones are tidal creek deposits that record evolution of the lagoon into a channeled estuary in a fashion similar to that described by Devine (1980, 1991) and Katzman (1991) for Point Lookout exposures in the northwestern San Juan Basin.

Approximately 2 mi north of this stop in the northern half of sec. 16, T17N, R2W, was the Arroyo No. 1 mine operated by A. J. Firchau. Operation dates were from 1979 to 1984, when the state of New Mexico revoked the mining permit. Total production was 57,214 tons. The coal mined at the Arroyo No. 1 was from the Cleary Coal Member, stratigraphically near the base of the Menefee Formation, just above the Point Lookout Sandstone. Any clinkered shale or black coaly material along this dirt road can be attributed to spillage from the haul trucks leaving the Arroyo No. 1.

After stop, turn around and return to NM-279. **1.3**

32.7 **Turn right** on NM-279 and proceed south. **0.2**

32.9 Mesa Prieta is capped by basalt flows dated at 2.2±0.3 Ma by Armstrong et al. (1976). The ancestral Rio Chacra draining the area now occupied by the upper Rio Puerco was thought to have formed the valley followed by these basalt flows (Bryan and McCann, 1936). **0.1**

33.0 High voltage powerline. Entering a major utility corridor between the San Juan Basin and the Albuquerque metropolitan area and points south. **0.3**

33.3 Bridge over Arroyo de los Cerros Colorados, a tributary of the Rio Puerco. Cattle guard, continue straight. **0.5**

33.8 Pass under high voltage powerline. **0.1**

33.9 Cross pipeline. **0.7**

34.6 Road to right connects with pipeline road. Dirt road follows the lower powerline and Gas Company of New Mexico major San Juan Basin pipeline that goes into Albuquerque. This pipeline road can be traversed in good weather and comes out southwest of Johnson Trading Post, not far from Torreon Trading Post. **0.3**

34.9 Cross gas pipeline; stock dam on right, Cabezon at 10:00. The Navajos call Cabezon Peak *Tse Najin* (Black Rock). Their legends recall that many years ago, a giant monster lived on Mt. Taylor. The Twin War Gods, important figures in Navajo mythology, attacked the giant and killed him. His head was struck off, bounced and rolled to the northeast, coming to rest in a puddle of gore seen today as Cabezon Peak. Legend also tells that blood gushing from the decapitated giant flowed south toward Grants and coagulated into the El Malpais lava flows (Preston, 1991).

Three small necks to the southwest of Cabezon at 10:30 are Cerro de Guadalupe (left), Cerro Chafo (middle) and Cerro de Santa Clara (right); large neck at 12:00 in front of Mesa Chivato is Cerro Cuate. **0.8**

35.7 Point Lookout Sandstone caps bluffs to right. Variation is similar to the transitional zone between the Mancos Shale and Point Lookout Sandstone seen in the vicinity of San Luis. **0.4**

36.1 Cattle guard. **0.5**

36.6 Road to left near crest or ridge, proceed to the right. **0.4**

37.0 Cabezon ghost town is between us and Cabezon Peak. **0.2**

37.2 Hill crest, road forks, **go left.** Right fork goes to Cabezon Community Reservoir and the northern end of Mesa Chivato. At 12:00 is Cerro Cuate (Fig. 1.17), a linear feature oriented at N26°E, a trend common to most dikes, faults, and even plug alignments in the Rio Puerco Valley. The double-spire plug at 1:00 is Cerro Parido. **0.2**

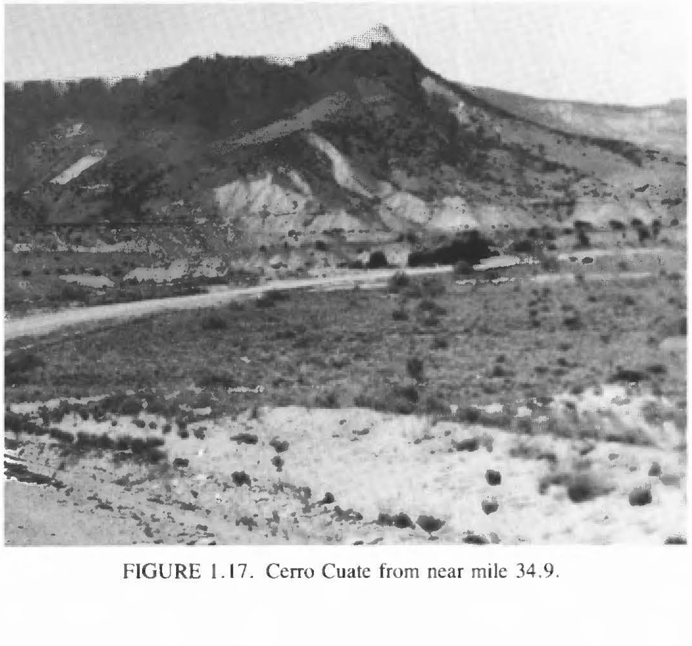


FIGURE 1.17. Cerro Cuate from near mile 34.9.

37.4 Gate and dirt road to left go to Cabezon ghost town. **0.4**

37.8 Cabezon ghost town at 9:00 (Fig. 1.18). Cabezon is one of the best preserved ghost towns in New Mexico. It consists of numerous low adobe buildings and ruins, including an old store and an intact church. Indeed, except for the deteriorating effects of solitude and the elements, the town seems little changed from the early part of the century, when Willis T. Lee photographed it during his studies of Cretaceous stratigraphy in the area (Lee, 1917, plates 25C, 26A). Spanish settlers arrived in 1767 but were chased out by the Navajos. Resettlement by the Juan Maestas family began in 1826. They raised livestock and farmed in the nearby valley. However, the family was soon driven out by raiding Navajos and Apaches and did not return until 1872, after the Navajos had been confined to their reservation.

During this time, the settlement of La Posta developed and served as an important station on the stagecoach route between Santa Fe and Fort Wingate (Yarney, 1981). The stage line was later put out of business by the Atchison, Topeka & Santa Fe railway in 1881 (Preston, 1991). This area was also an important stop for the Great Navajo Trail. For this reason, Cabezon grew into a major trading center for the Navajos. The surrounding land of the Rio Puerco valley was found to be favorable for agriculture, wheat was planted, and the Cabezon area was known for a time as the breadbasket of New Mexico (Chilton et al., 1984). The town's name was changed to Cabezon in 1891, when a post office was granted, and by 1915 it contained saloons, dance halls and general stores on both sides of the Rio Puerco serving a population of several hundred.

Two Anglos, John Pflueger and Richard Heller, arrived in the Hispanic village in 1888 and established a general store, which prospered. Heller bought Pflueger out and became a leading citizen of Cabezon for more than 50 years. At one time he was reputed to own 10,000 sheep and 2000 cattle, and it took as many as 40 wagons to transport his wool to market in Albuquerque (Sherman and Sherman, 1975). It was Heller who led the effort to construct the Catholic church, La Iglesia de San Jose, in 1894.

Gradually, however, the town's prosperity waned. Flooding caused most buildings to be moved beyond the banks of the Rio Puerco, and, later, the effects of drought, erosion and overgrazing made farming and ranching more difficult. The Santa Fe railroad decided against a branch through Cabezon, and it was bypassed by the main highways in the 1920s and 1930s. When the U.S. government purchased the Ojo del Espiritu Santo Grant in 1934, the Cabezon area was brought under strict land-management controls, a severe blow to the cattle ranchers.

FIGURE 1.18. Ghost town of Cabezon.

Then, in the early 1940s, a flood burst the dams farmers had built across the Rio Puerco and put an end to agriculture along the river (Varney, 1981). When Heller died in 1947, few residents were left. His widow kept the post office open for another year before moving to Albuquerque. By 1950, Cabezon was all but abandoned. Today, one or two families live at the townsite intermittently, protecting it from the ravages of people who would vandalize and dismantle it.

Note persistent sandstone (El Vado Member) in Mancos Shale here. This sandstone is locally very fossiliferous, especially in shark teeth, such as those described in the following minipaper. **0.3**

SELACHIAN FAUNA FROM THE UPPER CRETACEOUS (CONIACIAN) EL VADO SANDSTONE MEMBER OF THE MANCOS SHALE, SAN JUAN BASIN, NEW MEXICO

Thomas E. Williamson[1] and Spencer G. Lucas [2]

[1]Department of Geology, University of New Mexico, Albuquerque, New Mexico 87131-1116;
[2]New Mexico Museum of Natural History, 1801 Mountain Road NW, Albuquerque, New Mexico 87104-1375

New Mexico Museum of Natural History (NMMNH) locality 2606 is informally known as "shark-tooth" ridge because of the large numbers of selachian teeth present. This locality is in the El Vado Sandstone Member of the Mancos Shale in the NW1/4 NE1/4 sec. 11, T15N, R3W. Although NMMNH locality 2606 has been known for many years, the fauna has never been adequately documented. Unfortunately, most specimens consist of crown and crown fragments, making precise identification difficult. Also, the NMMNH collection is highly biased toward larger specimens (>2 mm), as almost the entire fauna was obtained by surface collection. A small amount of sediment collected from anthills was also sieved and picked, resulting in the discovery of small specimens. However, specimens less than about 2 mm, the size of most batoid taxa, were not recovered. Nevertheless, this fauna is relatively diverse, containing at least 10 selachian taxa (Table 1.1), briefly described here.

Hybodus sp. (Fig. 1.19A–B) is a rare component of this fauna represented by a single isolated tooth fragment. The tooth is relatively slender, slightly inflated and smooth except for strong, lateral carinae. The sides of the specimen are missing.

Two species of *Ptychodus* are present in this fauna. *Ptychodus mortoni* (Fig. 1.19D–E) is by far the more abundant and is easily identified by its high, rounded crown with the radiating pattern of plications. The second species, *P.* cf. *P. mammilaris* (Fig. 1.19C), is represented by only a few fragments. These fragments, however, show a very different crown ornamentation with central, coarse, transverse ridges and a rugose marginal area.

Teeth of *Scapanorhynchus raphiodon* (Fig. 1.19F–H) are relatively large. Anterior teeth have tall, narrow blades with fine vertical striations on the labial face. Several specimens of anterior teeth reveal the root morphology to be typical for *Scapanorhynchus*, with narrow, diverging roots and a deep nutritive groove on the lingual boss.

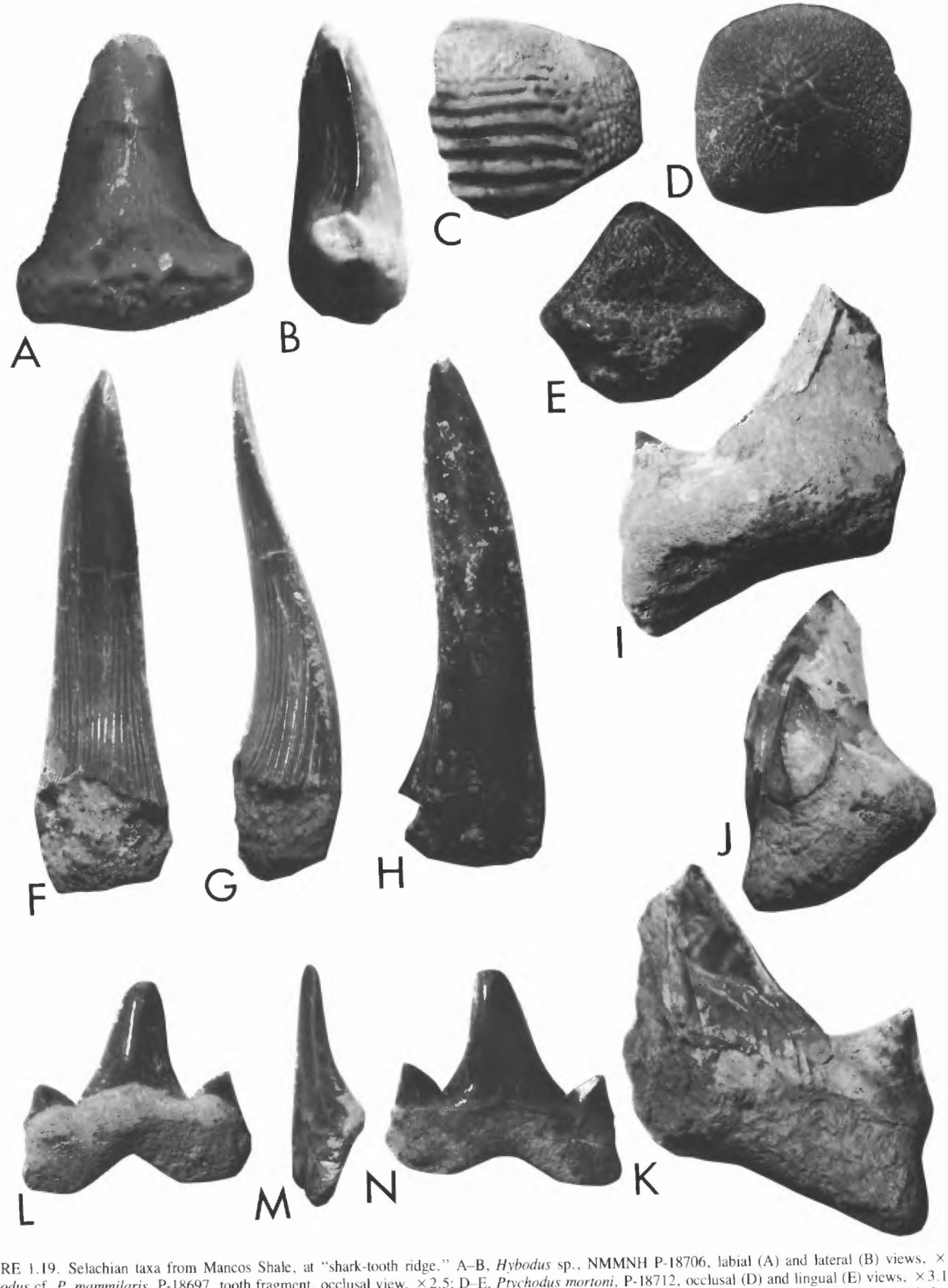


FIGURE 1.19. Selachian taxa from Mancos Shale, at "shark-tooth ridge." A–B, *Hybodus* sp., NMMNH P-18706, labial (A) and lateral (B) views, × 11; C, *Ptychodus* cf. *P. mammilaris*, P-18697, tooth fragment, occlusal view, × 2.5; D–E, *Ptychodus mortoni*, P-18712, occlusal (D) and lingual (E) views, × 3.1; F–H, *Scapanorhynchus raphiodon*, P-18699, tooth fragment, lingual (F), lateral (G) and labial (H) views, × 3.2; I–K, *Cretodus semiplicatus*, P-18710, tooth fragment, lingual (I), lateral (J) and labial (K) views, × 2.2; L–N, *Cretolamna appendiculata*, P-18695, lingual (L), lateral (M) and labial (N) views, × 3.

TABLE 1.1. Selachian taxa from El Vado Sandstone Member at "shark-tooth ridge" locality.

- Class Chondrichthyes
  - Order Eugeneodontiformes
    - Family Hyobodontidae
      - *Hybodus* sp.
    - Family Ptychodontidae
      - *Ptychodus mortoni*
      - *Ptychodus* cf. *P. mammilaris*
  - Order Lamniformes
    - Family Odontaspidae
      - *Scapanorhynchus raphiodon*
    - Family Lamnidae
      - *Cretodus semiplicatus*
      - *Cretolamna appendiculata*
    - Family Anacoracidae
      - *Squalicorax kaupi*
  - Order Rajiformes
    - Family Rhinobatoidei incertae sedis
      - *Pseudohypolophus mcnultyi*
    - Family Sclerorhynchidae
      - *Ischyrhiza mira*
    - Family incertae sedis
      - *Ptychotrygon triangularis*

Cretodus semiplicatus (Fig. 1.19I–K) is represented by large teeth with massively constructed, thick, low roots. The roots lack a nutritive groove and have a wide, relatively sharp lingual boss. The crown is thick with one pair of triangular lateral cusps. The crown-root juncture is marked by a wide band of striations on both the lingual and labial faces as well as the lateral cusps. Deep vertical folds extend up the labial face.

Cretolamna appendiculata (Fig. 1.19L–N) has flattened, triangular crowns, one pair of triangular lateral cusps and a low, flattened root. The roots lack a nutritive groove and have a flattened basal edge.

Teeth of *Squalicorax falcatus* (sensu Meyer, 1974) (Fig. 1.20A–B) are relatively large and flattened with serrated edges. These specimens have a relatively large apical angle (sensu Bilelo, 1969), the mesial edge of the blade is nearly straight and there is a marked posterior notch.

Several small teeth referable to *Pseudohypolophus mcnultyi* (Fig. 1.20C–D) are low, with a rectangular outline and have slightly rounded crowns and bilobed roots.

Ischyrhiza schneideri (Fig. 1.20E–L), a relatively uncommon component of this fauna, is represented by a single rostral tooth fragment and an oral tooth. The rostral tooth fragment consists of the peduncle. Unfortunately, it is not known whether the peduncle contains a pulp cavity. Presence of a pulp cavity is diagnostic for *I. mira*. However, the oral tooth strongly resembles the oral tooth referred to *I. schneideri* from Black Mesa, Arizona (Williamson et al., 1992), which has a relatively small and narrow apron.

A single species of *Ptychotrygon*, *P. triangularis* (Fig. 1.20M–O), is present in this fauna. Teeth of this species are relatively large for *Ptychotrygon*, attaining a size of nearly 7 mm in width. Three to four wavy transverse ridges form variable patterns. The crown is low and rounded.

Many of the taxa present in the "shark-tooth ridge" fauna have nearly cosmopolitan distributions and also have long stratigraphic ranges. *Cretodus semiplicatus*, *Scapanorhynchus*, *Cretolamna appendiculata* and *Ptychotrygon* have been reported from North America, Europe and Africa and are distributed through most of the Upper Cretaceous (Cappetta, 1987; Werner, 1989). *Pseudohypolophus mcnultyi* is known only from North America and has been reported from the Cenomanian of Arizona (Williamson et al., 1992), the Santonian of New Mexico (Williamson et al., 1989), and the Albian-Campanian (Cretaceous) of the Texas Gulf Coast (Meyer, 1974).

Several taxa allow more precise age assignment. *Ptychodus mortoni* is present in the Santonian of New Mexico (Williamson et al., 1989; Williamson and Lucas, 1990), and Meyer (1974) reported a Coniacian–lower Campanian range in the Texas Gulf Coast. *Ptychodus mammilaris* or *P.* cf. *P. mammilaris* has a more restricted range and is known from the Cenomanian of Arizona (Williamson et al., 1992), the upper Cenomanian–lower Turonian of New Mexico (reported as *P. anonymous* by Lucas et al., 1988) and Turonian-Coniacian in the Texas Gulf Coast (Meyer, 1974).

Species of *Squalicorax* range throughout the Upper Cretaceous and form a nearly continuous lineage, with distinction between various species being somewhat arbitrary (Meyer, 1974). However, *Squalicorax* teeth in the "shark-tooth ridge" fauna lack the mesial hump of teeth of the Santonian *Squalicorax kaupi*, reported from the Hosta Tongue of the Point Lookout Sandstone (Williamson et al., 1989), and show a closer resemblance to the older *S. falcatus*. *S. falcatus* is known from the upper Turonian–Coniacian of the Texas Gulf Coast (Meyer, 1974), the upper Cenomanian–Turonian of Arizona (Williamson et al., 1992) and the upper Cenomanian–lower Turonian of New Mexico (Lucas et al., 1988).

Ischyrhiza schneideri is known from the Santonian of New Mexico (reported as *Ischyrhiza* cf. *I. mira* by Williamson et al., 1989) and from the Turonian of Arizona (Williamson et al., 1992). The selachian taxa present at "shark-tooth ridge" are consistent with a Coniacian (Late Cretaceous) age assignment. This is in agreement with previous age assessments of the El Vado Sandstone based on invertebrates (Landis et al., 1974).

We thank many volunteers from the New Mexico Friends of Paleontology and especially Dan D'Andrea, Ron and Rod Peterson, and P. Sealey for their collecting efforts.

38.1 Bridge over Rio Puerco. **1.0**

39.1 Crest ridge. The road is now on a surface defended by tongues of the El Vado Sandstone Member of the Mancos Shale. **0.6**

39.7 Cattle guard. **0.5**

40.2 **Turn right** on inconspicuous dirt road as main road begins descent into Abra de los Cerros Canyon. **0.1**

40.3 **STOP 3,** to examine Cerro Chafo, discuss Rio Puerco necks (see following minipaper by Hallett), and eat lunch. The El Vado Sandstone Member of the Mancos Shale (Landis and Dane, 1967) crops out as the ledge-forming sandstones just above road level. The El Vado is a sandstone within the Mulatto Tongue of the Mancos Shale of Coniacian-Santonian age. Here, it contains some bivalve packstones (Fig. 1.21). After stop, retrace route (turn left on dirt road to NM-279). **0.6**

VOLCANIC GEOLOGY OF CERRO CHAFO

R. Bruce Hallett

New Mexico Institute of Mining and Technology, Socorro, New Mexico 87801

Cerro Chafo is a partially dissected remnant of a tuff ring located about 3 km southwest of Cabezon Peak. Tuff rings form when rising magma interacts explosively with water at or near ground surface, creating an initial explosive eruption caused by water turning to steam. The resulting crater lies on the pre-eruption surface and has relatively steep rims, which dip both inwards and outwards at approximately equal slopes (Wohletz and Sheridan, 1983; Cas and Wright, 1988). Volcanogenic deposits generated by tuff rings can be similar to those generated by maar volcanoes. However, the latter is distinctly different in that it lies below the pre-eruptive surface (i.e., Kilbourne Hole maar).

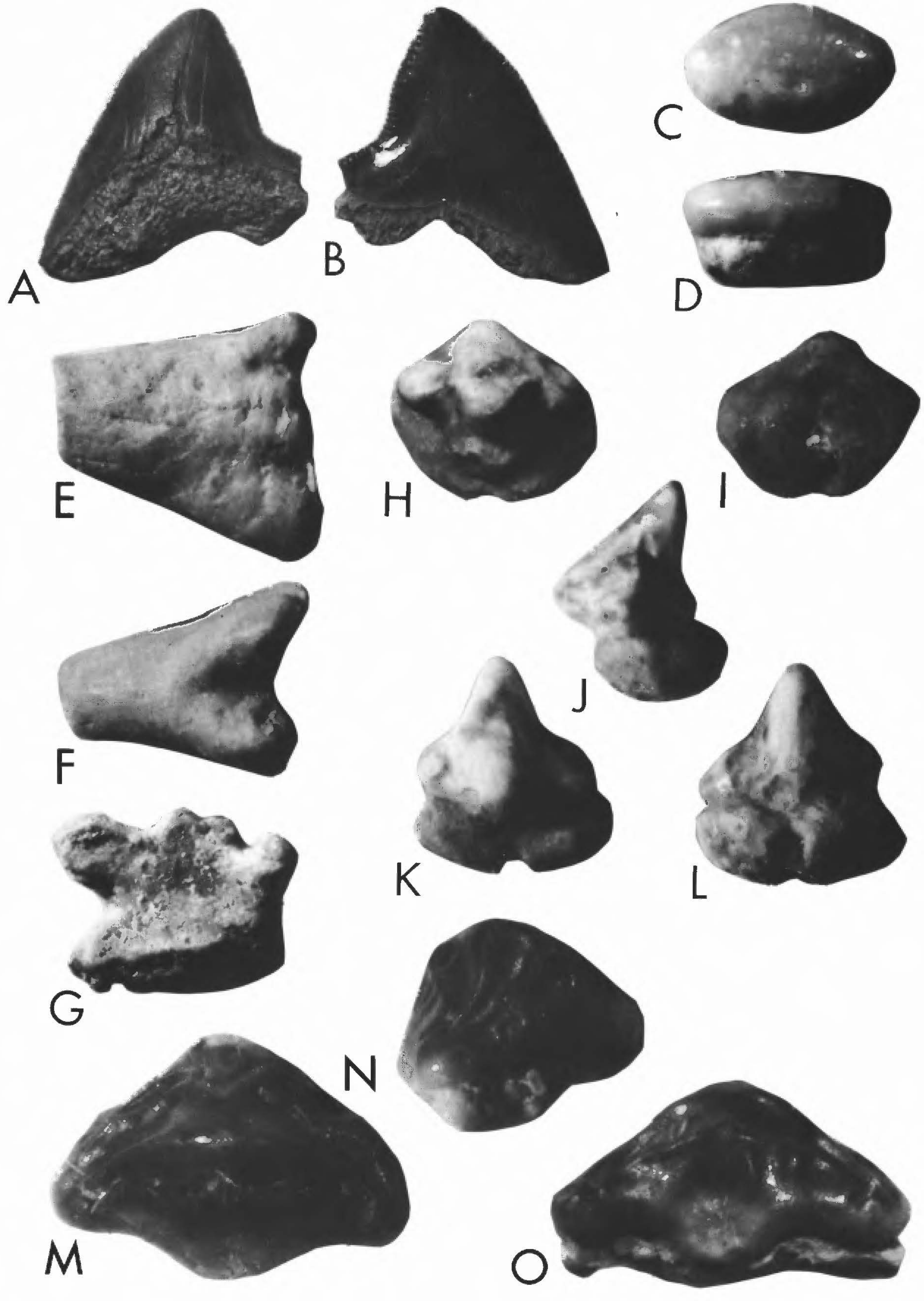


FIGURE 1.20. Selachian taxa from "shark-tooth ridge." A–B, *Squalicorax falcatus*, NMMNH P-18714, lingual (A) and labial (B) views, ×3; C–D, *Pseudohypolophus mcnultyi*, NMMNH P-18701, occlusal (C) and lingual (D) views, ×11; E–G, *Ischyrhiza schneideri*, NMMNH P-18704, rostral tooth fragment, dorsal? (E), posterior? (F) and basal (G) views, ×11; H–L, *I. schneideri*, NMMNH P-18705, oral tooth, occlusal (H), basal (I), lateral (J), labial (K) and lingual (L) views, ×11; M–O, *Ptychotrygon triangularis*, NMMNH P-18708, occlusal (M), lateral (N) and labial (O) views, ×11.

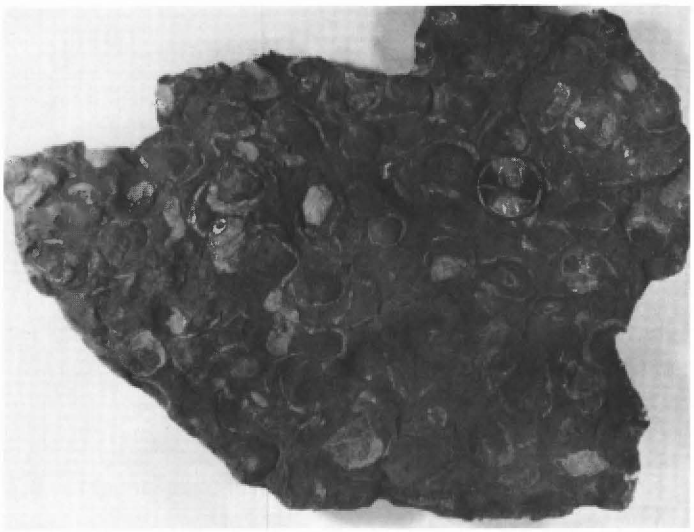
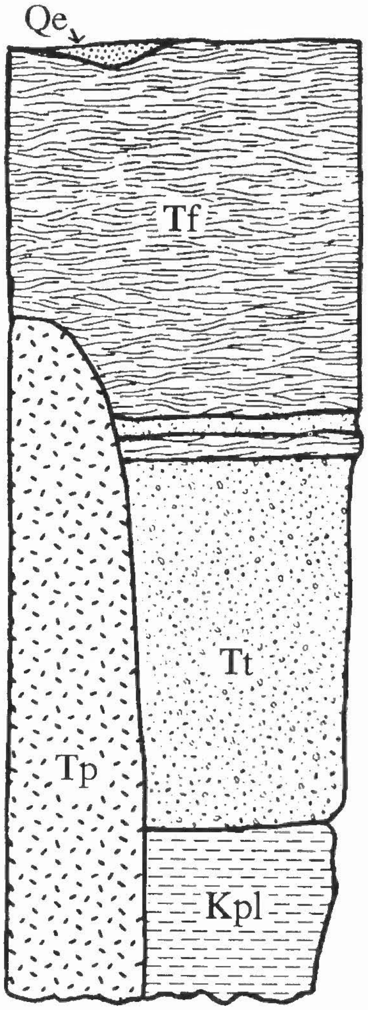


FIGURE 1.21. Bivalve packstone in El Vado Sandstone Member of Mancos Shale at Stop 3.

A geologic map and schematic stratigraphic column of Cerro Chafo are given in Figs. 1.22 and 1.23. The Cretaceous sediments underlying the volcanic deposits of Chafo are sandstones and siltstones of the El Vado Sandstone Member of the Mancos Shale. Dips on these beds cropping out near Chafo show no structural disturbance due to eruption or magma intrusion, and are consistent with the 2–4° N-NW regional dip of the area.

Lying directly on top of the sediments are pyroclastic deposits of lapilli tuff and breccia (Tt). However, with the exception of the northern and eastern sides of Chafo, these deposits are covered by a layer of colluvium. The two deposits occupy the same stratigraphic location and often grade into one another. The tuff consists of vesiculated juvenile basaltic lapilli and accidental sediment grains (quartz and clay) derived from the surrounding country rock. Basaltic lapilli are angular, whereas most sediment fragments are subangular to subrounded. Compared with the tuffs, the breccias are more poorly sorted and contain vesiculated juvenile basaltic material. Blocks and bombs are also more prevalent as is welding. In general, bedding in both types of deposits is poorly defined, with dip angles from 5–20° oriented mainly toward the crater. Minor amounts of palagonite and calcite cement are present in both the tuff and the breccia.



Qe Quaternary epiclastic deposit. Unconsolidated, basaltic pyroclasts, dominantly lapilli in size.

Tp Tertiary plug. Fine-grained, porphyritic olivine basalt. Columnar jointed in outcrop. Exposed only on the SE corner of Chafo.

Tf Tertiary basalt flow. Fine-grained, porphyritic olivine basaltic lava that dips gently (< 10°) back into the crater.

Tt Tertiary lapilli tuff/pyroclastic breccia. Well- to poorly-sorted fall deposit composed of fragmented basaltic lapilli and bombs and sedimentary clasts of various shapes and sizes. Calcite and palagonite occur in the interstices.

Kpl Cretaceous Hosta Tongue of the Point Lookout Sandstone. Pale-olivie to very pale orange, fine- to medium-grained, well indurated sandstone.

FIGURE 1.23. Idealized stratigraphic column of Cerro Chafo.

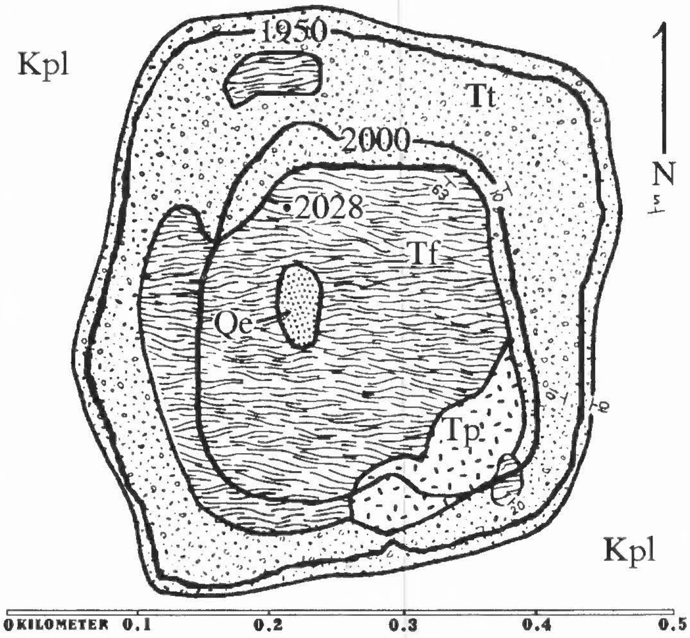


FIGURE 1.22. Geologic map of Cerro Chafo. Contour interval is 50 m. Kpl = Cretaceous El Vado Sandstone; Tt = lapilli tuff and pyroclastic breccia; Tf = lava and welded spatter-fed flows; Tp = plug; Qe = eolian sands.

A series of thin lava and welded-spatter-fed flows (Tf) are interbedded in the upper regions of the tuff/breccia. The flows are fine-grained, slightly porphyritic olivine basalts. They commonly form resistant benches, under which exposures of tuff can be found (Fig. 1.24). Lava flows cap most of Chafo, reaching a maximum thickness of 45 m. However, a thin epiclastic deposit consisting mainly of pyroclastic fall material occurs in a topographic low directly on the flows.

A plug (Tp) is exposed on the southeastern corner of Cerro Chafo. Compared with other plugs in the Rio Puerco Valley, it is relatively small and insignificant but very typical in its mineralogy and physical form. The plug is similar in composition to the flows and intrudes the tuff/breccia and flows. Columnar jointing, characteristic of most plugs in the Rio Puerco Valley, flares out in a radial pattern (Fig. 1.25) and formed perpendicular to the cooling surface. Xenoliths compose about 1% of total plug volume. Most common are small (<2 cm) xenoliths of sandstone and siltstone, followed by lesser amounts of peridotite. Several lower crustal xenoliths have been found in the plug and in cored bombs.

Cerro Chafo began as a phreatomagmatic eruption in which ascending magma contacted ground water near the paleosurface. The initial eruption produced a highly fragmented and well-sorted lapilli tuff. After the initial explosion, the eruption ceased being phreatomagmatic and became a magmatic eruption, after which the resultant deposits were

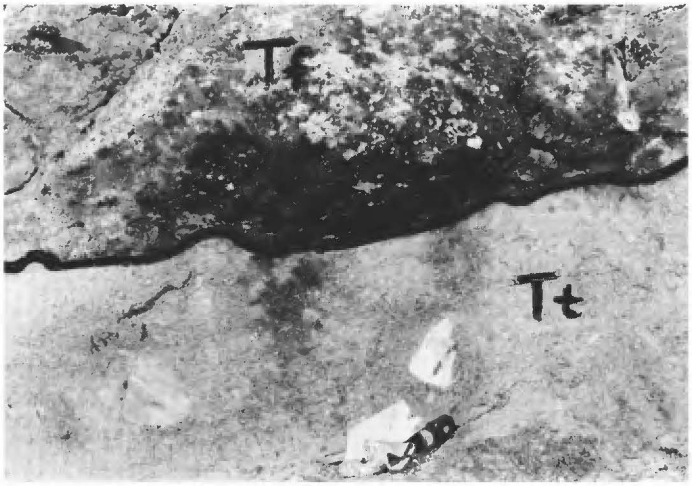


FIGURE 1.24. Contact between lapilli tuff/pyroclastic breccia (Tt) and spatter-fed flow (Tf). Notice the 0.25-m-wide, subrounded sedimentary clasts.

mainly pyroclastic breccias. In these deposits, welding of the pyroclasts was common but not everywhere present. The areal extent and grading between lapilli tuff and pyroclastic breccia is a function of vent location and physical properties of the magma. The interbedding between the tuff/breccia and lava- and spatter-fed flows observed up-section suggests a gradual decrease in the explosivity of Chafo with time. Eventually, as the magma supply waned and flows became sufficiently rigid, a small pod of magma intruded beneath the tuff/breccia and crystallized, producing a plug. Sometime following magmatic activity, the tuff/breccia was cemented by calcite.

Aubele et al. (1976) suggested that Cerro Chafo is a "deeply eroded maar," based primarily on the observation that it lies some 200 m below the average level of Mesas Chivato and Prieta. The data presented here support a tuff-ring interpretation for the origin of Chafo, based on several lines of evidence. First, the Cretaceous El Vado Sandstone, which forms the resistant ridges just to the east and south of Chafo, was the paleosurface at the time of eruption. The contact between the sandstone and overlying welded pyroclastic breccia is planar and, although not exposed everywhere, is easily traced on the eastern side of Chafo. There is no evidence that a crater exists below this surface, as is the case at Kilbourne Hole maar. Secondly, the pyroclastic deposits dip inward toward the crater at angles of 5–20°. Two distinguishing characteristics of maar volcanoes (Cas and Wright, 1988) are that their craters lie below the paleosurface, and their rims dip outwards from the crater. The field evidence presented above indicates that the volcano is some 75 m above the paleosurface and has rim deposits that dip inward, consistent with a tuff-ring morphology.

FIGURE 1.25. Columnar jointing in the plug (Tp) of Cerro Chafo.

FIGURE 1.26. Rio Puerco at crossing (mile 42.4).

40.9 Cattle guard. **0.6**
41.5 Road begins descent to Rio Puerco crossing. **0.9**
42.4 Cross Rio Puerco (Fig. 1.26). **1.0**
43.4 Yield sign, **rejoin NM-279, turn right. 0.6**
44.0 Road to right, continue to left. **0.5**
44.5 Cattle guard, pass under powerline. **1.2**
45.7 Cross Gas Company of New Mexico pipeline. **1.5**
47.2 Cattle guard, bridge over Rio Puerco tributary. Rio Puerco to right. **0.7**
47.9 Cattle guard. **0.4**
48.3 Enter San Luis. **2.1**
50.4 Leaving greater San Luis. **0.4**
50.8 Cattle guard. **0.5**
51.3 Bridge over Rio Puerco. **0.1**
51.4 Cattle guard. **0.2**
51.6 Road to right, stay left on main road. **0.5**
52.1 BLM "Ridge Road" to right; continue straight. **0.7**
52.8 Cattle guard. **3.0**
55.8 Intersection with NM-44, **turn left** to proceed north. **6.6**
62.4 Dragon Fly recreation area (Jemez Pueblo) road to left. **1.8**
64.2 La Ventana rest area on right. **1.5**
65.7 Old NM-44 to right is closed because it is washed out at a bridge about 1 mi to the north. **0.9**
66.6 Sandoval County Road 11 to right, to Farmguard Products humate mine. **1.4**
68.0 **Turn left** on dirt road to west, cross cattle guard. **0.1**
68.1 Bridge over Rio Puerco road is on Lewis Shale heading up La Guzpa Canyon through cliffs of La Ventana Tongue of Cliff House Sandstone. In 1967 the present right-of-way of New Mexico Highway 44 in the area between Cuba and La Ventana was being constructed. To avoid the cost of building three new bridges over the meandering channel of the Rio Puerco in this reach, a straight diversion channel was dug from the upstream end to the downstream of the reach shown in Fig. 1.27A. Earthfill dams were constructed to isolate the natural meandering channel, and the flow was diverted into the straight ditch. The initial effect of this construction was to significantly steepen the gradient by shortening the channel length of this reach.

Within one year (August 1968), the diversion channel had begun to meander (Fig. 1.27B) and flatten the gra-

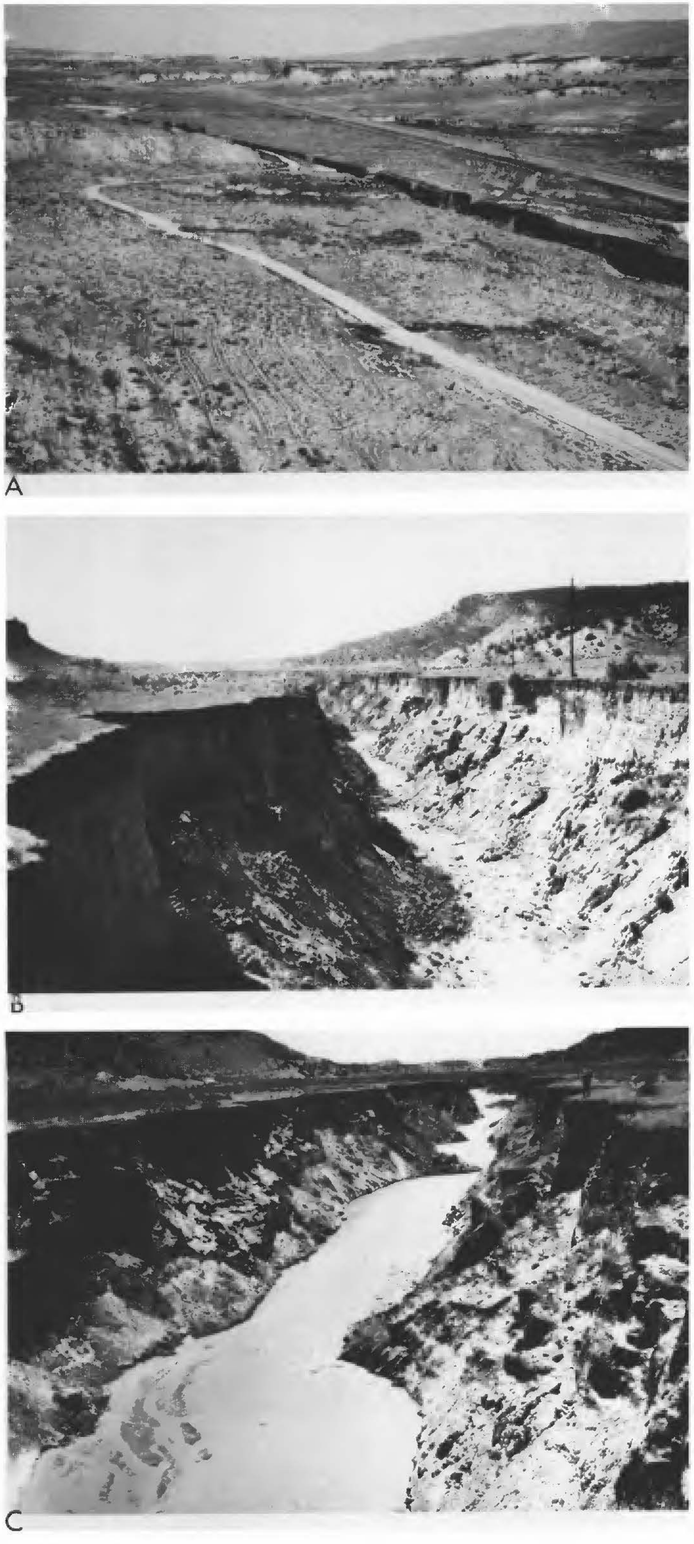


FIGURE 1.27. A, View (to north) of the valley of Rio Puerco in August 1967. Nacimiento Mountains on right horizon. NM-44 runs diagonally across photograph, and the original channel of Rio Puerco intersects the highway in two locations. The constructed straight channel parallels the highway. B, View to south of the constructed channel, originally a straight, steep-sided ditch in September 1968. Erosion by flowing water had begun to widen the ditch by bank cutting. C, View of the diversion channel in May 1969, showing initiation of the meander belt that is now present in the channel.

dient, and threatened to undercut the highway. By May 1969 the meanders had widened the diversion channel at stream level to more than twice its original width (see Fig. 1.27C). The meandering has continued and most evidence of the constructed straight channel have been eroded. **0.6**

68.7 Road bends hard right. **0.6**

69.3 Road bends hard right and is at level of La Ventana Tongue of Cliff House Sandstone. **0.2**

69.5 Cattle guard; mesa on skyline at 1:00 is Mesa Portales, capped by Ojo Alamo Sandstone. **0.5**

70.0 Sandstone to right of road is another thin sandstone in the La Ventana Tongue of the Cliff House Sandstone. **0.6**

70.6 Road now rises above La Ventana Tongue of Cliff House Sandstone to level of overlying Lewis Shale. **0.3**

70.9 Intersection, continue straight. Outcrops here are Lewis Shale. **1.0**

71.9 Road to right, continue straight. **0.2**

72.1 **Turn left on jeep trail. 0.8**

72.9 Gate, **turn left** on jeep trail just after gate. **0.2**

73.1 **STOP 4.** Stop just before arroyo to discuss Lewis, Pictured Cliffs, Fruitland-Kirtland and Ojo Alamo stratigraphy at Mesa Portales, as well as the Cretaceous-Tertiary boundary and Cretaceous sharks (see minipaper by Williamson and Lucas) in Pictured Cliffs Sandstone. The Cretaceous-Tertiary section at Mesa Portales (Fig. 1.28, 1.29) has figured prominently in debate about latest Cretaceous sedimentation and the Cretaceous-Tertiary boundary in the San Juan Basin. Smith discusses these issues elsewhere in this volume, but in brief, the exposed section of the Fruitland and Kirtland Formations at Mesa Portales is only about 240 ft thick, much thinner than to the north near Farmington, where the combined Fruitland-Kirtland thickness is 1300 ft. Workers from the University of Arizona have suggested that this thinning is depositional in origin whereas USGS geologists (e.g., Fassett and Hinds, 1971) have attributed this thinning to an angular unconformity at the base of the Ojo Alamo Sandstone. Fassett and Hinds (1977, pl. 2, cross section E–E′) showed that the Kirtland Formation is absent from

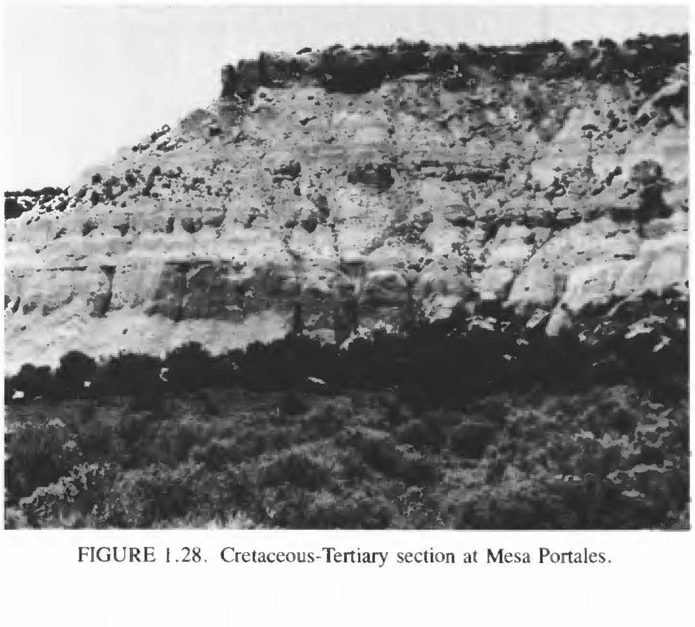


FIGURE 1.28. Cretaceous-Tertiary section at Mesa Portales.

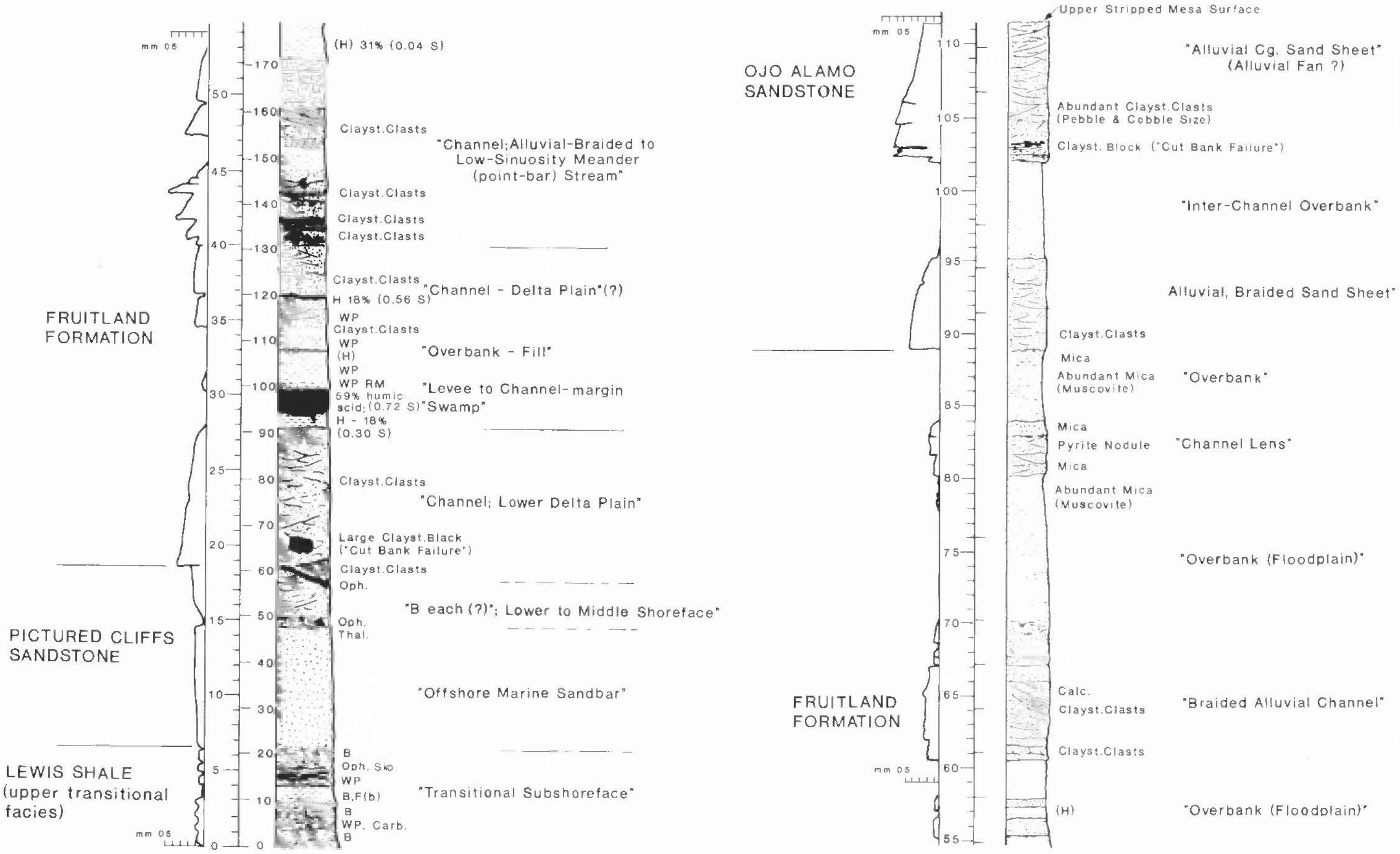


FIGURE 1.29. Measured section of Upper Cretaceous and Tertiary strata exposed on the east face of Mesa Portales (after Siemers et al., 1975).

the Mesa Portales area and indicated that this is the result of the angular unconformity. However, it is clear that in this area the coal-bearing Fruitland Formation is overlain by a green siltstone and sandstone that is equivalent to the Kirtland Formation. Thus, the northwest-southeast thinning of the Fruitland and Kirtland Formations must be depositional in origin. However, the Fruitland and Kirtland do not represent a clastic wedge originating from the northwest as suggested by Lindsay and his coworkers. All paleocurrent measures indicate flow from the southwest to the northeast during deposition of the Fruitland and Kirtland Formations (e.g., Hunt, 1984). It is thus likely that thinning was due to differential subsidence.

The other controversy at Mesa Portales concerns the two tabular sandstones, separated by shale, that cap and lie near the top of the mesa. Does the lower of the two sandstones indicate interfingering of the Ojo Alamo Sandstone and the underlying Kirtland Formation, or is the sequence of sandstones and intervening shales all part of the Ojo Alamo Sandstone, or is the lower sandstone just a large channel in the upper Kirtland? This problem is difficult to resolve based on outcrops, as the lower of the two sandstones cannot be traced onto other mesas. Subsurface studies may help to elucidate this problem (Smith, this volume). Resolution of this problem is important for studies of the magnitude of the unconformity at the base of the Ojo Alamo and of basinal tectonics during the K/T transition.

A band of black, coaly to carbonaceous material with occasional traces of burn at about the middle of the slope on Mesa Portales marks the top of the Fruitland interval. This is overlain by the shaly Kirtland Formation, and the mesa is capped by the Ojo Alamo Sandstone. Recent drilling northwest of Mesa Portales by the New Mexico Bureau of Mines and Mineral Resources found very little coal in the Fruitland Formation in this area of the basin. Fossils from the Lewis Shale and Pictured Cliffs Sandstone near and at Mesa Portales indicate a late Campanian age (see accompanying minipaper).

After stop, retrace jeep trail route to dirt road. **0.2**

PRELIMINARY REPORT ON INVERTEBRATE FOSSILS FROM THE LEWIS SHALE NEAR MESA PORTALES, SANDOVAL COUNTY, NEW MEXICO

Spencer G. Lucas and Paul L. Sealey

New Mexico Museum of Natural History, 1801 Mountain Road NW, Albuquerque, New Mexico 87104-1375

Little has been published on the invertebrate paleontology of the Lewis Shale in New Mexico and Colorado. Reeside (1924) listed the invertebrate fauna of the Lewis Shale from various localities in the San Juan Basin. Cobban et al. (1974) documented at least 11 ammonite zones in the Lewis Shale on the eastern side of the San Juan Basin. We report here invertebrate fossils from numerous NMMNH (New Mexico Museum of Natural History) localities (locality numbers 2607–2628) in the upper part of the Lewis Shale in sec. 14, T19N, R2W, near Mesa Portales.

A large number of inoceramids are present in the Lewis Shale near Mesa Portales. They include NMMNH P-20515 (two articulated valves: Fig. 1.30C), NMMNH P-20501 (Fig. 1.30A) and NMMNH P-20504

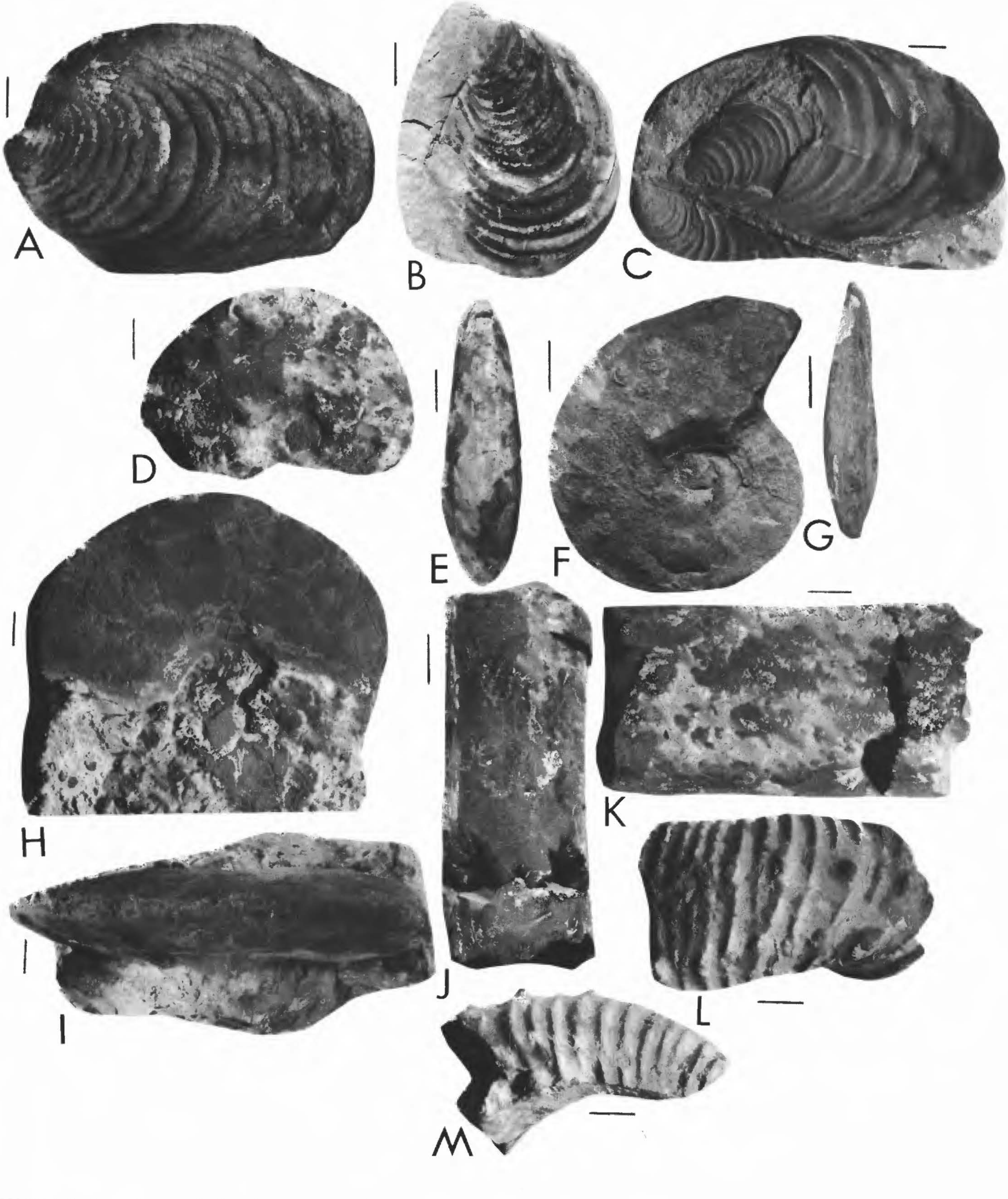


FIGURE 1.30. Invertebrate fossils from the upper part of the Lewis Shale near Mesa Portales. A–C, *Inoceramus vanuxemi*, NMMNH P-20501, P-20504 and P-20515, respectively. D–E, Lateral (D) and posterior (E) views of *Placenticeras syrtale*. NMMNH P-20506. F–G, Lateral (F) and posterior (G) views of *Placenticeras placenta*, NMMNH P-20512. H–I, Lateral (H) and posterior (I) views of cf. *Placenticeras planum*, NMMNH P-20518. J–K, Ventral? (J) and lateral (K) views of *Baculites* sp., NMMNH P-20514. L–M, Peripheral (L) and lateral (M) views of *Didymoceras cheyennense*, NMMNH P-20513. Bar scales are 1 cm long.

(Fig. 1.30B). These specimens are probably variants of *I. vanuxemi* Meek and Hayden (W. A. Cobban, written comm. 1992).

Placenticeras syrtale (Morton) is represented by NMMNH P-20506 (Fig. 1.30D–E) from locality 2625. A broad, flat venter, similar suture pattern, and three rows of prominent nodes (one along venter, one on flanks, and one on umbilical shoulder) are features shared with *P. syrtale* (Reeside, 1927, pl. 30, figs. 3–6).

A weathered inner volution of *Placenticeras placenta* (DeKay) (NMMNH P-20512: Fig. 1.30F–G) from locality 2628 is characterized by a very narrow and flat venter, small umbilicus, very compressed form, and nodes on flanks. *P. meeki* differs from *P. placenta* in the absence of a median lateral line of nodes (Reeside, 1927, p. 30).

A weathered specimen (NMMNH P-20518: Fig. 1.30H–I) from locality 2619 is identified as cf. *Placenticeras planum* Hyatt based on a poorly defined fragment of a suture, moderately stout shell, relatively broad and flat venter, and laterally smooth and rounded shell with possible nodes on the umbilical shoulder. "This species is not separable in some varieties from *P. newberryi* Hyatt except by the absence of large lateral nodes at all stages" (description by Hyatt in Reeside, 1927, p. 31).

NMMNH P-20514 (Fig. 1.30J–K) from locality 2622 is assigned to *Baculites* sp. It resembles *Baculites ovatus* Say var. *baculus* in its large size, moderately simple suture with opposite branches of the first lateral lobe widely separated, and ovate cross section (Gill and Cobban, 1966, p. A33). The suture pattern on the NMMNH specimen has its closest resemblance to that of *B. ovatus* var. *baculus* (Meek, 1876, pl. 20, fig. 2C; Reeside, 1927, pl. 5, fig. 12), but we are reluctant to identify a single baculite to species.

Didymoceras cheyennense (Meek and Hayden) (NMMNH P-20513: Fig. 1.30L–M; locality 2623) is represented by a single, nonseptate section of a whorl with ribbing that is coarse, widely spaced and oblique. The fragment possesses two rows of nodes on each side of the venters in *Didymoceras*. It differs from *D. stevensoni* (Whitfield) by the absence of an impressed area on the side adjacent to the next older whorl (Gill and Cobban, 1966, p. A32). *D. nebrascense* (Meek and Hayden) varies from NMMNH P-20513 in its finer and much more closely spaced ribs.

The occurrence of *Didymoceras cheyennense* indicates a late Campanian age for the NMMNH Lewis Shale localities near Mesa Portales. The presence of *D. cheyennense* with *Placenticeras* and *Inoceramus* suggests correlation with the upper part of the Pierre Shale at Turkey Creek, Colfax County in the Raton Basin of northeastern New Mexico (Sealey and Lucas, 1991).

VERTEBRATE FAUNA FROM THE UPPER CRETACEOUS (CAMPANIAN) PICTURED CLIFFS SANDSTONE, MESA PORTALES, NEW MEXICO

Thomas E. Williamson[1] and Spencer G. Lucas[2]

[1]Department of Geology, University of New Mexico,
Albuquerque, New Mexico 87131-1116;
[2]New Mexico Museum of Natural History, 1801 Mountain Road NW,
Albuquerque, New Mexico 87104-1375

The Mesa Portales shark tooth locality was first reported by Fassett (1966) and Fassett and Hinds (1971, USGS locality 29200, NMMNH locality 347) and is located within the Upper Cretaceous (late Campanian) Pictured Cliffs Sandstone (SW¼ SW¼ sec. 10, T19N, R2W) on the southeastern end of Mesa Portales. This site was mentioned again by Rigby and Clement (1983), who were the first to use screen-washing techniques to recover fossil specimens from a relatively small amount of bulk sediment. Approximately six tons of sediment were collected in 1989 by the NMMNH and is still being processed. To date, several thousand identifiable specimens have been recovered from this locality.

The Mesa Portales shark tooth locality contains a mixture of marine and nonmarine vertebrates and marine molluscs. Specimens are found as disarticulated and isolated elements, including oyster valves, teeth, tooth fragments, bone and bone fragments. The most abundant fossils from this locality are of selachians. At least 15 selachian taxa have been identified (Table 1.2).

Hybodus sp. (Fig. 1.31A–C) is represented by numerous isolated teeth. These teeth are relatively large (up to 10 mm tall) and slightly inflated. Unworn teeth have a pointed cusp, but most are worn with blunt, rounded tips. The crowns are marked by a band of vertical striations near the base. Lateral carinae extend from the central cusp. The sides of the teeth are invariably missing, usually broken off close to the central cusp.

Squatina sp. (Fig. 1.31D–G) is represented by many isolated teeth having a high, sinuous central cusp and low lateral shoulders. These teeth are distinguished from those of the similar genus *Cretorectolobus* Case, known from the Campanian of Montana and Wyoming (Case, 1978, 1987), by the lack of a variably developed groove extending from the basal foramina to the lingual foramina. Several of the teeth from Mesa Portales do possess a median recess in the root behind the overhanging apron but have no hint of elongation of the basal foramina.

A few teeth similar to *Cantioscyllium descipiens*, but probably representing a new species, are also present. These teeth are taller than those of *C. descipiens*, and the vertical striae are restricted to the central part of the labial face of the central cusp.

Teeth of *Odontaspis* cf. *O. sanguinei* (Fig. 1.31H–J) are distinguished by their relatively flattened blades. Anterior teeth are relatively narrow and sinuous, with one pair of lateral cusps. Posterior teeth are lower and wider, with two to three pairs of wide, triangular accessory cusps. A central nutrient groove marks the lingual boss. Most teeth are completely devoid of ornamentation on the crown, though a small number of teeth possess a narrow band of vertical striations on the labial base of the crown, at the enamel-root juncture.

Odontaspis cheethami (Fig. 1.31K–P) superficially resembles *Scapanorhynchus* in possessing fine, vertical striations on the labial crown surface and having similar crown and root morphology but differs in being considerably smaller (generally not exceeding about 15 mm) and having two to three lateral cusps, even on anterior teeth.

Cretodus arcuata (Fig. 1.31Q–S) is the largest and most abundant lamnoid shark in this fauna. The teeth are robust, with triangular blades with a distinctive lateral curvature. There is one pair of lateral cusps. The root lacks a nutritive groove but may contain a single or several closely placed pores on the lingual boss. The basal margin of the root forms a smoothly concave outline, and the root lobes are rounded terminally.

A small lamnoid shark is tentatively identified as *Cretodus* sp. (Fig. 1.31T–V). These teeth have a triangular blade with several vertical wrinkles on the labial surface, one pair of lateral cusps and a very large, inflated lingual boss. The root lobes are very elongate.

A single species of *Squalicorax*, *S. kaupi* (Fig. 1.32A–B), is represented in the Mesa Portales shark-tooth fauna. Teeth of *Squalicorax* are easily identified by their flattened blades with serrated edges and simple roots. These teeth are relatively large and have a smoothly convex mesial edge and a high apical angle (sensu Bilelo, 1969), distinguishing them from *S. falcatus*. The posterior edge was a well-developed notch that distinguishes this species from *S. pristodontus*.

A single tooth fragment is tentatively identified as *Synechodus*. The root is flat and elongated with lingual basal notches. A small fragment of enamel on this specimen has vertical striations. However, this specimen is too incomplete to allow it to be distinguished from the similar genus *Paraorthacodus*, known from the Campanian of Montana (Case, 1978).

Batoids are relatively abundant and include a few specimens tentatively identified as *Myledaphus* sp. These teeth are subhexangular in outline with flattened crowns and have flat, vertical margins. The root is bilobed. These teeth differ from "typical" *Myledaphus* in lacking vertical striations on the tooth margins. Tooth histology is often critical to identifying batoid teeth, but the histology of these teeth has not yet been determined.

Protoplatyrhina renae (Fig. 1.32C–F) is very abundant in this fauna. The teeth are low and elongate, with rounded crowns and bilobed roots.

TABLE 1.2. Vertebrate fauna from the Pictured Cliffs Sandstone at Mesa Portales.

- Class Chondrichthyes
  - Order Eugeneodontiformes
    - Family Hyobodontidae
      - *Hybodus* sp.
  - Order Squatinomorphii
    - Family Squatinidae
      - *Squatina* sp.
  - Order Orectolobiformes
    - Family Hemiscylliidae
      - cf. *Cantioscyllium* n. sp.
  - Order Lamniformes
    - Family Odontaspidae
      - *Odontaspis* cf. *O. sanguinei*
      - *Odontaspis cheethami*
    - Family Cretoxyrhinidae
      - *Cretodus arcuata*
      - *Cretodus* sp.
    - Family Anacoracidae
      - *Squalicorax kaupi*
  - Order Galeomorphii incertae ordinis
    - Family Palaeospinacidae
      - cf. *Synechodus*
  - Order Rajiformes
    - Family Rhinobatoidei incertae sedis
      - cf. *Myledaphus*
      - *Protoplatyrhina renae*
    - Family Sclerorhynchidae
      - *Ischyrhiza mira*
      - n. gen. et sp.
    - Family incertae sedis
      - *Ptychotrygon "boothi"*
      - *Ptychotrygon "blainensis"*
- Class Osteichthyes
  - Order Aulipiformes
    - Family Enchodontidae
      - *Enchodus* sp.
  - Order Elopiformes
    - Family Phyllodontidae?
      - *Paralbula* sp.
- Class Reptilia
  - Order Chelonia
    - Family and Genus unident..
  - Order Plesiosauria
    - Family Elasmosauridae
      - Genus unident.
  - Order Crocodylia
    - Family Alligatoridae
      - Genus indet.
  - Order Saurischia
    - Family and Genus unident.
  - Order Ornithischia
    - Family Hadrosauridae
      - Genus indet.
- Class Mammalia
  - Order Allotheria
    - Family Neoplagiaulacidae
      - *Cimolomys* sp.
  - Order Theria
    - Family and Genus unident.

There is a small uvula overhanging the root labially. Posterior foramina located on the root open into canals which penetrate to the medial groove.

The sawfish *Ischyrhiza mira* (Fig. 1.32G–K) is represented by relatively large rostral teeth with relatively large pulp cavities within their peduncles. Oral teeth of this species have relatively large, inflated aprons, and large root lobes separated by a median groove.

A single tooth of a new genus and species of Sclerorynchidae is relatively small, with roots extending beyond the crown margin. The crown is rounded in outline with a high central cusp and vertical striae on the labial surface of the apron.

Ptychotrygon is a common component of Upper Cretaceous selachian faunas of North America. Its teeth are triangular in outline with two root lobes divided by a medial groove. Species are distinguished by crown morphology and ornamentation. Rigby and Clement (1983) reported five species in the Mesa Portales fauna. However, we were able to distinguish only two species of *Ptychotrygon*. The first is *P. "boothi,"* similar to the holotype of *P. boothi* from the Campanian of Wyoming (Case, 1987), with three to four variably developed, somewhat wavy transverse ridges and an inflated central region. The second species is similar to *P. blainensis* from the Campanian of Montana (Case, 1978) with a pointed central cusp, one transverse ridge and vertical striations on the labial face of the apron. Batoids (Fig. 1.32N–P) are common at Mesa Portales.

Non-selachian vertebrates include marine and nonmarine taxa. The marine taxa include two identifiable bony fish, the predatory *Enchodus*, represented by large, palatine fangs, and *Paralbula* cf. *P. casei* (Fig. 1.32Q–S), with low, globular teeth possessing a rugose ornamentation of radiating reticulations and a large number of unidentified teleosts consisting of numerous isolated teeth. An indeterminate plesiosaur, which are generally rare as fossils in Cretaceous marine deposits of New Mexico (Lucas et al., 1988) is present and represented by several vertebral centra and paddle bones. The vertebral centra are compressed discs reaching 5 cm in diameter. The paddle bones are cylindrical and up to about 3 cm in length. Relatively large tooth fragments, circular in cross section, may pertain to a mosasaur.

Fossils of nonmarine taxa are generally less abundant than those of marine taxa. Indeterminate turtles are represented by shell fragments. Indeterminate crocodilians are represented by a few isolated teeth and a scute fragment.

Dinosaurs are also present and are represented by isolated teeth and tooth fragments. An indeterminate hadrosaur is represented by a well-worn isolated tooth. Indeterminate carnivorous dinosaurs are represented by tooth fragments that preserve serrated cutting edges. Relatively large bone fragments may also pertain to indeterminate dinosaur but these tend to be very highly abraded.

Mammals are represented by isolated teeth. These teeth are rare and generally are very small. A multituberculate molar is referred to *Cimolomys* sp. (Fig. 1.32T). In addition, there are fragments of multituberculate incisors and several isolated premolars and tooth fragments of therian mammals.

This fauna is very similar to Campanian assemblages reported from marginal marine deposits of Montana and Wyoming (Case, 1978, 1986) and the Texas Gulf Coast (Meyer, 1974). The large number of taxa common to these various faunas and the wide Late Cretaceous distribution of many of these taxa (Cappetta, 1987) underscores the usefulness of selachians for correlation (Williamson et al., 1992).

Nicholls and Russell (1990) identified two vertebrate faunal subprovinces of the Late Cretaceous (early Campanian) Western Interior seaway. These faunal subprovinces were based on relative abundance of taxa rather than presence-absence of taxa. Their "northern interior subprovince" is characterized by low diversity of all vertebrates. The "southern interior subprovince" is characterized by a high diversity in all groups and is dominated by sharks, turtles and the mosasaur *Clidastes*. However, we find that the high diversity of northern Late Cretaceous selachian faunas of Montana and Wyoming documented by Case (1978, 1986) and their similarity to more southern faunas of New Mexico (this fauna) and Texas (Meyer, 1974) argues against the biogeographical subdivisions proposed by Nicholls and Russell (1990).

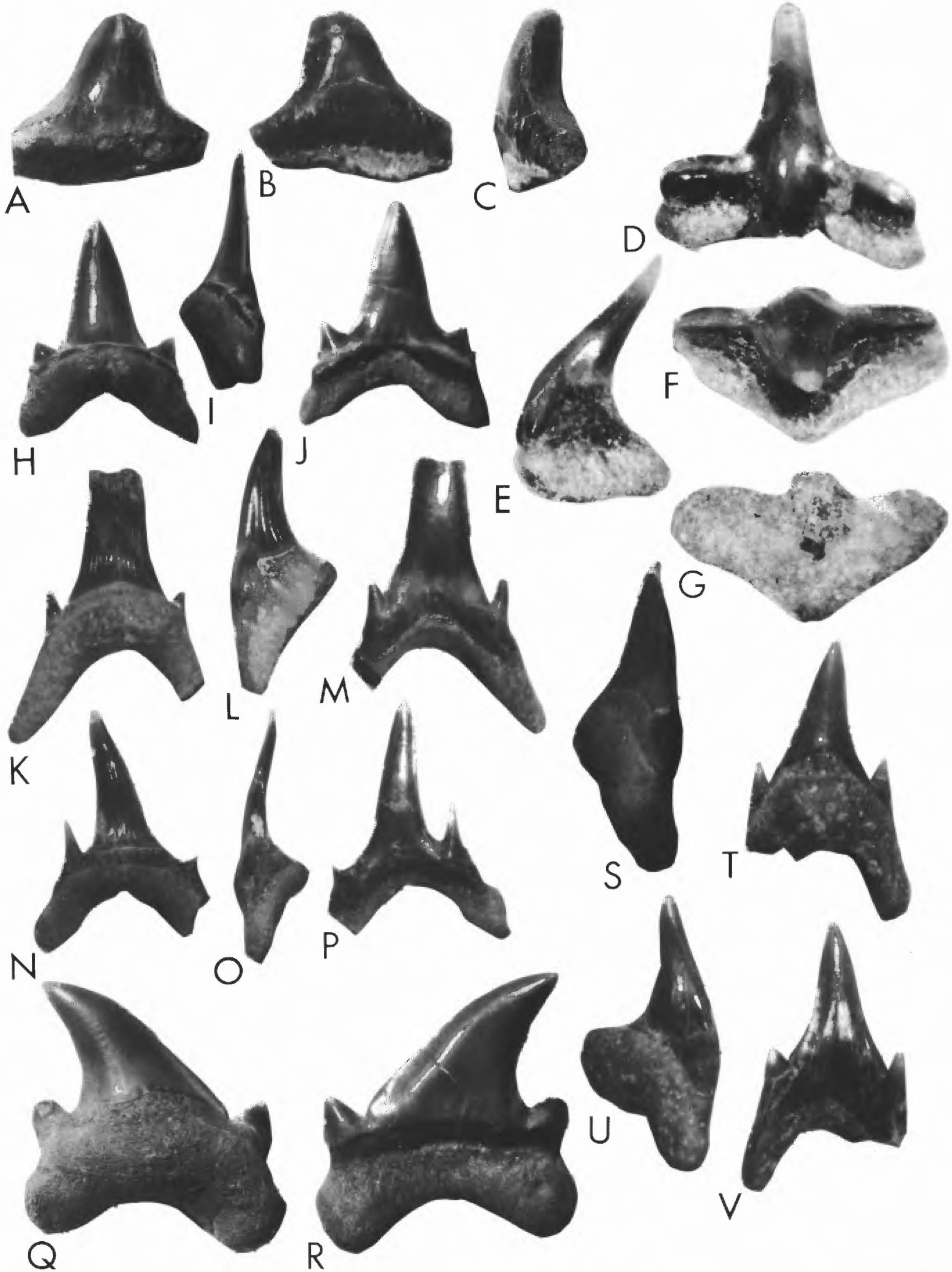


FIGURE 1.31. Selected selachians from the Mesa Portales shark tooth fauna. A–C, *Hybodus* sp., NMMNH P-18610, lingual (A), labial (B) and lateral (C) views, ×3.7; D–G, *Squatina* sp., NMMNH P-18615, labial (D), lateral (E), occlusal (F) and basal (G) views, ×10; H–J, *Odontaspis* cf. *O. sanguinei*, NMMNH P-18624, lingual (H), lateral (I) and labial (J) views, ×2.75; K–M, *Odontaspis cheethami*, NMMNH P-18678, anterior tooth, lingual (K), lateral (L) and labial (M) views, ×6; N–P, *O. cheethami*, NMMNH P-18692, lateral tooth, lingual (N), lateral (O) and labial (P) views, ×6; Q–S, *Cretodus arcuata*, NMMNH P-18680, lingual (Q), labial (R) and lateral (S) views, ×2.7; T–V, *Cretodus* sp., NMMNH P-18667, lingual (T), lateral (U) and labial (V) views, ×8.

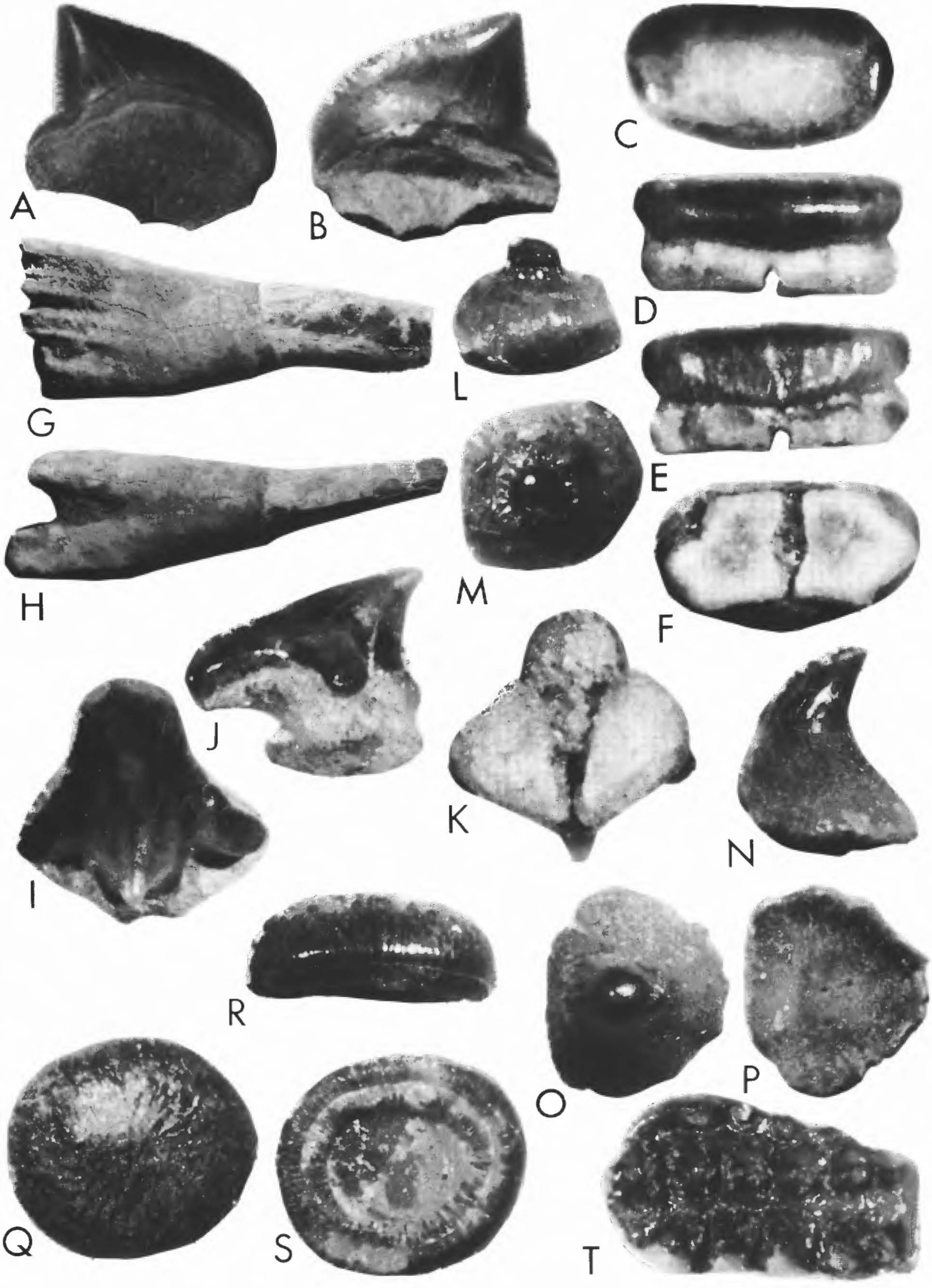


FIGURE 1.32. Selected vertebrates from the Mesa Portales shark tooth fauna. A–B, *Squalicorax kaupi*, NMMNH P-18674, lingual (A) and labial (B) views, ×4.2; C–F, *Protoplatyrhina renae*, NMMNH P-18658, occlusal (C), labial (D), lingual (E) and basal (F) views, ×13; G–H, *Ischyrhiza mira*, NMMNH P-18602, rostral tooth, dorsal? (G) and anterior (H) views, ×3; I–K, *I. mira*, NMMNH P-18605, oral tooth, occlusal (I), lateral (J) and basal (K) views, ×9.7; L–M, Selachian dermal denticle, NMMNH P-18368, lateral (L) and dorsal (M) views, ×9.2; N–P, Batoid rostral tooth, NMMNH P-18629, dorsal? (N), distal (O) and basal (P) views, ×7.8; Q–S, *Paralbula* cf. *P. casei*, NMMNH P-18686, tooth, occlusal (Q), lateral (R) and basal (S) views, ×11.5; T, *Cimolomys* sp., NMMNH P-18643, left M^1, occlusal view, ×17.5.

73.3 **Turn right** through gate. **0.8**

74.1 **Turn right** on main dirt road to west. Road now will pass around southern flank of Mesa Portales. **0.3**

74.4 Major road to left, continue straight. This road is known as the Piedra Lumbre road and eventually intersects with the Gas Company of New Mexico pipeline road that intersects the Bureau of Land Management road to Cabezon, east of San Luis. The entire Menefee Formation is traversed by the Piedra Lumbre road southward from this intersection. **0.9**

75.3 Note Cabezon at 9:00 in the distance. **0.3**

75.6 Cattle guard. **1.5**

77.1 Curve in road and fork, stay right. Road is on southern edge of Zambarmo Lake. **1.2**

78.3 Cattle guard. **0.1**

78.4 High voltage powerline. **0.3**

78.7 Crest of hill, gray bluffs at 2:00–4:00 in distance are Nacimiento Formation. **0.1**

78.8 Road curves sharp right; we now drive directly down dip into the San Juan Basin. **0.7**

79.5 Cattle tank to right of road. **0.2**

79.7 Road curves sharp left. **1.1**

80.8 Road to left leads to the Media Entrada and Media Entrada Southwest oil fields, producing from the Middle Jurassic Entrada Sandstone at 5200+ to 5300+ ft, capped by the Todilto Formation, which is also the source rock (Vincelette and Chittum, 1981). Production is from the very permeable and porous eolian sandstones of the Entrada. The reservoir rock also contains large amounts of water that are produced with the oil. Stratigraphic relief on top of the Entrada Sandstone in the Media fields is in excess of 100 ft, reflecting in large part the topography of ancient dune axes and troughs (Fig. 1.33). This relief produced the stratigraphic traps of oil in the field (Vincelette and Chittum, 1981). Several of the wells in the Media Entrada fields were owned by the defunct Petro Lewis Corporation. These wells are now owned by Merrion Oil and Gas. **1.0**

81.8 Cattle guard, stop sign, intersect paved NM-197. Bluffs ahead are tan-buff Ojo Alamo Sandstone above Fruitland-Kirtland Formation just as at Mesa Portales. **Turn right** and proceed east on NM-197. **2.1**

83.9 Curve in road, Ojo Alamo bluff to left, we are "cresting" Mesa Portales, which is not a mesa at all but instead an escarpment that dips gently into the San Juan Basin. **2.2**

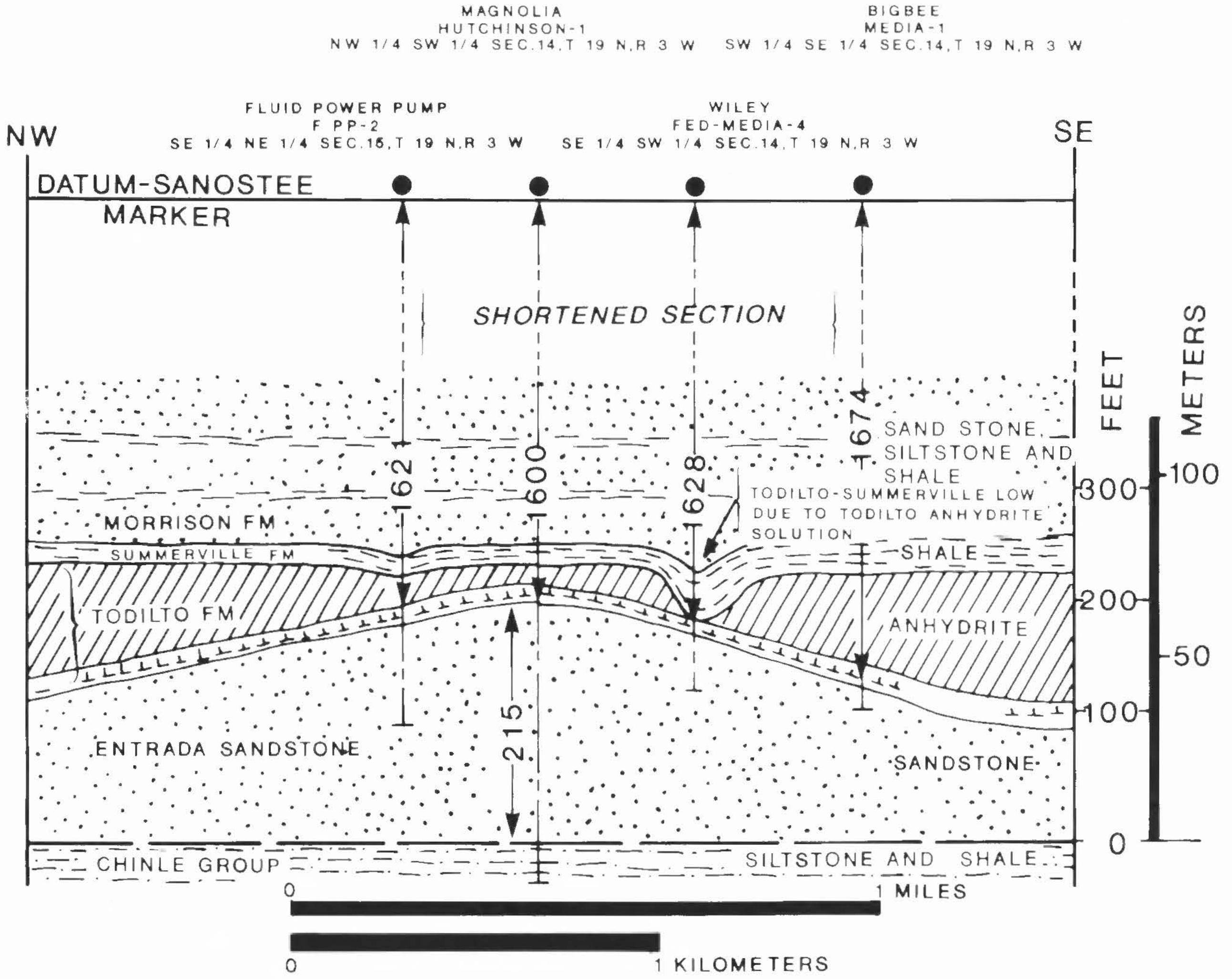


FIGURE 1.33. Stratigraphic cross section of Media field. Cross section was constructed using Cretaceous Sanostee marker as horizontal datum, and drawing base of Entrada Sandstone parallel with Sanostee. Cross section is shortened vertically approximately 1600 ft (488 m) from Sanostee to base of Morrison Formation for ease of viewing (after Vincelette and Chittum, 1981).

86.1 Road from Ojo Encino and Star Lake enters from left. Mesa de Cuba at 12:00. **3.1**

89.2 Big canyon to left is Arroyo Chijuillita. **0.6**

89.8 Unpaved road to right; at 10:00 good view of Mesa de Cuba section reveals type section of Nacimiento Formation overlain by basal Cuba Mesa Member of San Jose Formation (mesa-capping sandstones) (Fig. 1.34). **1.4**

91.2 Dirt road to left, **turn left,** pass through gate and proceed to Mesa de Cuba. **0.1**

91.3 Road forks, **go right. 0.2**

91.5 **STOP 5** at outcrop edge to discuss Nacimiento Formation. This area was the type area of the "Puerco Marls" of Cope (1875), who visited the San Juan Basin as part of the Wheeler Survey of 1874. The American vertebrate paleontologist, Edward Drinker Cope (1875, p. 92) first used the term "Puerco marls" for the strata that are now termed the Nacimiento Formation. Cope (1875, p. 89) described these "marls" as follows:

> . . . the varied green and gray marls formed the material of the country, forming bad-land tracts of considerable extent and utter barrenness. They formed conical hills and flat meadows, intersected by deep arroyos, whose perpendicular walls constituted a great impediment to our progress. During the days of my examination of the region, heavy showers of rain fell, filling the arroyos with rushing torrents, and displaying a peculiar character of this marl when wet. It became slippery, resembling soap in consistence, so that the hills were climbed with difficulty, and on the levels the horses' feet sank at every step. The material is so easily transported that the drainage-channels are cut to a great depth, and the Puerco River becomes the receptacle of great quantities of slimy-looking mud. Its unctuous appearance resembles strongly soft-soap, hence the name *Puerco,* muddy. These soft marls cover a belt of some miles in width, and continue at the foot of another line of sandstone bluffs, which bound the immediate valley of the Puerco to a point eighteen miles below Nacimiento [Cuba].

The "Puerco Marl" was later found to be very fossiliferous and produced the first Paleocene mammals discovered in North America. Two main fossil zones were recognized, a thin zone near the base of the formation, and a much thicker zone higher in the section. These zones are separated by an interval devoid of fossil vertebrates (Williamson and Lucas, 1991).

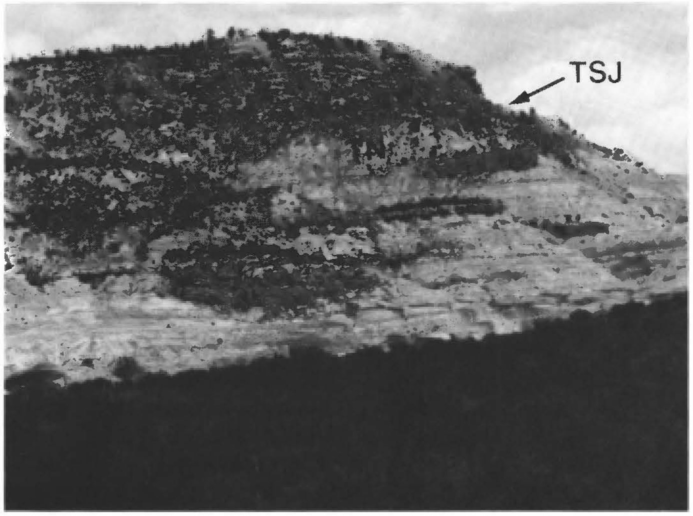


FIGURE 1.34. View of Cuba Mesa, showing Cuba Mesa Member of San Jose Formation (Tsj) above Nacimiento Formation (Tn).

These two zones each produced a very different and distinct fauna. Later, Matthew (1897) restricted the name Puerco Formation to those rocks which produced the "Puercan fauna" (the lower zone) and introduced a new name, the Torrejon Formation for those rocks which produced the "Torrejon fauna" (the upper zone). The boundary between these two formations was not specified by Matthew but was sometimes considered to be the lowest horizon that yielded typical Torrejonian mammals (Sinclair and Granger, 1914). Later workers recognized that these formations were not defined on lithologic criteria, and the names Puerco and Torrejon are now restricted to their respective faunas. Keyes (1906) used the "Nacimiento Series" to refer to these rocks, and Gardner (1910) termed them the "Nacimiento Group." The Nacimiento Formation eventually came to replace the "Puerco Marls" as defined by Cope (Dane, 1946; Simpson, 1948, 1959; Fig. 1.35).

Simpson and a crew from the American Museum of Natural History searched these outcrops of the Nacimiento Formation here, and in and around the town of Cuba, for fossil vertebrates in the late 1940s (Simpson, 1959). They were successful in recovering several specimens representing typical Torrejonian fossil mammals. The lowest came from a locality approximately 100 ft above the base of the Nacimiento Formation, and the highest came from only 50 ft below the base of the overlying San Jose Formation (Simpson, 1959).

Williamson and Lucas (this volume) recognize two members of the Nacimiento Formation at the type locality. The lower, Arroyo Chijuillita Member is the drab, greenish and grayish mudstones and sandstones. The upper member is the Ojo Encino Member, which is much more variegated with red and yellow bands and lenticular sandstone bodies. The base of the Ojo Encino Member is placed at the distinctive black lignite band visible about 200 ft above the base of the Nacimiento Formation. The uppermost member of the Nacimiento Formation, the Escavada Member, is absent from this area, probably removed by the erosional unconformity at the base of the San Jose Formation (Williamson and Lucas, 1992).

After stop, retrace route to NM-197. **0.3**

91.8 Gate, intersection with NM-197, **turn left,** proceed to Cuba. Road will skirt southern and eastern sides of Mesa de Cuba. **0.2**

92.0 Note old landslide remnants protecting badlands of Nacimiento Formation from degrading episodes of erosion and agricultural subjugation. **1.1**

93.1 Ojo Alamo Sandstone in roadcuts on left. **1.0**

94.1 Entering greater Cuba. Cuba (population 760; Spanish for trough or tank) was named Nacimiento when it was originally settled by grantees of the San Joaquin del Nacimiento land grant in the 1760s. The Navajos made farming and ranching impossible for these early colonists, and the area around Cuba was resettled on a permanent basis in the early 1870s. The vertebrate paleontologist Edward D. Cope, exploring the area as part of the Wheeler expedition in 1874, referred to the

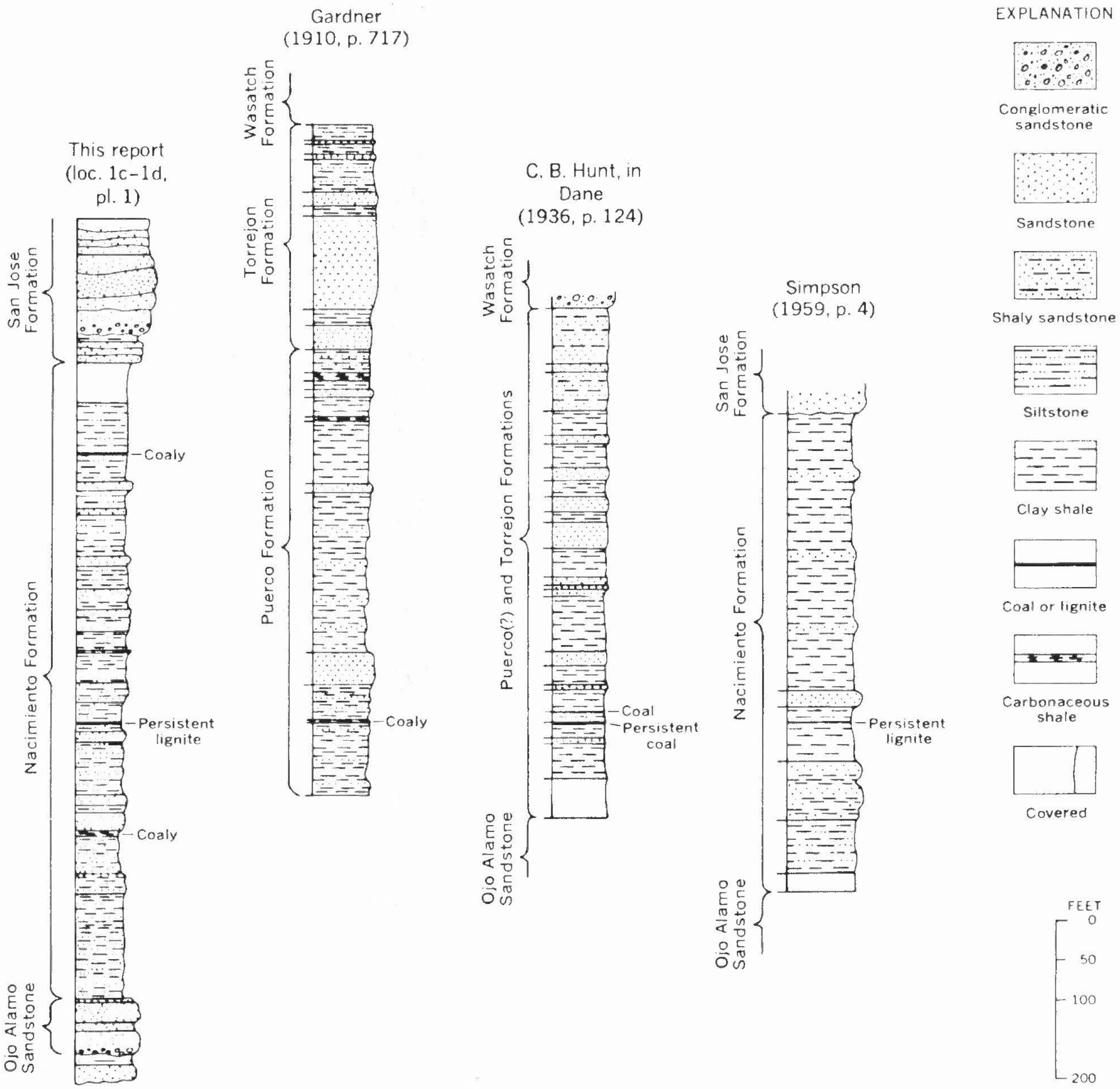


FIGURE 1.35. Comparison of stratigraphic sections of exposures at type locality of Nacimiento Formation, south end of Mesa de Cuba (from Baltz, 1967).

village of Nacimiento in his description of the geology of the area (Cope, 1875).

Located near the head of the Rio Puerco, close to feeder streams from the nearby San Pedro and Nacimiento Mountains, the town seemed well situated to become a thriving agricultural community. Stories are told of lush grasslands and 6-ft-tall buffalo grass in meadows around the town in the late 19th century (Chilton et al., 1984). Irrigated farming in the early years gave way to sheep and cattle ranching as the main economic activity of the area for many decades. For many years the cattle were driven at the end of each summer down the Rio Puerco for sale in Bernalillo more than 60 mi away. Cuba gained a reputation as a rough town, noted for gunfights, cattle rustling and bootlegging in the early part of the 20th century (Fugate and Fugate, 1989). Gradually, however, as in so many other parts of the region, overgrazing, erosion and drought made ranching an increasingly difficult endeavor. To some extent lumbering and intermittent copper mining nearby augmented ranching, but in the past few decades the main economic activity of Cuba has been providing services to travelers on NM-44. As the largest town along the eastern side of the San Juan Basin for a distance of 165 mi between Bloomfield and Bernalillo, Cuba offers a range of services for a large surrounding area that is unusual for a town its size. **0.4**

94.5 Road curves right. In 1989, during excavation of a gravel pit in Pleistocene gravels next to the brown house on the left, a mammoth jaw was encountered and destroyed. **0.7**

95.2 Bridge over Rio Puerco. **0.7**

95.9 Intersection with NM-44 at south edge of Cuba. **End of First-Day Road Log.**