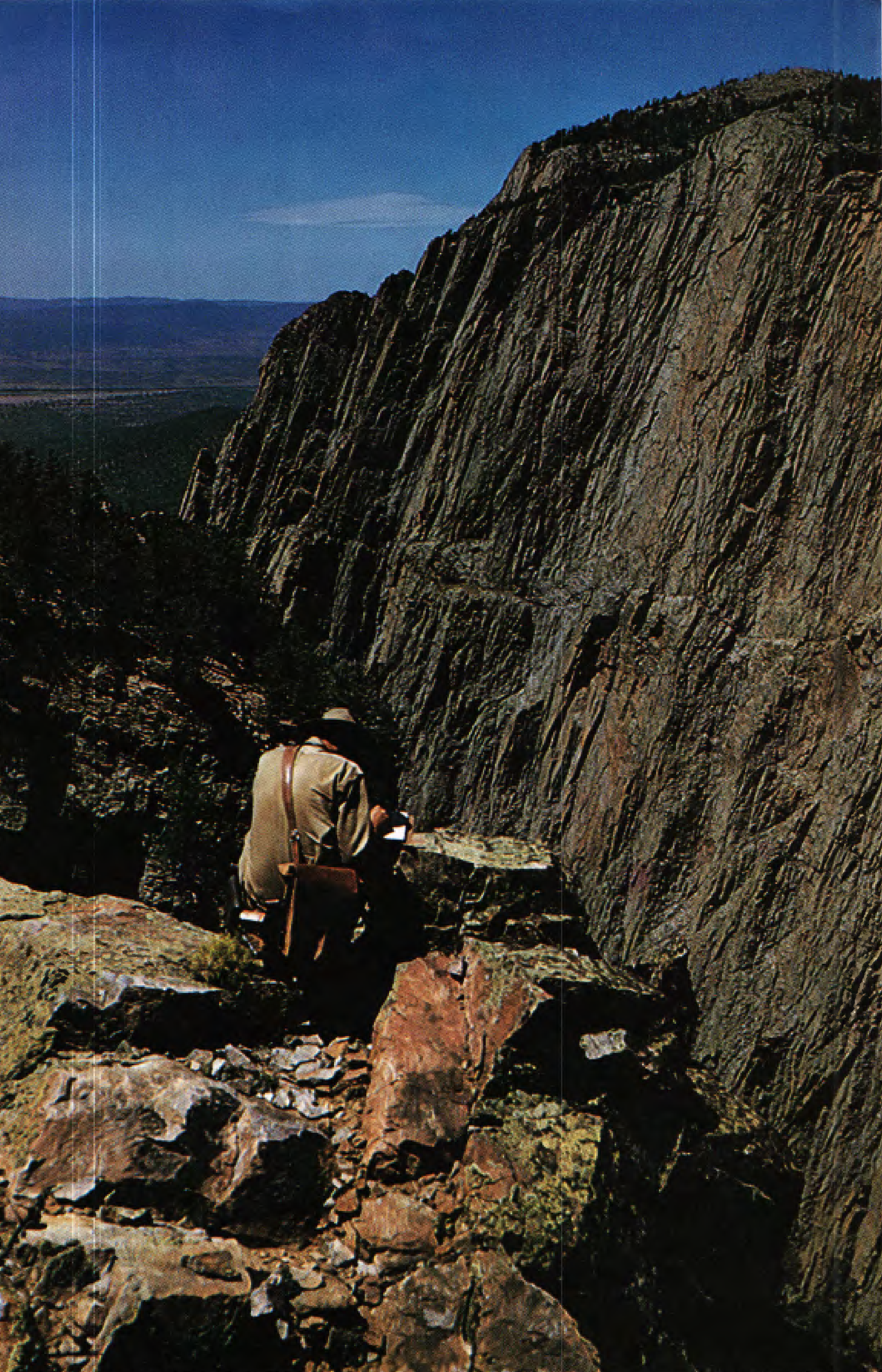
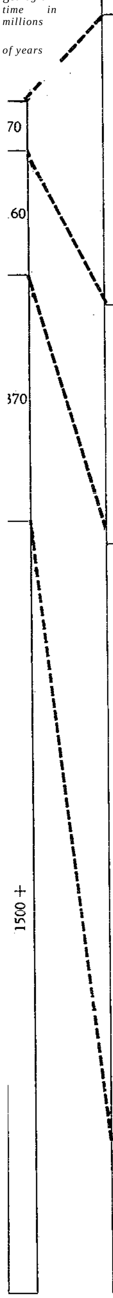
Española-Chama-Taos

A Climb Through Time

SCENIC TRIPS TO THE GEOLOGIC PAST NO. 13



Scale of geologic time in millions of years



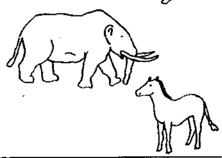
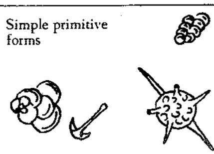
Era	*Geologic age*	*Rocks*	*Dominant life*	*Other geologic areas*
CENOZOIC	Neogene: Pleistocene	Bandelier volcanic ash, basalts, sand dunes, river gravels, glacial & lake beds.	Man 	Cedar Breaks National Monument, Utah; Rio Grande Valley, New Mexico
	—1 my— Pliocene —11 my— Miocene	Volcanic rocks of Mt. Taylor, early Valle Grande & Gila region; Santa Fe, Gila, and Ogallala Fms.	Mammals 	Jemez Mts. and ranges of western New Mexico; Bryce Canyon National Park, Utah; Cedar Breaks National Monument, Utah.
	—25 my— Paleogene: Oligocene	Datil, Espinaso, and other volcanic rocks.		
	—40 my— Eocene —60 my— Paleocene	Baca, Animas, Nacimiento, San Jose, Raton, Poison Canyon, Galisteo, El Rito, Blanco Basin, & Cub Mountain Fms.		
MESOZOIC	Cretaceous	Upper sandstone, shale, & coal. Mesaverde, Pierre, & Niobrara. Dakota Ss. and Mancos Sh.	Dinosaurs 	Northwestern New Mexico; Mesa Verde National Park, Colorado
		Volcanic rocks, limestone, sandstone, and conglomerate.		
	—135 my— Jurassic	Morrison Fm., Summerville Fm., Zuni Ss., Todilto Ls. & gypsum, Entrada Ss.		North of U.S. 66 from Grants to Gallup; Zion National Park, Utah
	—180 my— Triassic	Wingate Ss., Dockum Fm., Chinle Fm., Santa Rosa Ss., Moenkopi Fm.		Petrified Forest National Park, Arizona; Vermillion Cliffs, Utah.
PALEOZOIC	Permian	Rustler Dolomite; redbeds Castile gypsum, Salado Salt.	Amphibians 	Grand Canyon National Park, Arizona; Carlsbad Caverns National Park, New Mexico
		Artesia Grp.—Capitan reef San Andres Ls.—Goat Seep reef Glorieta Sandstone Yeso Fm.—Bone Spring Fm.		
		Abo Redbeds—Hueco Ls.		
	—280 my— Pennsylvanian	Mostly limestone; beds of shale & sandstone; lenses of gypsum, salt, and coal.		Sandia and Sangre de Cristo Mountains, New Mexico; Garden of the Gods, Colorado
	—310 my— Mississippian	Helms & Paradise Fms. Rancheria Ls. Lake Valley & Escabrosa Lss. Arroyo Penasco & Tererro Fms.	Fish 	Grand Canyon National Park, Arizona. Franklin Mountains, Texas, and numerous mountain ranges in southwestern New Mexico
	—345 my— Devonian	Percha Shale, Ouray Ls. northern dol., ss, and sh. / erosion		
	—400 my— Silurian	Fusselman Dolomite / erosion		
	—425 my— Ordovician	Montoya Dolomite El Paso Limestone Bliss	Invertebrates 	
	—500 my— Cambrian	Sandstone / erosion		
PRECAMBRIAN		quartzite, gneiss, rhyolite, andesite, granite, pegmatite, schist, greenstone.	Simple primitive forms 	Grand Canyon National Park, Arizona; Sangre de Cristo and Sandia Mountains, New Mexico; Franklin Mountains, Texas; Black Canyon of the Gunnison, Colorado

TABLE OF GEOLOGIC TIME

Española- Chama-Taos

A Climb Through Time

Cover-RISTRAS OF RED CHILES

Scenic Trips to the Geologic Past
No. 13

New Mexico Bureau of Mines & Mineral Resources

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

Española-Chama-Taos

A Climb Through Time

by
William R. Muehlberger
and
Sally Muehlberger

Illustrated by Debra Vetterman

Frontispiece—BRAZOS BOX
east of Tierra Amarilla

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Preface

Northern New Mexico is a region of spectacular contrasts in scenery: from slightly vegetated desert valleys and lava-covered plateaus sliced by deep gorges, to towering forested mountains with jagged peaks that are the highest points in New Mexico. Each town that occupies these varied settings is different and reflects the remarkable interplay of the Indian, Spanish, American, and even French influences in the development of the region.

This is a region of gorgeous color—in the great variety of rocks and their myriad erosional forms, or in the sky that can range from a deep blue to dark-gray storm clouds and finally to multicolored sunsets. This quality of light has drawn to the region many artists who have made several of the places in this guidebook familiar to the tourist.

Many people have shared their knowledge and friendship with us during our many summers living in the Chama, Ojo Caliente, and Taos areas. We have fond memories of them and of our time in this region. Ken and Donna Lively, long-time residents of Chama, deserve special thanks for the years of hospitality and for sharing their intimate knowledge of the Chama area. Our thanks go to Hugh Doney for the use of his photographs and his review of the cross section across the region that he mapped (Tierra Amarilla-Tres Piedras log); and to the many students and individuals from other institutions who worked in parts of this region and have contributed important pieces to the still incomplete jigsaw puzzle of geologic history. To Tom Williams, Southern Methodist University, goes our appreciation for letting us use the facilities and library at Ft. Burgwin Research Center near Taos. The New Mexico Bureau of Mines and Mineral Resources provided financial support for the preparation of this book while we developed the road logs and text during the early summer of 1979. All photos were taken by the authors except where otherwise indicated. We also thank the Bureau editorial staff for their patient and thorough work.

William R. Muehlberger
Professor of Geology
University of Texas

Austin, Texas
November, 1981

Sally Muehlberger

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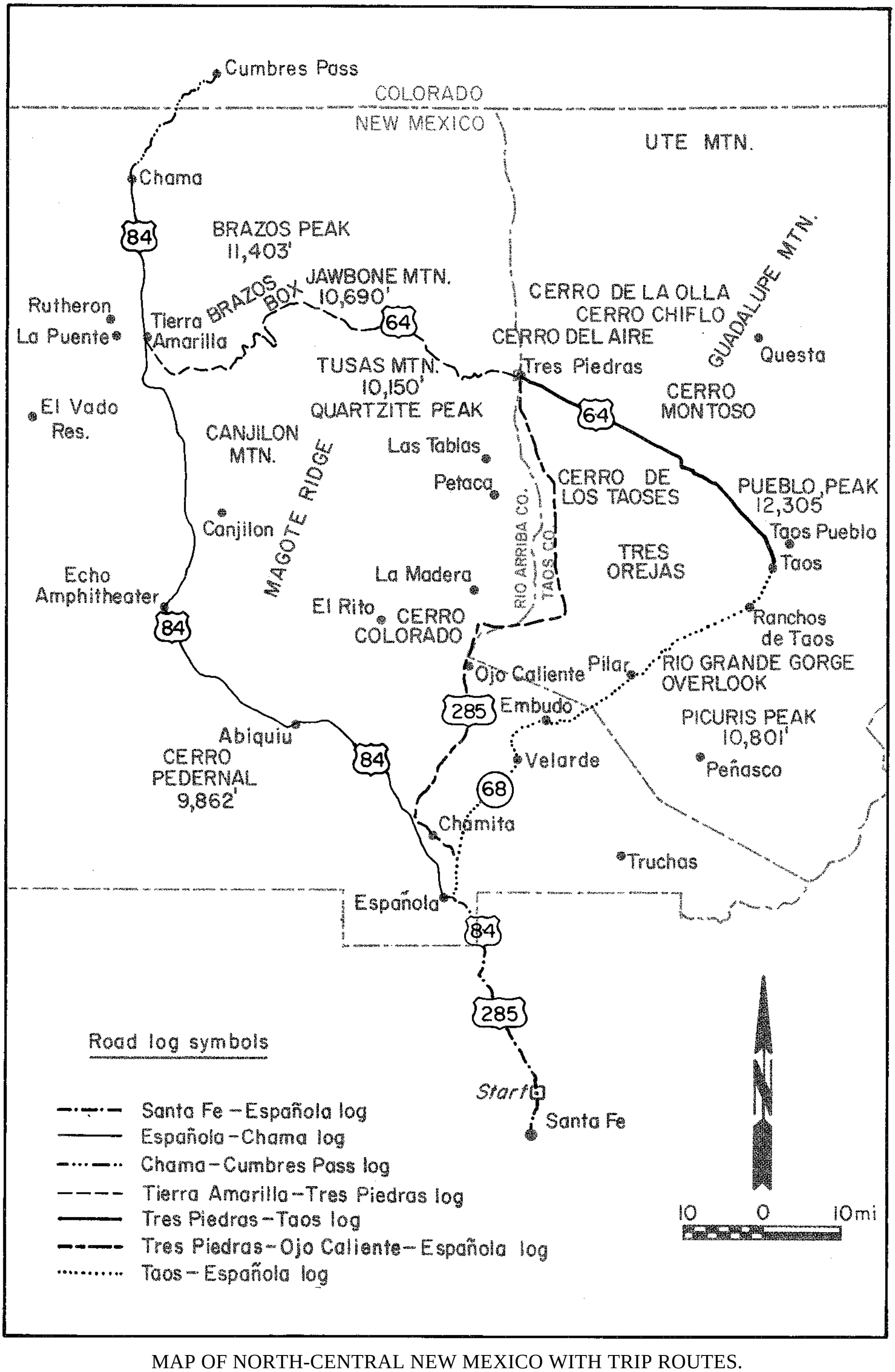
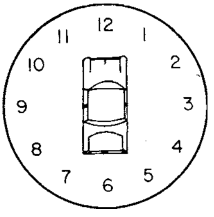


MAP OF NORTH-CENTRAL NEW MEXICO WITH TRIP ROUTES.

How to use this guidebook

This guidebook was written to help the traveler explore this region by traveling either one long or two shorter loops. The book also can be used as a guide on one-way segments of longer trips through the region.

The clock system is used to point out features of interest; the front of your car is considered 12:00, the rear represents 6:00, and locations in between are as indicated below. The cumulative mileages (on the left side of the pages) may not agree with odometers of some vehicles because of different tire sizes or other peculiarities, but the intervals (at the end of each entry) should agree closely. The distance to each succeeding point of interest is given in bold face type at the end of each discussion so that you can tell how soon to begin looking for the next point.

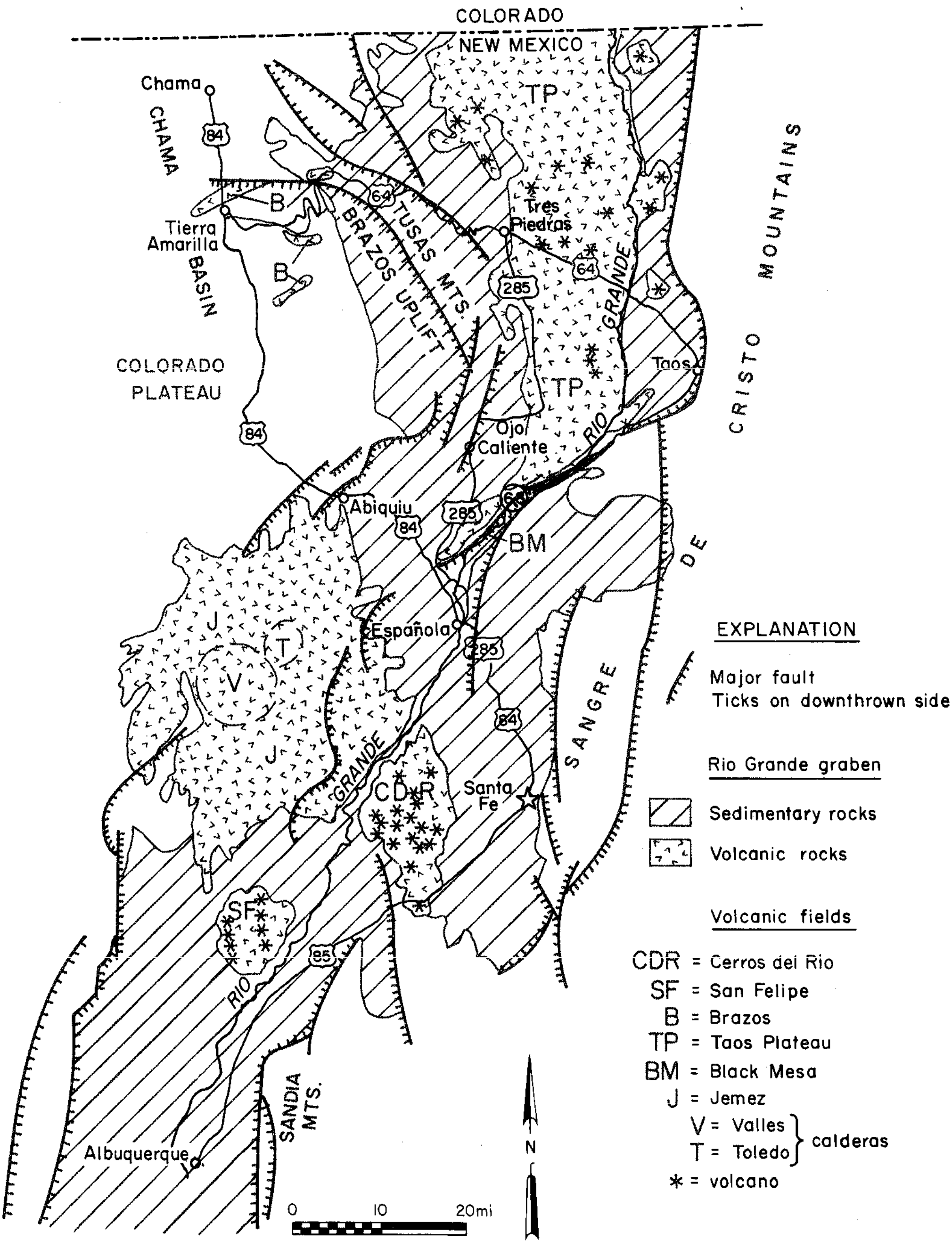


The region covered in this guidebook is almost entirely in Rio Arriba ("upper river") and Taos Counties. The main route north traces the Rio Chama nearly to its source. The lower Rio Chama crosses the older part of the young Rio Grande rift. A few miles west of Abiquiu, the route crosses onto the Colorado Plateau and continues to climb both in terms of geology and elevation. The road next crosses the Tusas Mountains, which separate the Rio Chama from the Rio Grande. This segment continues to climb from the Chama Basin to its eastern rim. The route then crosses the high Taos Plateau, passing through the progressively younger rocks of the Rio Grande rift, and continues south along either the Rio Ojo Caliente or the Rio Grande to the junction of the latter with the Rio Chama near Española. These routes pass the major geologic features that illustrate the development of the Rio Grande rift - a topographically low area bordered by the highest mountains in New Mexico. Although this region is low relative to the mountains, it is more than a mile above sea level.

The upper Rio Grande and its principal tributaries in New Mexico provide passages for the major access routes to north-central New Mexico, a region of spectacular scenery with a wide variety of geological wonders.

Completion of the entire loop (Santa Fe-Española-Chama-Taos-Santa Fe) in one day permits the traveler to make only the briefest of stops and to appreciate only the highlights of the spectacular scenery. Instead, we suggest some alternatives.

If you start in Santa Fe and stay overnight in Chama, you will have time in the afternoon to explore this scenic region. A leisurely drive to Cumbres Pass parallels the route of the Cumbres and Toltec Scenic Railroad and allows you to follow the narrow-gauge train as it descends the grade to Chama (Note: check train schedules beforehand). If you would like to combine a day on the train with this trip, be sure to make reservations well in advance.



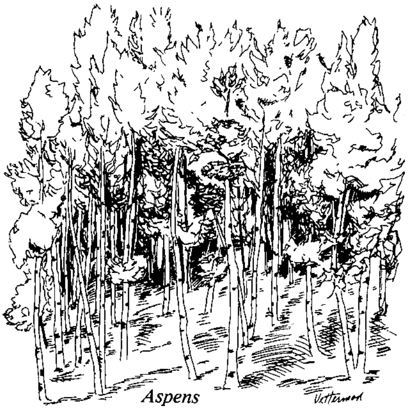
GENERALIZED GEOLOGIC MAP OF THE REGION WITH ROUTES OF TRAVEL.

The route from Chama to Taos can be traveled in a leisurely day, allowing time for picnicking, fishing, or hiking at Hopewell Lake, a walk across the Rio Grande Gorge bridge, and a walking tour of Taos.

From Taos to Española to Santa Fe is a relatively short trip. You will have time to search for mineral specimens in Hondo Canyon, explore the Rio Grande Gorge, or detour through Dixon to the Harding mine. Permission to enter the mine is required! The Harding pegmatite mine property has been donated to the University of New Mexico by Arthur Montgomery and is preserved as a mineral-collecting locality as well as a unique outdoor geologic laboratory. Visitors are welcome, but first must sign the necessary release forms. These forms may be obtained from the Chairman, Department of Geology, University of New Mexico, Albuquerque, NM 87131. Please restrict your mineral collecting to a few samples for your personal collections and be sure that your trash goes home with you. DO NOT ENTER THE UNDERGROUND WORKINGS.

If Española is the starting point, the loop through Chama-Tres Piedras-Ojo Caliente makes a good day's trip. On the second day, retracing the route past Ojo Caliente to Tres Piedras and following the route through Taos allows ample time to walk across the Rio Grande Gorge bridge, visit Taos, and return.

Have an enjoyable trip!



Aspens

Important dates in New Mexican history

Indian periods in New Mexico

1150-1350	Classic or great period of Pueblo culture.
1350-1700	Period of maximum expansion of Pueblo culture in New Mexico.
1700-present	Modern Pueblo period.

New Mexico under Spain

1598	Don Juan de Oñate took formal possession of New Mexico on the Rio Grande near El Paso del Norte, established the capital at San Juan Pueblo, and assigned Franciscans to missions in seven pueblos.
1598-1605	Oñate explored from the plains of Kansas to the mouth of the Colorado River.
1610	on Pedro de Peralta, third governor of New Mexico, established Santa Fe as the new capital.
1617	Eleven mission churches were established in New Mexico.
	(1620—Pilgrims landed at Plymouth Rock.)
1644-47	Religious persecution of Indians led to conspiracies and outbreaks against Spaniards.
1660	Severe conflict occurred between civil and religious authorities; Franciscans threatened to abandon New Mexico.
1680	Pueblo revolt was led by the Indian Popé on August 10; Spanish rule ended August 21; all Spaniards were either killed or driven out of New Mexico to El Paso del Norte, where the capital was maintained for 13 years.
1692	Don Diego de Vargas reconquered New Mexico.
1693	De Vargas officially claimed New Mexico and entered Santa Fe.
1695	Franciscan missions were reestablished.
1725	Spanish government forbade trade with the French; trade with the Plains Indians was limited to those Indians coming to Taos and Pecos.
	(July 4, 1776—U.S. Declaration of Independence)
1776	On July 29, Friars Silvestre Velez de Escalante and Francisco Dominguez, with eight other friars, left Santa Fe to find a commercial route to California. Their route into central Utah was the first stage on what was to be the Spanish Trail from Santa Fe to Los Angeles.
1807	Lieutenant Z. M. Pike, arrested by the Spanish for building a fort in their territory, was sent to Mexico; he was finally released on the Louisiana frontier.

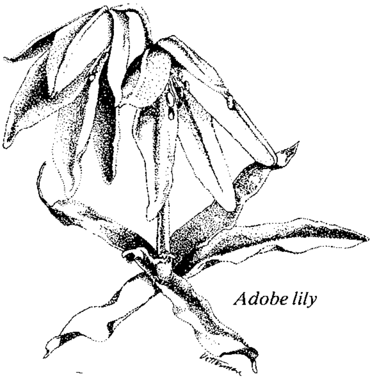
New Mexico under the Republic of Mexico

1821	Independence of Mexico from Spain; New Mexico became a province of Mexico.

1822	William Becknell, father of the Santa Fe Trail, brought the first wagons from the east to Santa Fe.

New Mexico as a United States Territory

1846	The United States declared war on Mexico and made plans to invade New Mexico. General Kearney occupied Santa Fe peacefully and declared the beginning of United States rule. Charles Bent was declared civil governor.
1847	Taos revolt led by revolutionaries and Indians; Governor Bent was killed in Taos; the revolt ended a month later at the Taos Pueblo church.
1853	Christopher (Kit) Carson was appointed Indian Agent in New Mexico.
1859	Capt. J. N. Macomb led an expedition from Santa Fe to the junction of the Grand and Green Rivers. Macomb, commander of the Corps of Topographical Engineers was accompanied by geologist J. S. Newberry. They produced the first reasonably accurate map of the area and a geologic report.
1872-74	Under the direction of George M. Wheeler, comprehensive geological and geographical surveys of the country west of the 100th meridian produced some of the earliest detailed information about north-central New Mexico.
1874	Famous vertebrate paleontologist Edward D. Cope traveled from Española to Tierra Amarilla in search of fossils.
1880	The Denver and Rio Grande Western Railroad entered New Mexico at Chama, with the Rio Grande valley and Santa Fe as future destinations.
1912	New Mexico became a state.



Adobe lily

Color Photo Gallery

(next eight unnumbered pages)

1—Camel Rock.

2—SACRED HEART MISSION, NAMBÉ *(photo by S. D. Blodgett)*.

3—CEMENTED SANTA FE FORMATION SOUTH OF ABIQUIU.

4—TODILTO FORMATION OVERLYING ENTRADA SANDSTONE AND CHINLE FORMATION SOUTH OF GHOST RANCH *(photo by S. D. Blodgett).*

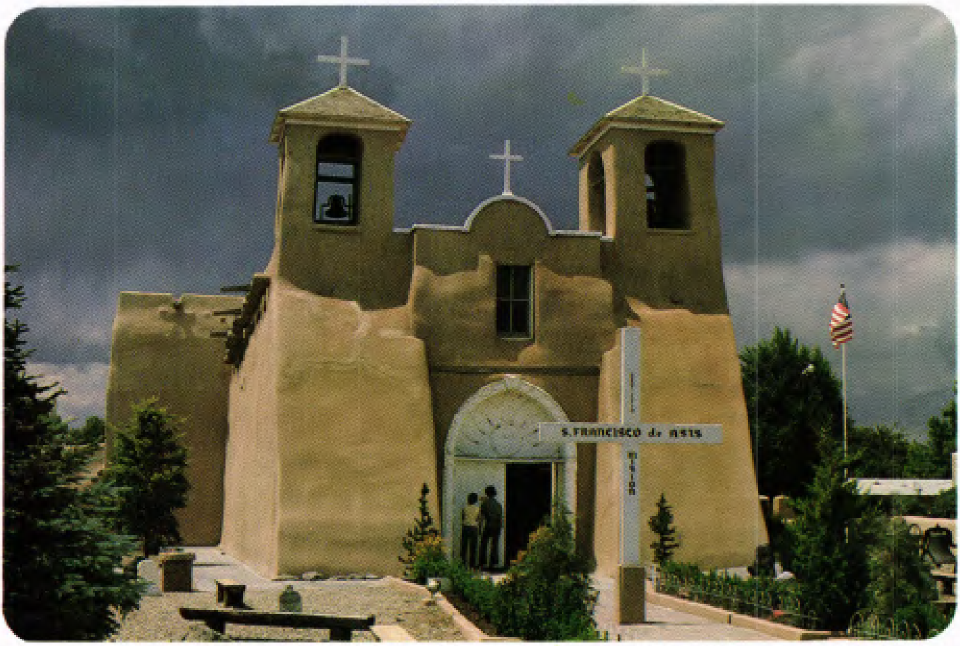
5—MESOZOIC SECTION NEAR GHOST RANCH *(photo by S. D. Blodgett).*

6—ECHO AMPHITHEATER *(Photo by S. D. Blodgett).*

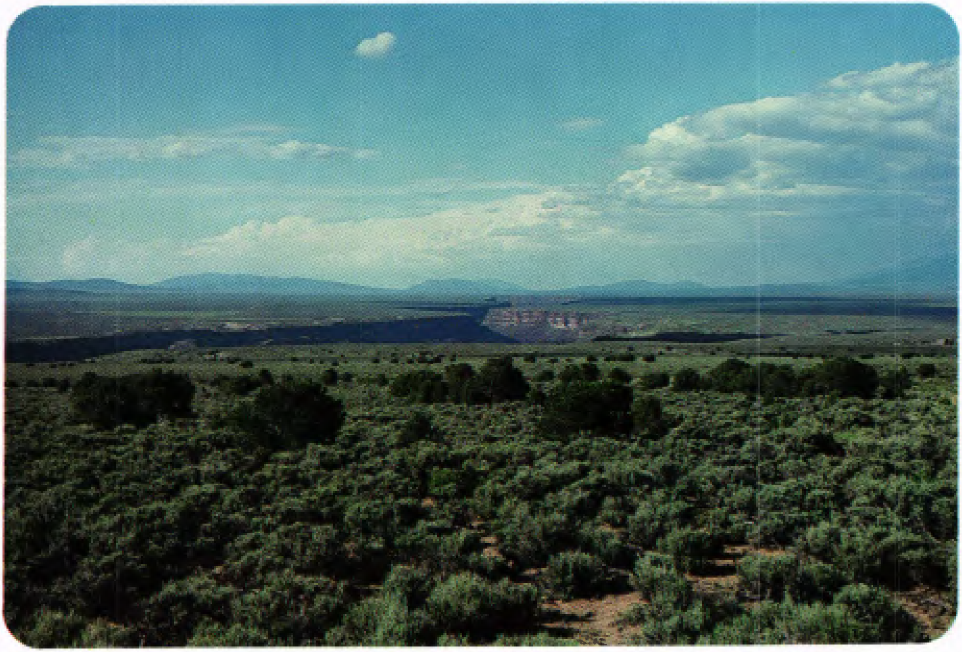
7—LOBATO RAILROAD SIDING NORTH OF CHAMA.

8—BRAZOS BOX OVERLOOK.

9—OLD SMOKY, TUSAS MOUNTAINS.



10—St. Francis Church, Ranchos de Taos.



11—Rio Grande Gorge overlook south of Taos *(photo by S. D. Blodgett).*

12—RISTRAS OF RED CHILES, VELARDE.

13—PILAR, LOOKING SOUTH DOWN RIO GRANDE.

14—EL VADO RESERVOIR.

Geology

The spectacular scenery of this region is a result of geologic processes still active today. Our route passes some of the oldest rocks exposed in the state. The Mesozoic continental-to-marine transition is beautifully displayed in the Chama Basin, and thick sequences of continental deposits are preserved in the younger Rio Grande rift.

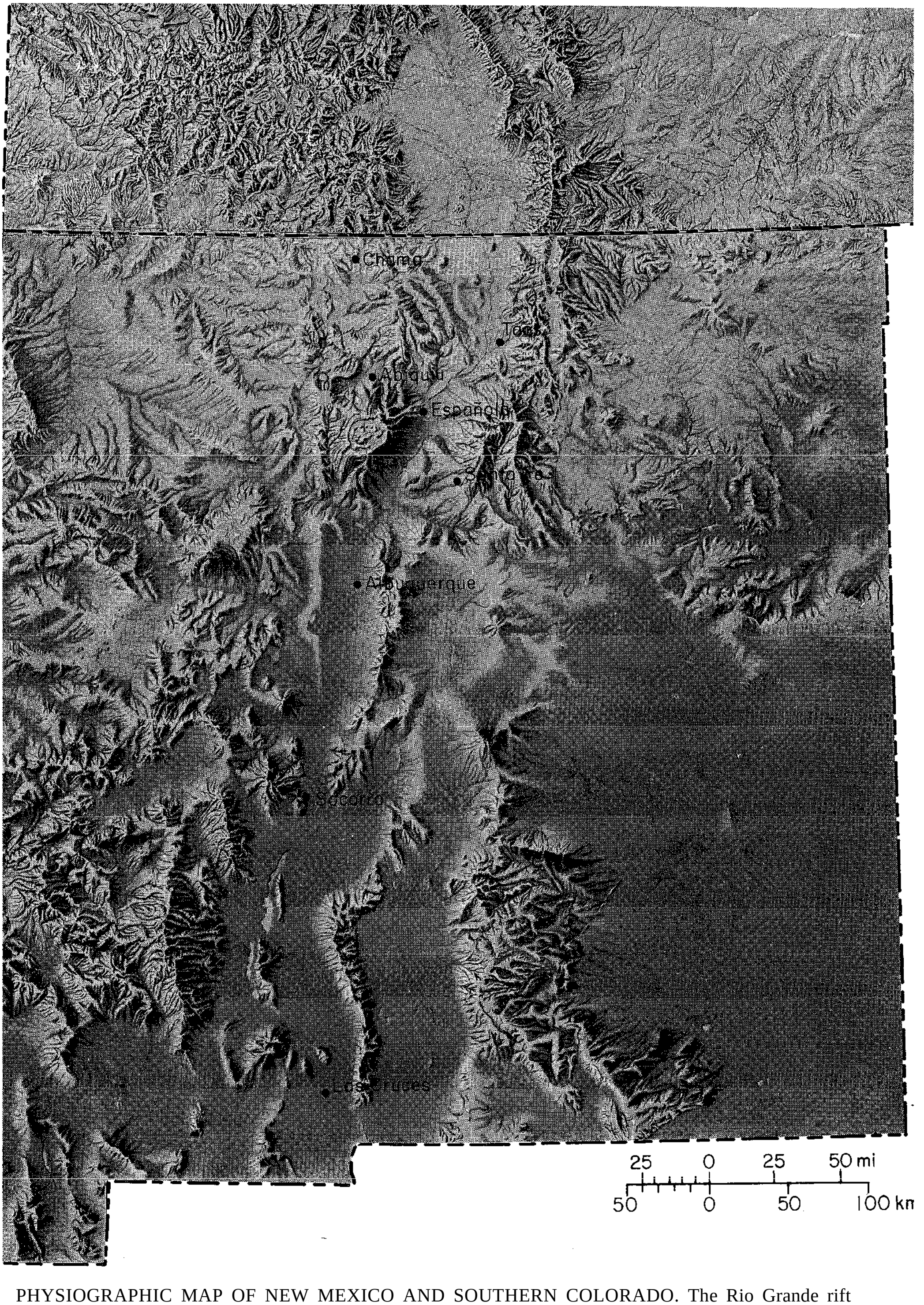
The impressive Sangre de Cristo Mountains form the eastern skyline for most of the trip. Their jagged peaks are underlain by the oldest rocks: Precambrian schist, amphibolite, quartzite, and granite. The smooth, more rounded peaks and ridges are covered by Pennsylvanian sandstone, shale, and limestone. A similar cap of sedimentary rocks forms the skyline of the Sandia Mountains east of Albuquerque. On the Taos-Espanola leg of the trip, Precambrian quartzite and schist are visible where the Picuris Mountains (a western extension of the Sangre de Cristos) reach the Rio Grande Gorge.

The Tusas Mountains uplift trends northwest from Ojo Caliente to the New Mexico-Colorado border. The Precambrian spine of this uplift exposes a variety of rock types, including quartzite, schist, amphibolite, gneiss, and granite, along our route from Tierra Amarilla to Tres Piedras. Another cross section of the Tusas uplift is visible along the railroad route from Chama to Antonito, Colorado (covered in Scenic Trip 11).

Paleozoic rocks are seen in only one set of exposures at the edge of the Colorado Plateau, west of Abiquiu on the Española-Chama leg. These exposures consist of Cutler Formation (Early Permian) stream deposits derived from erosion of the remnant of the Uncompahgre highlands. During the early Permian, the highlands occupied most of the area of our route and much of south-central Colorado. The Sangre de Cristo Mountains preserve a thick sequence of Pennsylvanian rocks deposited in a rapidly subsiding trough covered by an arm of the sea, adjacent to the east flank of the Uncompahgre highlands. (These rocks are not exposed along our route but are visible near Santa Fe and are described in Scenic Trip 1.) As the shoreline gradually retreated south and east during the Permian, a remarkable sequence of reefs developed; rimming the Permian Basin of southeast New Mexico and west Texas. These reefs are now the site of major oil and gas fields. Spectacular exposures of these reefs occur in the Guadalupe Mountains west of Carlsbad. Carlsbad Caverns are in part of the reefs.

Our route across the Chama Basin passes beautiful exposures of Mesozoic rocks. The route progressively climbs through these rocks so that we can study the sequence in chronologic order; in effect, we can climb through time. The Chinle Formation (Late Triassic) was deposited on top of the eroded Cutler Formation. No rocks preserved in this region record the missing 100 m.y. (million years) that separate these two units. The Chinle was formed when coarse materials from mountains north and east of our route were transported by streams to broad river plains and, later, to rivers that were bringing sand and mud from highlands to the southwest. Lakes existed in the Four Corners region during part of this time. Bentonite layers in the Petrified Forest Member of the Chinle mark volcanic eruptions far to the southwest.

Eventually the slow-moving rivers draining to the northwest were overwhelmed by sand dunes of the Entrada Sandstone (Early Jurassic). The wind blew from



PHYSIOGRAPHIC MAP OF NEW MEXICO AND SOUTHERN COLORADO. The Rio Grande rift extends from Leadville, Colorado, south to El Paso, Texas; the rift continues southeast along the Rio Grande to Big Bend National Park, Texas (from U.S. Geological Survey).

what today is north-northeast, but when we restore the continents to their earlier positions, we find that the wind direction during Early Jurassic was from the west (as it is today). The total thickness of sandstone ranges from 200 to 265 ft in the Echo Amphitheater region. This dune sand extends west to Las Vegas, Nevada, and to Zion Canyon National Park, Utah, where the sand deposits are much thicker. Large, sweeping crossbeds are characteristic of the lower part of the Entrada Sandstone. Parallel-bedded units in the upper part mark the rise of shallow lakes or high ground-water levels during formation of the dunes.

The overlying Todilto Formation was formed when brackish lakes covered much of north-central New Mexico. The fetid odor of the limestone when broken and the scarcity of fossils indicate that circulation within the lake was highly restricted. The overlying gypsum member occupies a smaller region and consists of belts of transverse dunes resembling the modern gypsum dune field at White Sands National Monument near Alamogordo, New Mexico. The Todilto Formation caps the Entrada Sandstone cliffs.

By Late Jurassic time, mountains rising to the west and southwest caused large, sluggish streams to bury the Todilto dune field and to deposit the grayish-white sand and distinctive purplish or greenish mudstones of the Morrison Formation. The coarser parts of these stream deposits, and their included plant remains, contain the major uranium reserves located in the Gallup-Grants area southwest of our route.

The last major river system that drained across the region is marked by the Burro Canyon Formation (Early Cretaceous). In the southern Chama Basin, this formation is composed of northeast-trending, conglomeratic, channel sandstones that contain reworked Morrison Formation stripped from the uprising Mogollon slope to the southwest. By this time a shallow continental sea extended from the Arctic Ocean to central Colorado. As the sea expanded westward and southward to the Gulf of Mexico, its western shoreline transgressed this region during deposition of the Dakota Sandstone (110 m.y. ago). The conspicuous, brownish sandstone cliffs of the Dakota form the topographic rim of the Abiquiu Reservoir-Echo Amphitheater region. Farther north, the Dakota Sandstone caps the anticlines exposed west of our route to Chama. Excellent exposures also are evident along the route north of Echo Amphitheater.

The shoreline remained to the southwest during the deposition of the Mancos Shale, a dark-gray to black, thin-bedded shale with minor limestone. The Mancos forms the rolling surface over most of the Chama Basin north of Echo Amphitheater. Exposures are rare; most exposures are of the limestone layers, or they are in roadcuts and stream banks, usually covered by slides.

To the southwest, rising mountains caused a northeast movement of the shoreline as major rivers deposited immense amounts of sand and silt. About 80 m.y. ago, the shoreline once again crossed this region and left the Mesaverde Sandstone as evidence. Later (78 m.y. ago), the shoreline transgressed to the southwest; black, silty, marine muds once again were deposited.

The next pulse of mountain building to the west drove the shoreline northeastward; by 72 m.y. ago, the shoreline was near Raton. Mountain building reached a climax during the Laramide orogeny. Uplift of this entire region formed mountains that again occupied the Uncompahgre uplift (Tusas uplift) and built the Rocky Mountains 65 m.y. ago. This event lifted the Chama Basin relative to the

San Juan Basin and the Tusas uplift relative to the Chama Basin. The east front of the Rocky Mountains must have been as imposing then as it is today, even though today's Rockies represent a younger generation of uplifting.

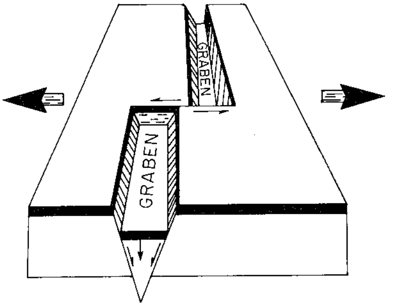
Erosion of the Laramide Rockies produced vast aprons of alluvial debris. The Blanco Basin (from Brazos Box north to Chama) and El Rito (from Brazos Box south to Abiquiu) formations, are remnants of those alluvial aprons. They are found only along the western rim of the Tusas uplift and in the yellow and pink cliffs north of Chama. The coarse gravels of these units indicate the steepness of the alluvial slopes. These rivers drained west and then north into the enormous lakes (Uinta and Goshiute) of Utah, western Colorado, and southwest Wyoming. The Green River Shale that contains vast oil-shale resources was deposited in these lakes.

The Tusas Mountains also preserve two formations from the southern edge of the enormous San Juan Mountains volcanic field of southwest Colorado. The first is the Conejos Formation (35-30 m.y. ago): the lower unit comprises tuffs, conglomerates, and sandstones; the upper unit comprises andesite lava flows, flow breccias, and debris flows. The upper unit forms mesas and benches near the summits north of our route (Tierra Amarilla-Tres Piedras log); the tuffs and gravels of the lower unit extend to our route.

The second formation, the Treasure Mountain Tuff (30-24 m.y. old), also is in two parts: a lower unit comprises tuff, sandstone, and conglomerate; an upper unit is welded ash-flow tuff. This material erupted from the Platoro caldera, the final event of a volcanic complex that included the earlier Conejos shield volcanoes. Explosive rocks of similar type and age also occur in a fault block in the Taos Plateau near the Rio Grande. These rocks are the westernmost known material associated with the Questa caldera, now high in the Sangre de Cristo Mountains.

The evolution of the Rio Grande rift began approximately 25 m.y. ago (early Miocene). Most of this region had long since been eroded to low relief, but, in the early Miocene, faulting began again along any of the major zones formerly active during the Laramide, late Paleozoic, and Precambrian mountain-building episodes. During these earlier episodes, the eastern border of the Uncompahgre uplift was raised. The uplift has since moved in the opposite direction and now marks the eastern and lowest part of the Rio Grande rift from Taos north to Colorado. Today the Sangre de Cristo Mountains tower above the Taos Plateau, but during both the late Paleozoic and Laramide revolutions the situation was reversed. During these earlier times, the Taos Plateau and the Tusas Mountains to the west were sites of high mountain ranges, flanked along their eastern borders by arms of the ocean (the site of the present Sangre de Cristo Mountains and adjacent plains to the east).

The Embudo fault zone connects the present actively subsiding segments of the Taos Plateau and Espanola Basin. The fault resembles a transform fault, like the fault connecting two segments of mid-ocean ridges. As the walls of the rift pull apart, the central block subsides, causing the transform fault to move horizontally and form a strike-slip fault; a well-known example is the San Andreas fault in California. The Embudo fault has an additional complication—the rift valley segments that the Embudo connects are not subsiding uniformly, but are tilting in opposite directions, imparting a scissors motion to the fault. The high side of the



BLOCK DIAGRAM OF TRANSFORM FAULT CONNECTING TWO GRABENS.
This diagram shows the typical but simplified appearance of regions that are spreading: mid-ocean ridges, Rio Grande rift, and other features (see block diagram on p. 22).

fault to the south is the Picuris Mountains that border the east end of the fault; the low side occurs from Velarde to Los Alamos.

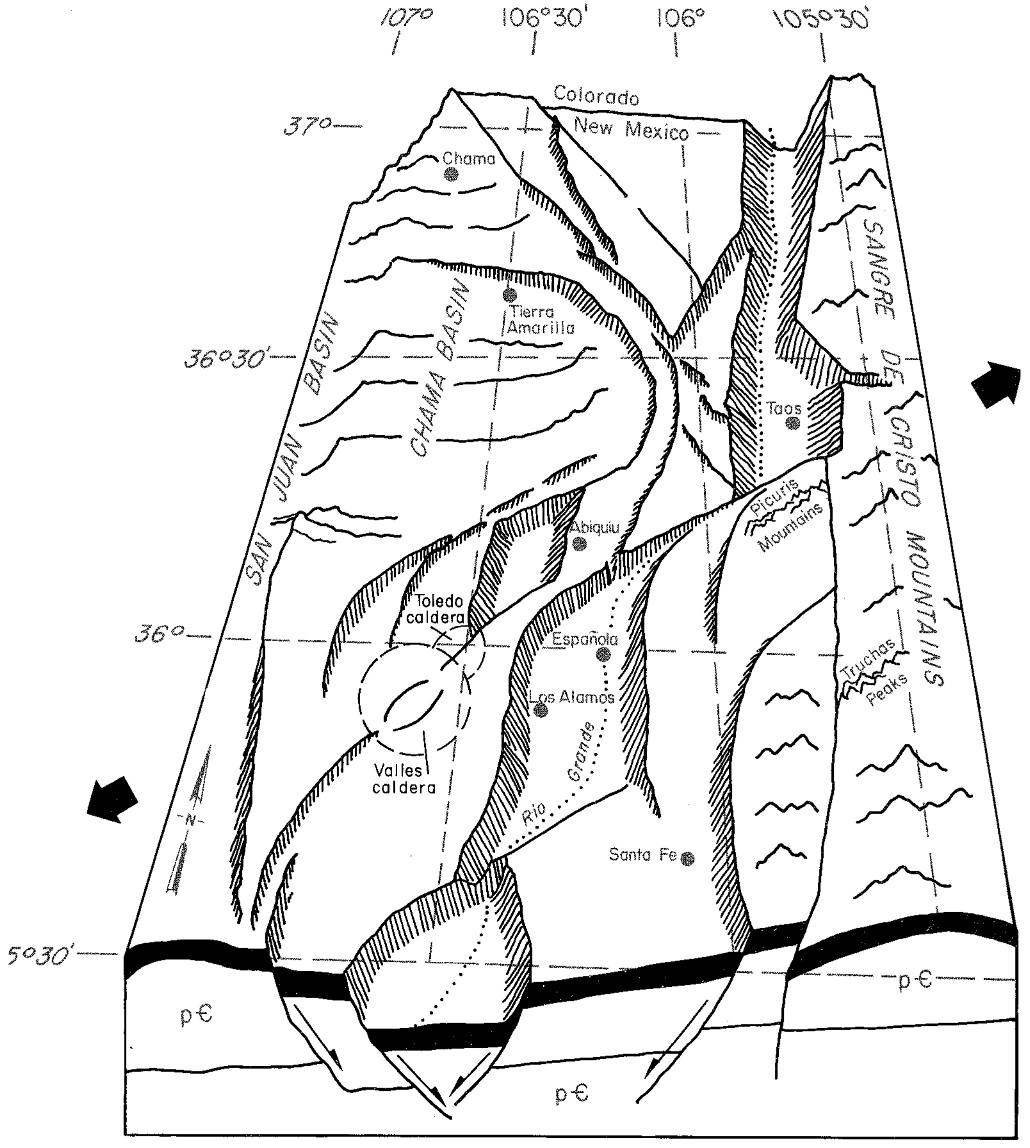
The subsidence of the Rio Grande rift is only partly understood despite extensive study. The earliest deposits in the rift are recorded in the Abiquiu region. Large amounts of white Abiquiu Tuff were deposited initially by streams flowing southwest, then south, and eventually southeast. These deposits, as well as material deposited until approximately 2.5 m.y. ago, filled closed depressions. A coarser grained equivalent of this material is found in the Tusas Mountains, where it consists of sand and gravel with rare basalt flows of Los Pinos Formation, or along the eastern margin of the rift in the Sangre de Cristo Mountains (Picuris Tuff). This material marks the erosional destruction of the San Juan Mountains and Questa volcanic fields.

As subsidence accelerated, the distant mountains were eroded, while nearby mountain ranges were uplifted further. Arkosic sediments derived from the Sangre de Cristo Mountains flooded the basin and produced the main sedimentary fill (Santa Fe Group) of the Española Basin. Included are alluvial fan deposits, lacustrine (lake) deposits, and thick accumulations of dune sand (Ojo Caliente Sandstone).

Starting about 9 m.y. ago in the western Española Basin, spasmodic volcanic activity gradually built a complex pile of basalt and andesite. Finally, violent eruptions produced the giant caldera of the Jemez Mountains (1.4 and 1.1 m.y. ago).

Volcanism in the Taos Plateau was concentrated into a relatively short interval from approximately 5 to 2 m.y. ago, except for Cerro Chiflo, a single 10-m.y.-old rhyolitic vent and flow. This episode produced an outer ring of rhyolitic volcanoes, a smaller ring of andesitic volcanoes, and a more concentrated central area of basaltic volcanoes. The basaltic volcanoes were extremely fluid, large-volume events that produced low, broad shield volcanoes and a cover of basalt over the entire plateau. Total thickness of these flows is unknown, but it exceeds the depth of the Rio Grande Gorge (650 ft) at the high bridge crossing on our route from Tres Piedras to Taos on US-64.

The Rio Grande that flows through this region is a relative newcomer; the river is older than the 2.4-m.y.-old basalts of the Cerros del Rio, because these basalts rest on gravels of the early Rio Grande. However, the river is younger than the



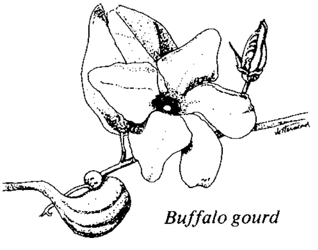
BLOCK DIAGRAM OF REGION OF THIS BOOK; the view is as if all sedimentary rocks of the region had been removed.

2.8-m.y.-old basalt that caps Black Mesa, because no Rio Grande gravels underlie the mesa.

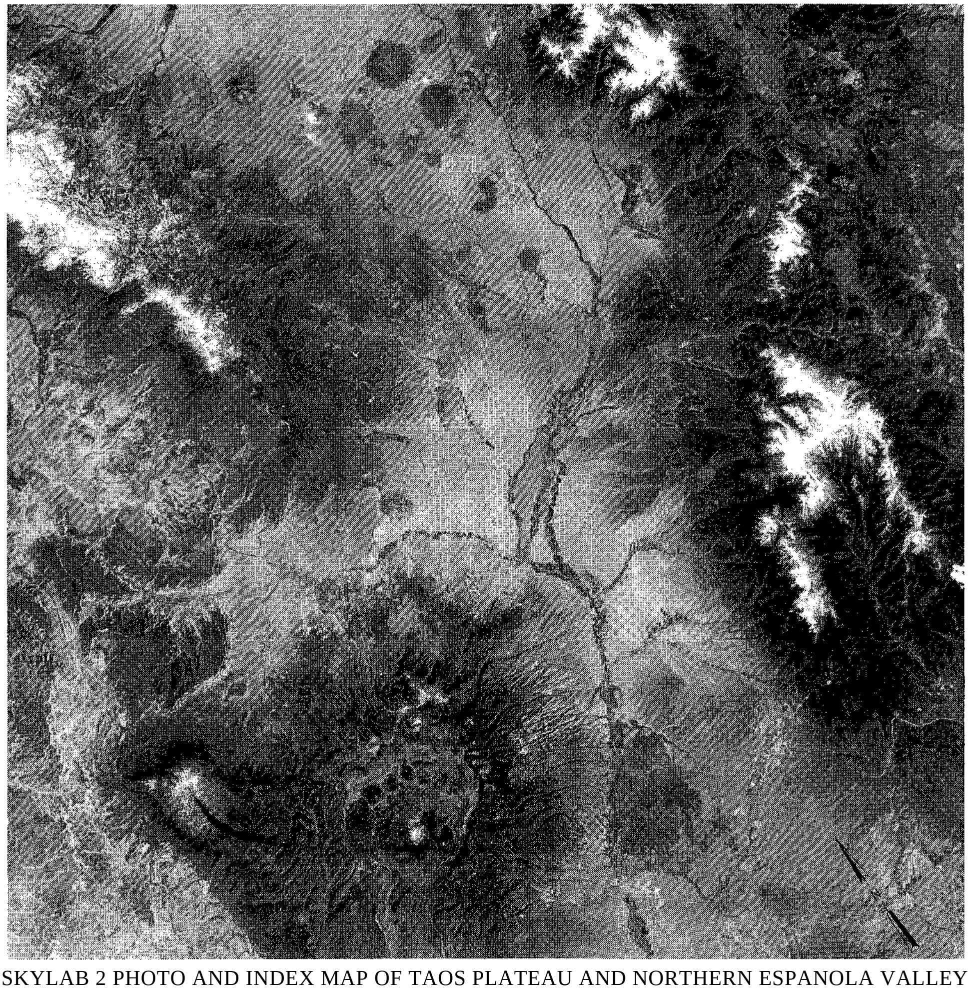
The Rio Grande is in the actively subsiding blocks of both the Taos Plateau and Española Basin. The river lies along the western edge of the Taos Plateau block, probably because rapid erosion of the high Sangre de Cristos built enormous alluvial fans completely across the valley during the early glacial episodes. Today the river has cut a deep trench and cannot meander across the valley as it does in the Española Basin. At the south end of the basin, the river cuts a canyon through the lowest place between the volcanic rocks that poured out from the Jemez Mountains on the west and the Caja del Rio on the east; eventually it flows south into the Albuquerque Basin.

Alpine glaciers and ice caps were the last major forces that sculpted features of the Tusas and Sangre de Cristo Mountains. Features easiest to recognize are the large ridges of glacial debris in the valley north of Chama and the succession of broad alluvial benches that flank the major rivers of the region and mark the melting phases of each glaciation. The thawing of the ground following the retreat of the ice triggered major landslides as the overdeepened valleys began to develop a more stable shape.

Today, snow, rain, rivers, and wind continue their relentless modification of the landscape. Far below the earth's surface, forces continue to deform the crust by slow warping, earthquakes, and plutonic activity.



Buffalo gourd



SKYLAB 2 PHOTO AND INDEX MAP OF TAOS PLATEAU AND NORTHERN ESPANOLA VALLEY REGION; Index map on facing page labels prominent features and trip routes; scale approximately matches index map. (photo SL2-10-020 courtesy of Technology Application Center, University of New Mexico.

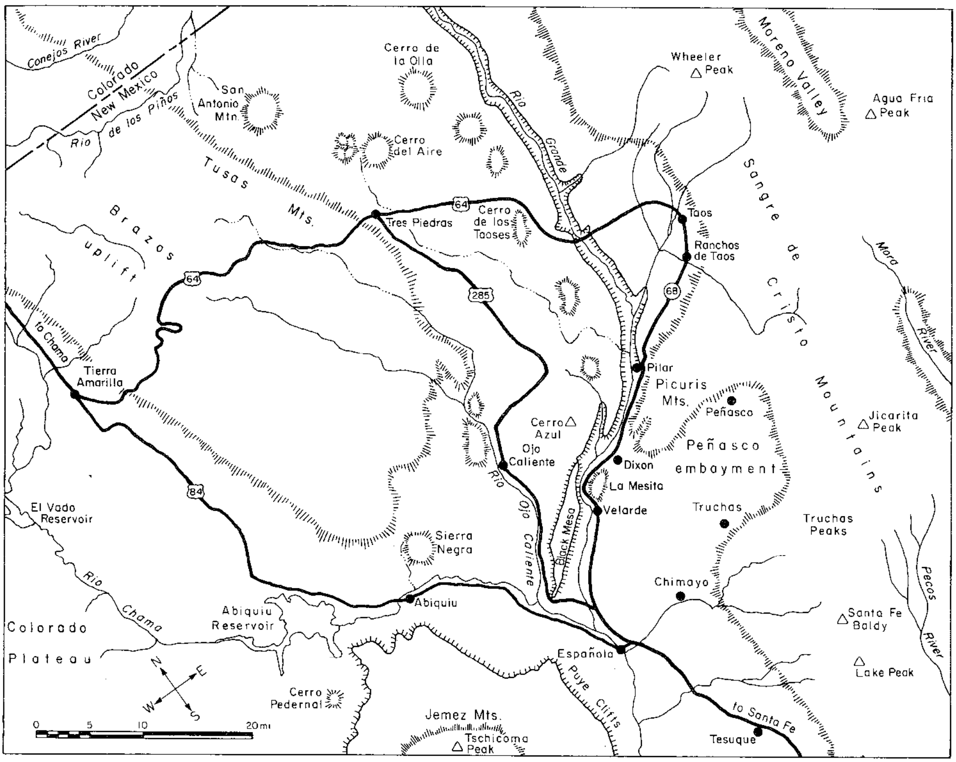
Trip 1
(21 miles)

Santa Fe-Española

This short log describes the southern Espanola Basin and its prominent badland exposures of several units of the Santa Fe Group. Rocks of the Santa Fe Group are part of the filling of the Rio Grande rift; these rocks record the various environments found in closed basins: alluvial fans and plains, lakes, sand dunes, and volcanoes.

Mileage

0.0 From the intersection of St. Francis Drive and Alameda *head north via the truck bypass. After 2.7 mi, the log begins at the divide between the Santa Fe River (south) and Rio Tesuque (north) on US-84- US-285 at the junction with Camino Encantado.* From this point, a panoramic view to the north, east, and south shows the geographic and geologic setting. Ahead is the Espanola Basin, a downdropped block of the Rio Grande rift. The rift comprises a set of fault-bounded valleys that extend southward from Leadville in the San Luis valley of southern Colorado to El Paso, Texas, where the rift turns southeast to Big Bend National Park. Throughout this distance the Rio Grande generally stays in the lowest fault block of each segment.



The Sangre de Cristo Mountains are the upfaulted block to the east (right). The Jemez Mountains lie in the western (left) portion of the basin and the Nacimiento Mountains (hidden by the Jemez Mountains) form the western upthrown block. The Sangre de Cristo Mountains are underlain by 1.4-b.y.-old Precambrian granite that intruded older sedimentary rocks now metamorphosed to quartzite and schist in the high peaks of the Truchas region (2:00). Detailed descriptions of the high Sangre de Cristos are in Scenic Trip No. 6.

Behind us are the Cerrillos Hills, site of early turquoise mining. To the right, mostly obscured by nearby hills, is the Cerros del Rio volcanic field, dated at 2.6 ± 0.2 m.y. (This region is described in Scenic Trip No. 1.) The flat-topped surface at this stop is graded to the volcanic field. This field dammed the ancestral Rio Grande several times and produced temporary lakes upstream until the Rio Grande again eroded through the lava dam and regained its former elevation.

Beyond the Cerrillos Hills on the horizon, the Sandia Mountains form the east margin of the Albuquerque Basin of the Rio Grande rift. (This area is described in Scenic Trip No. 9.)

Santa Fe ("holy faith"), at an elevation of 7,000 ft, is the capital of New Mexico and the oldest European community in the United States west of the Mississippi River. The city was founded as a villa by on Pedro de Peralta in 1610, after Oñate, the first Spanish governor and colonizer, moved his headquarters here. Peralta, instructed to establish a capital for the kingdom of New Mexico, chose an abandoned Tano Indian village site at the edge of the Sangre de Cristos. Until 1680, Santa Fe was the only incorporated Spanish town north of Chihuahua, Mexico. Santa Fe was evacuated on August 21, 1680, when the Pueblo revolt forced Governor Otermin and the colonists to leave. They fled south along the Rio Grande to Guadalupe Mission at El Paso del Norte, the present Ciudad Juarez. In 1692 and 1693 many of the colonists returned with Don Diego de Vargas, the new governor, who occupied the city without warfare. On August 18, 1846, American forces under General S. W. Kearny also occupied the city without firing a shot. Today Santa Fe is a cultural center that has museums, research institutions, and historical monuments which preserve our Indian, Spanish, and pioneer American heritage. (Santa Fe and vicinity are described in detail in Scenic Trip No. 1.) **1.4**

1.4 Junction with road to Tesuque. *Continue on the main highway.* At 11:30, 30 mi away, Black Mesa is capped by 2.8-m.y.-old basalt that marks the oldest known pre-Rio Grande unit in this region. On the road to Los Alamos, the oldest known gravels deposited by the Rio Grande are exposed along the present Rio Grande. These gravels are covered by 2.4-m.y.-old basalts of the Cerros del Rio volcanic field. The beginning of the Rio Grande as a through-flowing river is a recent event in the geological history of this region._

Beyond Black Mesa, forming the distant skyline from 11:00 to 12:00, the Brazos uplift consists of Magote Ridge and the Tusas Mountains. This uplift marks the boundary between the San Juan Basin to the west and the

Rio Grande rift to the east. The gentle eastward tilt into the Taos Plateau is visible even at this distance of 50-60 mi.

We are driving through the type region of the Tesuque Formation (Santa Fe Group), which consists of several thousand feet of arkosic sandstone, siltstone, and minor conglomerate derived from the Sangre de Cristo Mountains. The Santa Fe Group has been divided into several units that represent mainly alluvial fans derived from different regions; the units contain distinctive rock types, minerals, colors, and grain sizes. Where alluvial fans from different source areas coalesced, they produced an interlayering of deposits from both regions until one became the dominant source that controlled all deposition.

Many names of members (sub-divisions) of the Santa Fe Group are used in this book; a chart shows their relationships. **1.8**

3.2 The entrance to the Santa Fe Opera is on the left. The marker states:

> The Santa Fe Opera has become world famous for its summer presentations. With a few exceptions, operas are sung in English. Each season's repertory is divided between recent works and standard operatic favorites. Distinguished artists from the United States and abroad are presented.

Ahead on the right, the mesa surface is graded to the level of the 2.4-m.y.-old Rio Grande. **1.2**

4.4 *Cross bridge over Rio Tesuque.* The Nambé Member (lower Tesuque Formation) is exposed in ridges on the right. **2.0**

6.4 Tesuque Pueblo on the left, settled about 1250 A.D., is the southernmost village of the Tewa-speaking branch of the Pueblo Indians. The pueblo is not large (the 1970 census population was 260), but it has some two-story buildings that show what many small, prehistoric dwellings looked like. Most buildings are adobe and are arranged around a plaza, but some new low-cost housing has been built by the federal government. Most of the men are farmers, although some residents work in Santa Fe and Los Alamos. The annual fiesta and harvest dance are held November 12. **1.4**

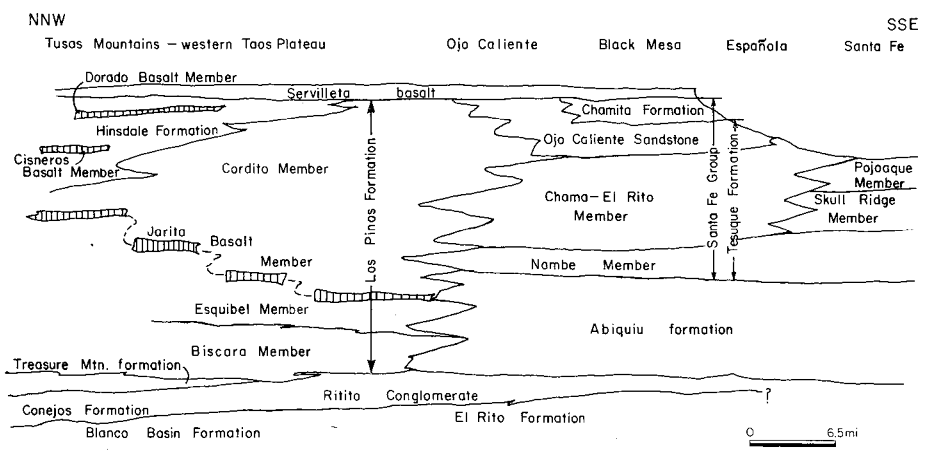


DIAGRAM SHOWING STRATIGRAPHIC RELATIONS OF ROCK UNITS DESCRIBED IN THIS BOOK.

7.8 Camel Rock; a picnic area is beside the highway, and a campground is

ahead on the left. Camel Rock is a result of differential erosion, mainly by rain but also by wind, that removed soft layers more rapidly than hard ones. The top layer (the camel's head) is sand whose grains have been cemented by calcite; lower layers are silt, with only a small amount of cement.

Camel Rock is carved from a few feet of the Skull Ridge Member (Tesuque Formation), a unit approximately 700 ft thick, mainly consisting of sand but also containing clay and conglomerate. The Skull Ridge Member is unique because it contains 37 distinct volcanic ash beds composed of fine, airborne particles of volcanic glass that blanketed the land surface. Later, much of the ash was blown away or was redeposited by streams. The base of the Skull Ridge Member is the prominent ash bed east of the highway. Some of these beds (white layers) are visible in the cliffs and badlands from here northward for the next 10 mi. These distinctive beds are especially helpful in matching beds across faults. Because each bed represents a very short interval of time, the beds are also important for dating the remains of extinct animals found locally. Through many years of excavation in this region, the American Museum of Natural History in New York City has acquired extensive collections of extinct camels, horses, rhinoceros, various carnivores, oreodonts, merycodonts, turtles, and rodents for the Frick Collection. **2.2**

10.0 Cuyamungué (Tewa Indian, "the place where they threw stones"). Pueblo ruins are along the Rio Tesuque bank at 9:00. **0.3**

CAMEL ROCK, mile 7.8, Santa Fe-Española log.

10.3 The highway enters the Pojoaque Indian Reservation. Pojoaque is the Spanish translation of the Tewa Indian name meaning "drinking water place." **1.1**

11.4 Summit. Ahead are the gently west-dipping sandstone cliffs of the upper Skull Ridge Member. Los Alamos is at 10:00 on the mesa at the foot of the Jemez Mountains. **0.6**

12.0 *Enter Pojoaque.* **1.1**

13.1 Junction with NM-4 to San Ildefonso Pueblo, Los Alamos, and Bandelier National Monument. *Keep right on US-84- US-285.* **0.2**

13.3 Junction on right with road to Pojoaque Pueblo. Nothing remains of the original village. The cliffs ahead are in the Pojoaque Member. For the next 5 mi, the route crosses the upper Skull Ridge Member near its contact with the overlying Pojoaque Member. **0.3**

13.6 Junction on right with NM-4 to Nambé Pueblo, Santa Cruz Reservoir, and Chimayo.

The Pueblo of Nambé (from the native name Nambe'e, "pueblo of the mound of earth") is located on the north bank of the Rio Nambé. Nambé dates back to 1300 A.D.; the people speak Tewa. Most men now work in Santa Fe or Los Alamos. Nambé was the first pueblo aided by HUD (Housing and Urban Development Agency), and Headstart and Home-Enrichment programs have been established. Pueblo construction consists of adobe houses around a plaza. The annual fiesta is held October 4.

Left of the highway, ahead, is the Nambé Mills showroom and factory where Nambé ware is produced. An alloy consisting of eight metals is cast into more than 80 beautiful household items, and no two pieces are exactly alike. Nambé ware has the appearance of silver but can be used safely in the oven or broiler. Brass and bronze alloys also have been developed with HUD funds.

Chimayo, site of the original Spanish weaving center of New Mexico, was founded in the early 19th century. The Bazan brothers came from Mexico to instruct the local craftsmen who had supplied the conquistadors. After American occupation, the old craft gradually was discarded but was revived when contemporary artists became interested in native crafts. Weaving again became a highly perfected art, and the crafts-men are producing woven goods of handspun, vegetable-dyed yarn that equals the best of the earlier products in quality. The gaily colored Chimayo blankets have been called the link between the Navajo blankets of New Mexico and the Saltillo blankets of Mexico. **1.1**

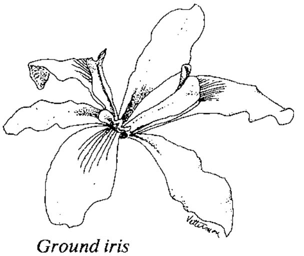
14.7 Low ridges on the left are capped by thick, white volcanic-ash layer. Other layers are exposed in the ridge to the right of the other ridges. 0.3 15.0 An ash bed is visible in the cliff on the left. The high mountain at 3:00 is Truchas Peak (13,101 ft). **0.8**

15.8 Crossing the divide between Arroyo Seco (ahead) and the Rio Pojoaque. **1.3**

17.1 The Three Sisters Buttes are the low hills at 1:00, approximately 1 mi away. A white ash bed forms a prominent collar on the left Sister and two thin bands on the center Sister. The right Sister is hidden from view. **1.4**

18.5 Crossing the valley of the Arroyo Seco. Badlands ahead are cut in the Pojoaque Member. **0.5**
19.0 State Police Headquarters, District No. 7, on the left. **0.7**
19.7 Junction on right with NM-106. **0.3**
20.0 Junction on left with NM-399 to La Mesilla. **0.2**
20.2 High roadcut in sands and silts of Pojoaque Member (Tesuque Formation). **0.5**
20.7 *Enter Espanola. Heavy traffic! Turn left at the highway junction ahead.* **0.4**
21.1 *Second traffic light; move into left lane to turn left. Continue on US-84-US-285.* The road straight ahead is NM-68 to Taos.

Log continues in the Española-Abiquiu-Chama segment.



Ground iris

Española-Abiquiu-Chama

Our route crosses the northwest segment of the Española Basin. As we pass the tip of Black Mesa a few miles north of Española, we cross the Embudo fault zone, a major transverse feature of the Rio Grande rift. Continuing deformation of the fault zone is shown by the broad, slow subsidence of elevation markers along the highway.

As we travel to the western edge of the Española Basin, we cross many faults that step up structurally through progressively older rocks, until we climb out of the Rio Grande rift and onto the Colorado Plateau. At this point, the highway cuts through nearly flat-lying Permian, Triassic, Jurassic, and Cretaceous rocks. Cliff exposures allow us to see all the geologic changes in this region during a 100-m.y. interval. The scenery is magnificent as we climb to the rolling forested segment of the Chama Basin.

The road remains near the axis of the Chama Basin as far as Chama. As we travel north, the structures that separate the Chama Basin from the San Juan Basin form the western skyline. Along the eastern horizon, the upturned margin of the Chama Basin is capped by young rocks that now tilt gently eastward into the Rio Grande rift.

Mileage

0.0 *Follow US-84-US-285 west from where it separates from NM-68.* Española (5,600 ft) is on the west bank of the Rio Grande and is a shipping point for fruit, stock, and other farm products. **0.3**

0.3 *Cross the Rio Grande.* **0.4**

0.7 Junction on left with NM-30 to Santa Clara Pueblo, Puyé, Los Alamos, and Bandelier National Monument. *Keep right on US-84-US-285.* **0.4**

1.1 Climbing onto the Pleistocene river level. Ahead is the south tip of the basalt-capped Black Mesa. **0.8**

1.9 The road on the right is the truck bypass of US-84-US-285 to Fairview. View of Sangre de Cristo Mountains is on the right. **0.8**

2.7 Historic marker:

> Oñate's Route, 1598-1605. Don Juan de Oñate colonizer of New Mexico, traversed this area on his numerous exploring trips from San Gabriel, first capital of this northernmost Spanish province which he founded in 1598. His explorations took him east to the plains of Kansas and west to the mouth of the Colorado River.

Roadcuts are in the Santa Fe Group capped with a river-gravel terrace. **0.5**

3.2 Roadcut in alternating coarse gravel (main river channel) and sand (floodplain deposits), deposits from an earlier Rio Grande. **0.2**

3.4 From 11:30 to 1:30 is Black Mesa; at 1:30, the Rio Grande Canyon; 1:30 to 2:00, La Mesita; at 2:30 are the Picuris Mountains; and behind on the distant skyline are the Sangre de Cristo Mountains near Taos.

Black Mesa and La Mesita, capped by 2.8-m.y.-old basalt, are the southernmost extensions of that part of the Taos Plateau covered by basalts and other volcanic rocks. This basalt marks the last known volcanic event prior to initiation of the Rio Grande as a through-flowing river in this region. Before that time, the basins composing the Rio Grande rift were separate, closed drainage basins. The Chamita Formation, youngest unit of the Santa Fe Group, is preserved under the southern end of Black Mesa and in the hills (at 12:30) in the foreground.

Near the foot of Black Mesa, at 1:00, is the site of San Gabriel del Yunque, the Spanish capital established in 1598 by Oñate. It remained the capital until Santa Fe was so designated in 1610. San Juan de los Caballeros was the name of the pueblo on the east bank of the Rio Grande where the Indians had moved. **2.0**

5.4 On the left, the Santa Fe Group is exposed in the bluffs with a river-gravel cap. **1.5**

6.9 The routes divide; US-285 goes to the right. *Continue ahead on US-84 north.*

At 12:00, the ridge through the gap is part of the Santa Fe Group, cemented by chemicals in ground water passing through a major fault zone. This fault is one of many north-trending faults in the valley ahead, and it places the Chama-El Rito Member (near face) against the Ojo Caliente Sandstone Member (opposite face). Approximately 4 mi away on the left, diatomaceous earth has been quarried; it is used mainly for filters.

For the next several miles the region ahead is subsiding gradually, as has been shown by the resurveying of highway elevation markers. The subsidence zone appears to coincide with the Embudo fault zone. That this subsidence has continued for millions of years is indicated by the wedge of the Chamita Formation (the youngest pre-basalt unit) under the basalt cap of Black Mesa and by the tilt of the mesa toward the fault zone. **1.2**

8.1 The bluffs on the right expose Ojo Caliente Sandstone and a thin veneer of Chamita Formation under Black Mesa basalt of the Servilleta Formation. **0.8**

8.9 Roadcuts show a basalt flow interbedded in the Ojo Caliente Sandstone Member (Santa Fe Group). **0.6**

9.5 *Enter Village of Chili.* At 3:00, the Rio Ojo Caliente joins the Rio Chama. **0.5**

10.0 *Cross bridge over Rio del Oso* ("bear river"). The bluffs at 3:00 are cemented and faulted Ojo Caliente Sandstone Member (Santa Fe Group). **1.0**

11.0 At 12:00, Sierra Negra Mesa (8,052 ft) has a thin basalt cap at the right end; the mesa is an outlier from the Jemez Mountain volcanic field. The main slopes of the mesa to the right are in the Chama-El Rito Member and are in fault contact with white Abiquiu Tuff on the left. The ridge on the skyline at 1:00 is Magote Ridge. **3.1**

14.1 On the skyline at 1:00, red Permian and Triassic rocks lie beyond the western edge of the Rio Grande rift. These cliffs are the most southeasterly exposures of the Colorado Plateau units that cover the Four Corners region.

Our route now crosses some faults that step up to the west and expose progressively older rocks until the route climbs onto the Chama Basin segment of the Colorado Plateau ahead.

Behind Sierra Negra at 1:30, Magote Ridge is capped by Mesozoic and early Tertiary rocks. At 2:00 the east-tilting mesa is capped by clastic rocks of Los Pinos Formation (mid-Tertiary). These rocks are part of the initial filling of the Espanola Basin that was derived from the San Juan Mountains, far to the northwest. At 2:30 the Ortega Mountains, composed of Precambrian quartzite, jut up to the skyline.

The pink badlands to our right are in the Chama-El Rito Member. Several stream-terrace surfaces form prominent grass-covered mesas when viewed from above. **0.3**

14.4 The gravel cap of Espanola Formation is at 9:00. **1.5**

15.9 At 9:00 is the Lobato Basalt cap of the mesa. Ahead are bluffs of Ojo Caliente Sandstone. **1.2**

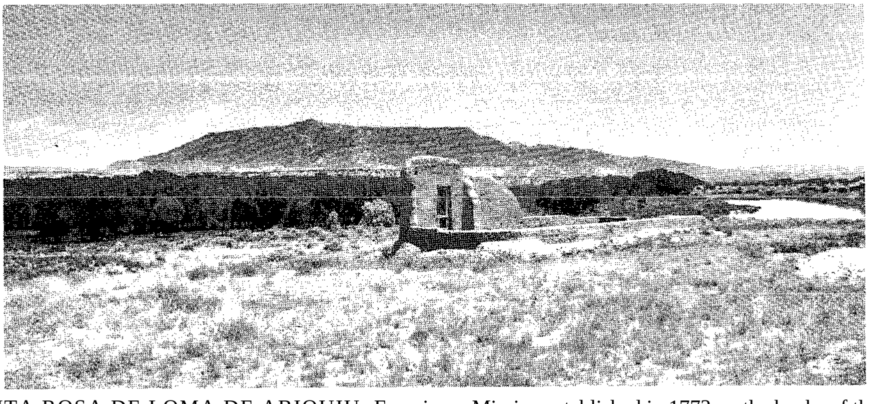
17.1 At 12:30, on the lower left slopes of the Sierra Negra, are ribbed bluffs of the Abiquiu formation, faulted against the Chama-El Rito Member (red-dish) on the lower right slopes. **2.3**

19.4 Junction on right with NM-96 to El Rito. **1.3**

20.7 At 4:00, major faults bring the Abiquiu formation on the left against the Chama-El Rito Member on the right in segments of the bluffs below Sierra Negra. **0.8**

21.5 The ruins of Santa Rosa de Loma de Abiquiu, a Franciscan mission established in 1773, are approximately $1^1/4$ mi east of the present town of Abiquiu. The ruins are the site of the original town, established by 20 Spanish families in 1744. The permanent settlement of modern Abiquiu, made in 1754, was the site of a chapel built prior to that date.

On July 29, 1776, leading an expedition of 10 friars, Fathers Dominguez and Escalante left Santa Fe and headed for Monterey, capital of California. They stayed at Abiquiu for a day on their way to the present site of Ghost Ranch, approximately 17 mi away. They had hoped to open a route through the mountains to the northwest that would provide access to the newly opened California missions. After reaching Utah Lake and Great Salt Lake, they turned back because of bad weather and geographical barriers. Escalante's journal and the maps of the expedition were extraordinary, and they proved later to be of great historical significance. This route was the forerunner of the famous Spanish Trail. **0.2**



SANTA ROSA DE LOMA DE ABIQUIU, Franciscan Mission established in 1773 on the banks of the Rio Chama (mile 21.5, Española-Abiquiu-Chama log); Sierra Negra on skyline.

21.7 Picnic tables. At 11:00, Lobato Basalt cap lies on Ojo Caliente Sandstone.

At 3:00, the northwest rim of the Espanola Basin is marked by white Abiquiu Tuff in cliffs at the far side of the valley. The tuff is downfaulted into the Rio Grande rift against the red Permian-Triassic beds (the lightly forested hills on the skyline) of the Colorado Plateau. **0.4**

22.1 Lobato Basalt caps Ojo Caliente Sandstone at 12:00. At 1:00 is a fault zone in Ojo Caliente Sandstone. **1.0**

23.1 The main town and plaza of Abiquiu are on the mesa to the left. Historic marker:

> Abiquiu, established on the site of an abandoned Indian pueblo. Abiquiu in the mid-eighteenth century became a settlement of genizaros, captives ransomed by the Spaniards from the Comanche and Apache Indians. In 1830 the settlement became one of the stops on the Spanish Trail, which linked Santa Fe with Los Angeles, California.

The church, begun by Fray Toledo in 1755, was not completed until the 1770's. The people spoke Spanish and were non-Pueblo Indians who lived in the Spanish manner. Pottery, found during the excavation of the ruins of an old Indian pueblo, included such a wide variety of pre-Spanish types that the pottery may indicate the custom of an annual multitribal fair at Abiquiu, carried over from early Indian times. Such a fair was first mentioned by Father Dominguez in 1776.

In later years Abiquiu was the final outfitting point for trappers, traders, and settlers going to the northwest wilderness. In 1846 Abiquiu became an outpost for a section of General Kearny's forces which conducted military explorations. **0.4**

23.5 We can see that the fault at 3:00 placed Abiquiu Tuff (white) up against the Ojo Caliente Sandstone (buff). **0.9**

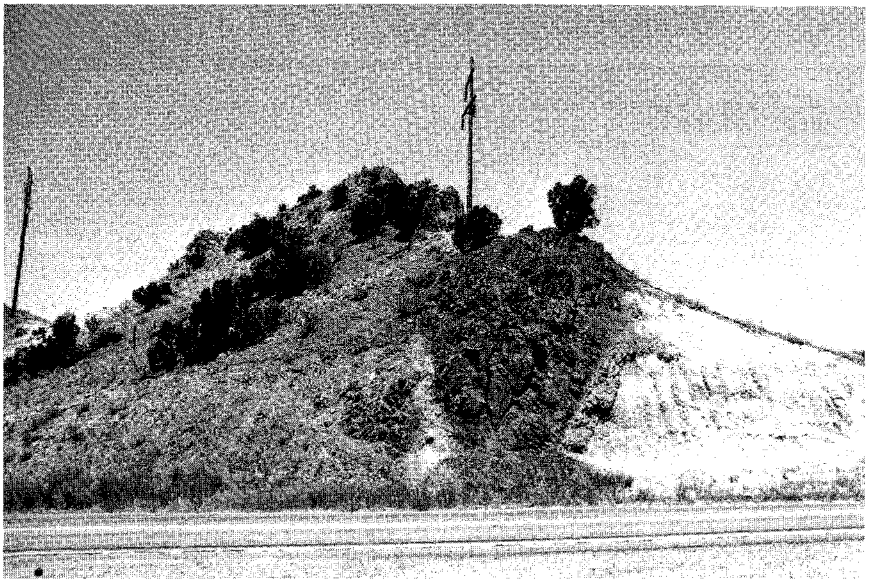
24.4 At 1:00, a black basalt dike forms part of a ridge of Abiquiu Tuff. The ridge is resistant to weathering because it was baked when the basalt intruded as a molten rock with a temperature near 1,200°C. At 9:00, a dike weathered reddish-black holds up another ridge of white Abiquiu Tuff. **0.6**

25.0 Dike in roadcut on the right. Metamorphosed (baked) 2-ft-thick Abiquiu Tuff is well exposed to the right of the dike. Banding in the dike is a result of flow while cooling, and fracturing parallel to the contact during cooling. **0.1**

25.1 At 3:00, the red beds are in the Ritito Conglomerate that overlies the El Rito Formation (basal Tertiary unit). These red beds are the oldest Tertiary units exposed in this region; they lie unconformably across the eroded edges of the older rocks rimming the Laramide structures of the Chama Basin. The units predate the Rio Grande rift and are probably middle to late Eocene. A dike can be seen in fault contact. **1.5**

26.6 Visible from 12:00 to 2:30, massive sandstones, mainly river-channel sands, are the lowest unit in the Chinle Formation (Triassic). They are underlain by purplish to brick-red muds and sands of the Cutler Formation (Permian). Up the arroyo at 3:00, Jurassic sandstones dip west against the main border fault of the Rio Grande rift.

Cerro Pelon at 9:00 is capped by late basalts that flowed down to an



BASALTIC DIKE CUTTING ABIQUIU TUFF; well-developed baked zone along right margin (mile 25.0, Española-Abiquiu-Chama log).

earlier level of the Rio Chama and by the Tschicoma Formation (intermediate-composition lavas). **0.4**

27.0 Roadcuts on the right show Abiquiu Tuff (Tertiary) unconformably lying on red El Rito Formation, which in turn unconformably overlies Entrada Sandstone (Jurassic). **0.3**

27.3 Crossing the western border fault of the Rio Grande rift, we enter the Chama Basin segment of the Colorado Plateau. **0.1**

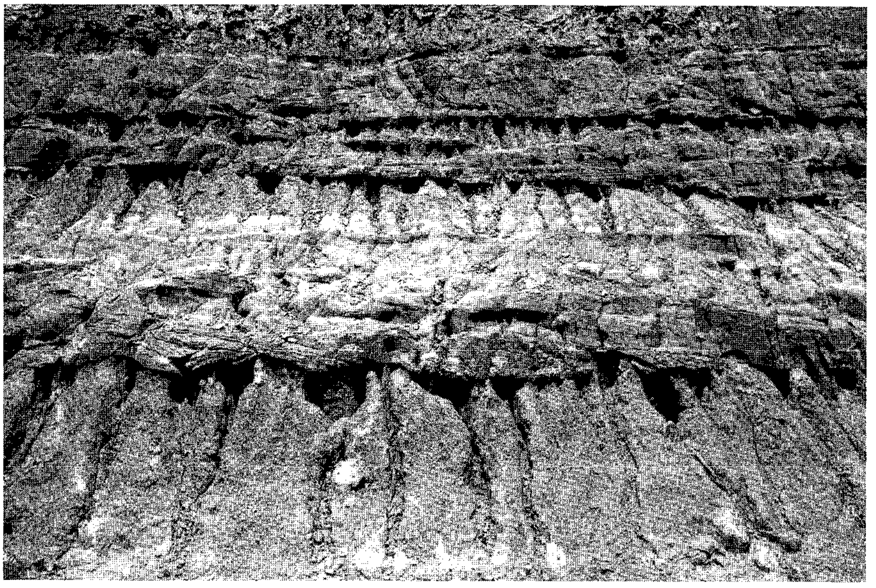
27.4 The ribbed cliff is composed of Cutler sandstone (lower Permian) and mudstone. Crossbedded stream-channel sands are well exposed in the roadcut opposite milepost 287.

The massive, buff cliff at the top is basal, channel sand of the Chinle Formation (upper Triassic). Between these two river-system deposits is a major time gap (unconformity), but the two units have approximately the same attitude (dip) in this region.

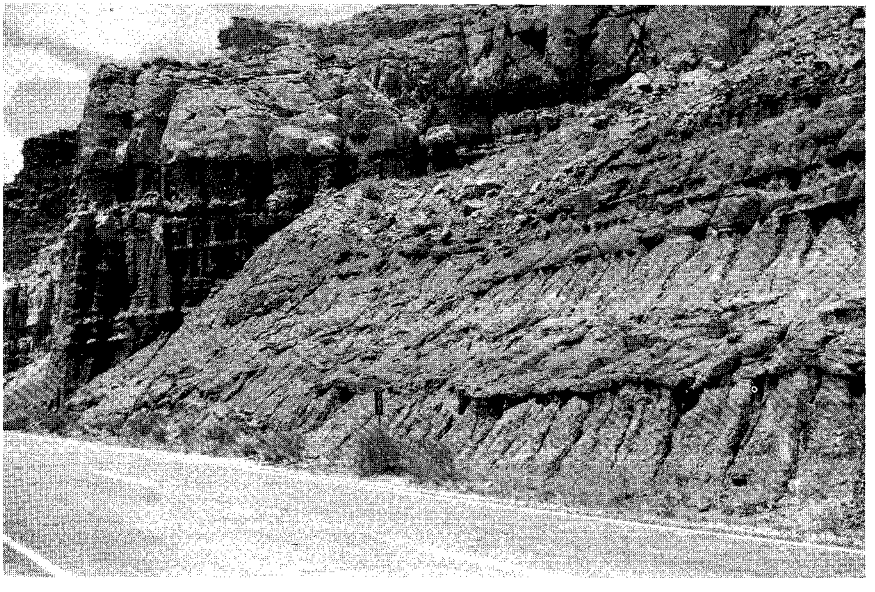
The change from broad, sluggish streams of the lower Permian to steeper (but still low) gradients of the upper Triassic was caused by gradual uplift of the area to the north and northeast. The streams of the Cutler Formation (Permian) meandered south and southeast toward the Permian Basin of west Texas. In contrast, the streams of the Chinle Formation (Triassic) flowed southwest on higher gradients as is indicated by the larger channels and coarser deposits in the Chinle. **0.2**

27.6 From 9:00 to 10:30, the trace of the border faults can be distinguished by the changes in color and rock type seen on ridges or slopes on opposite sides of the faults.

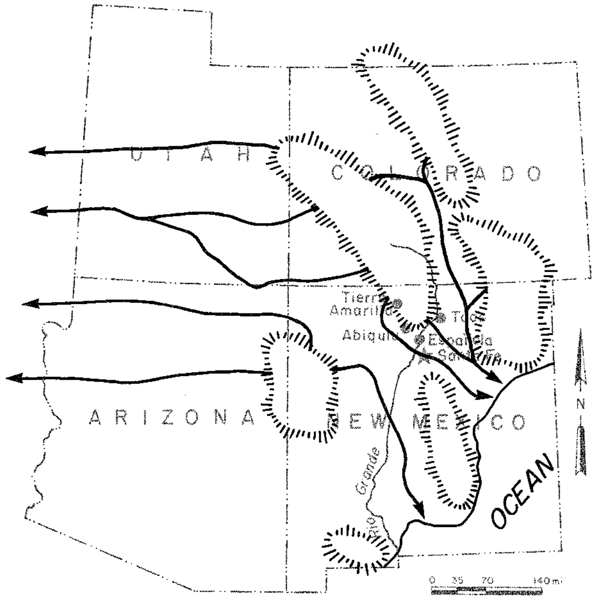
The skyline cap of basalt is not faulted; therefore, the last movement of this fault is older than the Lobato Basalt. Elsewhere, other branches of this



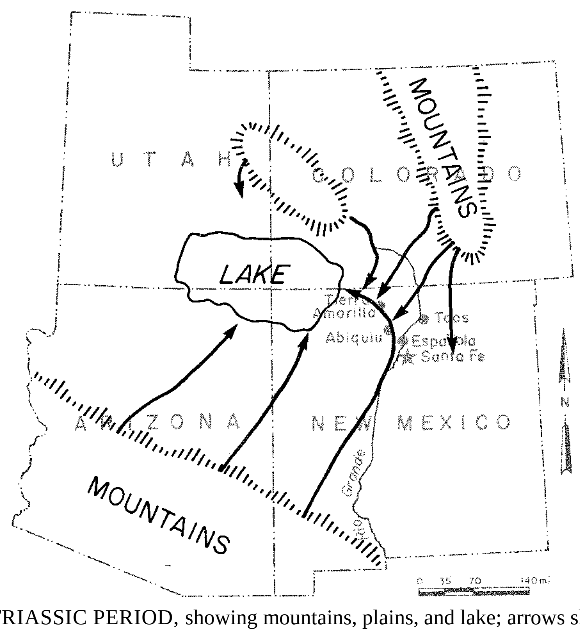
CUTLER FORMATION (PERMIAN) STREAM DEPOSITS; characteristic sequence (repeated several times) of crossbedded, coarse-grained stream-channel deposits. The deposits, cut downward into an earlier cycle, grade upward into finer grained channel fill and overbank floodplain deposits (mile 27.7, Española-Abiquiu-Chama log).



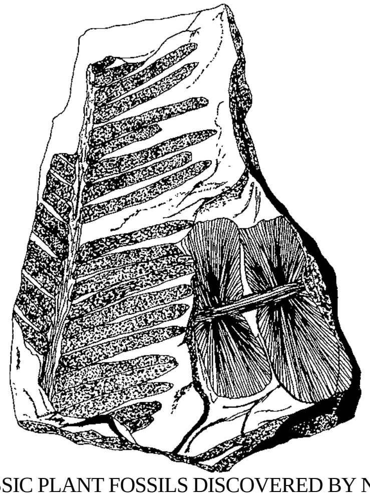
MASSIVE, CLIFF-FORMING, TRIASSIC STREAM-CHANNEL DEPOSITS resting unconformably on Permian floodplain and more sluggish meandering stream-channel deposits (mile 27.7, Española-Abiquiu-Chama log).



BEGINNING OF PERMIAN PERIOD, showing mountains (hachured), plains, and ocean; arrows show directions of river drainages.



UPPER TRIASSIC PERIOD, showing mountains, plains, and lake; arrows show directions of river drainages



UPPER TRIASSIC PLANT FOSSILS DISCOVERED BY NEWBERRY (1876) IN CANON DE COBRE, ABOUT 4 MI NORTH OF US-84; APPROXIMATELY 1/2 NATURAL SIZE.

border fault zone offset the basalt cap as well as younger units visible from here. However, the 1.1-m.y.-old Bandelier Tuff, a product of the climax eruption from the Valles caldera, is not faulted. 0.1

27.7 Purplish Cutler Formation is faulted against the reddish Chinle Formation (Triassic) ahead. The Rio Chama flows in the canyon on the left. 0.5 28.2 Picnic tables on the right. At 9:00 yellow, white, and red sands of the Entrada Sandstone are downfaulted to the left. The Lobato Basalt cap of Cañones Mesa is not offset by the fault.

The canyon of the Rio Chama at 9:30, as well as hills ahead to the right, are in a lower unit dominated by river-channel sandstones of the Agua Zarca Sandstone Member (Chinle Formation). 0.5

28.7 The roadcut in river-channel sands is in the Chinle Formation. 1.0

29.7 Junction on the left with NM-96; 2 mi to Abiquiu Dam, which has boating, picnicking, and camping facilities. The earth-fill dam is in the Agua Zarca Sandstone Member. Ahead and to the left, a broad, flat valley is eroded into the Chinle Formation. The lower sandstones form the floor of the valley. At 9:00, Cerro Pedernal (9,862 ft) is capped by basalt. The smooth skyline ridge at 10:00 is underlain by Precambrian granite of the Nacimiento Mountains. This smooth surface was cut by an advancing shoreline in Pennsylvanian time and has been reexposed to erosion only .recently. At 11:00, the valley of the Rio Chama and the Abiquiu Reservoir are visible in the middle distance.

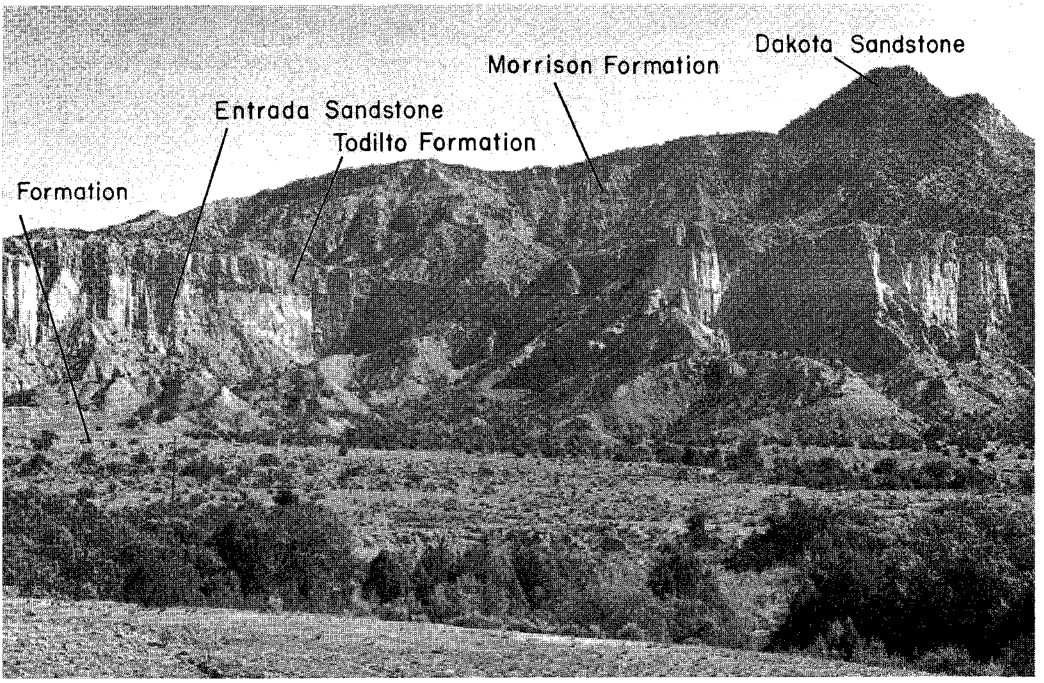
From 10:00 to 2:00 are the following rock units (in descending order):

Cretaceous—DAKOTA SANDSTONE: tree-covered cliffs

Jurassic MORRISON FORMATION: mostly debris-covered slopes of sands and red-purple muds

TODILTO FORMATION: grayish-white gypsum and thin limestone at base; cap of lower cliff

ENTRADA SANDSTONE: yellow, white, and red sand of windblown origin; cliff former



MESOZOIC SECTION SOUTHEAST OF ECHO AMPHITHEATER; view to northeast from mile 39, Española-Abiquiu-Chama log.

Triassic— CHINLE FORMATION: varicolored muds forming badlands and valley surface, grading down to the channel sands we just crossed. **0.4**

30.1 Roadcut is in the Chinle Formation, composed of red muds and sand-stones. 2.1

32.2 Cliffs ahead are composed of Entrada Sandstone (ancient sand dunes) with purplish Chinle clays at the base. At 2:00 is Comanche Canyon, with exposures of Entrada Sandstone and distant, capping cliffs of Dakota Sandstone. Sands of the Chinle Formation at 3:00 dip gently to the west into the Chama Basin, the broad valley to the left. **2.3**

34.5 Picnic table at left. Ahead, the multicolored clays of the Chinle Formation are the same clays as those exposed in the Painted Desert near Petrified Forest National Monument, Arizona.

At 9:00 is Cerro Pedernal ("flint mountain"). On the west (right) flank are flint deposits that were the main source of arrowheads and axes for the Indians of this region. One of the first mineral deposits worked by early man in North America is on the western slopes of Cerro Pedernal. The chert (flint) ranges from white to pearly gray with local tints or spots of pink, red, and yellow. Artifacts of this chert have been found hundreds of miles away and date from 10,000 to 11,000 years ago (earliest human occupation in New Mexico) to the 20th century. The mountain contains evidence of quarries, workshops, and camps of many Pueblo Indians. The

quarries are generally small, horizontal cuts into the face of chert beds ranging from 10 to 20 ft thick. Erosion has blurred the actual Indian quarrying sites, but notched tools, axes, hammerstones, and blocks are off-site evidence of man's use of the quarries. Campsites and finishing shops were found on soil-covered knolls of structural and alluvial terraces. Three miles east is the 14th-century defensive pueblo of Tsiping ("flaking stone mountain").

This unique chert bed, nearly 5 ft thick in the lowest part of the Abiquiu Tuff, is a geological rarity and enigma. Usually chert occurs in elongate globs a few inches to a few feet long and an inch to a few inches thick. How this bed formed is still being debated by geologists. The obsidian frequently found with the Pedernal chert beds had its source south of here on Polvadera Peak.

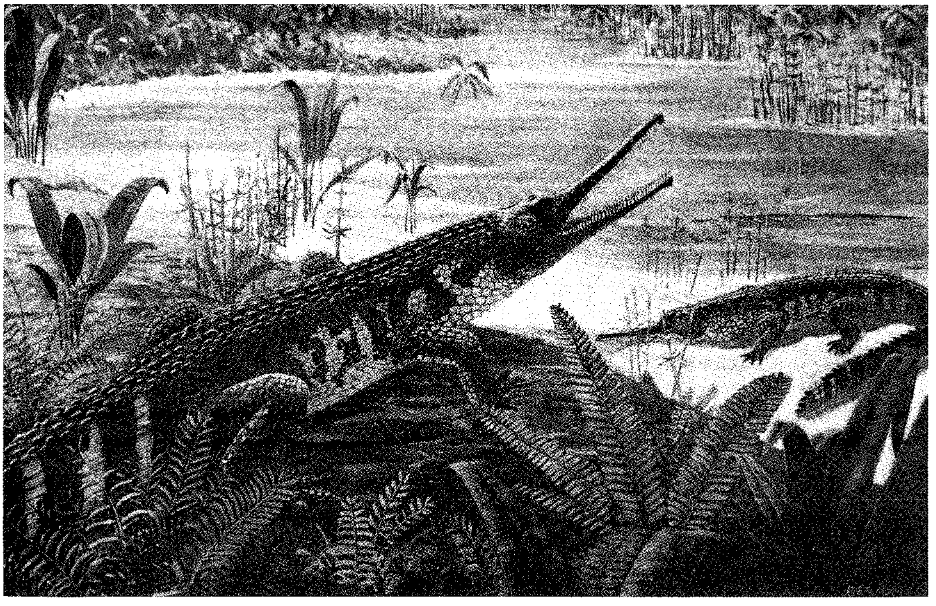
At 2:30, jagged points on the cliff edge in the Entrada Sandstone are caused by erosion along the fractures. **1.5**

36.0 Junction on right with road to Ghost Ranch, a program center of the United Presbyterian Church. Badlands at the base of the bluffs on the right have yielded a large number of Triassic vertebrate fossils. **1.6**

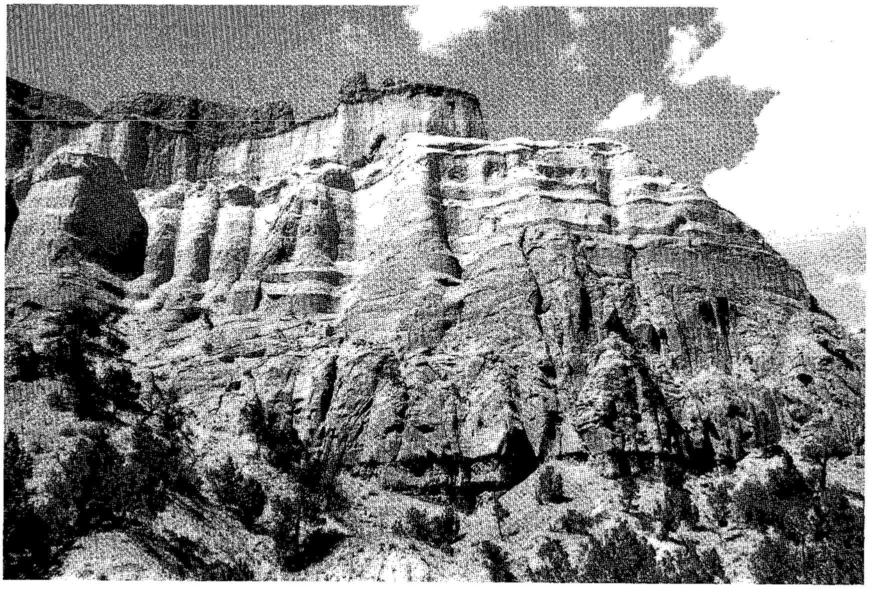
37.6 The Carson National Forest-Ghost Ranch Visitor Center features an outdoor exhibit of native plants and animals. Bluffs to the right expose all rock units from the Chinle Formation up to the capping Dakota Sandstone. **1.6** .

39.2 At 10:00 are well-developed arches in the base of the Entrada Sandstone cliff. **1.0**

40.2 Echo Amphitheater. Cliffs rimming the amphitheater beautifully display the broad crossbedding of dune sand and the horizontal layering of fossil



REPRODUCTION OF THE TRIASSIC PHYTOSAUR, **RUTIODON**, WHICH ONCE LIVED IN THE GHOST RANCH AREA
(American Museum of Natural History).



ENTRADA SANDSTONE CLIFFS AT ECHO AMPHITHEATER; red Chinle Formation muds at base, with grayish-white gypsum and thin, black limestone at base of capping Todilto Formation; mile 40.2, Española-Abiquiu-Chama log.

water tables (upper pink, white, and yellow cliffs). The capping, grayish-white Todilto Formation is gypsum deposited from a lake that evaporated. At the base is a very thin, dark-gray limestone that sometimes preserves skeletons of herring-sized fish.

This amphitheater was formed by the normally dry waterfall above scouring a plunge pool; also, the gradual seepage of ground water dissolved cement between sand grains in the base of the Entrada Sandstone that overlies the impermeable Chinle clays. Dissolution by ground water is common where these cliffs become oversteepened, and large natural arches form as the sandstone under the arch collapses. **0.5**

40.7 From 12:00 to 1:00, a cliff of Entrada Sandstone is capped by Todilto gypsum. Well-exposed alternating bands of parallel and crossbedded sands can be seen. Dakota Sandstone is on the high skyline. **1.3**

42.0 Cliffs on the left show exceptionally thick grayish-white gypsum of Todilto Formation. **1.2**

43.2 Martinez Canyon to the right; cliffs of Dakota Sandstone are on the skyline. Morrison Formation purplish clays are exposed in slopes on the right for the next half mile. **0.9**

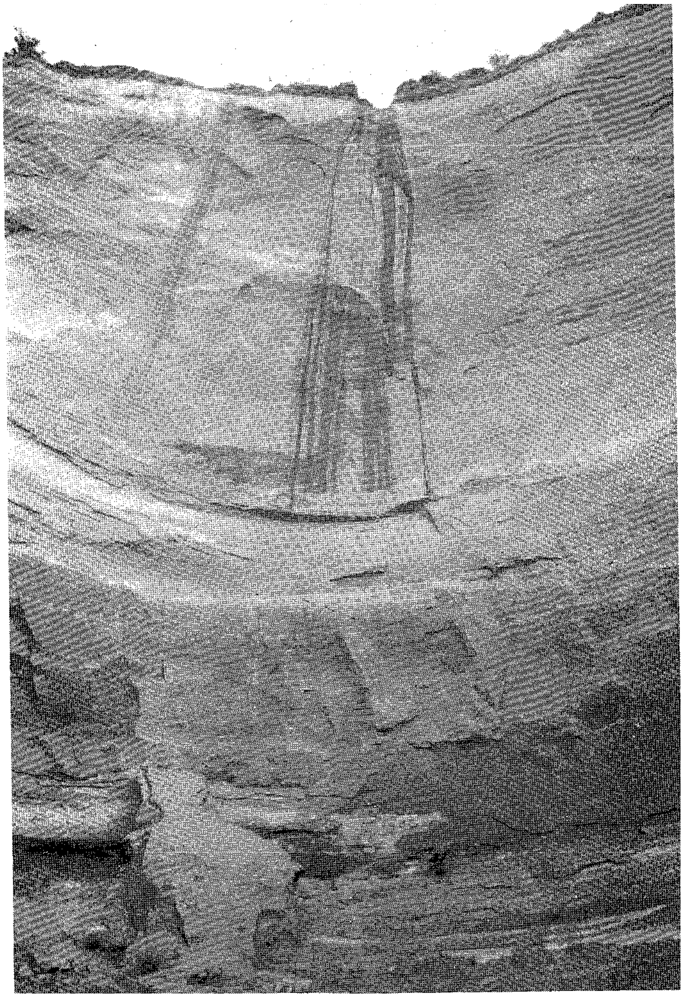
44.1 Cliffs of Dakota Sandstone are between 9:00 and 1:00 on the skyline. **1.0**

45.1 Cliffs of Dakota Sandstone are at 1:00. **0.4**

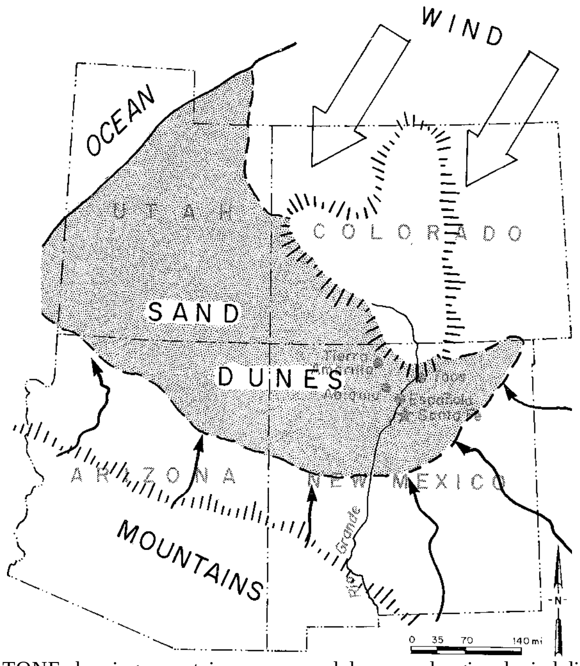
45.5 Roadcut on the left in the upper Morrison Formation displays interbedded sandstones and purplish and green muds that are floodplain deposits. **0.2**

45.7 The roadcut on the left-is in the Burro Canyon Formation. Major stream channels and point-bar, crossbedded sands are well exposed. **0.4**

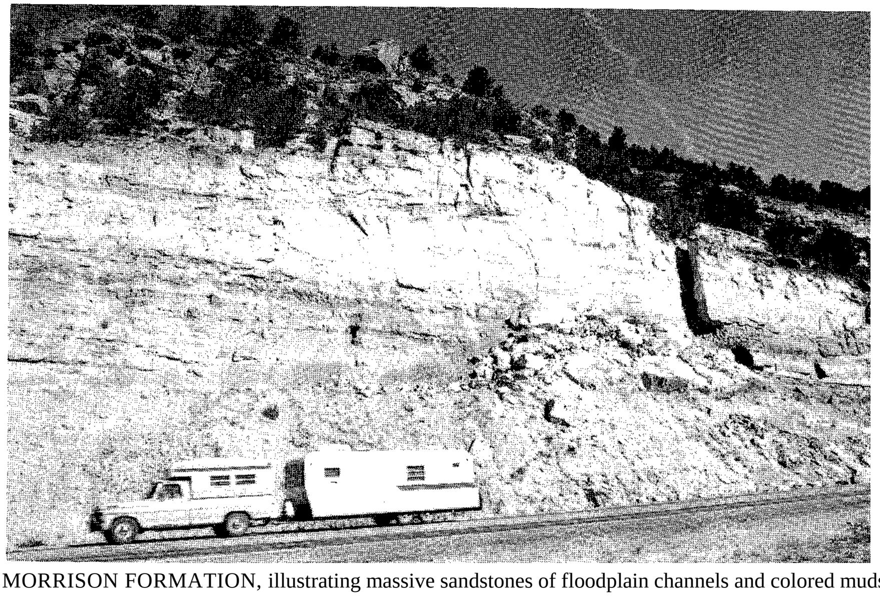
46.1 Roadcut on the left exposes the contact of Dakota Formation with the underlying Burro Canyon Formation. Channels are well exposed at the up-



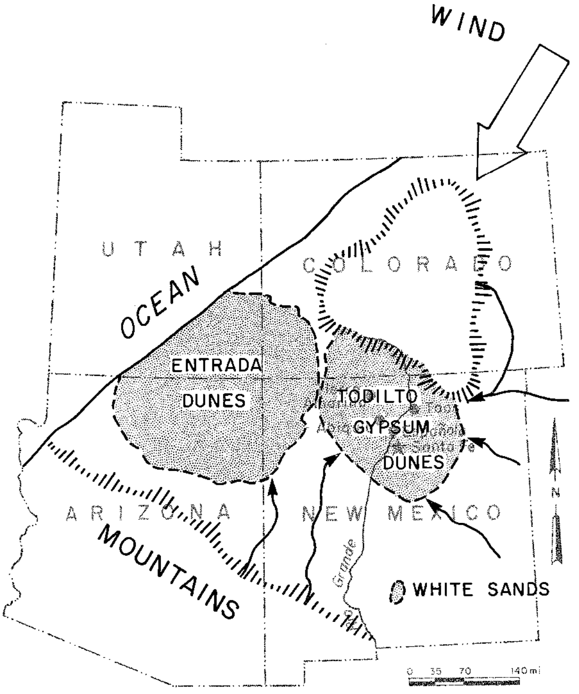
DRY WATERFALL AT ECHO AMPHITHEATER; Mile 40.2, Española-Abiquiu-Chama



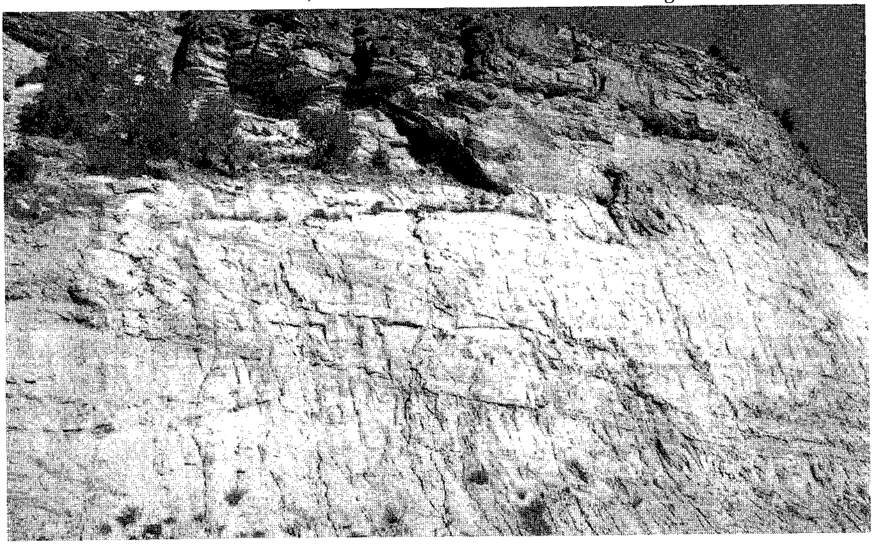
ENTRADA SANDSTONE showing mountains, ocean sand dunes, and regional wind direction; black arrows denote directions of flowing rivers.



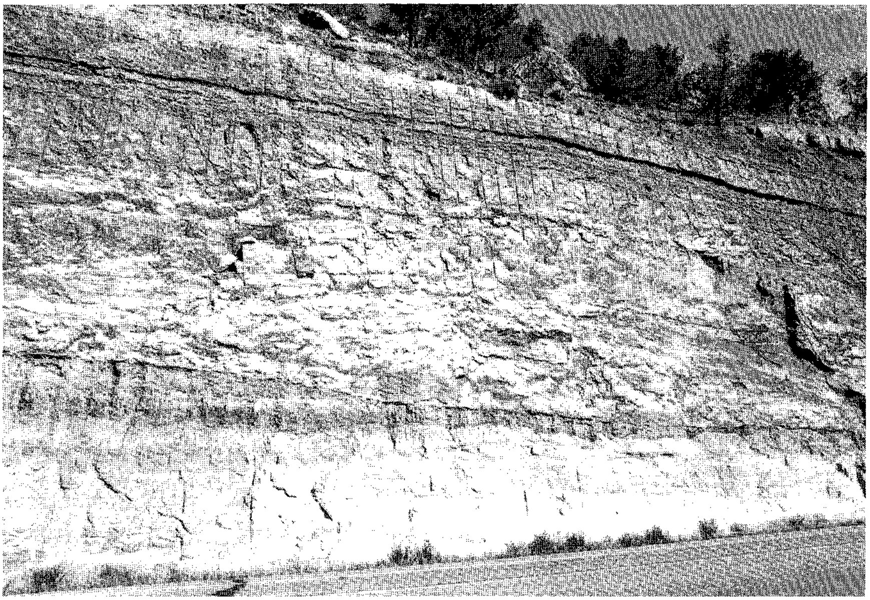
MORRISON FORMATION, illustrating massive sandstones of floodplain channels and colored muds of overbank floodplain deposits.



TODILTO GYPSUM DUNE FIELD COMPARED TO THE MODERN COUNTERPART AT WHITE SANDS NATIONAL MONUMENT; black arrows denote directions of flowing rivers.



SPECTACULAR DISPLAY OF FLOODPLAIN CHANNEL DEPOSITS OF BURRO CANYON FORMATION. Whether or not these beds represent the notheasternmost Burro Canyon Formation is unknown.



BURRO CANYON FORMATION TRUNCATED BY THE OVERLYING DAKOTA FORMATION:
mile 46.1, Española-Abiquiu-Chama log.

46.3 Carbonaceous sands and muds of middle Dakota Formation are exposed. Thin coals are present locally. **0.5**

46.8 On the cliff top to the left are parallel-bedded sandstones of beach fancies of the Dakota Formation. These sandstones represent the first marine rocks of this tour. Ahead, the vista opens onto sagebrush-covered plains cut in the marine Mancos Shale. **0.4**

47.2 *Watch for narrowing pavement.* Gray, barren, clay slopes ahead and to the right change upward into weathered, yellow clay in the Mancos Shale. **2.2**

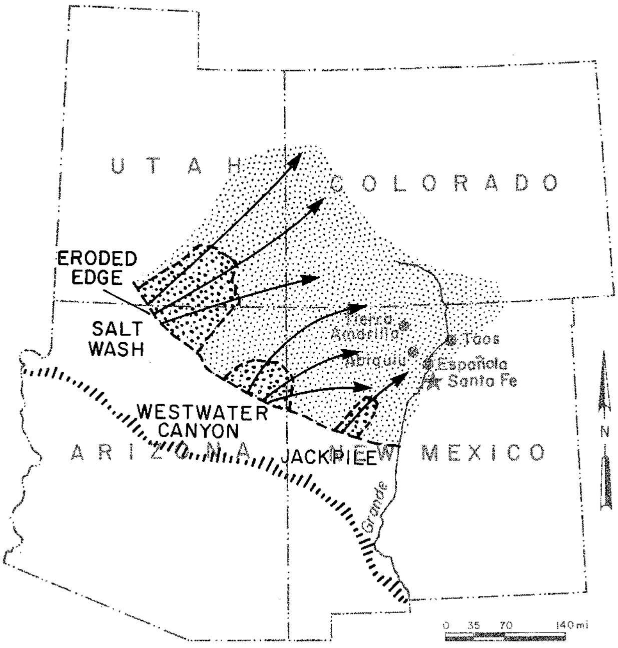
49.4 Ahead, cliffs of Mesaverde sandstone dip westward (away from us) into the San Juan Basin. These cliffs mark the edge of the monocline that forms the eastern and northern rim of the basin. The rim extends as far west as Durango, Colorado, and Mesa Verde National Park, Colorado.

At 11:00 is Gallina Mountain, a faulted anticline that exposes yellow, white, and red Entrada Sandstone on the upper side of the fault. The fault dies out where the Entrada cliff plunges toward the north. **1.9**

51.3 Junction on right with NM-119 to Canjilon and Canjilon Lakes. We pass through piñon and juniper forests with meadows of sagebrush and grass. **1.9**

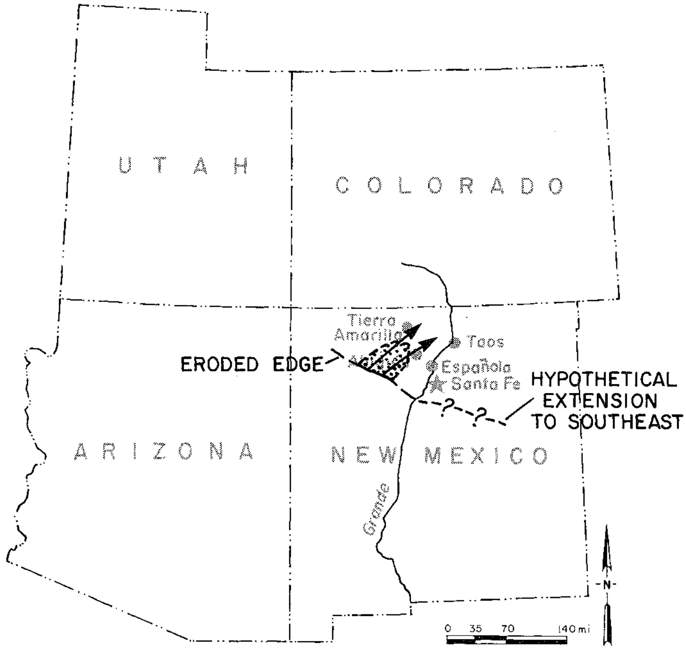
53.2 Picnic table and a stand of ponderosa pine. **0.5**

53.7 Approaching Cebolla. At 12:30 on the distant skyline is Chama Peak (12,027 ft). At 2:00 on the skyline, the grass-covered, sloped peak with a forested cap is a pleistocene cinder cone, one of six along the ridge top. The second vent and flow is a tree-covered hill below the skyline at 3:30,

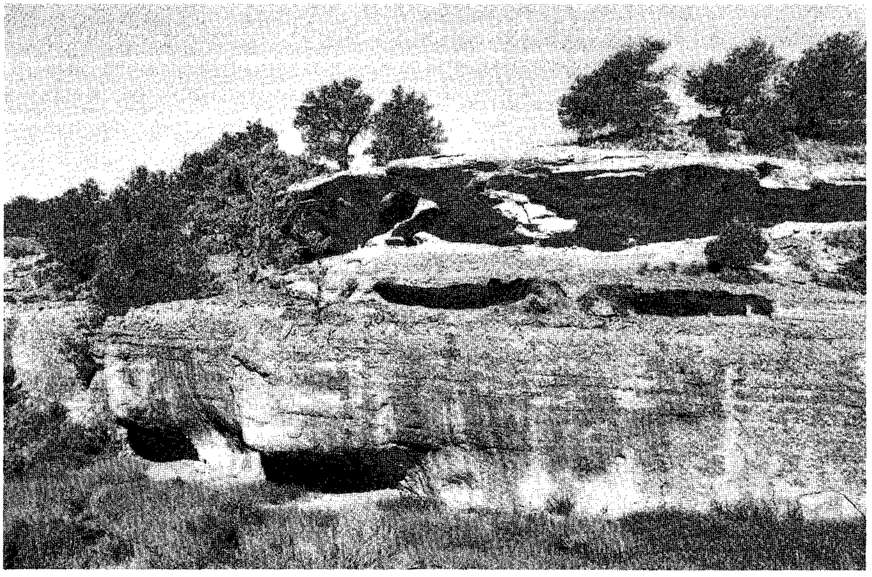


UPPER JURASSIC RIVER-SYSTEM DEPOSITS BECOME YOUNGER TO THE EAST; EACH IS AN IMPORTANT HOST FOR URANIUM; arrows denote directions of flowing rivers.

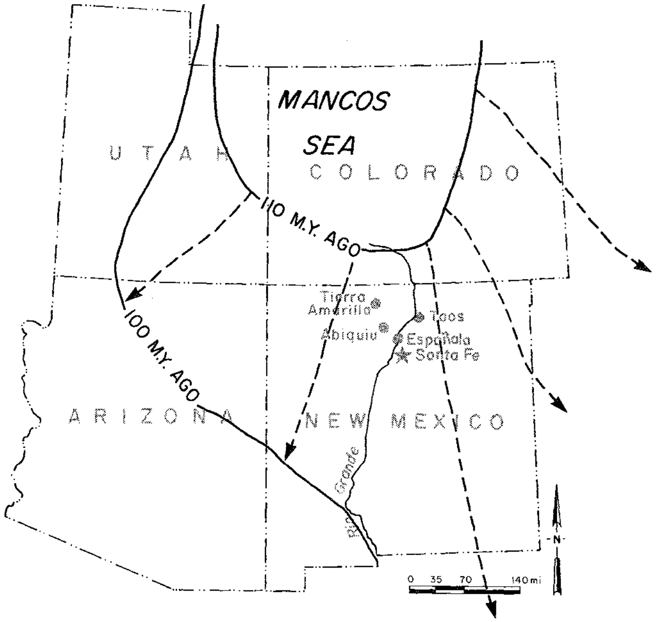
BASE OF MAJOR RIVER CHANNEL OF DAKOTA FORMATION truncating earlier river deposits of Burro Basin.



EARLY CRETACEOUS BURRO CANYON RIVER SYSTEM IS ALSO AN IMPORTANT HOST FOR URANIUM; arrows denote directions of flowing rivers.



PARALLEL-BEDDED BEACH SANDSTONES OF THE UPPER PART OF THE DAKOTA FORMATION. Fossils of clams, oysters, snails, and burrow traces can be found in the top beds and in the overlying marine Mancos Shale.



SHORELINES OF DAKOTA SANDSTONE, showing southward expansion of the Mancos sea.

visible from town. Basalt lava underlies the ridge extending into the Chama Basin. **3.0**

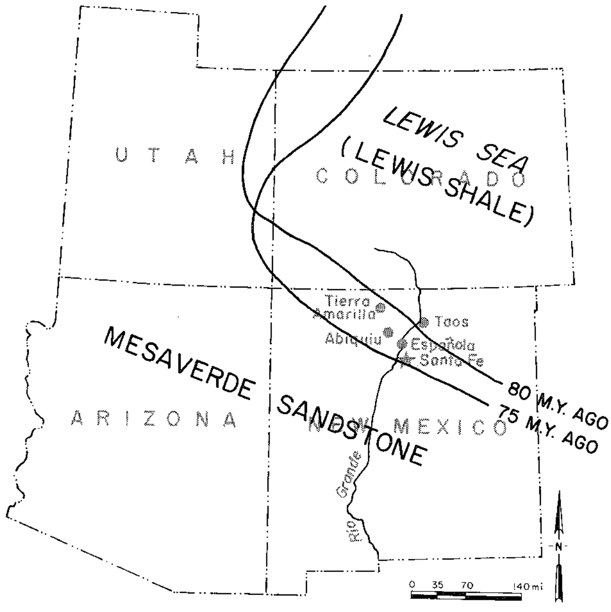
56.7 Picnic table. A Mesaverde-capped ridge is at 12:00. At 1:00, 5 mi ahead, Mesaverde sandstone underlies the skyline ridge in the shape of a shallow bowl, the bottom of which forms the Chama Basin. Behind the ridge, at 1:30 on the distant skyline, is Chama Peak.

The ridge at 2:30 is capped by Mesaverde sandstone that gently slopes into the Chama Basin on the left. The higher ridge to the right is capped by red El Rito Formation and younger Tertiary volcaniclastic rocks that dip to the right into the Rio Grande rift. The barren gray bluffs with a weathered, yellow cap are cut into the Mancos Shale.

US-64 leads up the valley beyond the barren bluffs and crosses the skyline approximately 2 mi north of the volcano at 3:30. **1.1**

57.8 At 9:00 is Gallina Mountain with Entrada Sandstone cliffs. **1.0**

58.8 The Mesaverde Formation straight ahead is very thin (compared to the skyline cliffs from 9:00 to 10:00) because it is near the eastward pinchout of the three-part sequence of 1) marine sandstone, 2) coal-bearing continental rocks, and 3) marine sandstone. To the east, the Mesaverde wedges out, and the Mancos Shale continues directly upward into the Lewis Shale, both marine muds. This area of continuous mud deposition



NORTHEASTERNMOST EXPANSION OF MESAVERDE SHORELINE (80 M.Y. AGO) AND SOUTHWESTERNMOST EXPANSION OF SUCCEEDING LEWIS SHALE (75 M.Y. AGO).

was east of the encroaching sands deposited by rivers running east and northeast from the mountainous areas in central Arizona. **3.5**

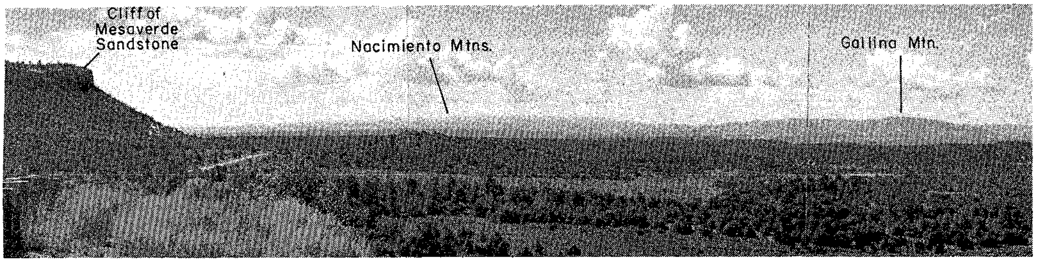
62.3 At 3:00 are small coal-mine dumps in the Mesaverde sandstone (milepost 322). The upward gradation from marine mud, to delta sandstone, to beach sandstone is beautifully displayed in the cliffs ahead. **2.3**

64.6 *Turn out on left near crest of the grade.* Panoramic view from west to south.

From 8:00 to 9:00 on the skyline is Mesaverde sandstone. The nearer forested ridges below the horizon are Dakota-capped anticlines. At 9:00 is El Vado Reservoir. The forested ridge at the north end of the lake is an anticline capped by Dakota Sandstone. The ridge is separated by a valley (the west-trending Brazos fault) from the Mesaverde-capped skyline ridge (Tecolote Mesa) at 10:00. Sawmill Mesa is partly hidden by the near hill.

The Nacimiento Mountains are the high, smooth surface on the distant skyline at 7:30. At 6:00 is the western edge of the Jemez Mountains. The view of Cerro Pedernal has just disappeared behind the near Mesaverde-capped ridge. The boulders in the roadcut are concretions, calcium-carbonate-cemented nodules, in the upper Mancos Shale. Fossils are abundant in these concretions.

The gravel-capped ridges of this region mark earlier episodes of rapid



PANORAMA TO SOUTHWEST AT MILE 64.9, ESPANOLA-ABIQUIU-CHAMA LOG. *(photo by S. D. Blodgett).*

downcutting during spring and summer melting of ice in the high mountains. **1.1**

65.7 Junction on right with NM-162 to Tierra Amarilla.

At 2:30 is the first view of the Brazos Box and the Brazos Cliffs in Precambrian quartzite. The steep, slabby appearance is caused by the rock's breaking along bedding surfaces (broad surfaces) and joints (narrow surfaces). (See photo gallery.)

The gap in the cliff is a 2,000-ft-deep canyon cut by the Brazos River through the box canyon. **0.6**

66.3 Junction with US-64. This log continues north to the narrow-gauge railroad terminal of the CATS (Cumbres and Toltec Scenic Railroad) at Chama. The next log begins at this junction and continues east along US-64 to Tres Piedras. At 11:30 is Chama Peak. At 11:00 is Navajo Peak or V-Mountain (11,330 ft). The conical peak on the broad flat top at 10:30 is Chromo Peak (9,916 ft).

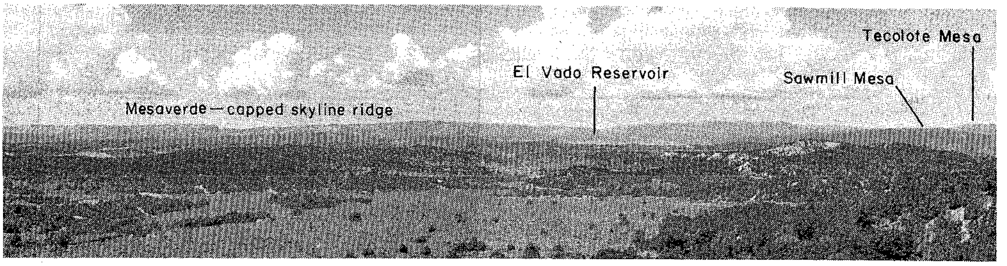
At 12:30 Tierra Amarilla ("yellow earth") is the county seat of Rio Arriba County. The town was settled in 1831 and named Las Nutrias ("the otters"). The first post office was built in 1866. In 1871-72, Tierra Amarilla was the ration headquarters for the Ute and Jicarilla Apache Tribes. After 1872, the Ute were moved to a reservation in San Juan County, and the Apache were sent to the western part of Rio Arriba County. **0.9**

67.2 Junction with NM-531; Tierra Amarilla is to the right. El Vado State Park is 17 mi away, to the left. Historic marker:

> Tierra Amarilla, founded 1858, population 1,246, elevation 7,460. The Tierra Amarilla land grant, comprising almost 600,000 acres, was given to Jose Manuel Martinez by the Mexican government in 1832. U.S. soldiers were dispatched here in 1865 to protect settlers from raids of Apache and Ute Indians. Many descendents of Jose Manuel Martinez still live in this area. **1.2**

68.4 Milepost 328. The Brazos fault passes under us near this point. The fault extends from south of the Brazos Box (3:00), through the Pleistocene volcano (grassy hill on the skyline), and through the gap in the forested mesas on our left (9:30). The flat surface we are crossing is Durango glacial-outwash gravel (Pleistocene) capped with basalt from the 250,000-yr-old volcanoes on the skyline at 3:00.

The small Chavez and West Chavez Boxes, cut into Precambrian quartzite, appear along the ridge between 2:00 and 2:30. The Precambrian quartzite dips westward into the Chama Basin underneath the Chinle Formation and younger rocks. This highway traverses the approximate center of the Chama Basin. At 3:00 is the village of Ensenada. **0.2**

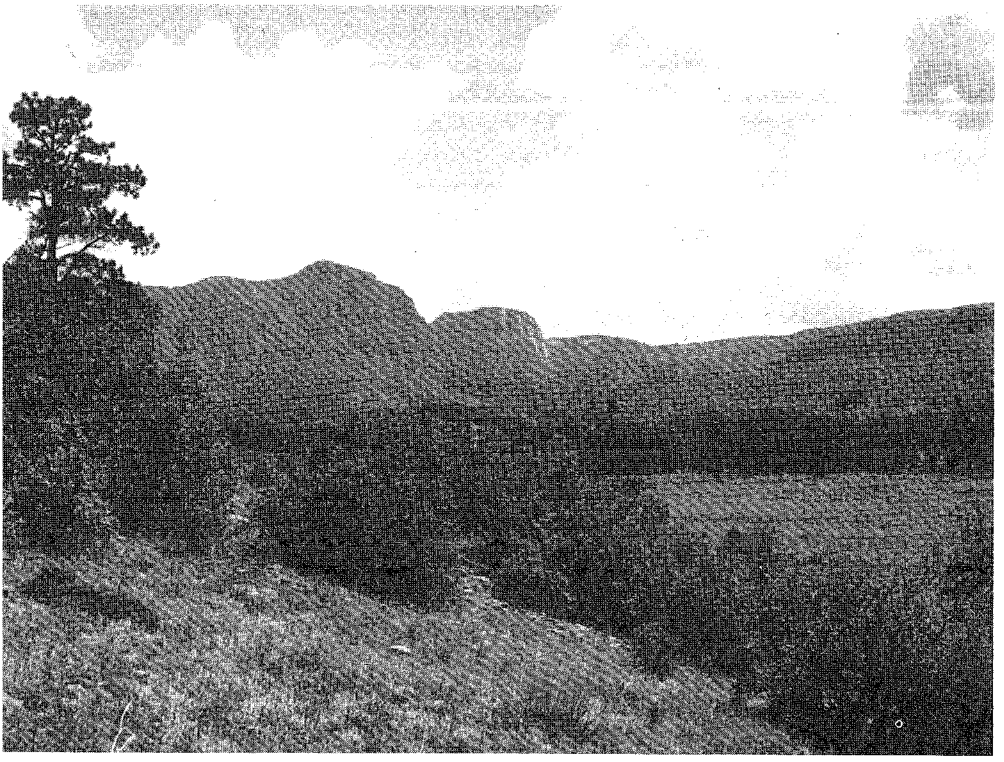


68.6 Junction on left with NM-112 to El Vado State Park, which has fishing, boating, and camping. **0.3**

68.9 The roadcut exposes soil and basalt from the volcanoes at 3:00. Well-developed columnar joints formed during cooling; rough, fragmented surface debris called as is clearly visible. The village of Brazos is to the left. The road descends to a Wisconsinan glacial-outwash surface. **0.9**

69.8 Junction on left with NM-95 to Parkview, Rutheron, and Heron Lake. At 3:00 is a good view of the Brazos Box, approximately 2,500 ft from cliff top to river level. **0.6**

70.4 After crossing the Brazos River, we descend to the modern floodplain.



VIEW EAST FROM TIERRA AMARILLA TO BRAZOS Box *(photo by S. D. Blodgett).*

From here to Chama, we traverse the modern floodplain or the higher Durango-age terrace. **1.0**

71.4 Junction on right with NM-512-NM-162 to the mouth of the Brazos Box and resort lodges. **0.9**

72.3 The timbered slope below the skyline at 2:00 is a dip slope of Dakota Sandstone. The ridge on the skyline is underlain by basal Blanco Basin Formation (Tertiary), a lateral equivalent of the El Rito Formation. The Blanco Basin Formation gently dips away from us toward the Rio Grande rift. The Rio Chama flows on the far side of the broad floodplain to our left. **1.6**

73.9 Picnic table at left. **1.0**

74.9 Chama Peak at 11:30. **0.4**

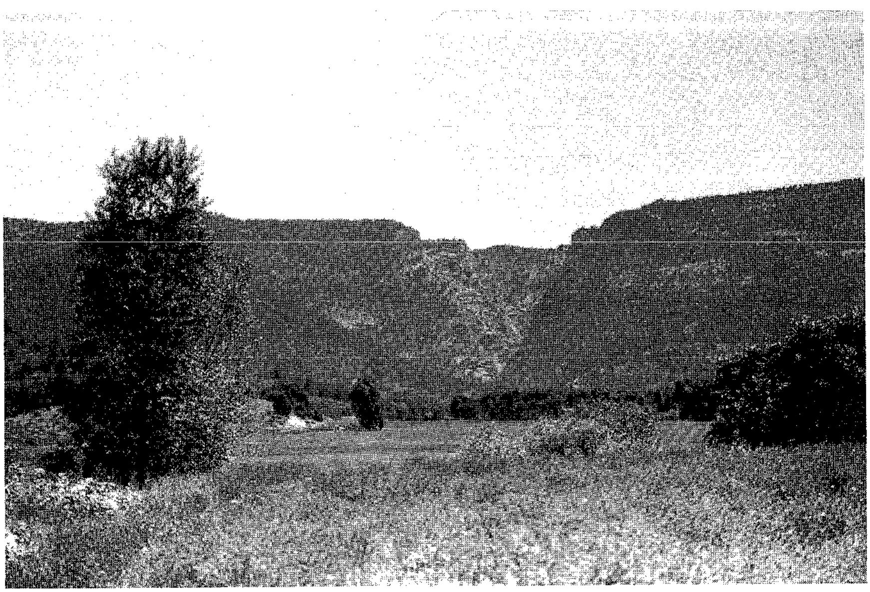
75.3 At 3:00 (milepost 335) Cañones Box, cut in Precambrian quartzite, has a smooth upper surface of quartzite, with the Chinle Formation forming the stripped edge and dipping toward us into the Chama Basin. **1.3**

76.6 The low hills on the left are gravel caps on the anticline that expose Dakota Sandstone. On the right, cleared strips up the mountainside mark the fence line of a private elk preserve. At 1:00 the low, scrub-oak-covered hills lie atop a dip slope of Greenhorn Limestone. **1.3**

77.9 From 11:00 to 12:00 are the easternmost Mesaverde cliffs. No middle coal-bearing unit occurs here; only very thin representatives of the lower and upper marine sandstones appear. Rabbit Peak (8,641 ft) is at the east end (11:45). **0.7**

78.6 Historic marker at left:

> Escalante's Trail, 1776 A.D. In a dual effort to establish a commercial route between Santa Fe and Monterey, California, and to spread Christianity among the In-



CANONES BOX; view to east from mile 75.3, Española-Abiquiu-Chama log.

dians, Fray Silvestre Velez de Escalante pushed westward with an expedition in 1776. The explorers followed the Rio Chama from Abiquiu, but failed to reach the Pacific after eight months of travel. **0.8**

79.4 Historic marker at right:

Chama, population 899, elevation 7,860. Historically a center of the lumber, ranching and sheep raising industries. Today Chama is a recreation center due to its natural location near fishing and hunting grounds, boating waters and snowmobile trails. The Cumbres and Toltec Scenic Railroad also attracts vacationers and rail-road fans.

Chama Peak is at 12:00. **0.6**

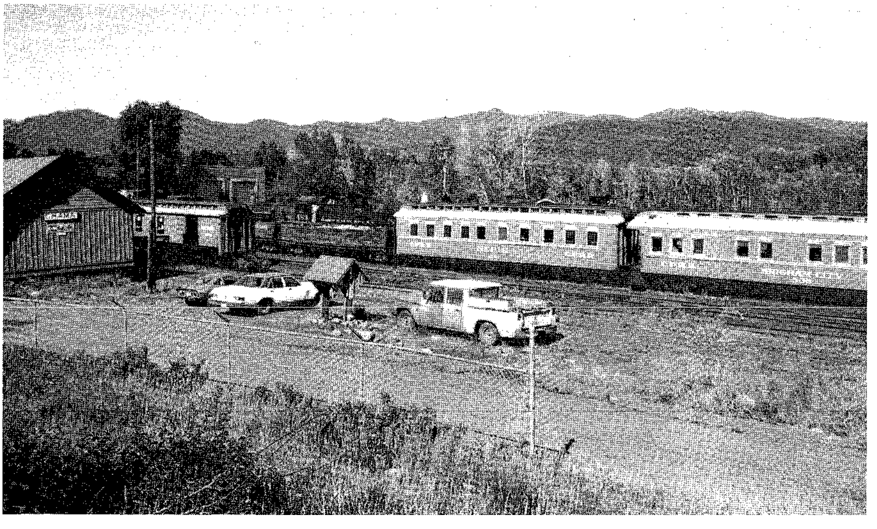
80.0 Bridge over Rio Chama. **0.3**

80.3 Junction of US-64-NM-84 (to the left) and NM-17. *Continue straight ahead on NM-17.* **0.9**

81.2 *Cross wye (y) of CATS narrow-gage railroad.* This wye was used to turn the engines around. **0.6**

81.8 Terminal of the Cumbres and Toltec Scenic Railroad. At 12:00 are yellow and pink cliffs of the Blanco Basin Formation. The bare slope on the skyline at 2:00 is Slide Rock Point, composed of Treasure Mountain Tuff. The rest of the features on the skyline to 3:00 are in Conejos andesite. The nearer slopes from 2:00 to 3:00 are dip slopes of Dakota Sandstone.

The name "Chama" may have come from the Indian word for the river running through town. In 1865 Chama was a stopover for troops and travelers between New Mexico and Colorado. In 1880-81, the Denver and Rio Grande Western narrow-gage line was laid as an extension of the 500-mile line connecting Denver with Silverton, Colorado. The railroad opened up the mining regions of the Rocky Mountains. Because of steep (4 percent) grades, hairpin curves, tunnels, a 137-ft-high trestle, and a track section 1,000 ft above Los Pinos River, construction of the 64-mile line between Antonito, Colorado, and Chama took more than a year. This me-



TERMINAL YARD OF THE CUMBRES AND TOLTEC SCENIC RAILROAD, CHAMA. The cars with C.P.R.R. painted on them were made especially for a motion picture: mile 81.8. Española-Abiquiu-Chama andering route crosses the Colorado-New Mexico state line 11 times. Cumbres Pass (10,023 ft) is the highest railroad pass in the United States. The railroad has been called one of the most spectacular examples of narrow-gauge railroading in North America. The original railroad made its final passenger run in 1951 but hauled freight until it was abandoned in 1968. The line reopened in 1971 as the Cumbres and Toltec Scenic Railroad, and a sightseeing train operates from June to October. The train passes through evergreen and aspen forests, alpine meadows, and fields of wildflowers. Ghost towns and movie sets can be seen along the route between Antonito and Chama. (More details are in Scenic Trip No. 11.)

END OF LOG. *Return to US-64-US-84 junction south of Tierra Amarilla to continue the route to Tres Piedras.*

The drive up NM-17 to Cumbres Pass (10,023 ft) is 12.7 mi. The road crosses the CATS Railroad track four times as the railroad climbs along Wolf Creek on the 4 percent grade to the summit. This spectacular scenic route crosses glacial-outwash surfaces and passes through a gorge cut in the Dakota and Morrison sandstones (faulted at 2.9 mi). The gorge opens into a broad glacial valley at Lobato siding (4.2 mi). The road then climbs the lateral and recessional moraines of Wolf Creek that are dotted with huge boulders dropped as the glacier melted away (5.5-7.5 mi). At 8.5 mi the road enters Colorado, and at 10 mi the canyon cut by Wolf Creek again exposes steep, west-dipping red beds of the Morrison Formation (Jurassic). Here these beds are overlain by an angular unconformity of nearly horizontal, yellowish, arkosic conglomerate beds of the Blanco Basin Formation (Eocene). The final curves to Cumbres Pass bring the railroad (above) and the highway (below) past Windy Point, whose rugged cliffs expose Conejos andesite-flow breccias and mudflows.

Golden columbine

Tierra Amarilla-Tres Piedras

Our route crosses the Chama Basin and climbs onto the Brazos uplift (Laramide). As we cross the uplift (Tusas Mountains), we traverse the thin cover of post-Laramide sedimentary rocks that fills the valleys between the ridges and peaks of Precambrian rocks. The valleys are mostly fault controlled, and their last period of movement usually uplifted the east side. Thus, as we descend gradually to the edge of the Taos Plateau at Tres Piedras and cross each fault, we return to the same unit through which we have just climbed.

Mileage

0.0 This log begins at the junction of US-64-US-84. *Go east on* US-64. The road ahead descends into the Tierra Amarilla valley and continues up the valley. **0.2**

0.2 Junction on left with NM-162 to Tierra Amarilla. **1.4**

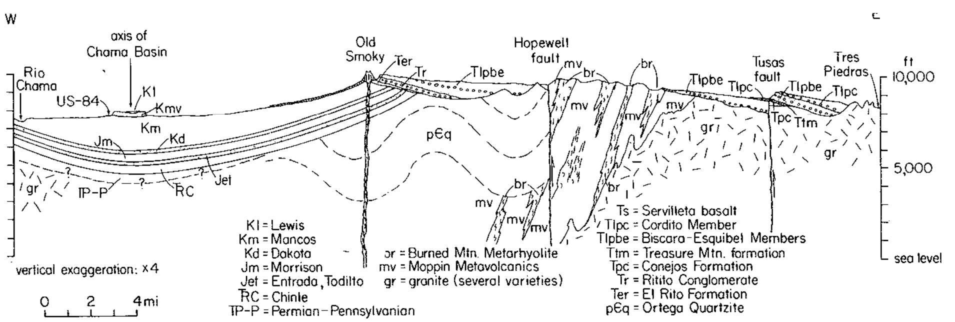
1.6 Exposures of Mesaverde sandstone are at 9:00 on the near ridge. The benches on the forested ridge from 1:00 to 3:00 are gravel-covered surfaces, former levels of this stream.

In 1874 Lieutenant G. S. Anderson of the 6th Cavalry was looking for a new wagon route from Fort Garland, Colorado, to Fort Wingate, New Mexico. At that time the mountains made it necessary to detour via Santa Fe. He surveyed and recommended a route close to that which US-64 now follows from Tierra Amarilla to Hopewell Lake. **2.0**

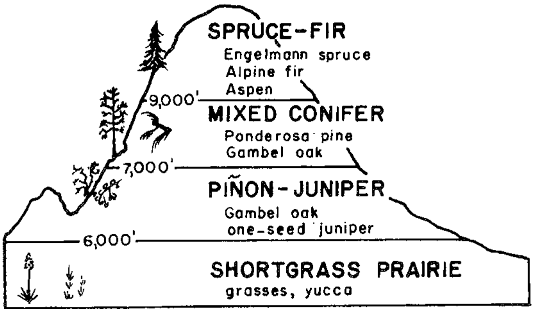
3.6 At 12:00 on the skyline is a late Pleistocene volcano, Old Smoky. At 11:00 the wooded skyline ridge of Peñasco Amarillo (10,712 ft) is capped by El Rito and Ritito conglomerates that dip gently eastward. The conglomerates unconformably overlie the westward-dipping Mesaverde Sandstone and its veneer of overlying Lewis Shale. Slopes covered with scrub oak and scattered pine trees are visible from 10:00 to 11:00. **0.7**

4.3 The long sloping ridge on the skyline at 12:00 is underlain by late Pleistocene basalt. The skyline ridge at 11:00 is underlain by yellow Ritito and red El Rito conglomerates, the lowest Tertiary units of the region. **0.7**

5.0 At 9:00 is a Mesaverde Sandstone cliff. **1.7**



SCHEMATIC CROSS SECTION FROM RIO CHAMA (NEAR TIERRA AMARILLA) TO TRES PIEDRAS.



VERTICAL DISTRIBUTION OF TREE SPECIES IN NEW MEXICO (modified from Martin, 1964, New Mexico Geological Society, Guidebook 15th field conference, Ruidoso Country, p. 173).

6.7 Milepost 130. At 12:00 is Old Smoky. Basalt lava flows extend from the volcano to the ridge at 12:30. **2.0**

8.7 Milepost 132. A low, scrub-oak-covered ridge marks the downhill edge of the huge landslides that cover the entire mountainside beyond. The ridge probably also marks the downhill extent of the glaciers in this region. The coarse, gravel veneer on the ridge is probably glacial outwash. **1.4**

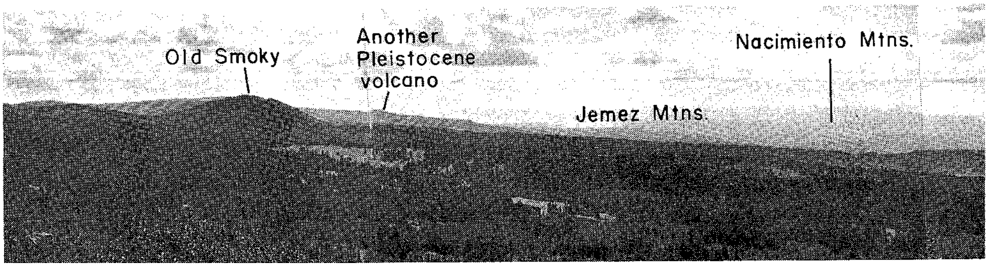
10.1 We are crossing the end of the ridge with a gravel veneer derived from the Ritito and El Rito conglomerates along the skyline ridge. The road, which now climbs more steeply up the surface of the landslide, has fallen away and has been repaired in many places. Slumps are common in the roadcuts.

Views to the west and south are more scenic as we climb to the crest of the Tusas Mountains. We will describe the view from the picnic areas at the summit. Enjoy the scenery!

Wild iris and skunk cabbage grow in marshy meadows; aspen grows in moist areas, spruce and fir on slightly drier sites; white fir and Douglas fir grow on even drier sites, with ponderosa pine and juniper on well-drained, lower elevation sites. **7.6**

17.7 Turnout on the right; better views are beyond! Roadcuts on the left in Ritito Conglomerate are composed of cobbles of Precambrian quartzite. **1.2**

17.9 Summit. The road now travels along the divide (elevation between 10,500 and 10,000 ft) for the next 3.5 mi. **0.5**



PROMINENT FEATURES VISIBLE AT MILE 18.4, TIERRA AMARILLA-TRES PIEDRAS LOG; view to southwest.

18.4 Stop at picnic area on the left and enjoy the beautiful scenic view to the west and south. Below, the road winds up the landslides of glacial debris on Mancos Shale, an excellent generator of landslides. To the right of the upper curves of the road is Peñasco Amarillo; its cap of Blanco Basin-El Rito (red) and overlying Ritito Conglomerate is the same unit on which we are now parked.

Beyond to the right of the road and below the distant skyline (youngest Cretaceous sandstones of the San Juan Basin) are the Mesaverde sand-stone cliffs that were our western skyline at the start of this tour leg. Beyond the road and forming the nearer skyline, Gallina Mountain is the faulted anticline with a cliff (facing us) of yellow, white, and red Entrada Sandstone. Through a gap in Gallina Mountain, the plains of the San Juan Basin are visible.

The distant skyline farther south is formed by the broad, smooth-surfaced Nacimiento Mountains and the irregular Jemez Mountains (left). Cerro Pedernal, the butte-shaped mountain, is just below the skyline (see mile 34.8 on Española-Chama log). A Dakota-capped mesa (the forested ridge) forms the near margin of the distant grassy valley in the Echo Amphitheater-Abiquiu Reservoir region.

The wooded skyline ridge to the south stretches for 10 mi to its southern end above Canjilon Lakes. The wooded ridge sloping to the right below the distant skyline is underlain by late Pleistocene basalt; its source volcano is the conical bump on the ridge.

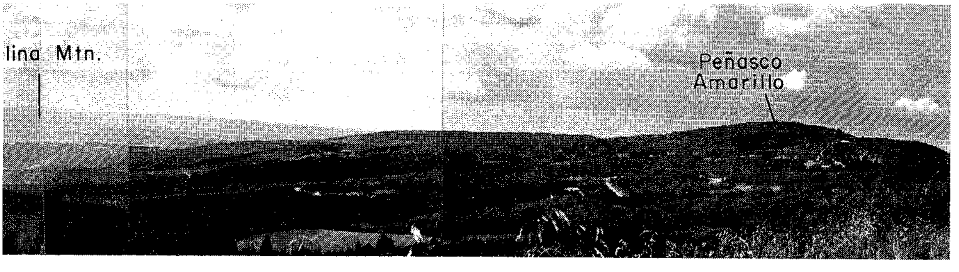
A few miles south of us, just below the skyline, is Old Smoky. **0.4**

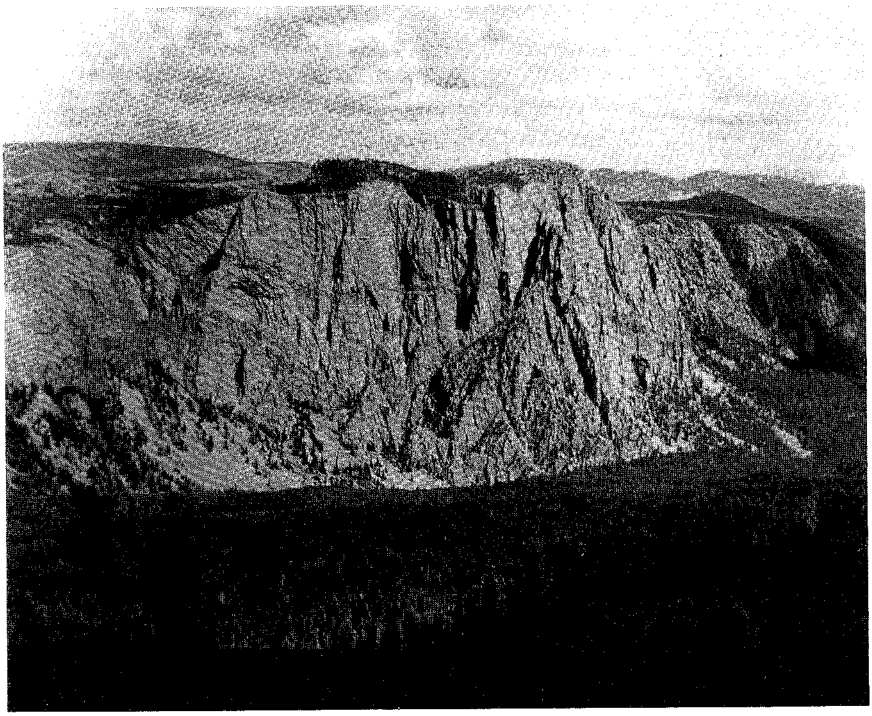
18.8 Milepost 142. **0.3**

19.1 Picnic tables at left. The spectacular view to the north and west is dominated by the Brazos Cliffs. The smooth faces are dip slopes on bedding surfaces in Precambrian quartzite.

To the left, the distant forested mountain with the flat mesa on the right edge is Chromo Peak. Behind it, forming the (usually) snowcapped skyline, are the San Juan Mountains north of Durango, Colorado. To the left of Chromo Peak, the long ridges underlain by Mesaverde sandstone lie below the skyline; Archuleta Mesa, capped by a Tertiary sill, is on the skyline. To the left of Archuleta Mesa are the La Plata Mountains in the southwest corner of Colorado.

To the right of the Brazos Cliffs, in the nearby high country, are





VIEW LOOKING NORTH FROM PENASCO AMARILLO TOWARD BRAZOS BOX AND BRAZOS CLIFFS (photo from H. H. Doney, 1968, New Mexico Bureau of Mines and Mineral Resources, Bull. 92).

forested valleys between quartzite ridges. On the distant skyline is Chama Peak (12,027 ft) in southern Colorado. At 11:45 is the high, lightly forested Grouse Mesa (11,403 ft), capped by the southernmost Conejos andesite, which flowed to this point from a source nearly 50 mi to the north. To the right, at 12:00 and slightly closer to us, the grass-covered ridge is the conglomeratic unit that underlies our stopping point.

On the distant skyline to the right of the highway the pink cliff is underlain by Treasure Mountain rhyolite, a welded tuff (ignimbrite) erupted from the Platoro caldera 60 mi to the north. To the east, at 3:00 on the distant skyline, are the Sangre de Cristo Mountains, east of Taos. **1.7**

20.8 Picnic tables at left. Another spectacular view! The reddish hills north of the picnic area are late Pleistocene volcanoes, approximately 250,000 yrs old. The lava from these volcanoes poured down the canyon below and flowed northward into the Rio Brazos, then through the Brazos Box and out onto the river valley floodplain, 10 mi from the mouth of the box. We crossed this lava flow north of Tierra Amarilla (mile 69.2, Española-Chama log).

To the west are the Mesaverde sandstone rims beyond El Vado Lake; Dakota-capped forested mesas (anticlines) are between the Rio Chama valley in the middle distance and El Vado Lake.

Red El Rito and capping, yellow Ritito conglomerates are exposed in the cliffs along the upper edge of Peñasco Amarillo, the ridge to the left of the valley. These are the westernmost exposures of the El Rito and Ritito conglomerates. Rocks similar in age to the El Rito and Blanco Basin Formations, but finer-grained, occur in the San Jose Formation on the most distant western skyline beyond El Vado Lake. These conglomerates indicate the existence of mountains to the east that had a broad alluvial apron extending to the west. The streams draining from the mountains during El Rito-Blanco Basin time continued west and northwest, ending in the huge lakes Uinta and Goshiute. Preserved in the lake sediments are the enormous oil-shale deposits of the Green River Formation.

From here to Tres Piedras, we cross the early Tertiary deposits that buried this Laramide mountain range. Our route turns east (right) and closely follows the gentle, easterly dip of these Tertiary rocks until the road climbs into Precambrian quartzite hills. After traveling less than 1 mi to the east, we will have passed beyond the upturned edge of the San Juan Basin Mesozoic sedimentary cover. These sediments buried the Precambrian rocks exposed ahead. Precambrian quartzite is the most erosion-resistant rock in this region and commonly forms whitish-gray peaks. This quartzite also composes much of the material for the conglomerates flanking the old, high areas exposed along the edge of this picnic site. **1.4**

22.2 Jawbone Mountain (10,850 ft) at 12:00 is a conglomeratic phase of the Precambrian quartzite. **1.3**

23.5 *Enter Carson National Forest.* **0.6**

24.1 A major fault extends across the road and continues north along the foot of the slope. Roadcuts ahead are in Ritito Conglomerate that contains large quartzite clasts. **0.9**

25.0 Turnout on the right. **0.5**

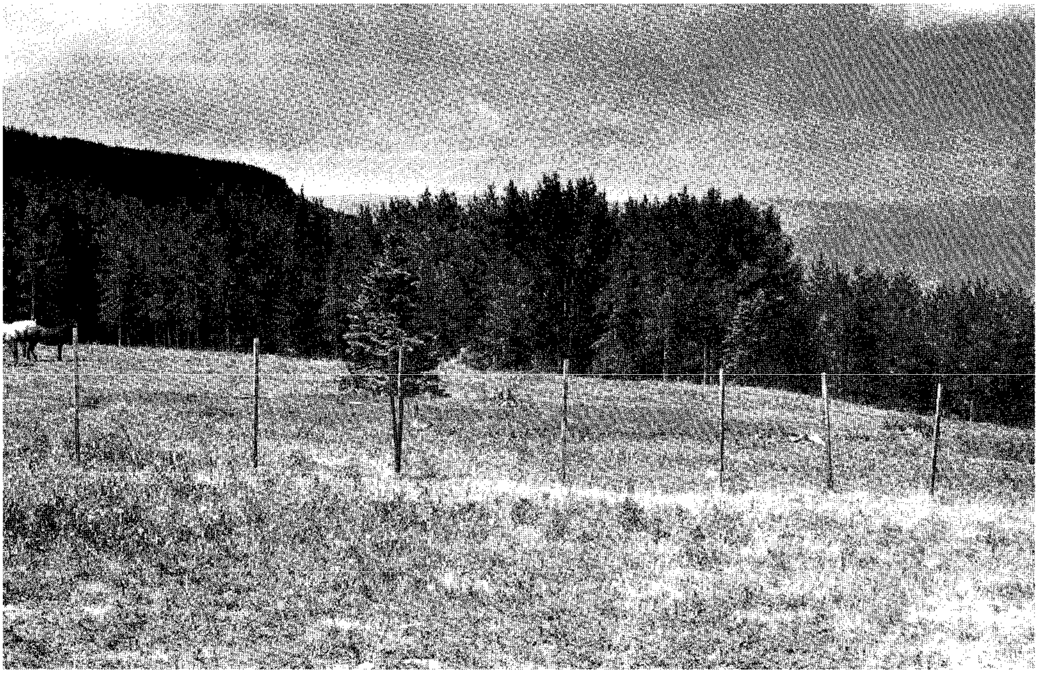
25.5 We are crossing the divide. This is the last time we get above 10,000 ft on this tour. The Sangre de Cristo Mountains are at 11:00.

At 9:00 is the conglomerate phase of quartzite in the hills. We are crossing Los Pinos gravels (volcanic clasts derived from the southeast side of the San Juan Mountains), the initial filling of the Rio Grande rift. Near Abiquiu we saw the Abiquiu Tuff, which is the fine-grained, downstream equivalent. **2.8**

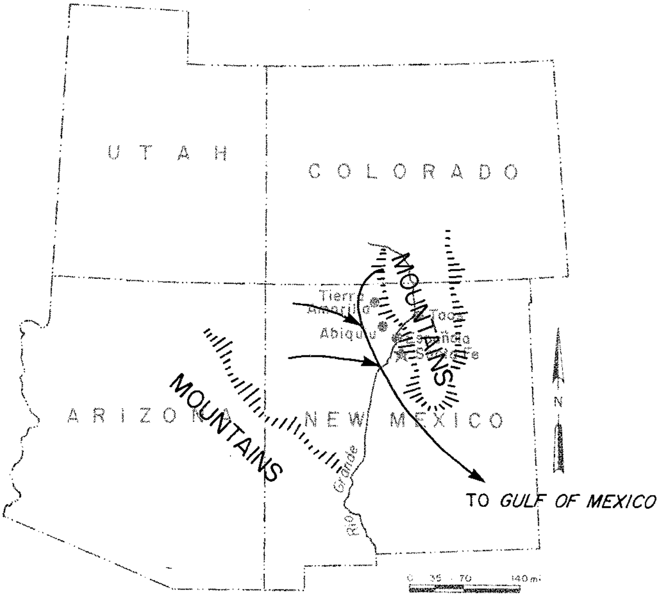
28.3 The test pit on the left is in a quartz vein in Maquinita Granodiorite (fine-grained, foliated, pink orthoclase), which in turn intrudes metavolcanics (now chlorite-amphibolite schist). **0.4**

28.7 Hopewell Lake is on the right. Down the valley is the Hopewell mining district. The earliest mining (late 1870's) was at the Fairview gold placer on Placer Creek, just beyond Hopewell Lake dam. Lode deposits in Precambrian schist became a prime source of gold, silver, copper, and lead in the next few years, but depletion below the oxidized surface zone stopped operations by 1890. In 1903, an extensive hydraulicking operation proved unsuccessful. Since then, intermittent efforts by individuals and corporations have produced small amounts of ore. **0.4**

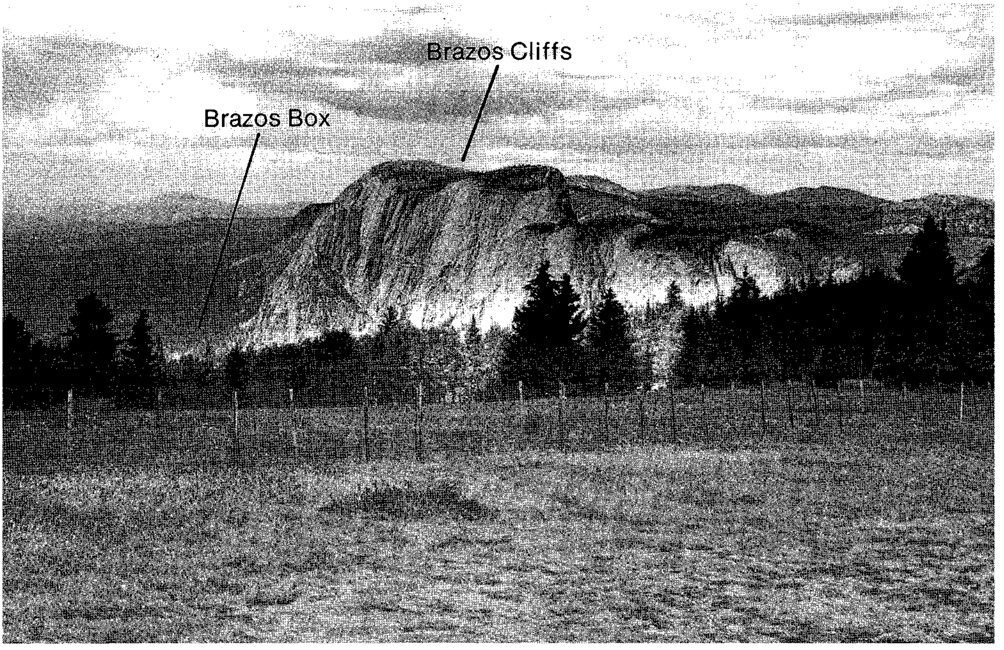
29.1 Entrance to Hopewell Lake; camping and fishing. **0.4**

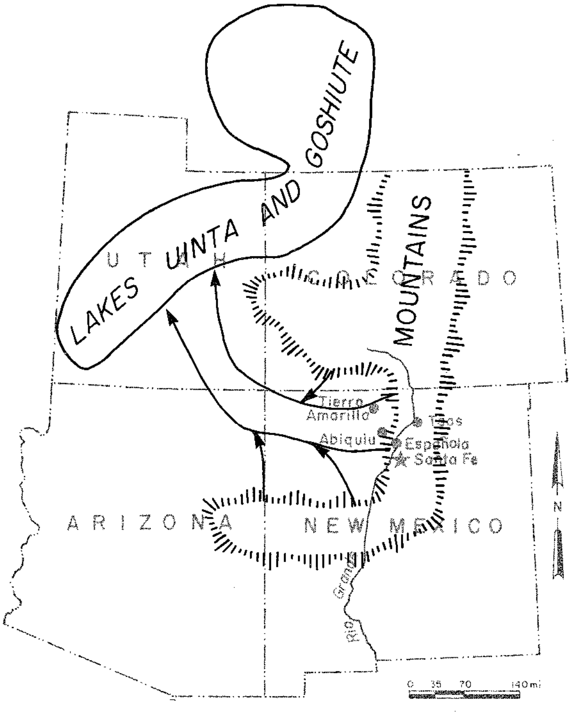


PRINCIPAL FEATURES SEEN FROM MILE 20.8, TIERRA AMARILLA-TRES PIEDRAS LOG; view to west.

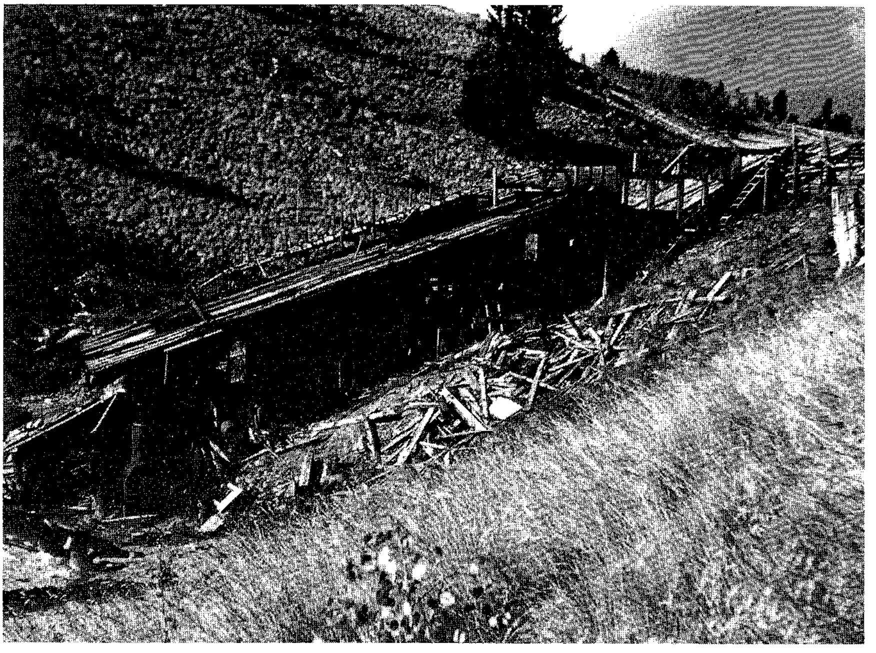


PALEOCENE WASATCH MOUNTAINS AND PLAINS (END OF LARAMIDE OROGENY); arrows denote directions of flowing rivers





MIDDLE EOCENE SAN JOSE-BLANCO BASIN IN EL RITO TIME. By late Eocene, drainage connected west to Lakes Uinta and Goshuite; arrows denote directions of flowing rivers.



REMAINS OF A STAMP MILL ALONG PLACER CREEK, HOPEWELL MINING DISTRICT, ABOUT 1956 (photo from H. H. Doney, 1966).

29.5 Visible along Deer Trail Creek is a dip slope in the Cordito Member, youngest unit of Los Pinos Formation. **1.9**

31.4 Ahead on the skyline is Treasure Mountain Tuff overlying Conejos tuff; the bluffs below are in the Biscara-Esquibel Member (Los Pinos Formation). A fault separates the two exposures. A major fault in the valley lies at the base of the white Los Pinos bluffs. **1.9**

33.3 The road turns right into the valley of Tusas Creek, paralleling a major fault zone. The upthrown side to our left (east) exposes Precambrian metavolcanics and granodiorite on the lower slopes, Conejos tuff at the intermediate levels, and Los Pinos Formation along the upper slopes. To our right (west) is a dip slope of the Cordito Member. **2.3**

35.6 At 3:00 on the skyline, Tusas Mountain (10,150 ft) is a forested ridge underlain by Tusas granite. **1.0**

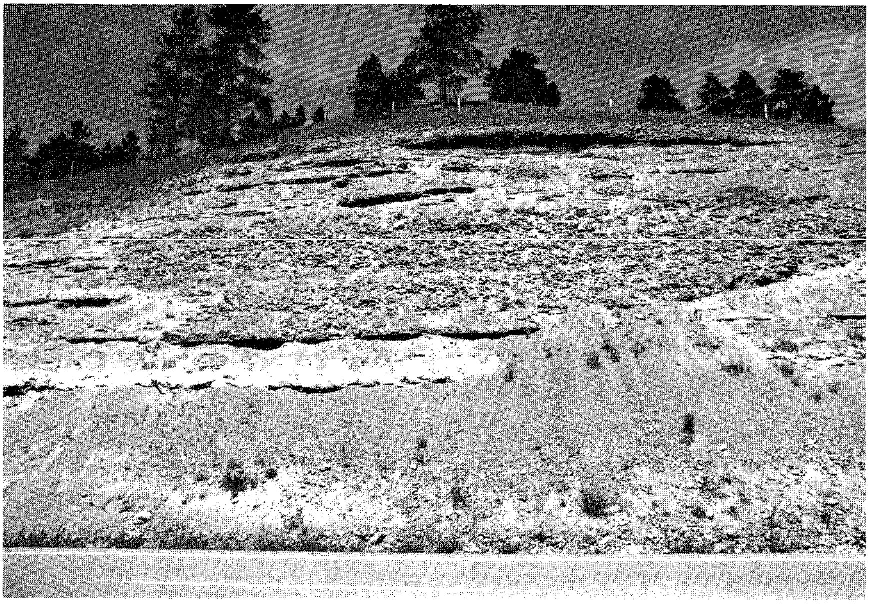
36.6 The steep dip of beds in the Cordito Member in the roadcuts was caused by drag on the fault. A fault cuts across the ridge ahead. **0.6**

37.2 Roadcuts for the next half mile are in the Cordito Member. A large, coarse (cobble to small boulder) gravel channel is in the last roadcut. **1.0**

38.2 More roadcuts in the Cordito Member; fluvial deposits. **0.7**

38.9 Turnout on the right. The Precambrian quartzite ridge on the skyline at 2:00 is Kiowa Mountain, with a fire lookout. The fault that our road has been following now gradually climbs the slope to our left, where it marks the base of the steep slope. **1.0**

39.9 Milepost 163. **0.2**



GRAVEL-FILLED CHANNEL, CORDITO MEMBER, LOS PINOS FORMATION (near mile 37.7, Tierra Amarilla-Tres Piedras log).

40.1 Ribbed, white Conejos tuffs are in the canyon at 10:00. **0.3**

40.4 The road cuts through tilted, buff sand-dune facies and red-brown, lacustrine facies of the Ojo Caliente Sandstone Member(?) (Santa Fe Group); these sandstones are capped by glacial-outwash gravels. **1.2**

41.6 Junction on right with NM-111 to Tusas. The green-roofed house in the valley was a trading post and post office from 1898 to 1930.

At 1:00, the Rio Tusas enters the gorge, cutting into Tusas granite. The road turns left, up a fault-bounded wedge in the wall of the main valley. The Biscara-Esquibel Member (Los Pinos Formation) forms hills on both sides. We are climbing a Quaternary surface. **0.9**

42.5 Road crosses the fault. **0.1**

42.6 A roadcut in sand dunes and gravel cap; the roadcuts in the grade ahead are in the Biscara-Esquibel Member. **1.6**

44.2 The summit of Tusas Ridge (8,819 ft) is the approximate boundary of the Cordito Member with the underlying Biscara-Esquibel Member. To the right, down the valley, are the Sangre de Cristo Mountains. The light scar of the Questa molybdenum mine is visible near the skyline behind Cerro Montoso, a broad, forested shield volcano on the Taos Plateau. **1.2**

45.4 Roadcuts are in the Cordito Member. **1.0**

46.4 Crossing Tres Piedras Creek. **0.5**

46.9 Outcrops of reddish-buff, Tres Piedras granite gneiss are ahead. **0.6**

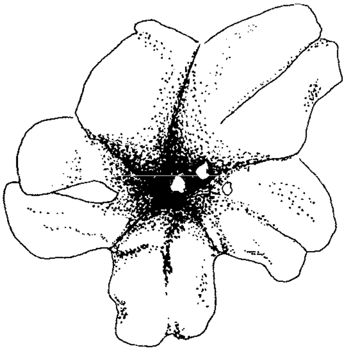
47.5 Leaving Carson National Forest. Exposures of Tres Piedras granite gneiss are ahead. **0.8**

48.3 *Enter Tres Piedras* ("three stones"). This small settlement was named for the granite outcrops that surround it. Originally Tres Piedras was a station on the Denver and Rio Grande Western Railroad narrow-gage line to Santa Fe. Cattle ranches are nearby, and potato and grain fields are visible from the highway. Scattered piñon and juniper border the road, and lupine and Indian paintbrush add color in the spring. **0.2**

48.5 Junction with US-285. The logs divide. The route to the right is US-285 to Ojo Caliente and Espanola (56 mi). The log of the Tres Piedras-Ojo Caliente-Española tour begins on page 88.

The route ahead is US-64 to Taos and NM-68 to Espanola (79 mi). The log of the Tres Piedras-Taos tour begins on page 65.

END OF LOG



Desert Four O'Clock

Tres Piedras-Taos

This leg of the tour crosses the Taos Plateau, a major volcanic field studded with volcanoes of many shapes and sizes. The route crosses the 650-ft-deep Rio Grande Gorge, a steep-walled canyon exposing a cross section of the volcano-covered plateau. Between the Rio Grande and the base of the Sangre de Cristo Mountains is the most actively subsiding block of the Rio Grande rift. The giant alluvial fans building outward from the Sangre de Cristo Mountains channel the Rio Grande along the western margin of the sinking block. Our route to Taos crosses this block and its cover of alluvial fans.

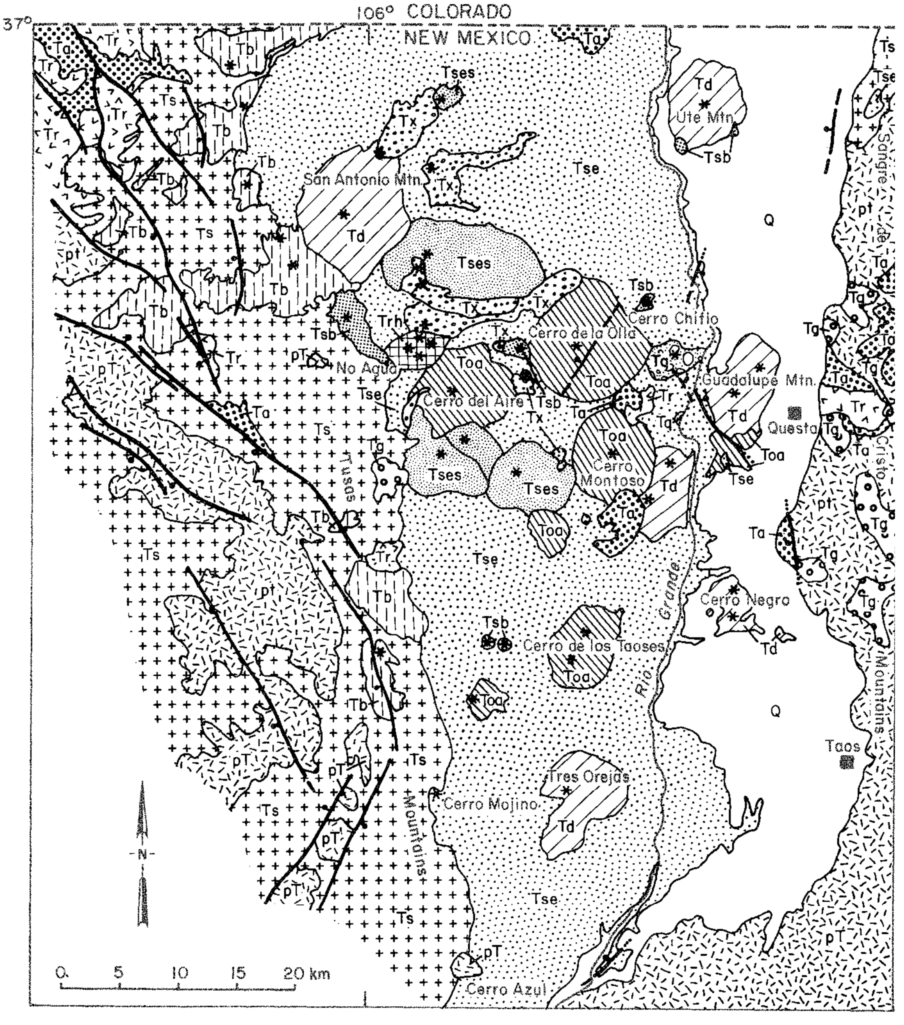
The volcanoes of the Taos Plateau are composed of a wide variety of rock types. The oldest volcanoes (26-5 m.y.), along the northwest margin, are composed of varieties of basalt interbedded with sediments of Los Pinos Formation. These sediments, derived from the San Juan Mountains, mark the earlier filling of the Rio Grande rift. Volcanic ash within Los Pinos sediments and Cerro Chifio quartz latite (10 m.y.) indicates that other, more silica-rich volcanoes existed elsewhere, and probably are buried by the younger basalt of the Taos Plateau.

A long, uplifted block within the rift exposes older pre-rift volcanic rocks similar in composition and age to the rocks of the San Juan Mountains to the northwest and to the rocks of the Questa region to the east in the uplifted Sangre de Cristo Mountains. The main exposures of this horst block are the San Luis Hills in Colorado and a group of low hills north and south of Cerro Montoso. Our route passes south of these exposures.

All volcanoes visible on this tour are between 4.8 and 2.3 m.y. old. More than 40 vents have been identified as belonging to this short episode of volcanism. Younger vents (up to 1.8 m.y. old) are hidden from view along the northern edge of the field. Whether or not this region will continue to have volcanic episodes culminating in violent explosions like that of the Valles caldera (west of Los Alamos) is the subject of a wide variety of studies. The question may only be answered by time or deep drilling.

Although no pattern in time has been recognized, a crude pattern of volcanic activity can be identified by composition. The high, steep-sloped rhyodacite volcanoes form an outer loop; two of the largest of these volcanoes form the northern skyline: San Antonio and Ute Mountains. An inner loop of slightly lower, more gently sloped volcanoes of olivine andesite forms the local skyline. The largest of these is Cerro de la Olla; Cerro del Aire, Cerro Montoso, and Cerro de los Taos are also prominent. The shield volcanoes that supplied most of the basalt covering the plateau are difficult to recognize because they are so broad and low. The three largest volcanoes form a cluster northeast of Tres Piedras and are only a short distance north of the tour route. These shield volcanoes are also the source of the layers of basalt flows exposed in the walls of the Rio Grande Gorge. Other shield volcanoes probably were buried by younger eruptions or by the extensive sedimentary cover along the eastern margin of the plateau.

This cover of young volcanic rocks hides the earlier history of the Rio Grande rift that is so well exposed in the deeply eroded Espanola Basin to the south. Geophysical studies suggest that a well drilled beside the high bridge over the Rio



VOLCANOS OF THE TAOS PLATEAU; legend on p. 67 (modified from Lipman and Mehnert, in Riecker, 1979).

Q Quaternary surficial deposits

Taos Plateau Volcanic Field

Trh Rhyolite

Tq Quartz latite

Td Rhyodocite

Toa Olivine andesite

Tx Xenocrystic basaltic andesite

Tsb Siliclc alkalic basalt

Tse Servilleta basalt

Tses Servilleta shield basalt

Ts Tertiary rift sediments (Includes Santa Fe Group and Los Pinos Formation)

Pre-rift and early-rift volcanic rocks

Tb Basalt flows

Tga Granitic intrusions

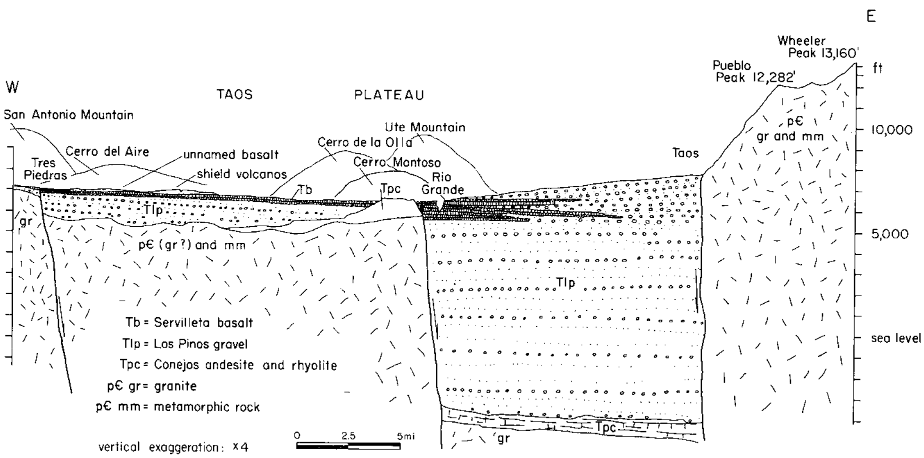
Tr Rhyolitic ash-flow tuffs

Ta Andesitic flows and breccias

pT Pre-Tertiary rocks, mainly Precambrian

* Vent

Fault
Bar and ball on downthrown side



SCHEMATIC CROSS SECTION FROM TRES PIEDRAS TO SANGRE DE CRISTO MOUNTAINS ROUGHLY PARALLEL TO THE TRES PIEDRAS—TAOS ROUTE; view to north.

Grande would have to go down approximately 10,000 ft before reaching pre-basin rocks like those exposed south of Cerro Montoso. Approximately the top 1,000 ft would be volcanic rocks of the plateau; the rest would be mostly sedimentary rocks similar to those of Los Pinos Formation or to those of the Espanola Basin.

Mileage

0.0 *Travel east on US-64.* **0.3**

0.3 Crossing the abandoned grade of the narrow-gage track of the Denver and Rio Grande Western Railroad. This track was laid from Antonito, Colorado, to Santa Fe, New Mexico, in 1880; the track was abandoned in 1941. At 8:00 stands the wooden water tank used by the railroad to refill boilers of the coal-burning steam engines used on the line.

At 8:30, 15 mi to the north on the skyline, San Antonio Mountain (10,935 ft) is the large shield volcano that stands 2,000 ft above the level of the Taos Plateau. This volcano is composed of rhyodacite with a silica content of 60-61 percent. The higher the silica content of lava, the more viscous it becomes; this high viscosity is the cause of the steep slopes on the flank of San Antonio Mountain (3.1 m.y.). **0.5**

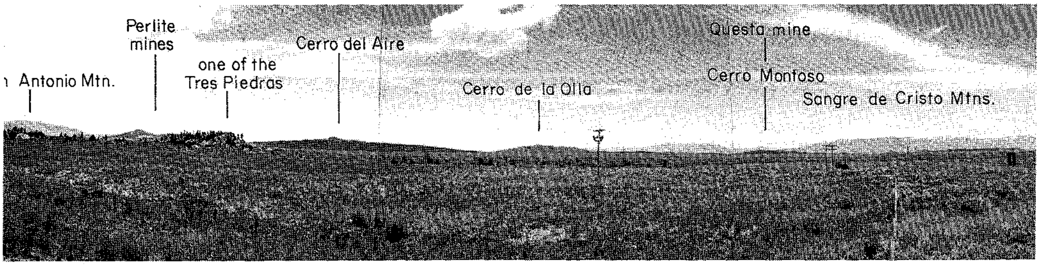
0.8 *Cross narrow bridge.* Good roadcut exposures of the Servilleta Formation basalt. West of the arroyo, the basalts display good examples of segregations, veins, and vesicle pipes—all features that develop during cooling and upward streaming of gas from the lava.

An undulating contact between two pahoehoe flows can also be seen here. Pahoehoe lava has a smooth surface in contrast to aa lava, which has a surface covered with angular, jagged pieces. The relief on the contact formed when the freezing surface of the older lava buckled into folds (pressure ridges) before it stopped moving. **0.2**

1.0 The Taos Plateau ahead, underlain by Servilleta Formation basalt, has a cover of windblown, sandy silt. **2.8**

3.8 Dip. Taos is at 12:30 at the base of the Sangre de Cristo Mountains. At 8:00 is Cerro del Aire (7 mi north), formed of olivine andesite with a silica content of 57-58 percent. A small spatter (cinder) cone is to the left of the summit crater. Compared with San Antonio Mountain, Cerro del Aire's slopes and silica content are both lower.

Two miles north, very low, broad shield volcanoes of the Servilleta basalt (silica content, 49-52 percent) underlie the low, timbered slopes



PANORAMA FROM A RAILROAD CUT 0.3 MI EAST OF TRES PIEDRAS; highway in right foreground is US-64; view to northeast from mile 0.3, Tres Piedras-Taos log.

silhouetted against the base of Cerro del Aire. These two shields are the largest exposed sources of the very fluid, low-viscosity Servilleta basalts that cover the Taos Plateau. A third large shield is hidden behind the other two. The volcanoes are approximately 3.6 m.y. old. At 9:00 is Cerro de la 011a and at 10:00 is Cerro Montoso, both forested shield volcanoes; at 9:30 is Cerro Chiflo, the four peaks that are nearly barren. **1.7**

5.5 The low mesa at 11:00 is composed of olivine andesite, similar in composition to that of Cerro del Aire. Because no volcanic vent is recognizable, the mesa may be considerably older than the other exposed volcanic rocks. Cerro de los Taos, at 1:00, is composed of olivine andesite. At 2:00 is Tres Orejas ("three ears"), composed of rhyodacite. The unnamed hill at 2:30 with a small butte on the summit is composed of olivine andesite. **4.9**

10.4 Junction with road to Arroyo Hondo. Our road curves right (south). At 9:00, 3 mi distant, are irregular hills formed by eroded, structurally complex, 22-25-m.y.-old volcanic rocks exposed in an uplifted horst block within the Rio Grande rift. These rocks are buried by younger volcanic rocks but continue to the north in the San Luis Hills of southern Colorado.

At 10:30, the spoil dumps of the Questa molybdenum mine appear as a conspicuous light scar high in the Sangre de Cristo Mountains, above the mouth of the Red River. Molybdenite mineralization is mostly fracture filling in granitic intrusions emplaced during an andesite and rhyolite volcanic sequence (22-25 m.y. old). The ages and compositions of the intrusions are similar to those in the horst block in the low hills to our left.

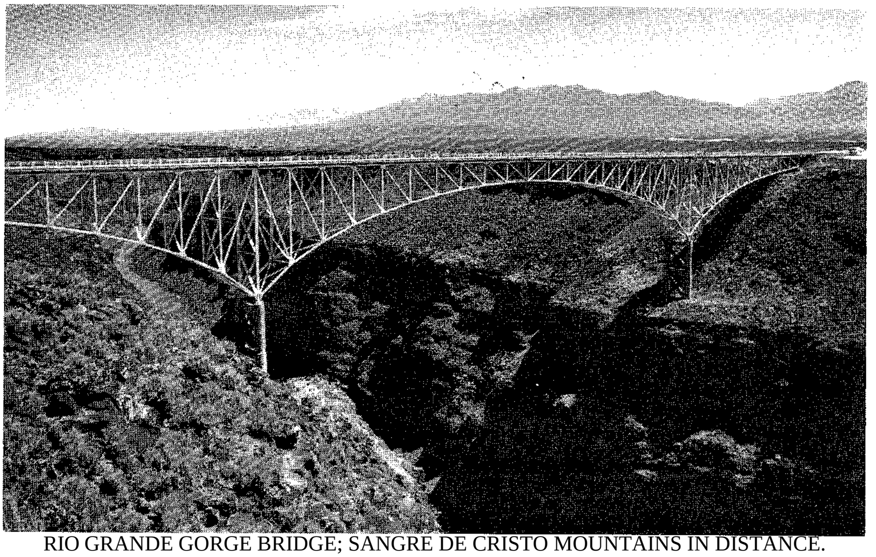
This structurally high block marks the western edge of the lowest block (graben) within the Taos Plateau segment of the Rio Grande rift. The eastern boundary of this graben is along the base of the Sangre de Cristo Mountains, marking the present-day eastern margin of the rift. The earlier margin lies farther east in the Sangre de Cristo Mountains and is poorly defined. North-trending segments of the Red River, Rio Pueblo de Taos, and Rio Fernando de Taos lie in fault zones that may mark the earlier fault boundary of the rift.

Cerro de la 011a is on the skyline at 8:00. At 8:30 Cerro Montoso, an olivine-andesite shield, rises above and covers the older rocks of the horst block. **0.2**

10.6 Roadcuts in basalts of the Servilleta Formation. **2.7**

13.3 Cattle guard. Straight ahead are the Picuris Mountains; the highest is Picuris Peak (10,810 ft). A fire tower can be seen on top if you have excellent vision or binoculars. The range is composed of Precambrian quartzite in the highest ridges on the skyline and a sequence of schist and quartzite in the lower ridges. These ridges are in large east-trending folds that have been offset to the south 25 mi along the Pecos-Picuris fault. The offset folds are in the Truchas Peaks area of the Sangre de Cristo Mountains, visible as high jagged peaks over the right shoulder of the Picuris Mountains. **0.7**

14.0 On the right, from 2:00 to 3:00, are Cerros de los Taos, two overlapping shield volcanoes of olivine andesite, similar to that of Cerro del Aire and Cerro Montoso. **4.5**



RIO GRANDE GORGE BRIDGE; SANGRE DE CRISTO MOUNTAINS IN DISTANCE.

VIEW UPSTREAM FROM RIO GRANDE GORGE BRIDGE. The six-man raft gives an idea of the canyon size.

18.5 The highway curves to the left. Tres Orejas Peaks are at 2:30. 0.6

19.1 *Rest area entrance; turn right.* **0.3**

19.4 *Rio Grande Gorge bridge; stop and walk onto the bridge.* The Rio Grande

is flowing 650 ft below. Float trips through this canyon are popular during the late spring and early summer runoff. The gorge here is approximately 1,200 ft wide and is cut in the Servilleta Formation, which consists of tholeiitic basalt flows and interlayered sediments. Ages of the flows in this canyon range from 4.5 to 3.6 m.y. Two main sedimentary units, comprising fluvial sand and gravel, are present in the gorge section but are largely covered by debris (talus). Typical basalt of the Servilleta Formation can be examined at the bridge abutment. The basalt is relatively coarse grained, has small gas holes, and contains small crystals of plagioclase, olivine, and augite. This basalt was erupted as highly fluid pahoehoe flows that traveled many miles; each flow was approximately 10 ft thick. The Servilleta basalt is nearly identical to basalt of the ocean floor.

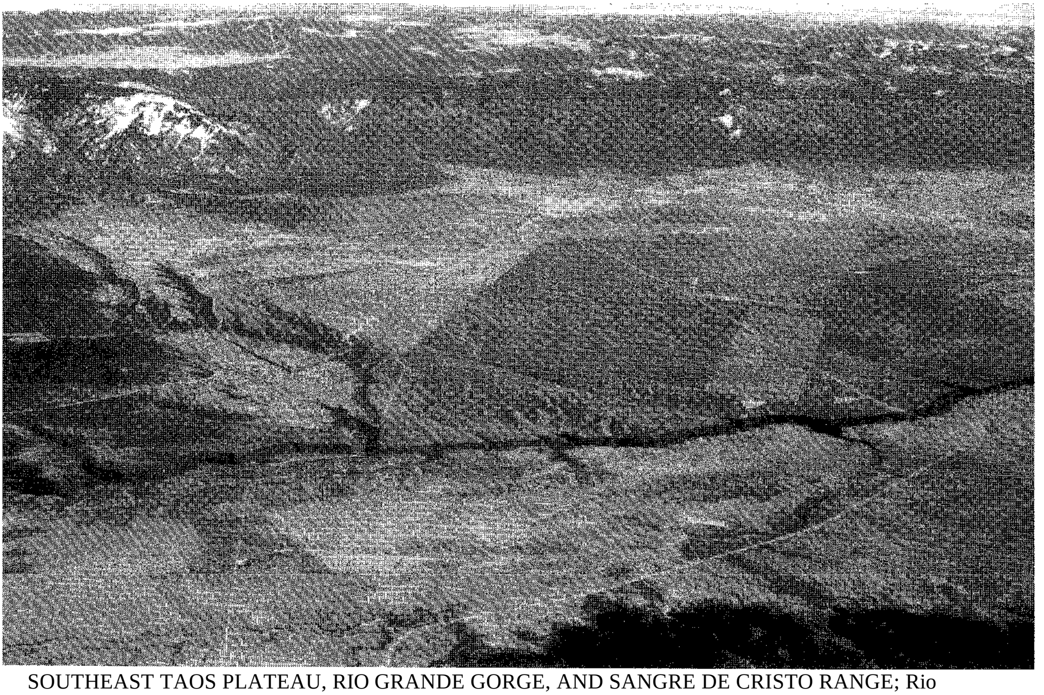
High bridge stop—regional discussion

Taos is in a topographic reentrant at the base of the Sangre de Cristo Mountains. The topographic low results from the absence of volcanoes and lava flows (like the volcanic area of Cerro Negro, north of Arroyo Hondo) combined with continued downdropping of the Taos Plateau against the foot of the Sangre de Cristo Mountains.

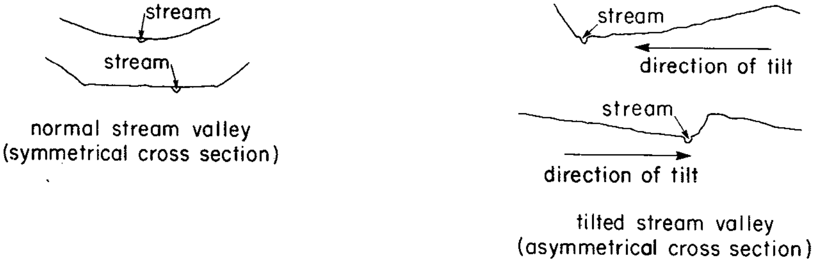
The Sangre de Cristo Mountains can be divided into two segments, each with its characteristic skyline. North of Rio Pueblo de Taos, the Taos Range has high, irregular peaks formed of Precambrian igneous and metamorphic rocks. To the south the lower, smooth, tilted surfaces are formed of Pennsylvanian sedimentary rocks; the older Precambrian rocks lie below valley level.

Precambrian granite is exposed in the north-trending ridges separating the Sangre de Cristo Mountains from the Picuris Mountains in the west. The west-trending ridges of the Picuris Mountains are underlain by mainly quartzite units of Precambrian metasedimentary rocks of the range. The north-trending Picuris-Pecos fault (probably Precambrian) east of Picuris Peak had 25 mi of right-lateral slip.

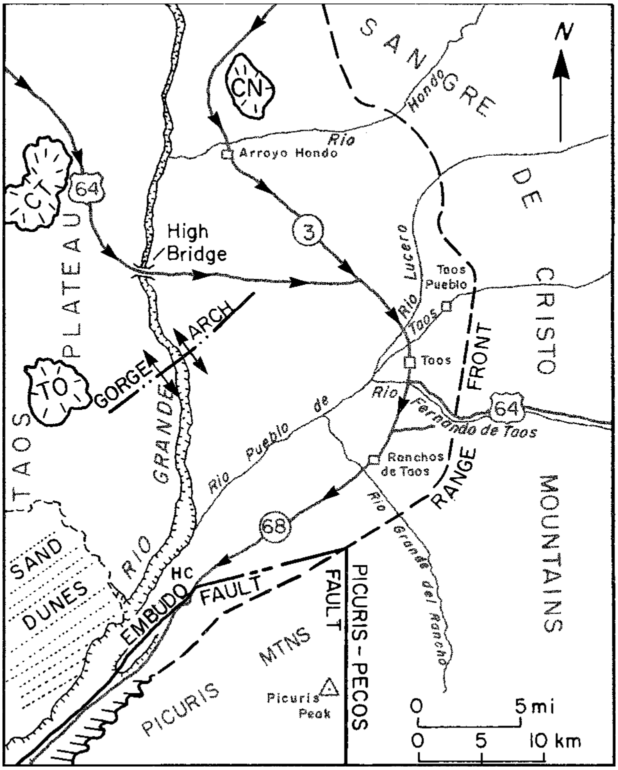
The Taos reentrant shows many drainage anomalies caused by warping and faulting that is younger than the Servilleta basalts of the Rio Grande Gorge. Near Taos a group of small faults, downthrown to the west, are in line with the northward extension of the Picuris-Pecos fault. This alignment suggests that the border fault of the rift has its location controlled by the older, major Picuris-Pecos fault. This older fault also has been the boundary of late Paleozoic and Laramide uplifts.



SOUTHEAST TAOS PLATEAU, RIO GRANDE GORGE, AND SANGRE DE CRISTO RANGE; Rio Grande Gorge bridge is at lower right; view to southeast.



SKETCHES OF NORMAL AND TILTED STREAM VALLEYS.



MAP OF TAOS REENTRANT showing drainage anomalies caused by growing Gorge arch and continuing subsidence of the Taos area along the main border (range-front) fault; CN = Cerro Negro; CT = Cerros de los Taos; TO = Tres Orejas.

Continuing deformation of the reentrant is indicated by the consistent asymmetries of the stream valleys, a broad anticline (Gorge arch) that developed in the Servilleta basalts across the gorge east of Tres Orejas, reverse faults in the frontal fault zone of the Picuris Mountains (Taos-Espanola log, mile 11.8), and scarps cutting late Quaternary surfaces along the base of the Sangre de Cristo Mountains. Taos is subsiding relative to the rest of the reentrant; as a result, all drainage from the high mountains is deflected east toward Taos. The Rio Pueblo de Taos lies along a structural low that aligns with the northeast extension of the frontal fault zone of the Picuris Mountains in the Rio Grande Canyon. Parallel to the Rio Pueblo de Taos is the anticlinal Gorge arch that causes the stream-valley asymmetry to change sides. The Taos Municipal Airport is on the topographic divide that marks this zone of change. **0.2**

19.6 *Rejoin US-64; turn right and cross the Rio Grande Gorge bridge.* **0.4**

20.0 East bridge abutment; Rio Grande Gorge bridge historic marker ahead on left. **0.4**

20.4 Upper sandy-gravel facies of the Servilleta Formation. From here to the valley of Arroyo Seco (mile 26.9, crossing Arroyo Seco), the roadcuts are in upper Servilleta Formation (sandy gravel) capped with brown, sandy alluvium or deposits of arroyo-terrace gravel. Soils with prominent horizons of clay and carbonate accumulation are commonly developed. **0.1**

20.5 Entering the first of many asymmetrical valleys that our route will cross on this portion of the Taos Plateau. Stream valleys are normally symmetrical because the stream is free to meander across its floor, but the streams in this region are in an area that is being tilted and folded. During tilting, the stream cuts against the downhill side only; the valley has a steep side (downhill) and a gentle side (uphill), the result of progressive lateral cutting to its present position. This valley has been tilted to the east, our travel direction; we will find that the next valley is asymmetrical in the same direction. **0.4**

20.9 This ridge is a divide in the direction of asymmetry. The valley ahead tilts west (toward us), and all further valleys tilt in the same direction until we cross the topographic crest (drainage divide) of the Gorge arch. This arch has folded the 3.6-m.y.-old basalts and their younger cover into a northeast-trending anticline; therefore, the drainage that was moving toward the Rio Grande is being diverted from the crest of the anti-cline. **1.4**

22.3 East-facing scarp in a broad, asymmetrical valley. **1.5**

23.8 Side road to Taos Municipal Airport. The airport is on the broad divide where asymmetry of stream valleys change sides.

Picuris Peak is at 2:30, with its bald side toward us. At 2:00 on the distant skyline is Jicarilla Peak (12,750 ft), with a tilted, flat top that is usually covered with snow patches all year. This peak is underlain by gently west-dipping Pennsylvanian rocks of the southern continuation of the Sangre de Cristo Mountains.

The road ahead leads to the valley of Rio Fernando de Taos, through which US-64 climbs to Eagle Nest, Cimarron, and Raton. To the north, the valley of the Rio Pueblo de Taos marks the prominent division of the Sangre de Cristo Mountains described at the Rio Grande Gorge bridge stop (mile 19.3). Taos Indian Pueblo is at the mouth of the valley. The Jemez Mountains are at 4:00 on the distant skyline. **0.5**

24.3 A divide, where asymmetry of valleys changes sides. **0.4**

24.7 Steep, west-facing scarp in asymmetrical valley. **0.2**

24.9 Roadcut in alluvium of upper Servilleta Formation. Note the well-developed soil profile. **0.2**

25.1 Asymmetrical valley. **0.3**

25.4 Viewpoint, with panorama of Sangre de Cristo and Picuris Mountains. **0.5**

25.9 Large asymmetrical valley. A long roadcut in Servilleta sandy-gravel facies is overlain by brown, sandy alluvium. **1.0**

26.9 Crossing Arroyo Seco. **0.5**

27.4 Here the sandy-gravel facies of the upper Servilleta Formation consist of pebbles and cobbles of Precambrian igneous and metamorphic rocks, as well as Tertiary volcanic rocks derived from the mountains east of Taos.

Common rock types are granite, gneiss, schist, amphibolite, and rhyolite. CAUTION! *Junction ahead.* **0.4**

27.8 Junction on left with NM-3 to Questa and Red River. Ahead, NM-150-NM-230 leads to the Taos valley ski area. *Turn right and continue southeast on US-64.* **0.3**

28.1 Descending to the upper end of the broad Rio Lucero valley. Wet meadows reflect convergence of drainage sources, augmented by flows of irrigation ditches, into this valley. **1.4**

29.5 At 9:00, a large fault scarp cuts across the base of the steep alluvial fan. **1.3**

30.8 *Enter Taos (6,950 ft).* The European community, southwest of Taos Pueblo, was settled in 1617 when Father Pedro de Miranda built a mission. This site was abandoned during the 1680-1692 Pueblo rebellion but was later resettled. French traders came to the Taos fairs in the 18th century, and Anglo-American trappers and traders arrived after 1820. Between 1815 and 1837 the mountain men trapped fur-bearing animals, fought the Indians, and scouted for parties opening new land. These were men of all races and cultural backgrounds. The most famous were Christopher (Kit) Carson, who was a scout, explorer, and Indian agent, and Charles Bent, who in 1846 became the first governor of the Territory of New Mexico. About 1890 Taos became popular with artists and writers (including D. H. Lawrence); any made Taos their permanent home. **0.5**

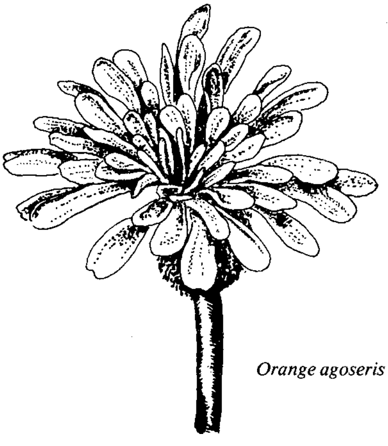
TAOS PLAZA.

31.3 Junction on left with Taos Pueblo Road. The pueblo, 3 mi to the northeast, had a 1972 population of 1,516 and a reservation area of 95,333 acres. According to the U.S. Department of Commerce (1974):

> The Spanish, under Hernando de Alvarado, discovered Taos Pueblo in 1540 much as it is today, with two large communal houses facing each other across Taos Creek. Colonists from Don Juan De Oñate's community soon settled nearby. A series of Indian revolts against the settlers culminated in the successful Pueblo Revolt of 1680 spearheaded from Taos and led by Popé, a San Juan Indian. The Spanish were driven from New Mexico, not to return for 13 years. The Spanish returned in 1693, and, in 1696, with the order by de Vargas that all pueblo governors be shot, effective resistance ceased. After the conquest of New Mexico by the United States in 1847, Taos again revolted against occupation troops and the American governor, Charles Bent, and others were murdered. The revolt was crushed and the leaders were hanged.
>
> The Indians of Taos have an ancient and rich cultural past, much of which continues to survive. They live in large communal houses, the upper stories of which are reached by ladders. Round outdoor baking ovens and strings of chili drying in the sun are typical. The underground kivas serve as meeting places for the men, with women admitted only on certain occasions. The Deer, Turtle, and Sun-Down Dances are unique and noted for their beauty and precision. The latter, given on September 30th yearly, is the most important ceremony and expresses thanksgiving for the harvest. Most of the Taos people are farmers, many are artists, and others find employment in the nearby town of Taos. The Taos are the least typical of the Pueblo Indians, for they share many characteristics with the Plains Indians, particularly the Kiowa with whom they have a linguistic relationship. **0.5**

31.8 Traffic light; Taos Plaza to the right. In Taos are Governor Bent's home, Kit Carson's home, art galleries, and other attractions. (For further in-formation and points of interest in Taos, see Scenic Trip No. 2.)

END OF LOG



Orange agoseris

Taos-Española

This log describes the route south to the end of the Taos Plateau at the base of the Picuris Mountains. As the highway descends to the lower Rio Grande Gorge, it parallels the Embudo fault zone almost to Espanola; this major transverse structure separates the Taos Plateau (lower San Luis Basin) from the Espanola Basin. At Espanola, this route and the Rio Grande turn south from the Embudo fault into the actively subsiding block of the Espanola Basin which occupies the same position that the river had in the Taos Plateau.

Mileage

0.0 *The tour begins on US-64 at the traffic light in the center of town opposite the plaza. Travel south on US-64.* **0.2**

0.2 Crossing the valley of Rio Fernando de Taos for the next 0.7 mi. **1.9**

2.1 Junction with NM-68. *Continue straight ahead on NM-68.* US-64 turns left to ascend the valley of Rio Fernando de Taos to Angel Fire, Eagle Nest, Cimarron, and Raton.

At 11:00 up the valley of Rio Grande del Rancho is Jicarilla Peak, the tilted mesa cap on the skyline. The highway through this valley follows the early Camino Real, the main route of travel between Taos and Santa Fe before the construction of the highway through the Rio Grande Canyon. Fort Burgwin, a U.S. Army cantonment occupied between 1852 and 1860, is in the valley. The fort and officers' quarters have been reconstructed, and a museum and research center are operated during the summer months by Southern Methodist University.

To the left of the valley are smooth slopes eroded from Pennsylvanian rocks. The ridge to the right is underlain by Precambrian pink granite with upturned Mississippian-Pennsylvanian rocks along the left slope of the ridge. The broad valley farther to the right is filled with Picuris Tuff, a unit that marks the earliest filling of the Rio Grande rift; the west wall of the valley is Precambrian granite that lies along the Picuris-Pecos fault. Picuris Peak is on the skyline beyond. **1.5**

3.6 Junction on left with NM-3. *Continue straight ahead on NM-68.* NM-3 leads to Fort (Cantonment) Burgwin (6 mi), Tres Ritos, Sipapu ski area, Mora, and Las Vegas. NM-3 goes through beautiful, heavily forested mountains.

Entering Ranchos de Taos, an old Indian farming center closely united with the Pueblo San Geronimo de Taos and the Spanish town of Taos (Don Fernando de Taos). Ranchos de Taos was founded by members of the Taos Pueblo who were looking for richer farm land. This frontier town was often raided by the Apache and Comanche Indians. **0.3**

3.9 St. Francis of Assisi Church is on the left. The original church was built about 1730; after a period of disuse, the church was rebuilt in 1772. This beautiful adobe church is famous for its high entry wall and massive stuccoed walls supported by great abutments. The equally striking interior has gigantic beams (vigas) supporting the nave and transept, a large reredos with carved pillars and wooden partitions, and many historical religious objects, including a mystery painting of Christ. Virtually every artist who has worked in Taos has rendered his or her version of this famous church. **0.2**

4.1 Crossing the valley of Rio Grande del Rancho. **0.3**

4.4 Llano Quemado; the road ascends to the fan surface of post-Servilleta terrace gravels. **0.2**

4.6 At the base of the mountain at 9:00, Ponce de Leon hot springs mark the intersection of two major fault zones. One is nearly parallel to the length of the mountain; the other is parallel to the mountain front. **0.6**

5.2 Crossing the alluvial slope at the north base of the Picuris Mountains. The surface is cut by asymmetrical valleys, with west-facing scarps which indicate that the Taos-Ranchos de Taos area is sinking relative to the Rio Grande ahead of us. **0.4**

5.6 Junction on right with NM-96: this road descends along the Rio Pueblo de Taos to the Rio Grande, where the road divides. NM-96 continues along the Rio Grande through Rio Grande Gorge State Park, which has picnic and camping facilities, to rejoin our route at Pilar (mile 16.6). The other road crosses the Rio Grande, continues to Carson and Taos Junction, and joins US-285 at mile 20.5 (Tres Piedras-Española log). Taos Junction is the abandoned narrow-gauge train station nearest to Taos. Railroad passengers going to Taos had to continue their journey by stage across the plateau, through the Rio Grande Gorge, and on to Taos. **0.9**

6.5 At 9:30 the view is up the valley of the Picuris-Pecos fault. Roadcuts ahead are in the upper Servilleta Formation. **1.6**

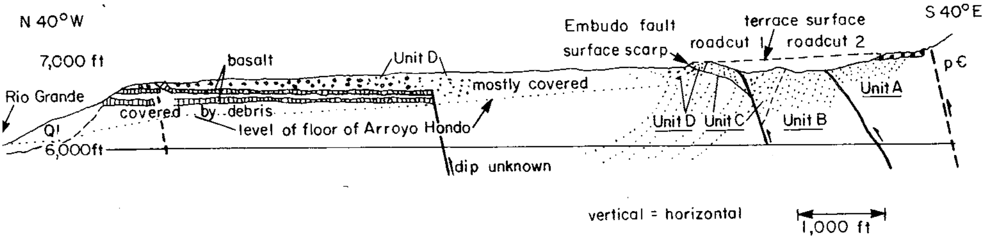
8.1 Stakeout Drive was so named because, according to local legend, near the base of the hills a posse once waited in vain for a gang of outlaws. An asymmetrical valley is ahead on the right. **0.8**

8.9 Large asymmetrical valley. **0.6**

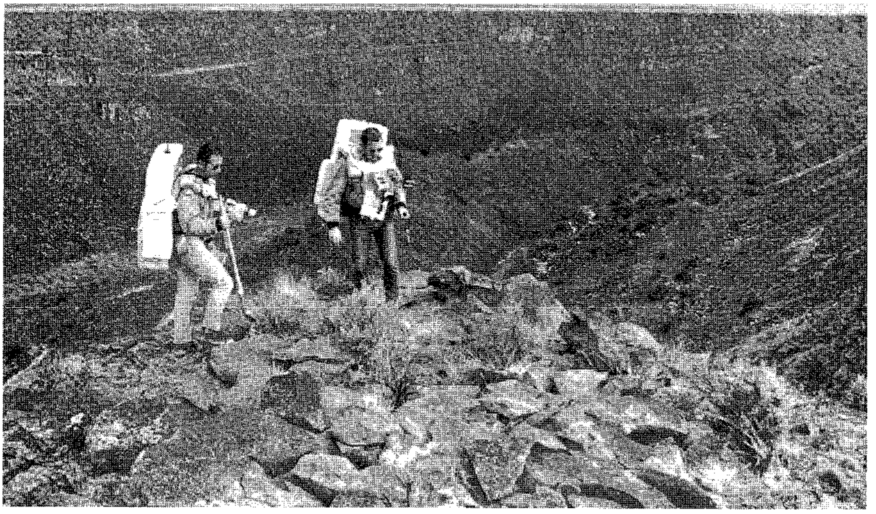
9.5 Straight ahead is Tschicoma Peak (11,561 ft) on the northeast shoulder of the Jemez Mountains. At 1:00, on the plateau, is Cerro Azul, composed of Precambrian quartzite. **0.2**

9.7 View to the right (3:00) up the Rio Grande Gorge. Gorge arch (anticline) is visible where it crosses the canyon. (See Tres Piedras-Taos log for map.) **2.1**

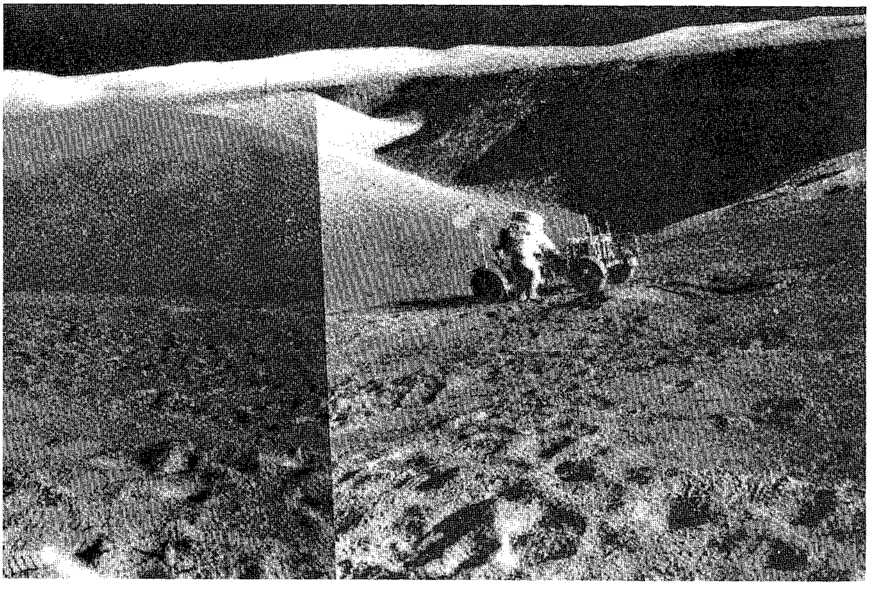
11.8 Stop at picnic area, Rio Grande Gorge overlook. This viewpoint at the southern edge of the Taos Plateau overlooks the Rio Grande Gorge and offers a superb panorama of the Taos Plateau and its bordering uplifts.



CROSS SECTION ALONG HONDO CANYON NEAR MILE 11.8, TAOS-ESPANOLA LOG; Unit A = Santa Fe Group; Unit B = Lower Santa Fe Group; Unit C = Upper Santa Fe Group; Unit D = Upper Servilleta Formation,



APOLLO 15 ASTRONAUTS DAVE SCOTT (RIGHT) AND JIM IRWIN (LEFT) on a geological field trip along the rim of the Rio Grande Gorge (courtesy of NASA; photo S-71-23475).



HADLEY RILLE, APOLLO 15 SITE ON THE MOON. Astronaut Jim Irwin stows rock samples while Dave Scott takes final photographs of sampling area. Hadley Rille and the Rio Grande Gorge (mile 11.8, Taos-Espanola log) have the same dimensions: 1 mi across and 600 ft deep (courtesy of NASA; photos AS15-85-11448, 11451).

Turning our backs to the Gorge and looking south along the highway in our direction of travel, we see a prominent fault scarp that crosses the roadcut approximately 100 yds ahead, marking the presently active trace of the Embudo fault.

A cross section of rocks exposed along the east wall of Hondo Canyon (on p. 78) shows the relations between the basalts of the Taos Plateau, the Embudo fault zone, and the upthrust border of the Picuris Mountains. When the Embudo fault last moved is unknown. Activity must have taken place before the settlement of the Taos Pueblo (more than 900 yrs ago), because an earthquake large enough to produce this scarp would have severely damaged, if not destroyed, all buildings in the area.

Take extreme care in walking along the roadcuts; this highway is very busy! Keep off the pavement. Descriptions of the next 5 mi occur in rapid succession; drive carefully. **0.1**

11.9 Roadcut 1 on right; the Embudo fault is a low-angle thrust fault. **0.1**

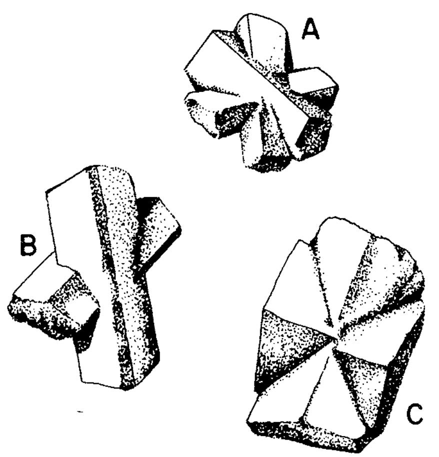
12.0 Roadcut 2 on left; the reverse fault probably is still active, although no scarp is visible to prove it. **0.2**

12.2 Crossing Hondo Canyon. Several miles up this canyon is the source of the twinned staurolite crystals that are for sale in many mineral shops. **0.3**

12.5 Roadcut on left; the Embudo fault is a steep reverse fault here. Down Hondo Canyon (right) is the southern termination (probably against a dead(?) fault) of the Servilleta Formation basalts of the Taos Plateau. **0.6**

13.1 Crest of the grade; picnic tables. The road now leaves the Taos Plateau and descends into the Rio Grande Gorge. **0.2**

13.3 Roadcut on left; here the Embudo fault is a steep normal fault. The surface trace of the fault continues southwest to Pilar (mile 16.6). A few hundred yards before the fault reaches the end of the mesa above Pilar, it reverses its surface expression from south side up (as it is here) to north side up.



STAUROLITE CRYSTALS (approximately twice natural size). A) triple penetration twins, B) 60 ° twin, C) 90° twin.

The downhill end of the roadcut exposes 40- to 50-ft-thick alternating bands of eolian sandstone formed from dune sand blown from the west, stream gravels derived from the Picuris Mountains to the south, and dark red-brown muds (lake or meadow deposits) of the Santa Fe Group. These bands may be equivalent to the Ojo Caliente Sandstone Member described in the Tres Piedras-Espanola log, mile 28.4. **0.5**

13.8 A roadcut on the right is in sand-dune facies of the Santa Fe Group. Many small reverse and strike-slip faults cut this sand and erode to form ridges because the fault zone is lightly cemented. **0.2**

14.0 Coarse alluvial-gravel facies on sand-dune facies of the Santa Fe Group. The Picuris Mountains are ahead to the left. **0.1**

14.1 A Servilleta basalt flow at 3:00 caps the mesa. The flow is absent for a short distance ahead; then the flow reappears and is continuous along the mesa edge to Pilar. On the opposite (Rio Grande) side, less than half a mile to the north, four or more basalt flows cap the mesa. The flows terminate against the fault zone, and only the top flow extends across the mesa to the outcrops above. This basalt and the underlying, rounded, stream gravel, derived from a source to the north, rest with a strong angular unconformity on the Santa Fe Group.

The gravel cap above the basalt is composed of rocks derived from the Picuris Mountains. This cap represents the last deposit laid down to the north across the mesa and toward the ancestral Rio Grande before the drainage was intercepted by the headward-growing canyon that we are crossing.

The low hills from 8:00 to 11:00 that form an embayment in the Picuris Mountains are underlain by tilted and faulted deposits (Santa Fe Group); these hills are capped by stream gravels of an earlier episode of valley development. **1.1**

15.2 The arroyo on the left is deeply incised into Holocene alluvium. Beyond the arroyo is a thick, stream-gravel cap on sand-dune facies and buff silt of the Santa Fe Group.

At 11:00 are scars from mining operations in a mica-rich phase of the Ortega Quartzite (Precambrian). **0.7**

15.9 *Crossing bridge over Rito Piedra Lumbre.* **0.2**

16.1 *Turn out on the right.* At 3:00 tilted, buff sand and gray gravel of the Santa Fe Group is overlain by (in ascending order) 40 ft of nearly horizontal gravel (source to the north), a single basalt flow, and a cap of gravelly alluvium derived from the Picuris Mountains to the south. The roadcut at 11:00 is in coarse, upper Pleistocene gravel derived from the Picuris Mountains. **0.5**

16.6 Enter Pilar. Junction on right with NM-96 to Rio Grande Gorge State Park. Pilar is the site of a primitive farming community established in pre-Spanish times by Indians whom the Spanish later would name Jicarilla Apache. In 1694 their village was destroyed by de Vargas. In 1822 the governor ordered that the Indians be allowed to live and farm in the new settlement of Cieneguilla (established in 1795), but the order never was enforced because of strong Spanish-Mexican opposition. After the territory became American, the Apaches revolted. From the historic marker:

In March, 1854, Apaches ambushed a detachment of U.S. Dragoons under Lt. John W. Davidson nearby, killing 22 soldiers. The wounded survivors escaped over the mountains to Cantonment Burgwin. Peace came later in the year when the Indians were forced to sign a treaty.

(See mile 3.6 of this log for turnoff to reconstructed Fort Burgwin.) The old bridge at Pilar was built in the early 1880's and is the most recent of a series of bridges built at this spot. The earliest bridge is believed to have been erected in 1598. **0.2**

16.8 *Stop at turnout on the right.* Good view northeast (4:00) up the Rio Grande to Pilar. The cross section exposed here includes the end of the mesa beyond Pilar. Notice the change in number and position of basalt flows across the active trace of the Embudo fault in the light-colored scar.

For the next 25 mi, enormous landslide blocks downstream flank the basalt-capped mesas along the Rio Grande Canyon. Black Mesa (across the river) and La Mesita (Velarde Mesa, downstream on this side) are underlain by easily eroded Santa Fe Formation; when the Rio Grande was a large river during the Pleistocene glacial age, the river undercut the slopes and caused these slides to move.

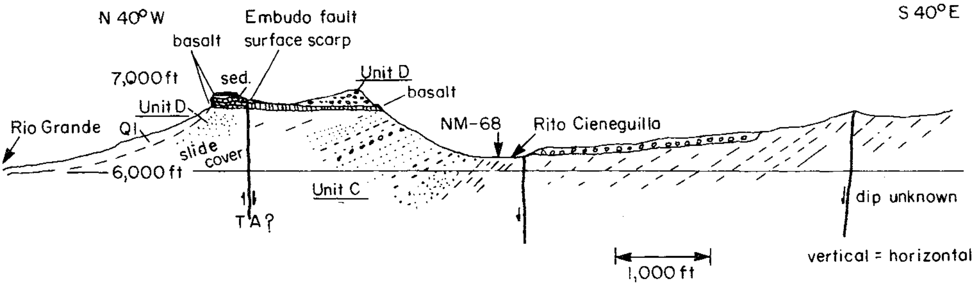
For the next 5 mi, the highway skirts the base of cliffs over 1,000 ft high (left) underlain by Precambrian quartzite and schist of the Picuris Mountains. The Rio Grande parallels the Embudo fault zone from Pilar to the end of Black Mesa near the San Juan Pueblo (25 mi). The trace of the fault scarp seen in the cliffs behind Pilar continues across the lower part of the landslides and generally is not visible from the road.

Across the road from the turnout, near-vertical beds contain abundant volcanic fragments and are probably composed of the Chama-El Rito Member (Tesuque Formation). **0.1**

16.9 Steeply southeast-dipping metarhyolite that is in fault contact (high on the cliff side) with overlying Ortega Quartzite (Precambrian). Approximately 2,500 ft are exposed before the unit passes upward (ahead) into alternating schist and quartzite units of the Rinconada Formation. This sequence forms the cliffs for the next 4 mi. **0.6**

17.5 Picnic tables at right. **0.6**

18.1 Precambrian rocks at river level on the right. The river usually forms the boundary between the Precambrian rocks and the toes of the landslides.



CROSS SECTION OF EMBUDO FAULT AT PILAR; Unit D = Upper Servilleta Formation (mile 16.8, Taos-Española log).

Apparently some major slides blocked and diverted the river, and later downcutting superposed it on the Precambrian rocks. The Precambrian rocks along the river are always highly fractured and altered, probably because they are close to or part of the Embudo fault zone that mainly lies under the landslide debris across the river. **0.8**

18.9 Turnout. Across the river are extensive spring-fed marshy areas in the landslide terrain. **0.4**

19.3 Suspension bridge across the Rio Grande to the former site of Glenwoody mining camp. In 1902 a town was laid out, a flume and 160-horsepower turbine were installed on this side of the river, and a hotel and other buildings were erected, but the gold-mining venture was a failure. The only remains are the bridge and some placer mine dumps along the edge of the river. **0.2**

19.5 Sheared Precambrian rocks across the river; Rio Grande river-gravel remnant on Precambrian rocks. Ahead on the right is a small placer mine in river gravel. **0.7**

20.2 Spring-fed trees and marsh across the river. **0.2**

20.4 Historic marker on right:

> Kit Carson Highway. Kit Carson, foremost of New Mexico's frontiersmen, was a frequent traveler over the route between Taos and Santa Fe during his long career as a hunter, trapper, scout, Indian fighter and Indian agent, 1828-1868. This route was followed by the Captain of the Spanish Conquistadores, Coronado, in 1541.

In the roadcut are samples of quartzite (some with kyanite or sillimanite) and white mica (muscovite) schists with garnet (red), biotite (black), and staurolite crystals (long gray rectangles). **1.2**

21.6 Roadcut in Pleistocene landslide (debris-flow) deposit. This flow moved southward from left to right toward the Rio Grande. The road climbs onto the deposit. **0.2**

21.8 Roadcut in debris-flow materials. Note the random mixture of materials and the irregular, hummocky surface—both characteristic features of these deposits. **0.4**

22.2 Roadcut in coarse, bouldery gravel of debris-flow deposit resting on Chama-El Rito Member (volcaniclastic facies). A small fault is near the south end of the cut. **0.2**

22.4 Village of Rinconada ("place in the corner") in the valley ahead. Basalt-capped La Mesita (Velarde Mesa) at 12:00. The bluffs at 10:00 are Chama-El Rito Member. The upward gradation from volcaniclastic gravel to buff sands is well displayed. **1.1**

23.5 Roadcut in crossbedded sand, probably the Ojo Caliente Sandstone Member. 0.6

24.1 At 1:00, below the skyline rim of Black Mesa, is a set of steplike, basalt-capped landslide blocks. **0.5**

24.6 Basalt-capped mesa ahead at 2:00. **0.4**

25.0 Roadcut on the right is in crossbedded sand-dune facies, Ojo Caliente Sandstone Member. **0.1**

25.1 *Cross Rio Embudo bridge.* Junction with NM-75 on left to Dixon, Harding pegmatite mine, Picuris Pueblo, and Peñasco.

The basalt cap of the mesa at 11:00 has a tilted block at the west end,

Probably part of the fault zone along which we have been traveling.

Horizontal ribs of crossbedded sandstone, low on the slope, mark ancient water tables. **0.3**

25.4 Road to Embudo at right. **0.2**

25.6 The route enters the Embudo-Velarde segment of Rio Grande Canyon, which is flanked by basalt-capped La Mesita (left) and Black Mesa (right). The Embudo fault zone widens here; some faults branch to the south (left), but the main zone leaves a structural depression along the river. Black Mesa and La Mesita tilt toward the Rio Grande, but La Mesita also has a fault that causes the mesa to step down toward the river. **0.4**

26.0 Tip of Black Mesa at 12:00. From the historic marker:

> Francisco Barrionuevo and Hernando de Alvarez, captains in the army of Francisco Vasquez de Coronado, passed this way enroute to Taos Pueblo in 1541, while exploring from Tiguex, Coronado's headquarters near Bernalillo.

On the right, the abandoned grade of the Chili Line, a narrow-gage roadbed of the Denver and Rio Grande Railroad to Santa Fe, winds its way down from the Taos Plateau to the level of the Rio Grande. This line was constructed in 1880 and abandoned in 1941. **0.8**

26.8 House built of river gravel on the right. **1.0**

27.8 The old bridge to Embudo (right), formerly a station on the narrow-gage line. **0.2**

28.0 The national historic landmark of the American Society of Civil Engineers (right) commemorates the establishment in 1889 of the first river-gauging station by the U.S. Geological Survey. **1.8**

29.8 The low dam in the Rio Grande diverts water into the Velarde irrigation system. **0.5**

30.3 Rio Grande Canyon historic marker to the right:

> In this canyon the forces of Don Diego de Vargas defeated the Taos Pueblo Indians in battle in September, 1696, bringing final submission after the Pueblo Revolt of 1680. The canyon is the Rio Grande's last hurdle in the high country before spreading out to the south as a turgid stream.

OLD EMBUDO BRIDGE ACROSS RIO GRANDE; mile 27.8, Taos-Española log.

Reconquest of New Mexico

Spanish rule in New Mexico ended August 21, 1680, when the Indians revolted. Popé, a Tewa Indian medicine man from San Juan Pueblo, led the revolt. The Spaniards were driven south from Santa Fe to El Paso del Norte, which remained the capital city for 13 years.

Don Diego de Vargas came from a wealthy family, distinguished for centuries of service to the church and the crown in Spain. In Mexico, de Vargas performed with honor and distinction in a succession of political posts. In 1688, the king appointed him governor and captain general of New Mexico. At his own expense, de Vargas outfitted an expedition of reconquest and took command of El Paso in 1691. He cited three reasons for reestablishing Spanish dominion: to restore the Indians to the church; to provide a northern buffer against the French; and to acquire the quicksilver (mercury) that was rumored to exist in the region in commercial quantities.

In 1692 de Vargas left El Paso with an army of 60 Spaniards and 100 Indians to enter an area populated by 25,000-30,000 Indians. The governor, a strong military leader, preferred to win by diplomacy, but sometimes he was cruel to the Indians. Because Popé had copied the oppressive ways of the previous white rulers, the loyalties of the Indians were divided. Taking advantage of this division, during a 4-month march de Vargas restored 23 pueblos to Spain without a fight, baptized more than 2,000 Indians, and captured great Zuni treasures for the crown. However, he found no quicksilver.

On December 16, 1693, de Vargas returned to Santa Fe and recolonized New Mexico with a group from El Paso consisting of 70 families, 100 soldiers, and 17 Franciscans. In 1695 the Franciscan missions were reestablished. The pueblos rebelled again in 1696, but after the governor ordered all of the rebel leaders killed, the pueblos caused no further trouble.

While the Spanish were gone, their abandoned horses had run wild and multiplied. The Indians, who had been forbidden to use horses before the Pueblo rebellion, discovered their usefulness for hunting and raiding; consequently, Comanches, Apaches, and Navajos were constantly stealing horses from the Spanish—a new problem for the conquerors.

We now leave the upper canyon section of the Rio Grande and enter the broad valley characteristic of the Rio Grande throughout much of New Mexico. From here to Espanola, the route is on either the modern floor or the low Pleistocene terraces of the broad inner valley of the Espanola Basin. **0.2**

30.5 *Enter Velarde*, a center of fruit growing; frontage road to the right. 1.0 31.5 South edge of Velarde; road ascends from the valley floor to the slope at the foot of the mesa. **0.7**

32.2 The outcrop at 11:00 on the skyline is a gravel cliff of the Cejita Member (Tesuque Formation). **2.4**

34.6 Black Mesa, on the skyline and to the right, is capped by 2.8-m.y.-old basalt of the Servilleta Formation. The Chamita Formation, the youngest unit under the basalt, is preserved as a wedge under the southwest part of the mesa. The landslides at 3:00 are well developed. **1.6**

36.2 The road to Jemez House is on the right. From 12:00 to 2:00 on the skyline are the Jemez Mountains. 2.4

38.6 Junction on right with NM-389 to Alcalde. 2.2

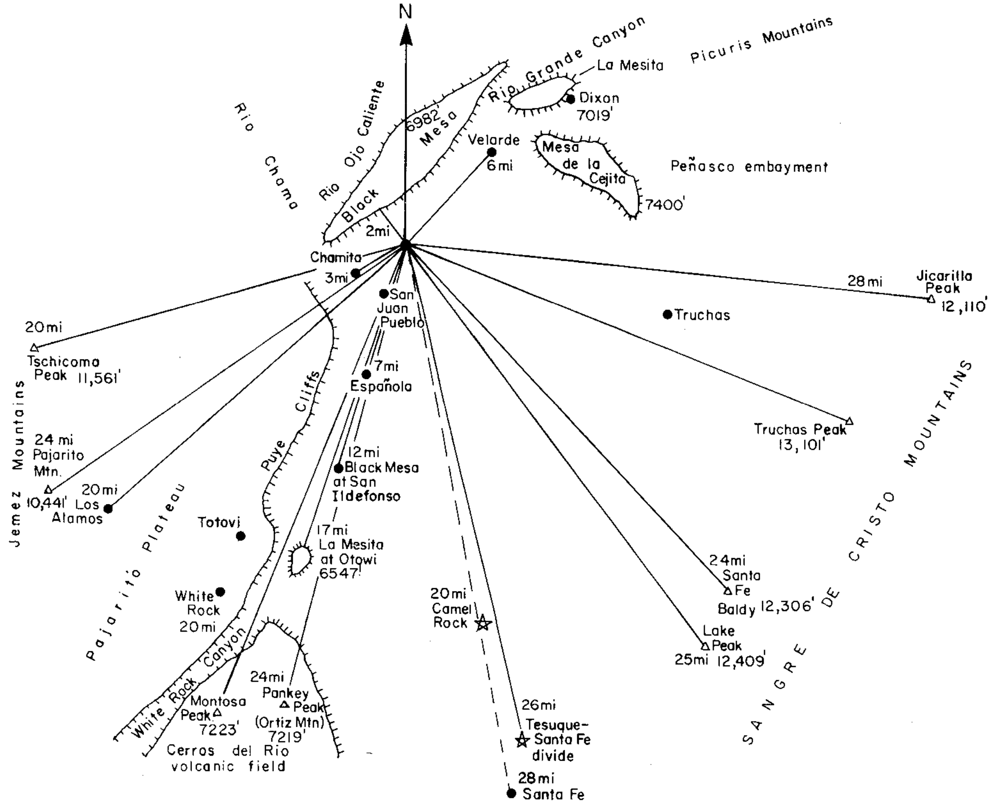
40.8 *Begin four-lane highway.* San Gabriel historic marker:

> The first Spanish capital in the western United States was established by colonizer Oñate, as San Gabriel del Yunque in 1598. The historic site lies just across the river from the present San Juan Pueblo. It remained the capital of this vast territory for ten years. **1.0**

41.8 Junction on right with NM-74 to San Juan Pueblo; this log joins the tour log from Tres Piedras. Historic marker:

> This pueblo was named San Juan de los Caballeros in 1598 by the colonizer, Oñate, because of the kindness shown to the Spaniards. San Gabriel, the first Spanish colony in the western United States, was established by Oñate across the river from San Juan Pueblo.

San Juan Pueblo is on the east bank of the Rio Grande and has been occupied since about 1300 A. D. In 1970 the population was approximately 1,500. The pueblo is of adobe construction with a modified street-type arrangement. Kivas are rectangular and are enclosed within the irregular house groups. The language spoken is Tewa. Most men farm; the women



PANORAMIC INDEX OF FEATURES SEEN FROM MILE 38.6 (Taos-Española log), ESPANOLA BASIN AT ALCALDE produce baskets and pottery of polychrome designs on polished red or black backgrounds, as well as any beautiful textile items. In 1969 the EDA (Economic Development Administration) gave 80 percent and the pueblo provided 20 percent of the funds needed to build a multipurpose training facility that houses programs- for pre-school Head Start, adult education, counseling, and arts and crafts. The annual fiesta and Corn Dance is held June 24.

Ahead from 11:00 to 1:00, the mesa surface is capped by the Cerros del Rio volcanic field (12:00-1:00). This surface marks the level of the valley at the inception of the Rio Grande as a through-flowing river. The Puyé Cliffs, from 1:30 to 2:30, are capped with gravels of this ancestral Rio Grande. Since then (2.4 m.y. ago) the Rio Grande has carved this valley. **1.1**

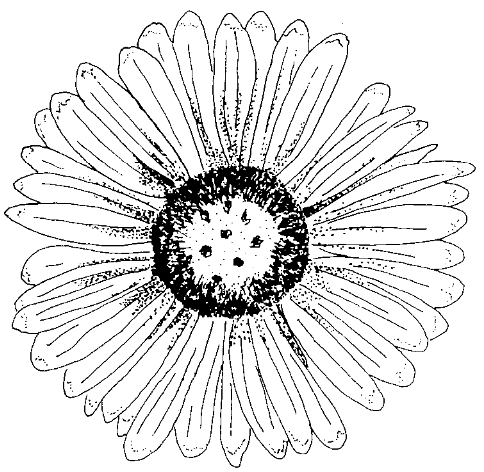
42.9 *Enter Espanola; this area is always congested, so drive carefully.* This log now gives only major intersections to its junction with US-84-US-285 near the center of town. **1.5**

44.4 *Traffic light; continue straight ahead (south) on NM-68.* Fairview Post Office is on the left and the US-84-US-285 bypass route is to the right. **0.7**

45.1 Junction on left with NM-76 to Chimayo. *Continue straight ahead.* **0.5**

45.6 Junction with US-84-US-285. To the right the route crosses the Rio Grande and the log from Espanola to Chama begins. Straight ahead the route backtracks along the road from Santa Fe to Espanola.

END OF LOG



Indian blanket

Trip 6

(53 miles)

Tres Piedras-Ojo Caliente-Española

This route crosses the southwest edge of the Taos Plateau volcanic field. The field consists of a few Servilleta basalt flows overlying Precambrian granite gneiss and a cover of Los Pinos Formation (as in the Tres Piedras region), or the thick fill of the Española Basin of the Rio Grande rift (as farther south along the Comanche Rim and Black Mesa). When the highway crosses the Comanche Rim, the route will be in the younger fill of the Española Basin from Ojo Caliente to Española.

Mileage

0.0 *Travel south on US-285 from junction with US-64.* The abandoned narrow-gage railroad line to Santa Fe is on our left and roughly parallels the highway for the next 21 mi.

A discussion of the Taos Plateau volcanic field and a map of the volcanoes is included in the log from Tres Piedras to Taos. **1.4**

1.4 Junction on right with Forest Road 675 to Las Tablas and Petaca (milepost 383). The mica-rich pegmatites of the Petaca district first were exploited when sheet mica was used for windows in Espanola and Santa Fe. Modern mining began here about 1870 when the large sheets of mica were used for stove doors. Electrical, painting, and roofing demands for scrap and sheet mica provide markets for continuing mining activity in this district. **0.3**

1.7 Outcrops of Precambrian granite gneiss are at 3:00. **1.8**

3.5 The Truchas Peaks (all over 13,000 ft) are on the distant skyline from 11:30 to 12:00. Ponderosa-pine-forested ridges on our right are underlain by Los Pinos Formation. The Servilleta basalt surface we are crossing laps up against these older, eroded, and eastward-tilted gravels. **2.5**

6.0 This basalt surface characteristically is covered with sagebrush, grass, and widely scattered piñon and juniper.

The only volcanoes in the southern part of the Taos volcanic plateau are Tres Orejas ("three ears"; only two ears are visible from here) at 11:00 and Cerro de los Taos at 10:00; they are, respectively, rhyodacite and olivine andesite in composition. **1.0**

7.0 Picnic tables. Entering piñon-juniper forest. **0.7**

7.7 Picnic tables. **1.9**

9.6 Picnic tables. Jicarilla Peak, on the distant skyline at 12:00, is composed of gently dipping layers (the tilted mesa) of Pennsylvanian rocks. The Picuris Mountains, at 11:00 and closer, are composed of Precambrian quartzite (similar to that of the Brazos Box and Jawbone Mountains area) and schist. The left end of the range is cut off by the north-trending Picuris-Pecos fault. The offset end of the range is now the Truchas Peaks area, 25 mi farther south on the skyline at 12:30. **2.9**

12.5 Open area. At 10:00, all three ears of Tres Orejas are now visible. Cerro Mojino is the low, tree-covered mountain at 12:30; it apparently was unfitted by an intrusive that domed the Servilleta basalt cover. The Comanche Rim at 3:00 is the cliff edge of the basalt-capped mesa that we are crossing. **2.5**

15.0 Roadcut in Servilleta basalt. To the left is the abandoned route of the narrow-gage Denver and Rio Grande Western Railroad **1.2**

16.2 At 2:00 is Cerro Mojino. **1.4**

17.6 At 11:00, near the far end of this plateau, sheer cliffs of Precambrian quartzite mark the far wall of the canyon of the Rio Grande. **2.1**

19.7 Communications relay station. Tres Orejas is at 3:30. **0.8**

20.5 Junction with NM-96, Taos Junction (abandoned) to Carson and through Rio Grande Gorge to Taos. Taos Junction was the railroad station nearest to Taos on the narrow-gage Denver and Rio Grande Railroad line that came south from Antonito, Colorado, through Tres Piedras to Santa Fe. The passengers to Taos disembarked here and then continued by stage-coach across the present route of NM-96—a long, bouncy, dusty ride. The grade of the railroad, abandoned in 1941, is visible to our left. **0.5**

21.0 A former narrow-gage railroad spur line to La Madera crosses the high-way. **0.5**

21.5 Communications relay station at left. Road ahead descends from Comanche Rim through roadcuts in the Servilleta basalt. The Jemez Mountains are on the skyline at 12:00. At 11:00 in the middle distance is Black Mesa, the southern tip of the Servilleta basalt cap of the Taos Plateau volcanic field. **0.4**

21.9 Road continues ahead into the valley of Rio Ojo Caliente, which we follow until near the far end of Black Mesa, where the Rio Ojo Caliente joins the Rio Chama. At 12:30 is Cerro Colorado, the reddish mountain of Precambrian metarhyolite (a rock that resembles granite) in the valley. Magote Ridge, at 1:00 on the skyline, is held up by a cap of El Rito Formation on Mancos Shale (Upper Cretaceous).

At 11:30 is Sierra Negra, the dark, flat-topped mountain below the skyline. The flat top is basalt, a remnant of flows erupted from the Jemez Mountains. Cerro Pedernal, the butte on the skyline, also is capped by basalt from the Jemez Mountains. These are features we saw more closely on the Española-Chama leg of this tour. **0.6**

22.5 At 3:00 is basalt-capped Comanche Rim. Canada de Comanche is the main valley below the rim. Kiowa Mountain, at 2:30 on the skyline, is composed of Precambrian quartzite. **1.7**

24.2 At 8:30 is Cerro Azul, a hill composed of Precambrian quartzite that projects through the Taos Plateau basalt cap. **1.6**

25.8 Black Mesa is on the skyline at 9:00. At 10:30 is Mesa Vibora, a small volcanic vent with a basalt cap. **1.0**

26.8 Leaving Carson National Forest. From 12:00 to 3:00, exposures of the Chama-El Rito Member (Santa Fe Group) are visible in the bluffs. Cemented (resistant) layers were caused by ground water diverted along north-trending fault zones. **1.6**

28.4 Roadcuts in the sand-dune facies expose the Ojo Caliente Sandstone Member (Santa Fe Group). Dark, red-brown silts are playa (lake) deposits. **0.5**

28.9 The Ortega Mountains at 2:00 on the skyline are the source of the name

OJO CALIENTE SANDSTONE MEMBER (SANTA FE GROUP) has sweeping crossbeds typical of dunes; note geology hammer for scale.

for the Ortega Quartzite (Precambrian). This quartzite is exposed intermittently from the Brazos Box near Tierra Amarilla to Hopewell Lake, then southeast to the Picuris Mountains, and beyond the Picuris Mountains to the Truchas Peaks region of the Sangre de Cristo Mountains. La Madera Mountain, at 3:00, is also of Ortega Quartzite, but in this mountain the quartzite contains distinctive radial bursts of sillimanite.

At 12:00 near the foot of Cerro Colorado is the Joseph mine, the southernmost mica mine in the Ojo Caliente-Petaca pegmatite mining district. In addition to mica, the major product of the district, this district has produced varying amounts of other pegmatite minerals, mainly columbite-tantalite, beryl, monazite, samarskite, and bismuthite. A large amount of feldspar has been produced from one mine, and kyanite has been mined from veins in the quartzite for use in refractory products, brick, and porcelain. **0.6**

29.5 Junction with NM-96 to La Madera, El Rito, Vallecitos, and Petaca. **0.2**

29.7 Pueblo ruin on the right. Mesas along this valley are commonly capped with pre-Columbian pueblo ruins. Archeological studies indicate that the people who built these pueblos are the link between the present Pueblo Indians and the ancient Pajaritan culture preserved at Bandelier National Monument near Los Alamos. **0.8**

30.5 Bluffs on the left of the road expose Los Pinos Formation, which grades laterally into the Chama-El Rito Member (Santa Fe Group). The differential erosion emphasizes the contrast between 1) cemented, coarse, river sands (purplish) that form ridges, and 2) less-cemented, finer, floodplain, silty sands (pink) that form reentrants.

Los Pinos Formation is derived from the erosion of the volcanic highlands of the San Juan Mountains to the northwest. The Santa Fe Group is derived largely from the granitic Sangre de Cristo Mountains.

Cerro Colorado at 3:00 and the nearer red hills are composed of Precambrian metarhyolite. **0.7**

31.2 Junction on right with NM-414 to the mineral hot springs of Ojo Caliente ("hot springs"). The hot springs lie along the major fault zone extending north from here into the Tusas fault zone (details in the Tierra Amarilla-Tres Piedras log, mile 33.3-42.5). This fault zone is a major zone of weakness that has been active any times in the geologic past. Historic marker:

> Ojo Caliente—this village was founded by Spanish colonists some time prior to 1735. In 1748, frequent raids by hostile Ute and Comanche Indians forced settlers to abandon their homes and Ojo Caliente stood deserted for the next 45 years. The village was re-settled in 1793 and has been occupied ever since.

The old, abandoned adobe church has a hand-hewn beam with the date 1689 carved in it, possibly the year the church was completed. Governor Juan Bautista de Anza camped at Ojo Caliente in August 1779 on his way north to Colorado. With 400 Spanish soldiers and 200 Indian allies, de Anza successfully fought the Comanches at Fountain Creek.

In 1810 Major Zebulon M. Pike passed through here as a prisoner on his way to Mexico. He had been arrested by the Spanish near Taos for building a fort in their territory (now southern Colorado). Pike described the village as a square enclosure of flat-topped mud houses that form a wall. The houses were all one story, "the doors were narrow, the windows small, and in one or two houses there were talc lights [window panes of mica]." A mill near the creek made flour for the 500 mixed-breed Indians. He also noted that, "the greatest natural curiosity is the warm springs, which are two in number [actually five], about 10 yards apart, and each affords sufficient water for a mill seat. They appeared to be impregnated with copper, and were more than 33° above blood heat."

The road to the right passes the old church and crosses the river to the mineral springs at the base of Ojo Caliente Mountain, where bathhouses, a pool, a hotel, and cottages are available. The five springs contain arsenic, iron, sodium sulfate, lithium, and soda; the springs range in temperature from 98° to 113°F. The Tewa Indians regarded the hot springs as a sacred place and valued them for medicinal purposes. **0.4**

31.6 Resistant beds along the river on the right are cemented by minerals from hot spring deposits. **0.7**

32.3 About 2 mi distant at 3:30 is Cerro Negro, a Los Pinos-age volcano. Remnants of lava flows extend south from Cerro Negro and underlie the ridge on both sides of the prominent arroyo. **0.5**

32.8 Roadcuts for the next 3 mi are in the Chama-El Rito Member (or Los Pinos). Across the river to the right, the pink Santa Fe beds show the transition downward into the Los Pinos or Chama-El Rito Member. The valley widens ahead as the river now erodes into non-cemented upper Santa Fe Group. **2.2**

35.0 Gravel caps on the left are river deposits from a time when the earlier Rio Ojo Caliente formed the terrace (bench) above us. **0.2**

35.2 Cemented zones in sand-dune facies of Ojo Caliente Sandstone Member (Santa Fe Group) mark ancient water tables. **0.5**

35.7 Black Mesa at 12:00 is capped by Servilleta basalts; locally, under the basalt are river-gravel deposits (from the ancestral Rio Grande?), red Chamita Formation (along the southern end of the mesa), and yellowish Ojo Caliente Sandstone. **0.4**

36.1 Modern sand dunes on the right. Their movement is in generally the same easterly direction as that of the ancient Ojo Caliente Sandstone dunes. **1.0**

37.1 Roadcuts on the left for the next mile expose ancient sand dunes of Ojo Caliente Sandstone. **1.5**

38.6 At 12:00, an exposure on Black Mesa displays Ojo Caliente Sandstone (yellow, lowest unit), Chamita Formation (buff or reddish), and a cap of 2.8-m.y.-old Servilleta basalt. **1.2**

39.8 In bluffs on the left, the Ojo Caliente Sandstone displays horizontal bands of cemented sandstone that mark ancient water tables. Old log and adobe houses are on the left. **0.6**

40.4 Ojo Caliente Sandstone is exposed in bluffs across the river on the right. The gray veneer is gravel, a remnant of river gravels that cap the benches from an earlier cycle of erosion. **1.3**

41.7 The basalt cap of Black Mesa, slightly more than 900 ft above us to the left, marks the last known volcanic event (2.8 m.y. ago) before the initiation of the Rio Grande as a through-flowing river in this region. Since that time, the Rio Grande and its tributaries have eroded the region to its present shape and exposed the rocks of the Espanola Basin, which were deposited while the basin was closed.

High cliffs of pink and yellow Chamita Formation are visible above ground-water-cemented Ojo Caliente Sandstone. **0.7**

42.4 The rugged badlands on the right are composed of Ojo Caliente Sandstone Member, locally cemented by minerals in ground water. **0.8**

43.2 More cemented Ojo Caliente Sandstone is visible on the left. The sloping layers deposited on the advancing edge of a sand dune are well exposed. **1.5**

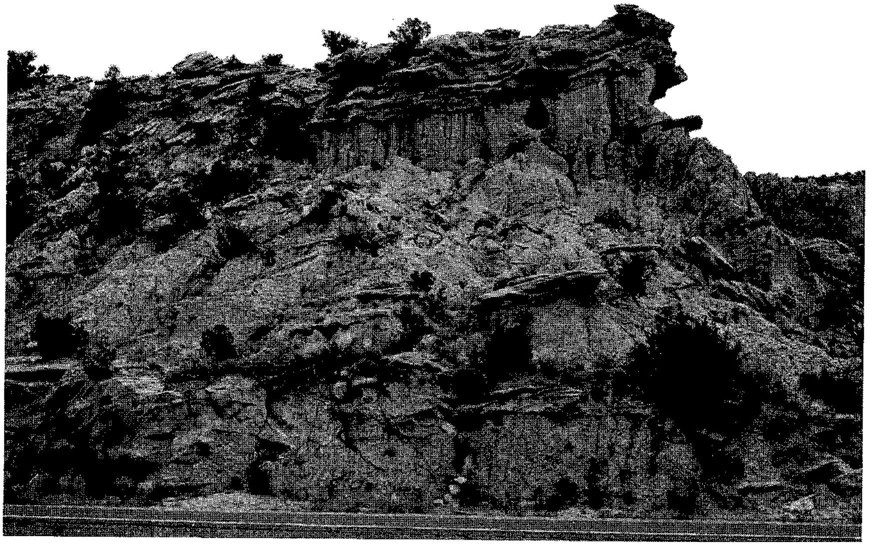
44.7 Straight ahead, the ridge with a spine lies along a major fault zone which diverted ground water that cemented the most porous parts of the layers. This cemented part is the far side of the fault from us as we drive past the ridge. **1.3**

46.0 A cemented zone at 3:00 along another north-trending fault zone now forms a ridge. **0.5**

46.5 The mesa on the skyline ahead is covered by basalt from the Jemez Mountains. This basalt is the oldest dated deposit (2.4 m.y.) to cover river gravels of the earliest Rio Grande. **0.6**

47.1 The road winds along the base of Black Mesa and the Rio Chama. The junction of the Rio Ojo Caliente with the Rio Chama is not visible from the road because of the trees. **0.5**

47.6 At 9:00, the southwest end of Black Mesa has a cap of 2.8-m.y.-old Servilleta basalt. The Rio Chama now runs beside us. **1.8**



OJO CALIENTE SANDSTONE BADLANDS WITH BANDS OF SANDSTONE CEMENTED BY GROUND WATER. The cemented zones are at the levels of ancient water tables, created either during accumulation of the sand dunes or during progressive downcutting of the Rio Ojo Caliente; mile 44.7, Tres Piedras-Ojo Caliente-Española log.

49.4 *Junction with NM-74. Continue straight ahead on NM-74.* US-285 turns right to cross the Rio Chama and joins US-84. **0.1**

49.5 *Enter Chamita.* **0.7**

50.2 The Española Valley ahead is broad because of the absence of an erosion-resistant volcanic cover (such as the cover of the Taos Plateau and Black Mesa). **1.2**

51.4 *Cross one-lane bridge over the Rio Grande. Enter San Juan Pueblo.* **0.7**

52.1 Central plaza of San Juan Pueblo; the pueblo is described in the Taos-Espanola log, mile 43.9. **0.9**

53.0 Junction with NM-68. Turn right toward Espanola. Join the Taos-Espanola log, mile 43.9, for the termination of the tour in Española. We hope this book has made your trip more enjoyable.

END OF LOG

Suggested reading follows

Suggested reading

HISTORY

Alsberg, H. G., ed., 1953, New Mexico, a guide to the colorful state: American Guide Series, New York, Hastings House, 471 p. This guide contains a wealth of data on the history and development of New Mexico. Road logs cover most of the major highways in New Mexico and include numerous stops at important geologic and historic sites near the route.

Beck, W. A., 1962, New Mexico, a history of four centuries: Norman, University of Oklahoma Press, 363 p.

Dutton, B. P., 1970, Let's explore Indian villages past and present: tour guide for Santa Fe area: Santa Fe, Museum of New Mexico Press, 46 p.

Horgan, Paul, 1954, Great River, the Rio Grande in North American history: New York, Rinehart and Co., 2 vols., 1020 p. This book is a beautifully written history of Indian, Spanish, Mexican, and American cultures and their interaction along the Rio Grande.

Pearce, T. M., ed., 1965, New Mexico place names, a geographical dictionary: Albuquerque, University of New Mexico Press, 187 p.

GEOLOGY

Several excellent field conference guidebooks of the New Mexico Geological Society describe various parts of this region. These guidebooks, designed for the professional geologist, contain road logs and articles that cover geology, archaeology, history, mining, oil, gas, and water resources.

New Mexico Geological Society, 1960, Guidebook 11th field conference, Rio Chama Country (north-ern New Mexico), 127 p. This guidebook contains road logs from Taos to Chama and Cumbres Pass by way of El Rito and Canjilon; logs cover the loop from Chama west to Dulce, then south along the continental divide for approximately 50 mi, and the return route by E1 Vado Lake; also described is the trip from Chama to Cuba by way of Gallina.

, 1974, Guidebook 25th field conference, Ghost Ranch (central-northern New Mexico), 384 p. Papers in this book update the geological knowledge of an area that covers much of the same region as New Mexico Geological Society Guidebook 11. This book describes the region of the loop through Espanola-Tierra Amarilla-Tres Piedras-Espanola, but in reverse; also covered are the routes from Ghost Ranch by way of Gallina to Cuba and the route from Espanola through the Jemez Mountains to San Ysidro .and Bernalillo.

, 1979, Guidebook 30th field conference, 310 p. This book, a comprehensive guide to the Santa Fe region, contains articles and the latest geologic data on a fascinating area. Road logs begin at Santa Fe and travel north by way of the old E1 Camino Real, through Truchas and Peñasco to Ranchos de Taos, and return through Espanola; also described is the trip from Santa Fe south through Galisteo, Cerrillos, Madrid, Golden, and the return to Santa Fe through Fagan; another log extends southeast to Glorieta, and up the Pecos River to Terrero.

Hawley, J. W., compiler, 1978, Guidebook to Rio Grande rift in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources, Circ. 163, 241 p.

Riecker, R. E., ed., 1979, Rio Grande rift: tectonics and magmatism: Washington, D.C., American Geophysical Union, 438 p.

Oetking, P., Feray, D. E., Renfro, H. B., compilers, 1967, Southern Rocky Mountain region, geological highway map of Utah-Colorado-Arizona-New Mexico: Tulsa, American Association of Petroleum Geologists, Map 2

OTHER SCENIC TRIPS

Three other-Scenic Trip books cover parts of northern New Mexico:

Baldwin, B., and Kottlowski, F. E., 1968, Santa Fe, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Scenic Trip No. 1, 52 p. This book describes a series of short trips that show the setting and geologic history of the area in and around Santa Fe.

James, H. L., 1979, Cumbres and Toltec Scenic Railroad: New Mexico Bureau of Mines and Mineral Resources, Scenic Trip No. 11, 73 p. This book describes the 64-mi route of the narrow-gage railroad from Chama, New Mexico, to Antonito, Colorado. A round trip on the train is a marvelous one-day trip during the summer or early fall.

Schilling, J. H., 1968, Taos-Red River-Eagle Nest, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Scenic Trip No. 2, 25 p. (in revision). This book describes a circle drive that loops around the Wheeler Peak Wilderness Area, a region of scenic beauty, ski and summer resorts, and mining, fishing, and hunting sites. Wheeler Peak is the highest mountain in New Mexico.

Glossary

aa—(Hawaiian word) basaltic lava that has a very jagged surface
alluvial fan—cone-shaped deposits of eroded material that slope gently outward, with decreasing gradients, from mountains onto the adjacent lowland
alluvium— clay, silt, sand, or gravel deposited by streams
amphibolite—crystalline metamorphic rock consisting mainly of amphibole and plagioclase minerals
andesite—volcanic rock composed principally of plagioclase feldspar
anticline---an upfold opening downward, the core of which contains stfatigraphically older rocks
arkose—coarse sandstone composed mainly of quartz and feldspar
augite—dark-greenish-black mineral, commonly found in basalt
badlands—extremely rough, gullied topography
basalt—dark-colored, dense, fine-grained igneous rock consisting of feldspar, olivine, and pyroxene minerals
bedding—layering found chiefly in sedimentary rocks
bentonite---clay derived from a volcanic-ash deposit
breccia--rock consisting mainly of highly angular, coarse fragments
butte—flat-topped mountain that is higher than it is wide; summit is smaller than that of a mesa
caldera—large, basin-shaped volcanic depression formed by the collapse following a violent volcanic eruption
carbonaceous sands—sand that contains fragments of plant material that are now bits of coal
chert—synonym for light-colored flint
cinder cone—conical hill formed by the accumulation of cinders and other pyroclasts, normally of basaltic or andesitic composition
columnar joints—hexagonal columns formed during cooling of a lava flow
concretion—rounded body found in sedimentary rocks, usually caused by chemical deposition around a tiny nucleus
conglomerate—sedimentary rock containing rounded fragments of various sizes in a fine-grained matrix of sand or silt
diatomaceous--rock composed of the shells of one-celled marine organisms (diatoms)
dike—a nearly vertical sheet of igneous rock that cuts across the bedding or foliation of the country rock
dip slope—the slope of the ground surface parallel to the slope (dip) of the underlying rocks
embayment—downwarped area containing stratified rocks, that extends into a terrain of other rocks
fault—fracture zone along which there has been a displacement of the two sides relative to one another and parallel to the fracture
fault scarp--steep slope or cliff formed directly by movement along one side of a fault
feldspar—common mineral in igneous and metamorphic rocks; feldspars are the most widespread of any mineral group and are usually white, clear, gray, or pink
fluvial deposits—deposits formed by the action of river water
fold--a curve or bend in rock, usually the result of deformation
foliation—the layering seen in metamorphic rocks
fracture--general term for a break in a rock; includes cracks, joints, and faults
gneiss—coarse-grained metamorphic rocks with the minerals arranged in a banded structure
graben—elongate, downdropped block that is bounded by faults on its long sides
granite—light-colored, commonly medium- to coarse-grained igneous rock consisting chiefly of alkali feldspar, quartz, and a small amount of black mica
granodiorite—light-colored, commonly medium- to coarse-grained igneous rock consisting chiefly of feldspar (both alkali and plagioclase varieties), biotite, hornblende, and minor quartz
gypsum—soft, white mineral mostly found in sedimentary rocks
horst—elongate uplifted block bounded by faults on its long sides
igneous—major rock classification; formed by solidification from a molten state
ignimbrite—gas-rich, volcanic material ejected from volcanoes. in a thick cloud, producing consolidated ash deposits
intrusive—igneous rock that penetrates or intrudes its host rock while still in a liquid state
lava—molten rock that flows from a volcano
mesa--very broad, flat-topped hill or mountain of moderate height capped by layers of resistant, nearly horizontal rock representing an erosion remnant

metamorphic—major rock classification; formed by pronounced increase in pressure, temperature, or chemical environment of a preexisting rock

metasedimentary--inetaniorphosed sedimentary rock

metavoIcanic--metamorphosed volcanic rock

mica—hydrous silicate mineral group, with sheetlike or platy structures, having perfect flaky cleavage

molybdenum—metallic element usually found in the lead-giay ore m olybdenite; used to harden steel

monocline—local steepening in an otherwise uniform gentle dip

obsidian—black, glassy volcanic rock with conchoidal fracture; commonly used for arrowheads

olivine andesite—olivine-bearing andesite

over deepened valleys—the degraded valley or channel of an alpine glacier, now occupied by a down-cutting stream

pahoehoe— (Hawaiian word) smooth, ropy-surfaced basaltic lava

pegmatite—igneous rock composed of large, coarse grains, usually in a dike or lens-shaped body

plagioclase—a group of the feldspar minerals

quartz—crystalline silica (SiO_2), an important rock-forming mineral

quartzite—metamorphosed sandstone

reentrant—see embayment

reverse fault--fault that dips toward a block that has been relatively raised

rhyodacite—group of extrusive, porphyritic igneous rocks, intermediate in composition between dacite and rhyolite, having quartz, plagioclase, and biotite (or hornblende) as the main crystals in a fine-grained or glassy groundmass

rhyolite—volcanic equivalent of granite; common minerals are quartz and alkali feldspar in a fine-grained or glassy groundmass

rift—interconnected series of grabens

right-lateral-slip fault—fault whose movement direction is horizontal and whose far side has moved to the viewer's right

sandstone—rock composed of cemented sand grains

schist—coarse-grained metamorphic rock with foliated texture; it can be readily split along the foliation because of the abundance of parallel flakes of mica

sedimentary—major classification of rock; formed by deposition of sediment from water, air, or ice

shale—dense, soft, usually slabby sedimentary rock, mainly consisting of minute particles of clay minerals with varying percentages of tiny particles of quartz

spatter cone—low, steep-sided cone of shabby volcanic fragments built up on a fissure or vent

strike-slip fault—fault whose motion is horizontal

thrust fault—low-dipping reverse fault

transform fault--a strike-slip fault that separates two plates

transverse structure—lies across the regional structural trends

tuff—volcanic ash consisting of minute fragmental particles

unconformity—buried surface of erosion or nondeposition representing an undocumented period of geologic time in the area of the unconformity

uplift—elevation of any extensive part of the earth's surface relative to some other part

vesicle pipes—gas tubes in volcanic rocks

volcaniclastic—adjective describing fine debris thrown from a volcano

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(italics denote definitions or discussions)