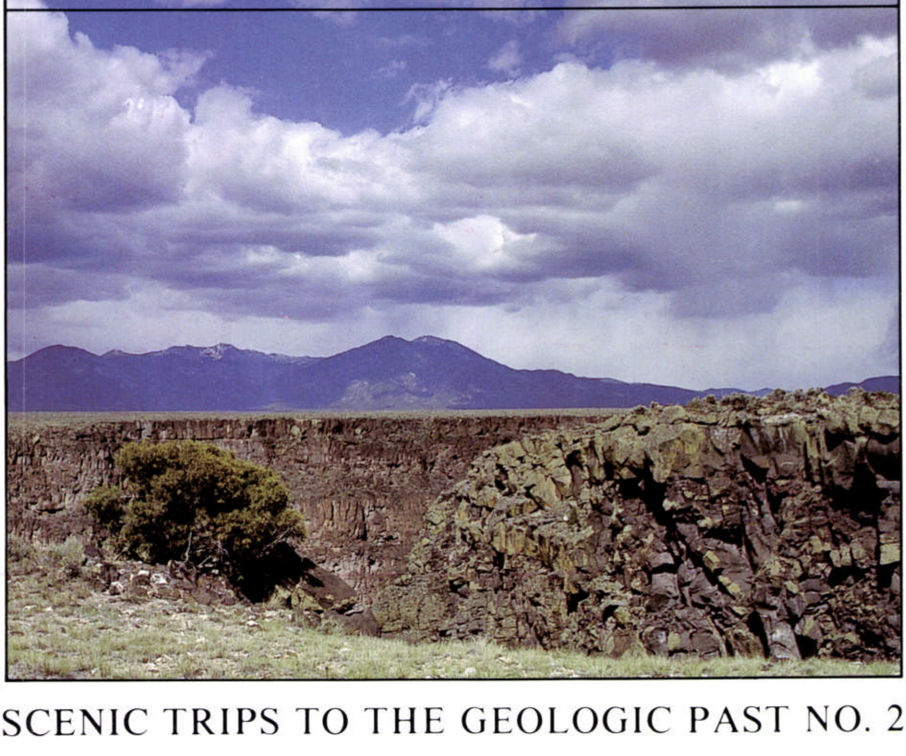
THE ENCHANTED CIRCLE

Loop Drives From Taos



SCENIC TRIPS TO THE GEOLOGIC PAST NO. 2

COVER—View from west side of Rio Grande Gorge to the southeast toward the Sangre de Cristo Mountains. Photo by John Nichols.

They rise above the mesas, plains and valleys; great rocks to cast their shadow on the land.

Ruth K. Hall

New Mexico Magazine, September 1958

Fairy slipper orchid or Calypso orchid *(Calypso bulbosa)*.

Red columbine *(Aquilegia triternata)*.

Teasel *(Dipsacus sylvestris)*.

Thistle, New Mexico thistle, or Bull thistle *(Cirsium neomexicanum)*.

Red columbine, as well as blue and yellow varieties, and the rare Fairy slipper orchid, an endangered species in New Mexico, prefer the cooler and wetter, forested mountains. Teasel and New Mexico thistle are common along roads and on grassy slopes. Cutting or attempting to move endangered native plants is illegal; their fragile natural habitats cannot be duplicated. Photos by J. Gordon Adams, Taos Photographic Laboratory, © 1991.

Scenic Trips to the Geologic Past
No. 2

New Mexico Bureau of Mines & Mineral Resources

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

The enchanted circle—loop drives from Taos

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Preface

Much of the research undertaken by the staff at the New Mexico Bureau of Mines and Mineral Resources is published in technical reports that are useful mainly to earth scientists. Many people not interested in these technical reports would like to know more about the geology of New Mexico. To meet this need, the Bureau publishes a series of books (Scenic Trips to the Geologic Past) designed to guide would-be explorers through many of New Mexico's scenic and geologic attractions.

The geology of north-central New Mexico is as diverse and spectacular as any place on Earth. The Taos area is rich in cultural as well as geologic history. A blend of American Indian, Hispanic, and Anglo traditions makes the region exotic and unique. The captivating landscape of mountains and plains is host to a fascinating variety of plants and animals. The enchanting character and beauty of this land draw us back again and again.

The contents of this guidebook have changed through the various editions. This fifth edition represents a major overhaul that includes adding color photos and a second loop drive around the Picuris Mountains south of Taos. We hope that these revisions and additions will make the guide more enjoyable and useful.

The trip consists of two loops that start from and return to Taos. Trip 1 (by John Schilling, Paul Bauer, and Jane Love), Enchanted circle, visits the Rio Grande Gorge Bridge, Questa, Red River, Elizabethtown, Eagle Nest, and Palo Flechado Pass before returning to Taos. Side trip 1A is a drive into the Rio Grande Gorge to a point on the river known as Dunn's Crossing. Side trip 1B follows a Forest Service road into the high country north of Red River. Trip 2 (by Paul Bauer, Joseph Taggart, Jr., and Jane Love), Picuris Mountains loop, guides us through the small villages of Rinconada, Dixon, Peñasco, Vadito, and Talpa. Side trip 2A takes us into the Rio Grande Gorge to pan for gold. Side trip 2B is a walking tour of the Harding *pegmatite* mine. **Before entering the Harding mine property, a permission–release form must be signed.** These forms may be obtained from the Chairman, Department of Geology, University of New Mexico, Albuquerque, New Mexico 87131. You may take these trips in any order, at any time. If you want to spend a lot of time panning for gold, fishing, collecting minerals, or visiting the villages en route, the trips could take more than a day.

All technical geologic terms are printed in italics when first used in the text and road logs and are fully explained in a glossary at the end of the book. If you are interested in further reading on particular aspects of the history, culture, or geology of this area, please check the suggested-reading list at the end of the book.

Before starting your trips be certain to read the section titled "How to use the road logs" on page 28.

ACKNOWLEDGMENTS—The authors have many to thank for their varied contributions to this revised edition's lengthy preparation and eventual publication: Arthur Montgomery, geologist and former owner of the Harding pegmatite mine; Al Greslin, former superintendent, and Bill O'Toole, former mine clerk, Molycorp Inc.; Frank E. Kottlowski, Director of the New Mexico Bureau of Mines and Mineral Resources; Robert W. Kelley and Joan C. Pendleton, former editors with the New Mexico Bureau of Mines and Mineral Resources; and William X. Chavez, Jr. and Mark Blazek for field assistance. Unless otherwise credited photographs were taken by the authors. Additional photographs were kindly provided by J. Gordon Adams, Taos Photographic Laboratory; Jim Bones; John W. Hawley, New Mexico Bureau of Mines and Mineral Resources; Rod Holcombe; Alan H. Johnson, Sky View of Taos; Wayne Lambert, West Texas State University; Robert W. Leonardson and Robert S. Young, Molycorp, Inc.; Christopher K. Mawer, Carpentaria Exploration Company; John Nichols; Mark Nohl, New Mexico Economic Development and Tourism Department; and Deborah Wilson. Historic photographs were reproduced with permission from the New Mexico State Records Center and Archives, Santa Fe, with the assistance of Al Regensberg and J. Richard Salazar; the Museum of New Mexico, Santa Fe; the Amon Carter Museum, Fort Worth; Cliff Mills, Las Quince Letras; Shirley Davis; and John Schilling. John Robinson produced the maps and geologic illustrations, and Jan E. Thomas did the botanical sketches. We also want to thank all those individuals who read parts of the manuscript and made valuable suggestions that substantially improved the book: Rodney C. Ewing, John W. Hawley, Paul F. Hlava, Frank E. Kottlowski, and Boyd C. Pratt.

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Aerial view south of the Taos Plateau, Rio Grande Gorge, and Picuris Mountains and Truchas Peaks in the background. Photo by Laura Gilpin, courtesy of Shirley Davis and the Amon Carter Museum, Fort Worth, Texas.

Introduction

Taos is located at the edge of two strikingly different landscapes. To the west stretches the Taos Plateau, level except for a few hills and the deep gorge of the Rio Grande. To the east towers the Taos Range of the Sangre de Cristo Mountains, including Wheeler Peak, the highest peak in New Mexico. To the south, the Picuris Mountains extend westward into the Rio Grande valley as a prong of the Sangre de Cristo Mountains. The contact between plains and mountains is abrupt, in places marked by high, near-vertical cliffs.

What geologic processes, working steadily through millions of years of time, contributed to the formation of these two contrasting landscapes? The geologist, like a detective, pieces together clues that, when correctly interpreted, yield a coherent history of the geologic past. When the geologist attempts to reconstruct a geologic event that took place during the previous years, the task may be more difficult than it would be if the event had occurred only a few days before, because many of the clues may have been destroyed. Imagine how difficult it is for the geologist to reconstruct events that took place hundreds of millions of years ago! Seldom are there enough clues to give a complete description of the geologic history of an area, and additional or more detailed study invariably results in the discovery of new clues that in turn will cause the geologist to modify previous interpretations.

After studying an area, the geologist may deduce that the rocks originally were sediments lying at the bottom of an ocean that slowly flooded the land and then retreated. The geologist may deduce further that ancient mountain ranges moved upward, only to be worn away by the slow but ceaseless process of erosion and that volcanoes spewed *lava* and ash across the landscape. The geologist also may make a geologic map showing the areas covered by the different rock types: the *limestone* deposited in the ancient ocean, the gravels from the eroded mountains, and the lava from the volcanoes.

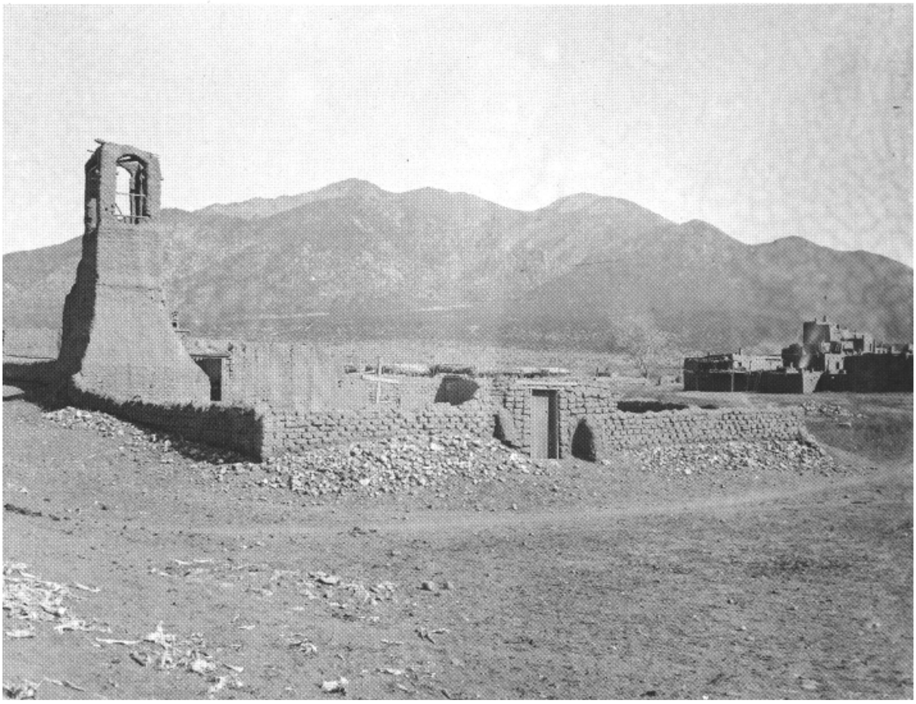
On a geologic map, the rocks are divided into units that have common characteristics. Each age group is designated by a different color; rock types within that age group are indicated by different shades or patterns. Geologic maps can be made with as much or as little detail as desired. Such geologic maps can be used in many ways. The prospector can often discover where certain ore deposits, such as those containing uranium or silver, are most likely to be found. The rancher, farmer, or water company exploring for water can be shown where to drill, the probable depth to water, and through how much hard rock he must drill before reaching the water. The oil company can be guided to the most promising areas for drilling wells. The civil engineer may be assisted in the search for a solid *bedrock* damsite. These are only a few of the many possible uses for the information gathered by the earth scientist.

A brief cultural history of the Taos area

American Indians have lived in the Taos area for at least 9,000 years. Evidence of these early people is found throughout the Taos Plateau and Sangre de Cristo Mountains. The earliest people survived predominantly by hunting. As much of the large game disappeared, these people experienced an extended time of transition from a hunting- to a farming-based subsistence. These farmers probably became the Anasazi, who in turn are the ancestors of the modern Pueblo Indians.

The first Europeans to reach this area were an exploratory party of Coronado's expedition from Mexico led by Captain Hernando de Alvarado that visited the Taos Pueblo in 1540. Spanish settlers began to come to the area in about 1615. The first Catholic mission of San Gerónimo de Taos was built at the pueblo in about 1626. As the Spanish attempted to abolish the Indian religion, tension mounted until the oppressed Indians killed a priest and several soldiers and destroyed the church in 1640. In 1680 the pueblos banded together in a successful rebellion that drove the Spanish south out of New Mexico. However, freedom was short lived as Don Diego de Vargas reconquered New Mexico in 1692. Resettlement of the Taos Valley began in about 1696. Another church, San Gerónimo de Taos, was built at the pueblo in 1726. During the 1700's the Taos Pueblo and the Spanish settlements became virtually surrounded by the hostile, nomadic Comanches, Utes, and Navajos. A Comanche attack in 1760 forced the settlers to abandon their haciendas, and by 1770 all were living in the fortified pueblo because of the safety it

North pueblo, circa 1905. Taos Pueblo is the only large, multi-storied pueblo remaining today. The north pueblo has five levels. Originally, for protection from nomadic Indian raids, the lower level was constructed without doors, and entry was gained by climbing a ladder and entering through a hole in the roof. Photo by B. G. Randall, courtesy of Las Quince Letras.



San Gerónimo de Taos, Taos Pueblo, circa 1905. Built in 1726, this church was destroyed in 1847 during the brief rebellion against U.S. occupation of New Mexico and the U.S. appointed governor. After the insurgents sought refuge in the church, U.S. Army howitzers battered down the walls and killed 150 individuals. Photo by B. G. Randall, courtesy of Las Quince Letras © 1986.

provided. When settlements outside of the pueblo were reestablished they were built around defensible plazas. The plazas for Ranchos de Taos and Fernando de Taos (present Town of Taos) were begun in 1779 and 1796, respectively.

Established as an agricultural community, Taos soon became an important trading center. Annual trade fairs, held at the pueblo as early as 1750, attracted Plains and other Pueblo Indians, traders from Mexico and Spain, and Spanish settlers from all over New Mexico. After 1802, when the Louisiana Purchase made the Mississippi River basin part of the United States, American fur trappers, the "mountain men," swarmed into the area. Not only did Taos provide a market for their pelts, but the beautiful señoritas and notorious "Taos lightning" (raw whiskey made locally) provided welcome entertainment. Kit Carson, the renowned scout and trapper, settled here and married a local woman named Josefa.

An important influence on Taos was Padre Antonio Jose Martinez. Born in Abiquiu, northern New Mexico, in 1792 and raised in Taos, he became the pastor of Taos in 1826. The popular and powerful priest guided his parish for over 30 years, which included the turbulent early years of American occupation and the brief but bloody Taos Rebellion. Until his death in 1867 he

Taos plaza, circa 1905. The two-story Victorian building with the cupola was originally the home of Juan de los Reyes Santistevan, a merchant and banker. Later it became the Taos Hotel. Photo by B. G. Randall, courtesy of Las Quince Letras.

fought ignorance and superstition and strove to educate the people. He established the first coeducational school in the Southwest and acquired a printing press in order to publish religious papers and educational materials for his classrooms. Padre Martinez's conflicts with Bishop Lamy of Santa Fe, the first bishop appointed by the American church to the Territory of New Mexico in 1851, are described fictionally in Willa Cather's *Death comes for the archbishop.*

In 1821 Mexico became independent from Spanish rule. In 1846 the United States declared war on Mexico and invaded New Mexico. No important resistance was met, and New Mexico was organized as a territory of the United States in 1851. Charles Bent, an influential fur trader who had settled in Taos, was the first U.S. appointed governor during the years of occupation between 1846 and 1851. On January 19, 1847, Spanish residents of Taos, displeased with the new U.S. government, incited the Taos Indians to assist in the scalping and murder of Governor Bent on the doorstep of his home. His family escaped by digging through the adobe wall of the house. Several other officials also were murdered. This attempt to overthrow the new government was subdued quickly when nearly 500 soldiers from Santa Fe and local volunteers surrounded some of the insurgents in the Taos Pueblo church, San Gerónimo de Taos. In the ensuing battle 150 Taos Indians were killed while fleeing the crumbling church. The ruins of the church and the graves of those who died can be seen at the pueblo (see Plate 2). The present church at the pueblo was constructed in 1897.

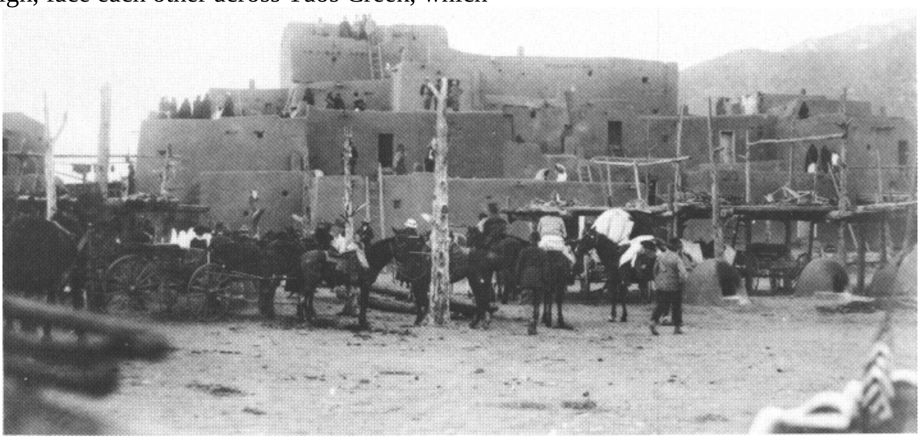
The Civil War had little effect on Taos. A group of loyal Union officers, led by Kit Carson, nailed the Stars and Stripes to a pole in the town plaza and made it clear that they expected it to stay there, and that settled the matter! A special act of Congress allows the U.S. flag to fly over the Taos plaza 24 hours a day.

As early as 1866 gold was found in quantity in the mountains. The bulk of the production came from the *placer* deposits at Elizabethtown, although some gold was recovered from the "Red River country," Amizette, Gold Hill, and the Rio Grande Gorge. In 1902, copper ore was discovered in the mountains near the head of the Rio Hondo, and the town of Twining was founded. However, by 1903 the mine had closed, and today the Taos Ski Valley occupies the old townsite. Other metals were mined in various areas, but none of these operations proved very profitable until Molycorp's molybdenum mine opened near Questa in 1923. The Harding pegmatite mine near Dixon is a famous mineral-collecting locality and has produced important amounts of the rare metals lithium, beryllium, tantalum, and niobium.

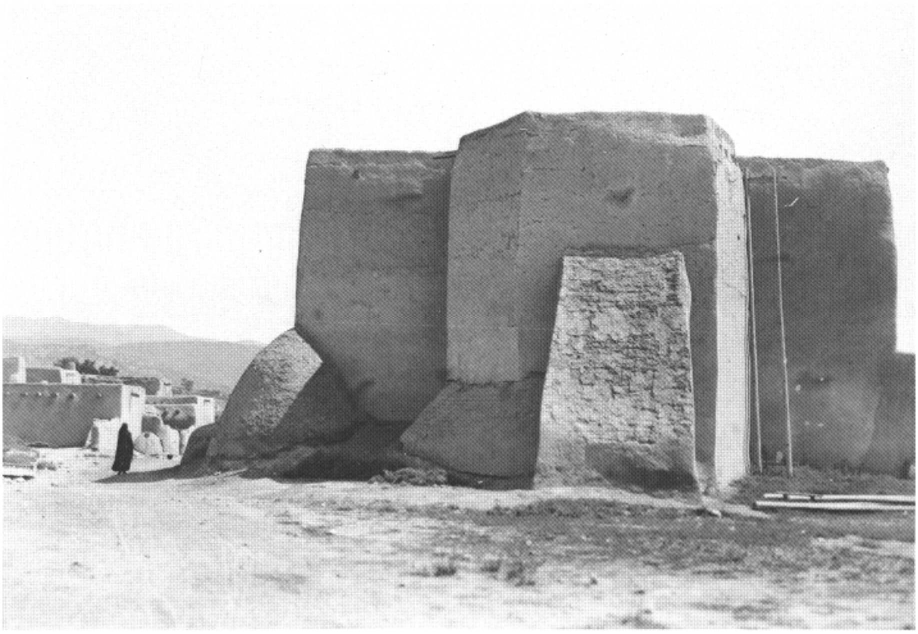
Today, Taos is a tourist mecca, art colony, ski resort, and trading center for the surrounding countryside. No railroads enter Taos County, and there is no heavy industry. The outlying villages are occupied mainly by farmers and ranchers. The mountain area is thinly populated; tourism, mining, summer grazing of cattle and sheep, and logging are the important sources of revenue.

Taos is actually three distinct towns: the Indian pueblo (San Gerónimo de Taos), the Spanish town (Don Fernando de Taos), and the old farming center (Ranchos de Taos), familiarly called Taos Pueblo, Taos, and Ranchos. This area, like much of present-day New Mexico, is a blend of Native American, Hispanic, and Anglo-American cultures. You'll hear English, Spanish, and Indian languages spoken on the streets.

Taos Pueblo appears much as it did when Spaniards first visited it, except that doors and windows have been cut in the adobe walls, and access to the rooms is no longer through hatchways in the roofs. The two large communal houses, four and five stories high, face each other across Taos Creek, which



Taos Pueblo, 1917. Photo no. 32006 from the Adella Collier Collection, courtesy of the New Mexico State Records Center and Archives.



Church of San Francisco de Asís, Ranchos de Taos, circa 1912. Photo by Jesse L. Nusbaum, courtesy of the Museum of New Mexico, negative no. 14159.

flows through the large central plaza. Huge, hand-hewn logs serve as footbridges across the creek. Tapestes (Spanish, "platforms") for storing corn and other produce and hornos (Spanish, "ovens") for baking are scattered along the edges of the plaza. Kivas, circular underground ceremonial meeting places, are marked by the tops of long ladders. Visitors are not allowed in the kiva areas. A few families keep small stores, usually indicated by a blanket hung outside the door.

Taos has many attractions, including museums, art galleries, shops of native crafts, and good restaurants and cafes. The Kit Carson Museum on Kit Carson Road was the famous mountain man's office and home from 1858 to 1866. The house of Governor Bent is now a museum also and is located nearby on Bent Street.

The Ranchos de Taos church (Church of San Francisco de Asís), which was built in 1815, is considered one of the finest examples of Spanish mission architecture in the Southwest. The renovation project of 1967 included substituting cement plaster for the old mud plaster, but in 1979 the decision was reversed, and the hard plaster was removed. Visitors are welcome.

Architecture of the Taos area

Our southern route around the Picuris Mountains intermittently follows the narrow, fertile valleys of several rivers—Rio Embudo, Rio Santa Barbara, Rio Pueblo, and Rio Grande del Rancho. The Pueblo Indians and later the Spanish settlers followed these and other perennial tributaries of the Rio Grande to find land to irrigate and farm. The Spanish settled parts of the 300-square-mile Embudo watershed by 1740, 400 or more years after the arrival of the Picuris Indians. In 1776 the town of Embudo, now Dixon, had a population of 69. East of the Sangre de Cristo Mountains, Spanish settlement lagged until the early 19th century because of the continual threat of attacks from the nomadic Utes and Comanches.

The earliest Spanish Colonial style homes were built much like pueblos. Thick walls were constructed of adobe blocks. Flat earthen roofs were supported by projecting peeled-log vigas. In some houses the elevation of the walls surpassed the roof, creating a parapet with canales (Spanish, "rain spouts") projecting through them. Rooms were built one at a time in a long single line or enclosed a placita (Spanish, "courtyard") or aspired to enclose a courtyard, as L-shaped and U-shaped floor plans indicate. Each room opened into the next, as well as opening outside. While the threat of Indian attack

Making adobe, circa 1905, Taos. The houses in the background face Ledoux Street, southwest of the plaza. The construction of adobe blocks has changed little. Adobe blocks, usually measuring 15 inches long, 12 inches wide, and 4 inches thick, are still made from local soils containing sand, silt, and clay; the addition of straw to the adobe soil, visible in the photograph, is still practiced to prevent the blocks from cracking while they dry under the hot New Mexico sun. Some old adobe blocks bear the hoof prints of deer that may have been tempted from the mountains to nibble on the straw; this adobe yard, however, appears to be fenced. Photo by B. G. Randall, courtesy of Las Quince Letras © 1986.

remained and before the widespread availability of glass, walls were only rarely interrupted by windows. Whereas the original pueblos were all multistoried communal dwellings, Spanish Colonial homes were usually limited to a single story. But, like the pueblos, rooms were added as the size of the family increased, and homes were often divided, along with the land, among the heirs. In some villages houses of unrelated families were joined together for protection.

The annexation of New Mexico as a territory after the Mexican–American war in 1846 opened the area to more American traders and settlers. American carpenters introduced milled lumber, brick, and glass, as well as the elements of the Greek Revival style popular in the East. Integrated with the Spanish Colonial tradition, it was named the Territorial style. Triangular pedimented lintels above larger doors and windows, transom and side lights above and on both sides of a single front entrance, and dentil courses ("toothed" brick cornices) on the parapet walls or, at higher, wetter elevations, pitched roofs are among the visible characteristics of the Territorial style. The large round wooden posts that supported the roof vigas of the Spanish Colonial portal (Spanish, "porch") were replaced with square columns and moldings at the top and bottom that faintly resembled the capitals and bases of Greek Doric columns.

With the arrival of the railroad to New Mexico in 1879, a succession of eastern Victorian styles, collectively known as the Railroad styles, further altered the traditional Spanish Colonial style. The railroad delivered factory-

Don Ramon Sanches and family, 1910, Peñasco. The transom, side lights, and wood molding that frame the entry are an adaptation of American neoclassicism known as the Territorial style because of its popularíty between 1846 and 1890. The portal with its ornate filigreed wood trím and lattice work may have been added later as it reflects a growing exposure to later eastern Victorian styles that were introduced after the railroad reached New Mexico in 1879. The board floor of the portal was typical; many are now concrete. Photo courtesy of Las Quince Letras.

made corrugated metal roofing and elaborate wooden gingerbread, scrollwork, latticework, and turned spindles.

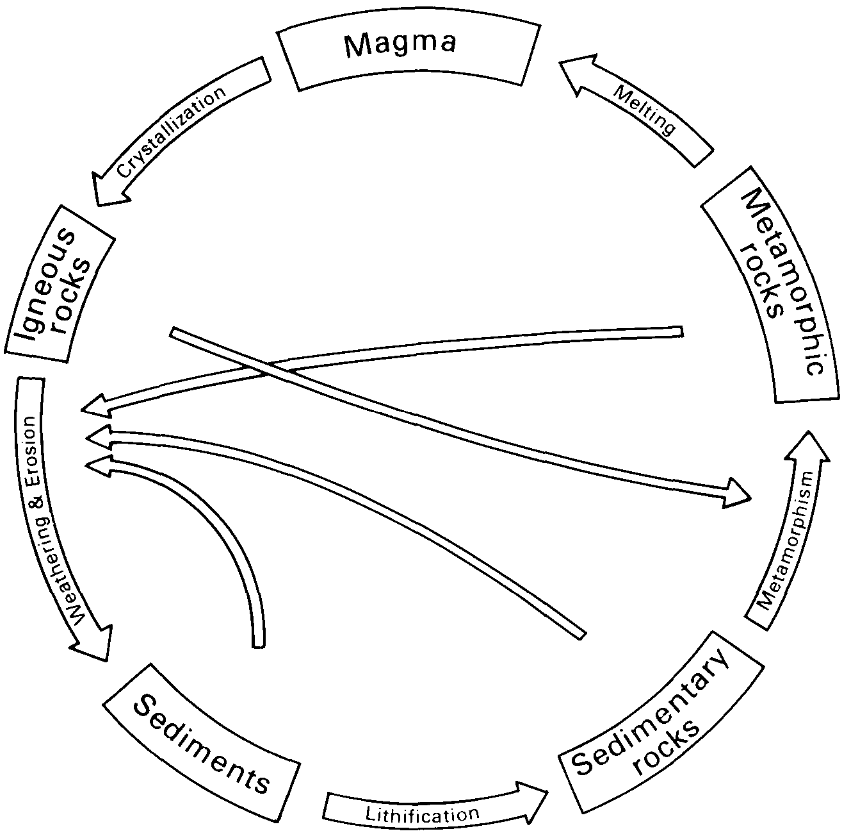
Many of the domestic and commercial buildings that we see today in Taos and Santa Fe are modeled after pueblo and Spanish Colonial architecture. Early in the 20th century architects in Santa Fe consciously tried to recapture the "style" of the Indian pueblos and the Spanish Colonial homes. Existing buildings were "restored" or, in other words, "puebloized." In their pursuit of a Spanish–Pueblo Revival style, Santa Feans in 1957 adopted an architectural control ordinance to restrict the external appearances of buildings within the city's historic district to the Spanish Colonial or Territorial styles. Among its requirements are flat roofs and the use of adobe or hard plaster in light to dark shades of earth color.

Many old rural houses in the Embudo watershed, as well as throughout northern New Mexico, are distinctly different from the Spanish–Pueblo Revival style prevalent today in Santa Fe and, to a lesser extent, in Taos and Albuquerque. Originally the older homes of rural northern New Mexico were constructed of adobe in the long linear floor plan that is Spanish Colonial, and at the turn of the century practically all had flat roofs. But an eclectic rural vernacular grew that reflects the succession of styles and materials that were introduced from the East and that also reflects the economic fortunes or misfortunes of the families maintaining the homes. After the Americans built sawmills (1850's) and lumber was more common, rural New Mexicans began building additions to their homes: pitched, gabled roofs, interior stairways to attic bedrooms with dormer windows, and portales. After the railroad reached New Mexico in 1879 corrugated galvanized steel roofing and hard stucco (cement and lime) were shipped west. Far more effective at keeping water away from adobe walls, these cover the flat earthen roofs and mud plaster of many older homes. Houses built after the arrival of the railroad have larger and more windows because glass became more affordable. Wood trim around doors and windows and wood columns and brackets supporting the portales became more elaborate, reflecting the later flamboyant Victorian Railroad styles. In the isolation of mountain valleys, rural carpenters mixed Spanish Colonial, Territorial, and Railroad styles with embellishments of their own design.

The geologic history of the Taos region

Geologists understand that the Earth's *crust* is continually undergoing change. This is as true in the Taos area as it is elsewhere on our planet. The material that weathers and erodes in one place is recycled to be deposited in another place. What may appear to be the wearing down and destruction of the land is the natural recycling of the Earth's crust. Such buildup, breakdown, transformation, and reconstruction of the rocks that compose the crust create a cycle, called the *rock cycle.*

The rocks that compose the Earth's crust are divided into three main types: *igneous rocks, sedimentary rocks,* and *metamorphic rocks.* Igneous rocks form when molten *magma* cools and solidifies. Sedimentary rocks form from the erosional debris of other rocks, from the remains of plants and animals, or from the precipitation of chemicals from water. Metamorphic rocks are igneous and sedimentary rocks that have been changed by heat, pressure, and the chemical action of fluids. A more detailed discussion of the three rock types begins on page 26.



Rock cycle.

Geologists have divided geologic time into ages and have given each age a name, much as the historians have divided human history into the stone age, bronze age...up to the space age. However, in geologic history, position as well as time changes. For example, on Trip 1 we will see fossil-bearing limestones in the roadcuts of US-64 southeast of Palo Flechado Pass that formed at the bottom of an ancient sea 300 million years ago during Pennsylvanian time. These limestones are not only extremely old, they are very far from the global position where they originated because of a phenomenon called *plate tectonics,* the physical movement of rigid plates of the Earth's crust and underlying *lithosphere* over the deeper *mantle* and *asthenosphere.* The ancient sea, where marine life thrived 300 million years ago and where limy mud preserved their skeletal remains for us to see along US-64, was actually very near the equator. When dinosaurs were roaming what is now New Mexico 200 million years ago they were roaming a continent also much closer to the equator and vastly different from our present environment.

Precambrian

Even though Precambrian rocks represent more than 80% of the rock history of the Earth and constitute 17% of the Earth's land surface our knowledge of Precambrian geology is incomplete. In north-central New Mexico, Precambrian rocks compose most of the highest mountain peaks and include a wide variety of rock types and ages.

The oldest rocks in the Taos Range appear to be igneous rocks that formed between 1700 and 1800 million years ago. At about 1700 million years, a thick pile of sediments accumulated in a large marine *basin* on top of the older igneous rocks. After being deeply buried these sedimentary rocks were subjected to major compressional forces that *folded* and *faulted* them. Metamorphism and melting of large volumes of the continental crust accompanied this mountain-building, or *tectonic,* event. About 1450 million years ago, large granitic intrusions were emplaced in the metamorphic rocks. The mountains built during these events have long since vanished from the landscape. Only the roots of these ancient mountains are exposed in modern mountains, like the Taos Range, which has reached its present height just in the last 25 million years. Nearly all of the Precambrian rocks exposed in the Taos region have been dramatically affected by this complex and dynamic history. However, from 1450 million years ago until well into Paleozoic time (a gap of over 1000 million years of time), very little is known of the geologic history of the Taos region.

We will see these ancient rocks on both loops of the scenic trip. On Trip 1, Precambrian rocks are found in the Red River Canyon, in the Cimarron Mountains, and near Palo Flechado Pass. On Trip 2, Precambrian rocks comprise most of the Picuris Mountains.

Paleozoic

When rocks of a certain age are absent, geologists must determine whether sediments were not deposited or whether sediments were deposited and later removed by erosive forces such as streams and rivers. In general, advance of a shallow sea promotes sedimentary buildup, and retreat of the sea and

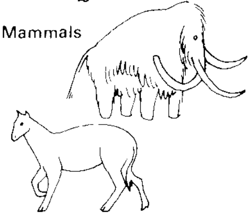
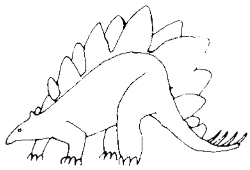
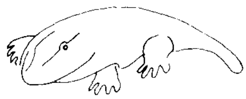
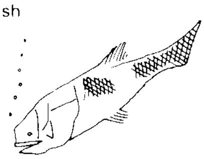
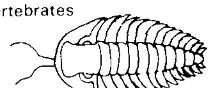
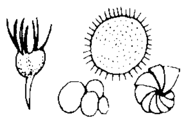
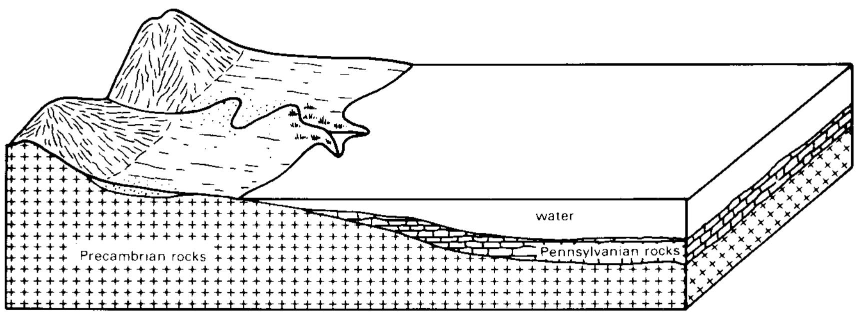
ERA	GEOLOGIC AGE				ROCKS		DOMINANT LIFE
CENOZOIC 66 million years	Quater.	Neogene	Holocene		alluvium landslide deposits glacial deposits Bandelier Tuff		Man 
			Pleistocene	1.6 m.y.			
	Tertiary		Pliocene	5.3 m.y.	Taos Plateau volcanics (Servilleta Formation) Ocate volcanics	Santa Fe Group	Mammals 
			Miocene	23.7 m.y.	Tesuque Formation Picuris Formation volcanics		
		Paleogene	Oligocene	36.6 m.y.	Bear Canyon pluton Amalia Tuff		
			Eocene	57.8 m.y.			
			Paleocene	66 m.y.	Poison Canyon Formation		
MESOZOIC 180 million years	Cretaceous			144 m.y.	Raton Formation Vermejo Formation Trinidad Sandstone Pierre Shale Niobrara Formation Carlisle Formation Greenhorn Formation Graneros Shale Dakota Group		Dinosaurs 
	Jurassic			208 m.y.	Morrison Formation Bell Ranch Formation Entrada Formation		
	Triassic			246 m.y.	Johnson Gap Formation Trujillo Formation Garita Creek Formation Santa Rosa Formation Moenkopi Formation		
PALEOZOIC 324 million years	Permian			286 m.y.			Amphibians 
	Pennsylvanian			320 m.y.	Sangre de Cristo Formation Alamito Formation Porvenir Formation Sandia Formation		
	Mississippian			360 m.y.	Arroyo Peñasco Group		Fish 
	Devonian			408 m.y.			
	Silurian			438 m.y.			
	Ordovician			505 m.y.			Invertebrates 
	Cambrian			570 m.y.			
PRECAMBRIAN 3230 million years	Proterozoic	Late		900 m.y.	qtz. monzonite of Old Mike Peak qtz. monzonite of Columbine Peak Piedra Lumbre Formation Pilar Formation Rinconada Formation Ortega Formation Marquenas Formation Glenwoody Formation Vadito Group		Simple primitive forms 
		Middle		1600 m.y.			
		Early		2500 m.y.			
	Archean			3800? m.y.			

Table of geologic time.

exposure of the landmass promote erosion. No rocks of Cambrian, Ordovician, Silurian, or Devonian age are presently found in the Taos region. Geologists infer that during this time, some sediments were probably deposited and then later removed by erosion.

During much of late Paleozoic time sediments were deposited in a large basin, called the Taos trough. In Mississippian time, shallow marine limestones were deposited in the trough. From Late Mississippian to Early Pennsylvanian time, mountains rose up adjacent to the trough. From Middle to Early Pennsylvanian time, sediments were carried southward and eastward into the trough. Further uplifting in Late Pennsylvanian to earliest Permian time formed more mountains and filled the trough with an enormous thickness of coarse-grained sand and gravel eroded from the mountains to the north. By Early Permian time the Taos trough was no longer filling with locally derived sediments. Instead, shallow marine sediments of the Yeso Formation blanketed much of the area. During Late Permian time, *sandstones,* limestones, and *shales* accumulated over much of the region that today surrounds Taos.

Paleozoic rocks are exposed over most of the southern part of the Sangre de Cristo Mountains. We will see excellent exposures near the end of Trip 1 on US-64 and good exposures on Trip 2 on NM-518 south of Taos. Shallow marine fossils of *trilobites, brachiopods, crinoid* stems, *cup coral,* and *pelecypods* can be found in the Middle and Upper Pennsylvanian rocks.

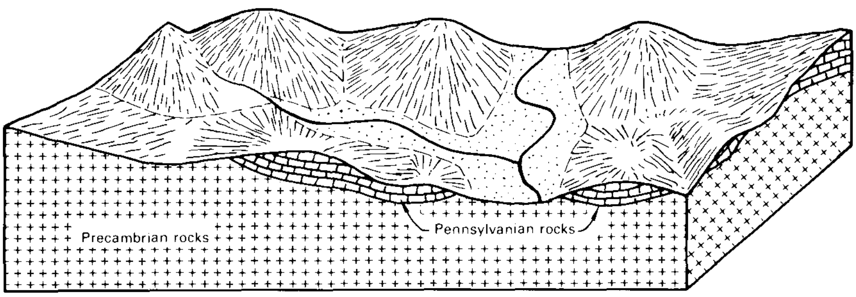


Pennsylvanian time.
Sea and coastal plain.

Mesozoic to middle Cenozoic

Nonmarine sandstones and shales were deposited episodically over much of what is now northern New Mexico during the Triassic and Jurassic periods. Beginning in Late Cretaceous time, dry land alternated with shallow sea as the shoreline advanced and retreated. Sand and gravel were deposited along streams on the flat coastal plain, and coal beds were formed in the numerous swamps. Dinosaurs roamed the plains, consuming lush plants, other animals, and one another. Shale, sandstone, and limestones were deposited on the sea bottom. Although no rocks of these ages are visible along our routes, they are exposed in the Moreno Valley, which we traverse on Trip 1. Exposures of Cretaceous rocks are abundant in the high plains to the east of the Moreno Valley.

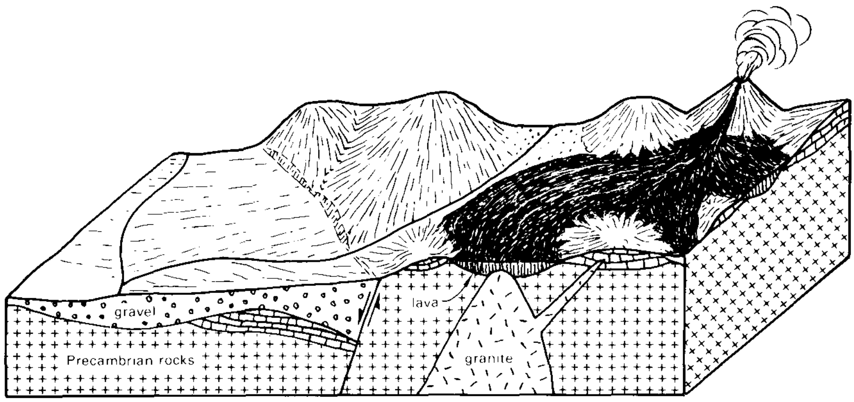
From Late Cretaceous time to early Tertiary time forces associated with the *Laramide orogeny,* a great mountain-building event, compressed the Earth's crust horizontally resulting in folding, major faulting, uplift, and erosion. The western half of what had been the Taos trough was eroded away, and by middle Tertiary time only rolling hills remained.



Early Tertiary time.
Mountains eroded to rolling hills.

Late Cenozoic

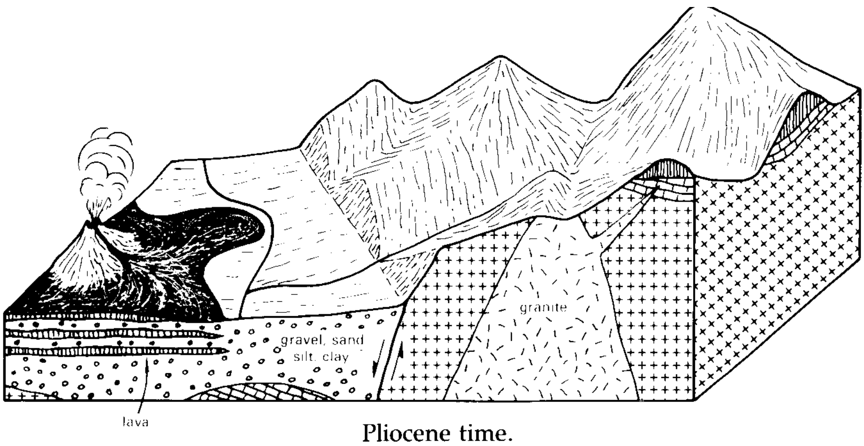
In Miocene time, another major mountain-building event began that dramatically affected the present shape of the land. With extension of the Earth's crust, the Rio Grande rift area began to subside relative to the Sangre de Cristo Mountains. Volcanoes erupted in the mountains, covering the hills with lava and ash. Hot, granitic magma moved upwards to solidify within these volcanic rocks, and the Questa *caldera* formed.



Miocene time.
Uplift and settling begin; eruptions in the mountains.

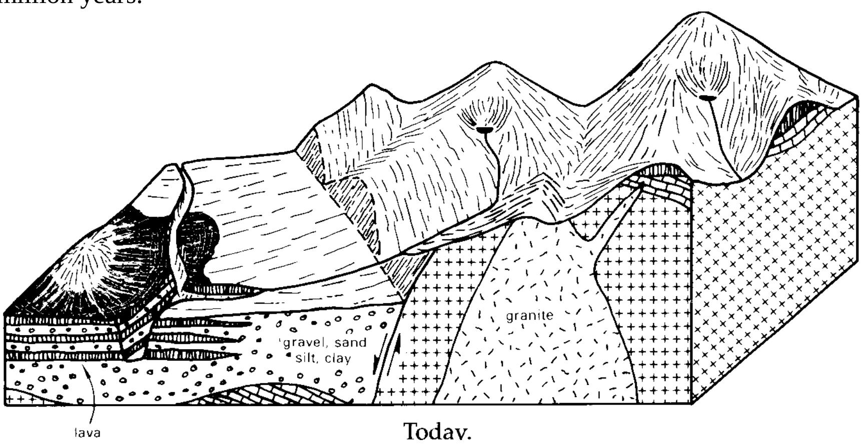
The uplift and resultant accumulation of late Tertiary sediments continued slowly until, by Pleistocene time, the Sangre de Cristo Mountains reached their present height. The plains area was still settling slowly, and the streams from the mountains carried gravel and finer-grained sediments into this topographic low. From time to time, while the rift basin was filling with sediments, volcanoes to the west erupted, blanketing these deposits with lava.

About 3 million years ago the Rio Grande, its ancient headwaters in Red River Canyon, began to cut through the sediments and lava, forming the modern gorge. During the Pleistocene ice ages, glaciers covered the higher peaks and scoured out U-shaped valleys and arcuate depressions called *cirques.* Some time after 600,000 years ago the Rio Grande expanded its headwaters to the mountains in southern Colorado through the San Luis Valley. Today the Red River flows from Red River Canyon into the Rio Grande southwest of Questa.



Pliocene time.
Continuing uplift and settling; erosion in the mountains; rift-basin sediments and lava cover plain.

Today, as uplift and subsidence continue, streams move weathered rock from the mountains to the plains. The uplifting takes place episodically by a series of small movements, each one resulting in an earthquake. These processes work so slowly that we see little or no change during our lifetimes. It staggers the imagination to visualize something that took millions of years to form. If, for example, the mountains had been uplifted only one inch per century, they would have risen almost 5 miles during the past 30 million years.



Todav.
Mountains, plain, and gorge; lakes high in the mountains are where glaciers scoured out depressions.

The three rock types

Rocks can be divided into three major groups: igneous, sedimentary, and metamorphic. Within each of these major divisions, rocks are further subdivided and named according to mineralogy, texture, and color. Texture refers to the size, shape, and orientation of mineral grains.

Igneous rocks originate from the crystallization of molten silicate rock, called magma, within the Earth. Individual minerals in igneous rocks generally interlock with each other in all directions. Magmas that erupt onto the surface of the Earth produce *extrusive (volcanic) rocks.* They cool so rapidly that crystals do not have time to grow large. Thus extrusive rocks are fine grained or glassy. Alternatively, magmas that crystallize below the surface produce *intrusive (plutonic) rocks.* They cool slowly and are therefore generally coarse grained. In some cases magma will cool slowly at first, then more rapidly. When this happens large crystals, *phenocrysts,* of *quartz* or *feldspar* start to grow but are then trapped in a mass of finer crystals, called *matrix.* Such a texture is called porphyritic, and the rock is called a *porphyry (i.e.* granite porphyry).

In a very general way igneous rocks with abundant iron and magnesium minerals *(mafic minerals),* such as *biotite, amphibole,* and *pyroxene,* are darker in color than rocks with abundant potassium, sodium, aluminum, and silicon minerals *(felsic minerals),* such as quartz, feldspar, and *muscovite.* Igneous rocks can therefore be roughly classified on the basis of texture and color.

Generalized igneous rock classification

	Color			
	Light		**Medium**	**Dark**
Texture	**Quartz**	**No quartz**		
Coarse-grained	granite	syenite	diorite	gabbro
Fine-grained	rhyolite	trachyte	andesite	basalt
No grains (glass)				obsidian

Sedimentary rocks fall into three groups: 1) those that have formed from the accumulation of older rock and mineral fragments that were mechanically transported and deposited by water, wind, or ice; 2) rocks that have precipitated from chemical solutions at the Earth's surface; and 3) rocks that have formed from the remains of plants and animals. The fossilized remains of dead animals and plants may be preserved in all sedimentary deposits. Consolidation by compression and cementation of grains produce solid rock. Within these three broad categories sedimentary rocks are further classified by composition and texture.

Generalized sedimentary rock classification

Origin of sediments	Rock name	Composition	Texture
mechanical (erosion)	conglomerate	gravel, cobbles boulders	coarse grained (over 2 mm)
	sandstone	sand	medium grained (1/16 mm-2 mm)
	shale	silt, clay	very fine grained (less than 1/256 mm)
chemical (minerals precipitated from water)	limestone	calcium carbonate	very fine to coarse grained
	dolomite	magnesium–calcium carbonate	very fine to coarse grained
	gypsum	calcium sulfate	fine to coarse grained
	rock salt	sodium chloride	fine to coarse grained
organic (remains of plants and animals)	limestone	calcium-rich remaíns	
	diatomite	silica-rich remains	
	coal	plant remains	noncrystalline

Metamorphic rocks are rocks that have formed in response to high pressures and temperatures and chemical changes encountered during deep burial. The process of metamorphism generally results in a new mineralogy, composition, texture, or internal crystal structure. Metamorphic rocks were never molten; instead they formed as solids under high stress. Consequently, their crystals commonly have grown in parallel alignment *(foliation).* Regional metamorphism occurs during deep burial, whereas contact metamorphism occurs at any depth when hot igneous magma bakes the adjacent *country rock.* Metamorphic rocks are classified according to foliation, grain size, and mineralogy or color (see figure on page 20 showing rock cycle). Commonly, shale is metamorphosed to *slate* or *schist,* limestone becomes *marble,* sandstone becomes *quartzite,* and *granite* turns to granitic *gneiss.*

How to use the road logs

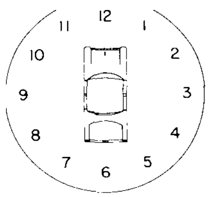
Each of the two road logs is a loop. Both logs begin at the Taos plaza in the center of town. Zero mileage is at the northeast corner of the plaza. We show cumulative mileage at the left of each entry, and the mileage between points is shown between each entry. Because mileages indicated here may vary slightly from those registered by your car, check-point mileages such as bridges, road intersections, and mile markers are logged.

The total mileage for Trip 1 is 100 miles, but the trip odometer is reset to zero at four locations, the junction of US-64 and NM-522, the junction of NM-522 and the dirt road leading into the Rio Grande Gorge at Dunn's Crossing, the junction of NM-38 and Mallette Road, and the junction of NM-38 and US-64, so that the road-log user can conveniently take Side trips 1A and 1B or take personal excursions up the Hondo Canyon to the Taos Ski Valley and into Eagle Nest before continuing the main loop tour.

The total mileage for Trip 2 is 62 miles. The trip odometer is reset to zero at the junction of NM-68 and NM-570 (mile 16.6), the less precipitous of two routes for Side trip 2A into the Rio Grande Gorge south of Taos. The trip odometer is again reset to zero at the junction of NM-75 and the turnoff for Side trip 2B, the walking tour of the Harding pegmatite mine.

Crucial directions and instructions to reset the trip odometer are printed in bold type. Turnoffs for the side trips as well as recommended stops along the route are also printed in bold type. "Stop" indicates points of special interest—places worth a stop. A picnic table next to an entry means picnic or camping facilities are available. Watch for traffic when stopping and walking along the highway.

The clock system is used to point out features of interest. Straight ahead is considered 12:00; 9:00 is due left; 3:00 is due right, and locations in between are as indicated below.



Don't try to read the road log yourself! Have a passenger watch the odometer and read the log aloud, keeping far enough ahead of your location so that the description can be completed before you reach the point of interest.

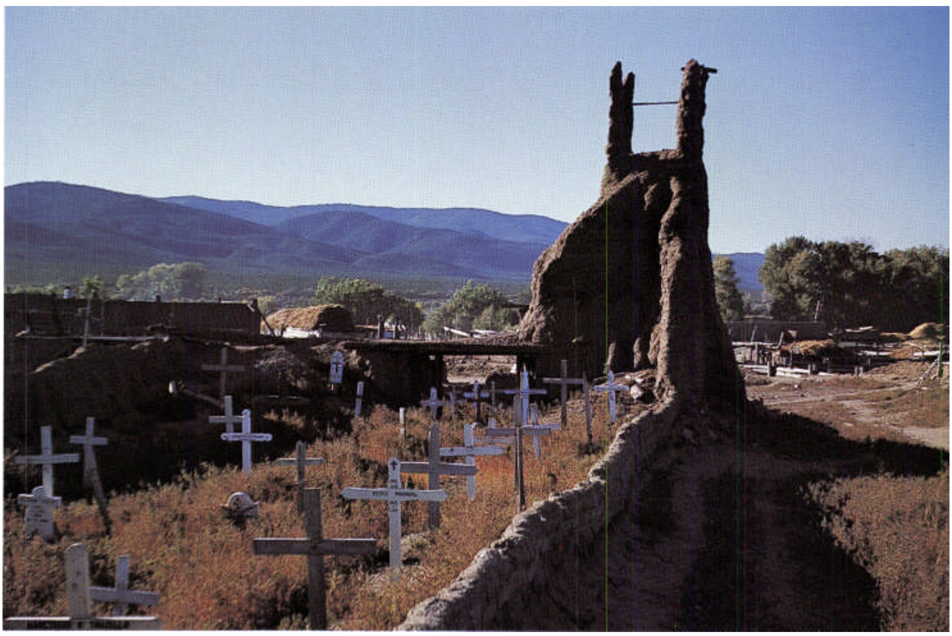
Color photo gallery

(next 12 unnumbered pages)

Cottonwood trees growing near a cienaga along the Rio Grande turn golden in October. Golden flowers in the foreground are chamisa or rabbitbrush (*Chrysothamnus nauseosus*), a ubiquitous silvery-gray, fall-blooming shrub.

Plate 2

Winter, Taos. Photo by Mark Nohl, courtesy of the New Mexico Economic Development and Tourism Department.



San Gerónimo de Taos, Taos Pueblo.

Winter, Red River Canyon.

Fall colors near Red River. Photo by Mark Nohl, courtesy of the New Mexico Economic Development and Tourism Department.

Plate 4

Naturally occurring June Bug alteration scar, Red River Canyon. Photo courtesy of Molycorp, Inc.

Aerial view of the Molycorp open-pit mine near Questa, September 10, 1975. Photo by Limbaugh Aerial Mapping Division, Bovay Engineering, Inc., Albuquerque, courtesy of R. Young.

Geologists at work, Picuris Mountains. Photo by R. Holcombe.

Plate 6

Bobcat in ponderosa pine, Picuris Mountains. Photo by P. W. Bauer.

Chile ristras drying in the late summer sun.

Rose muscovite and cleavelandite with quartz 2 1/8 inches (5.3 cm) across, Harding pegmatite mine. Photo by D. Wilson.

Marquenas Formation conglomerate; pen for scale.

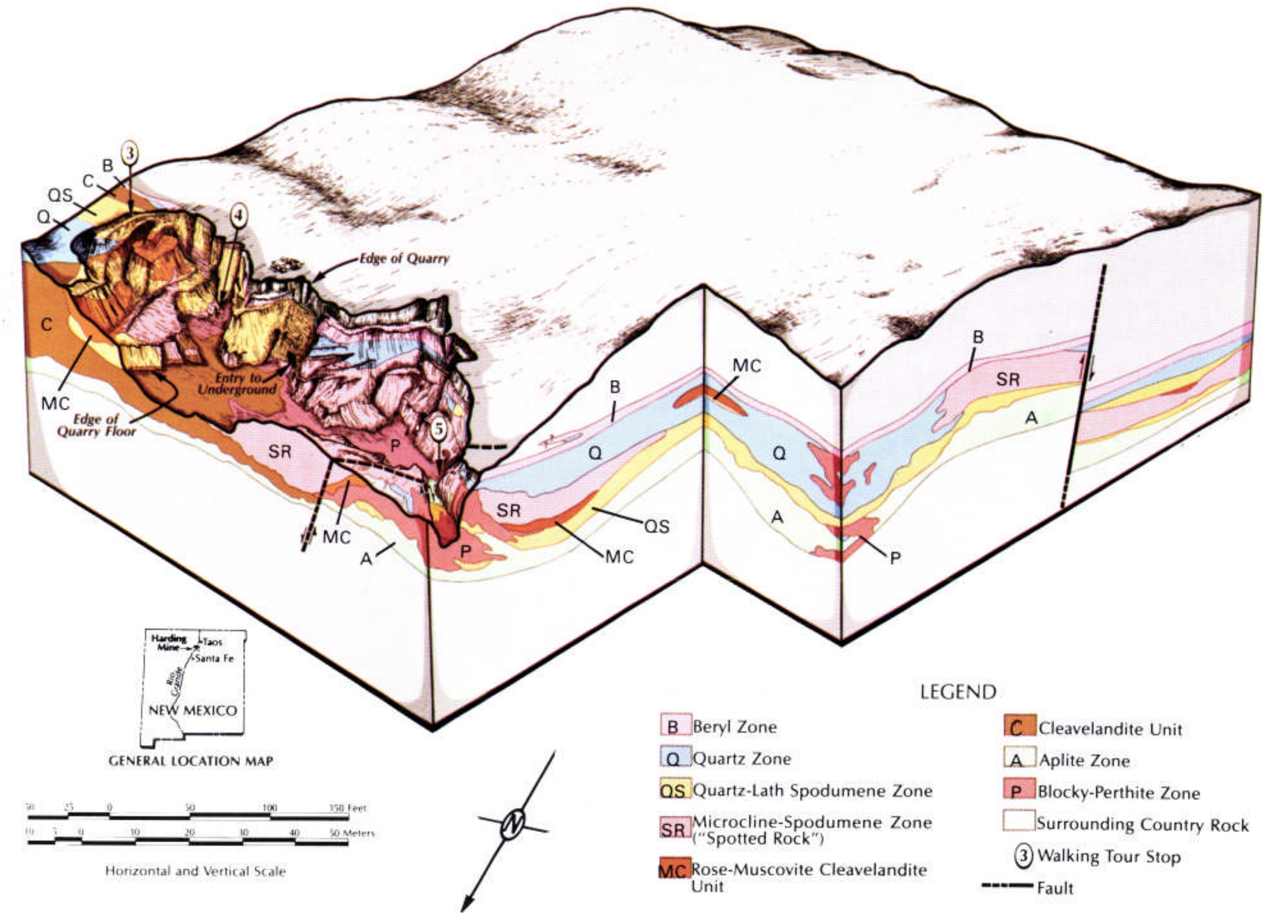
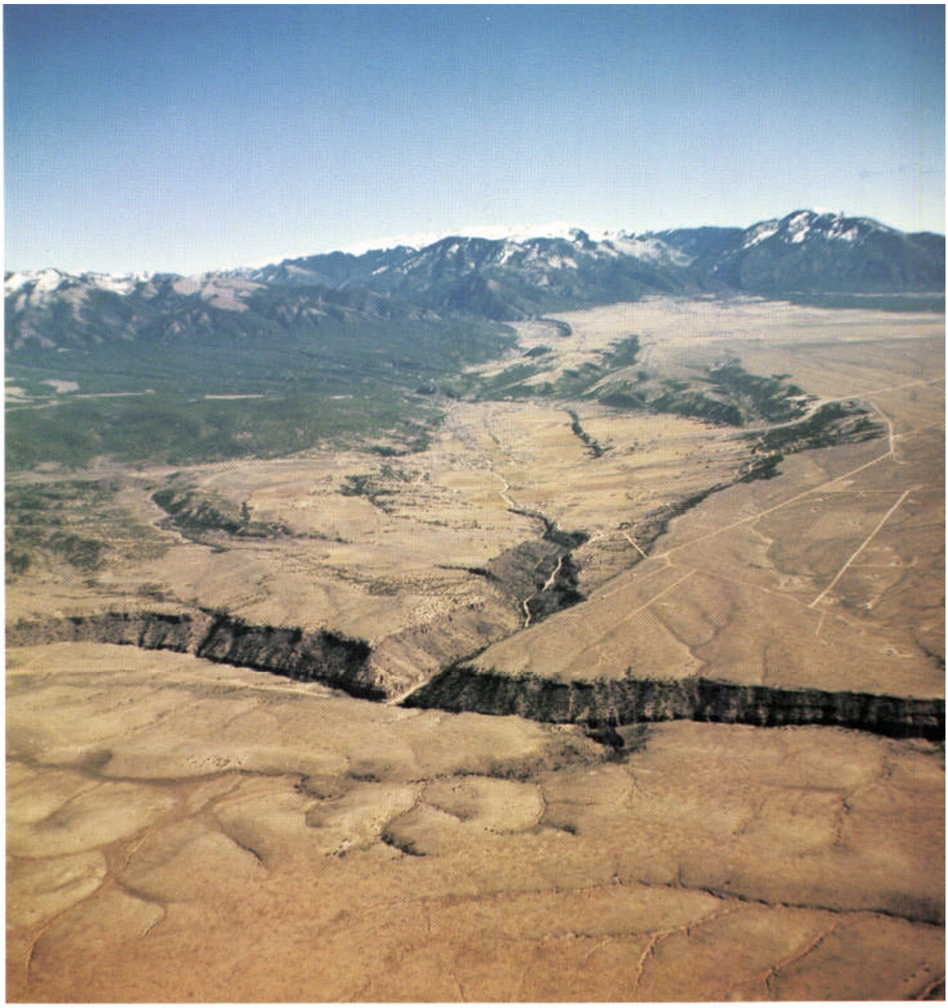


Diagram of the eight rock zones in the Harding pegmatite mine and surrounding country rock (after Jahns and Wright, unpubl. field map 1943); courtesy of the University of New Mexico Geology Department.



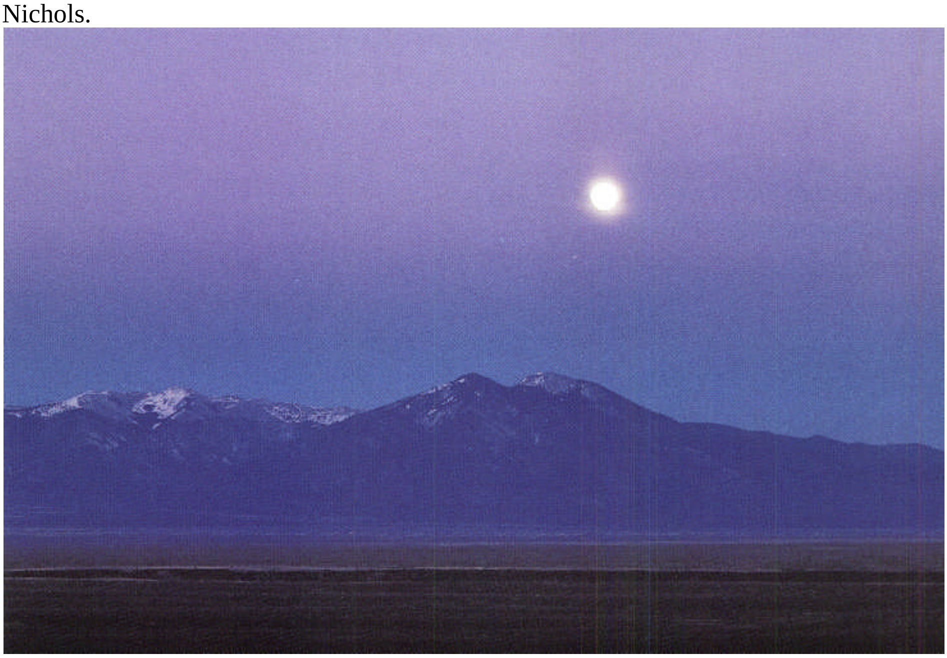
Aerial view of confluence of Rio Hondo and Rio Grande. Photo by Alan H. Johnson, Sky View of Taos, © 1991.

Plate 10

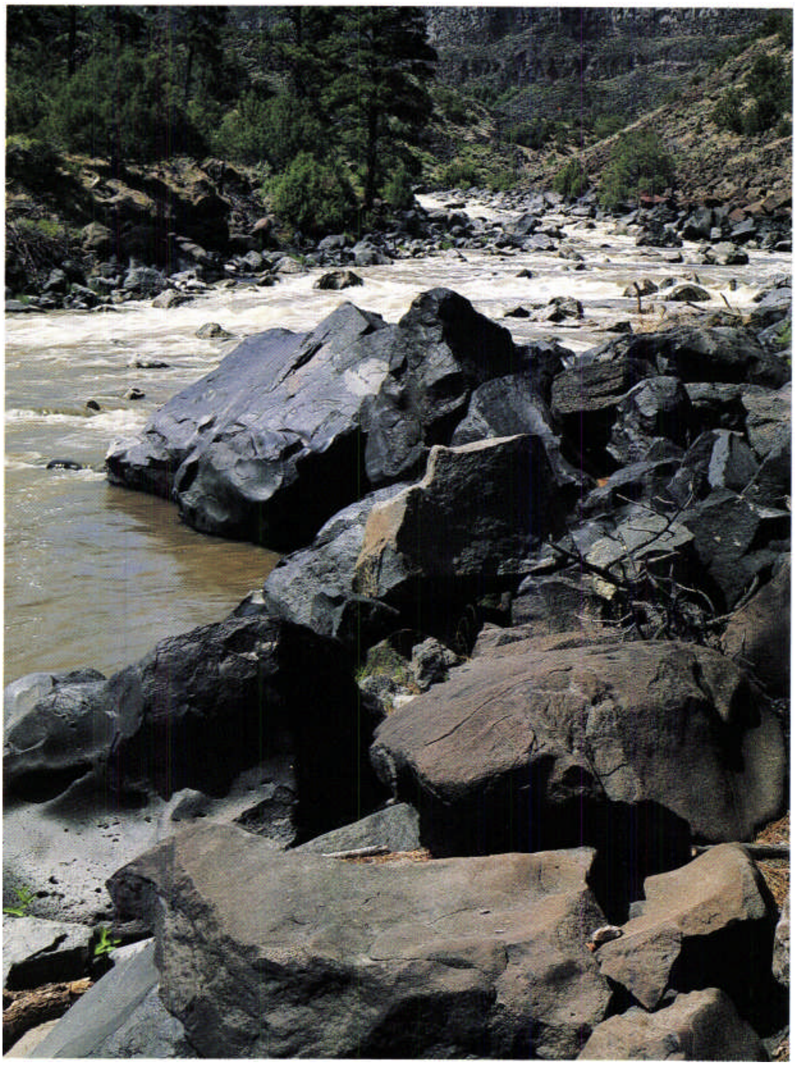
Aerial view north of the Rio Grande Gorge near John Dunn Bridge. Photo by Jim Bones.

View of extinct volcanoes west of the Rio Grande Gorge. Photo by John Nichols.

Winter sunset, Sangre de Cristo Mountains. Photo by John Nichols.



Moonrise over Sangre de Cristo Mountains; Rio Grande Gorge in the foreground. Photo by John Nichols.



Basalt boulders along the Rio Grande slowly develop a bluish-purple veneer of iron and manganese oxides, called rock varnish. Photo by Jim Bones.

Enchanted circle—Taos—Questa—Red River—Eagle Nest—Taos

The flat, dry plains of the Taos Plateau stand in marked contrast to the towering, heavily forested Sangre de Cristo Mountains to the east. Our main objective on this trip is to investigate and compare these two very different landscapes. The trip begins on the flat Taos Plateau north of Taos. We will then cross the imposing Taos Range of the Sangre de Cristo Mountains to the east, descend into the picturesque Moreno Valley, and travel south before recrossing the mountains to complete the loop. The driving time, without stops, is about 3 hours.

In addition to geology, we will point out evidence of early human inhabitants, describe plants and animals native to this area, and relate some of the fascinatíng, more recent human history. Bring your camera; there are lots of photo opportunities ahead.

Cumulative mileage

0.0 Leave Taos plaza from the northeast corner and **turn north** (left) onto North Pueblo Road (NM-522).

0.1

0.1 To the left, down Bent Street, is the house where Governor Charles Bent and his family lived.

250 feet

0.15 On the right is the entrance to Kit Carson State Park, last resting place of Kit Carson, the famous mountain man.

0.35

0.5 **Bear left to remain on** NM-522. Road straight ahead leads to Taos Pueblo (1 mile). Multistoried community houses provide the finest existing examples of the architecture that the Spanish explorers saw when they visited Taos Pueblo in 1540.

0.7

1.2 Road to right leads to Taos Pueblo. **Continue on highway.**

1.1

2.3 To the right, at 3:00, is the Taos Range on the skyline. Rio Pueblo de Taos flows through the canyon of the Taos Pueblo. Much of the farmland on the right is owned by Taos Pueblo. Well-vegetated *alluvial fans* from 2:00 to 3:00 on the right have spread outward from the Taos Range. These alluvial fans bury and are locally offset by the *faults* that border the uplifted mountains. Herds of bison may sometimes be seen on the right. Scenic Historic Marker on right reads:

> Taos. Population 3369. Elevation 6983. The Spanish community of Taos developed two miles southwest of Taos Pueblo. It later served as a supply base for the "mountain men", and was the home of Kit Carson, who is buried here. Governor Charles Bent was killed here in the anti-U.S. insurrection of 1847. In the early 1900s, Taos developed as a colony for artists and writers.

1.7

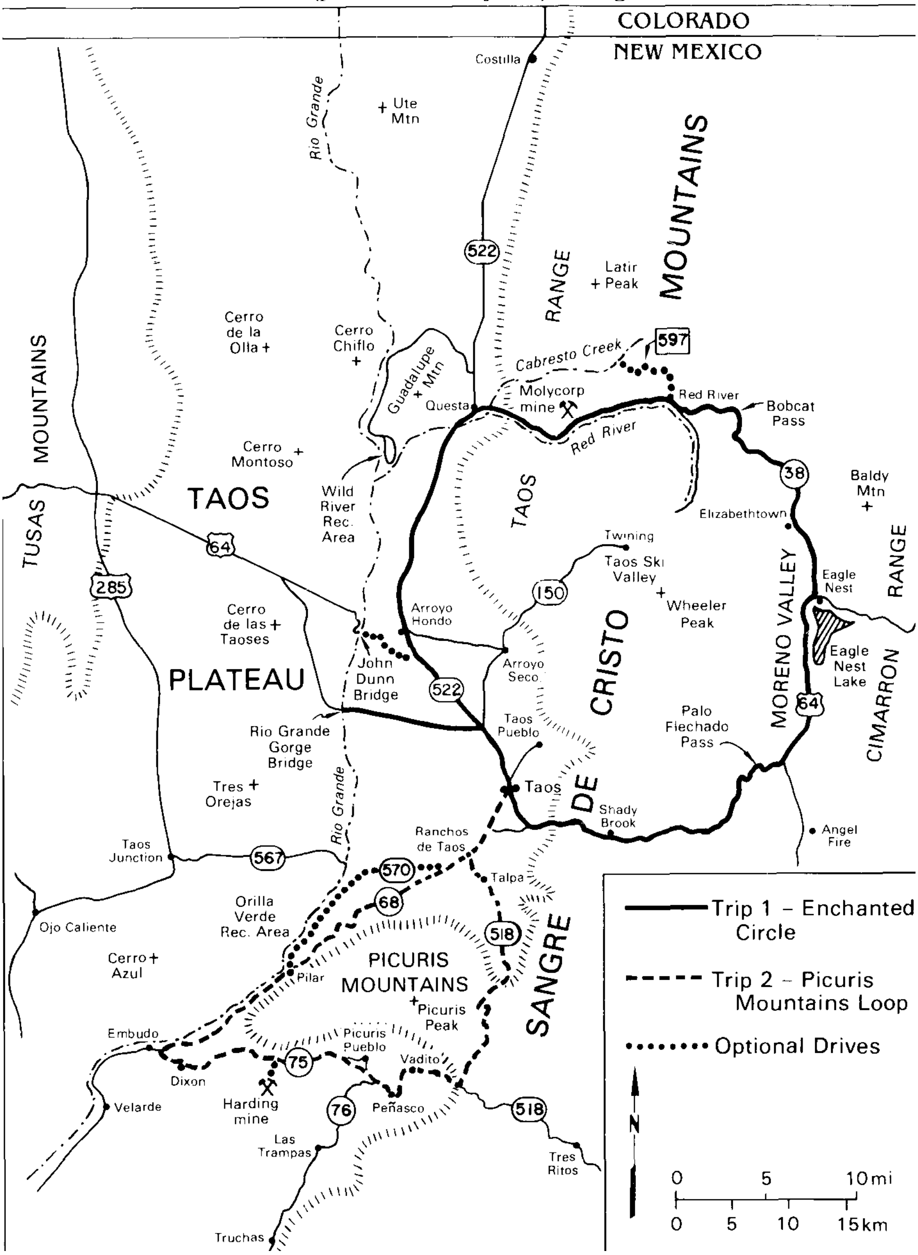
4.0 **Turn left on US-64** to the Rio Grande Gorge Bridge.

0.2

4.2 Crossing beneath natural-gas pipeline.

0.4

4.6 To the left, at 9:00, are the Picuris Mountains. At 10:00, on the far skyline, are the Jemez Mountains (pronounced Haymez). Straight



Map of north-central New Mexico and trip routes.

ahead, at 12:00, on the skyline are the Tusas Mountains (Spanish, "prairie dogs"). The small dark hills closer to us on the Taos Plateau are Tertiary-age volcanoes. In the foreground, at 11:00, are the Tres Orejas (Spanish, "three ears"). The larger, rounded peaks on the northern skyline, from 1:00 to 2:30, are also the remains of volcanoes.

1.2

5.8 Notice the steep slope on the east side of the drainage and the gentle slope on the west side. This is called an asymmetric valley. Such valleys are common on the Taos Plateau because of tilting after stream courses were established.

2.1

7.9 Taos Municipal Airport on the left. A 750-foot water well drilled at the terminal in 1990 penetrated about 420 feet of *basalt* and interbedded fine-grained stream and lake deposits below about 140 feet of sandy alluvial-fan deposits. The basal basalt flows and thin underlying stream gravels form the main aquifer zone below 510 feet. Clays and silty sands were also penetrated by the well bore below 565 feet and probably represent lake and floodplain deposits of streams dammed by the earliest basalt flows of the Pliocene Servilleta Formation.

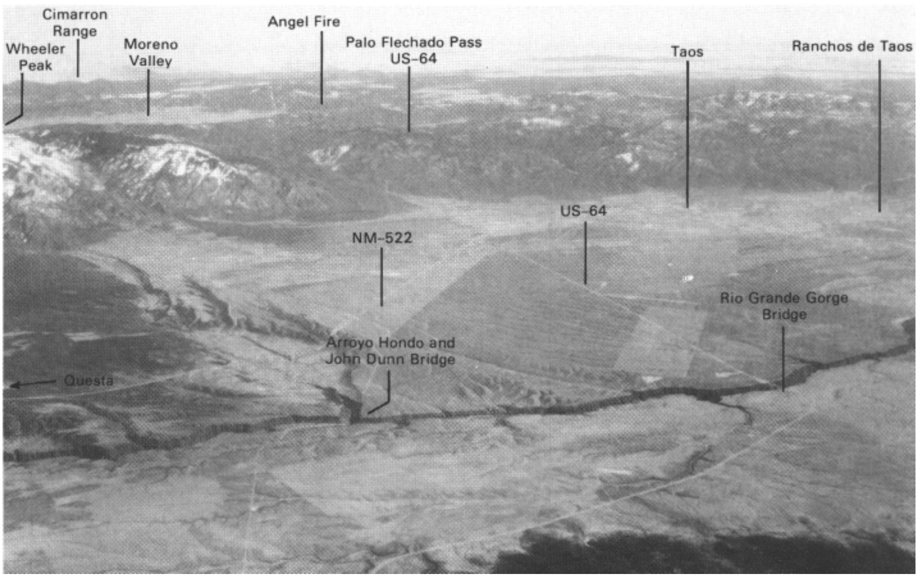
3.5

11.4 Sand and gravel operation on the right.

0.3

11.7 **Stop in the parking area on the right** (elevation 5,957 feet). Official Scenic Historic Marker reads:

Rio Grande Rift. A tremendous split in the earth's crust has resulted in the Rio Grande rift basin filled with thousands of feet of alluvium from



Aerial view southeast of the Taos Plateau, Rio Grande gorge, and Sangre de Cristo Mountains. Photo by J. W. Hawley.

Rio Grande Gorge Bridge (looking north) on the occasion of its dedication September 10, 1965. Photo no. 33930 from the Governor Jack Campbell Collection, courtesy of the New Mexico State Records Center and Archives.

bordering mountains and lava flows from deep within the earth. About 650 feet of this basin fill is exposed in the Rio Grande Gorge at the bridge crossing.

The bridge, which was completed in 1965, is 650 feet above the Rio Grande, making it the second highest bridge on the national highway system. On the west side of the bridge are a picnic area and restrooms.

We are standing on a layer of black basalt, the Pliocene Servilleta Formation. Across the gorge, at the same elevation, we can see an identical layer. Poorly consolidated sand and gravel are above and below the basalt. Other basalt layers are exposed in the steep walls of the gorge. Geologists who have studied the Servilleta Formation believe that it formed from highly fluid lava flows that erupted out of now-extinct volcanoes, the hills that we see to the west. But where did the gravel deposits come from? Notice that many different types of rocks are present in these gravels. These same rock types are in the gravel deposits on the opposite side of the gorge. If we had time to hike through the Sangre de Cristo Mountains to the east, we would find that identical rock types make up much of the mountain range. As the bedrock weathers and erodes, loose material is transported into the valley, mainly by streams.

View south from the Rio Grande Gorge Bridge; Picuris Mountains on the skyline.

The geologic history of the gorge area can be pieced together from the evidence in front of us. About 5 million years ago, in late Tertiary time, volcanoes located to the west erupted and covered the land surface with highly fluid lava flows. At the same time, high mountains to the east were being slowly eroded, and streams draining these mountains carried gravel and finer sediments into this large *basin,* burying the lava flows and forming alluvial fans. Renewed volcanic activity then spread lava over the alluvial fans. The lava at times dammed the streams, and fine-grained alluvium and lake sediments were deposited along the eastern margin of the lava flows. More sediment in turn buried these flows. Imagine how different this area must have looked during these volcanic eruptions. During the much wetter Pleistocene Epoch, the ancestral Rio Grande began cutting down into the basin-fill sediments and lava flows faster than the alluvial fans could grow. The Rio Grande continued downcutting, exposing the basalt layers and eventually forming the present-day gorge.

You may want to walk out onto the bridge. Watch for cars and stay on walkways.

Return to parking area and **backtrack to junction with NM-522.**

6.0

17.7 Straight ahead in the middle distance is Taos Pueblo and the canyon of the Rio Pueblo de Taos.

1.7

19.4 Junction with NM-522.

0.0 **Set trip odometer to zero** and **turn left onto NM-522**. Road straight ahead (NM-150) follows the Hondo Canyon into the mountains to Twining (16 miles), once a copper mining camp, now the Taos Ski Valley. The scenery is well worth a trip, especially in the fall. At the end of the road, backpacking trails lead to the high wilderness country around Wheeler Peak (elevation 13,161 feet), the highest point in New Mexico.

1.1

1.1 The large walled building complex on the right is the home of famed Navajo artist R. C. Gorman.

0.4

1.5 Scenic Historic Marker on the left reads:

> The Rio Grande Gorge Bridge. Second highest bridge on the National Highway System rises 650 feet above the stream of the Rio Grande. Dedicated Sept. 10, 1965, it is a lasting monument to the untiring efforts of Governor Jack M. Campbell and the citizens of Northern New Mexico to open this scenic area to the public.

To the right, from 2:00 to 3:00, the steep rugged canyon is Hondo Canyon, through which winds the road that goes to Twining and the Taos Ski Valley. Beyond Hondo Canyon, at about 3:00, are the high peaks of the Wheeler Peak Wilderness.

0.8

2.3 Straight ahead, at 12:00, on the distant skyline is San Antonio Mountain, an extinct volcano near the Colorado border. The low hills in foreground include No Agua Peaks (Spanish, "no water") and other small volcanoes. At 12:30 the other low shield shape is Cerro de la Olla, another extinct volcano. Cerro Montoso is just to the left of and in front of Cerro de la 011a. At 11:00 the darkly vegetated low hills are Cerro de los Taoses. Cerro is the Spanish word for peak or hill.

1.4

3.7 To the right, at 3:00, is the village of Arroyo Seco (Spanish, "dry wash") at the mouth of Hondo Canyon (Spanish, "deep"). The highway dips into the valley of Arroyo Hondo.

1.7

5.4 **Side trip 1A to Dunn's Crossing in the Rio Grande Gorge.**

> **Set trip odometer to zero** and **turn left** onto poorly marked dirt road. Turnoff is just after signs indicating "curve left" and "steep grade" and just before the highway begins final descent into the valley. The dirt road is often rutted and rough. If you wish to take the side trip, turn to page 70 for road log.

0.0 If you choose not to take the side trip, **set trip odometer to zero** and **continue north on** NM-522.

0.1

0.1 The gravel in the roadcut is similar to the gravel exposed in the Rio Grande Gorge. The highway dips into the Rio Hondo valley and crosses a high flat *terrace.* This terrace, a former valley bottom, has been left high and dry as the Rio Hondo continues to cut down.

0.1

0.2 Highway cuts through sand and gravel deposits of upper Santa Fe Group alluvial fans. Straight ahead is Arroyo Hondo.

1.2

1.4 Village of Arroyo Hondo.

0.2

1.6 Bridge crosses Rio Hondo.

0.1

1.7 Roadcut through basalt flow. Begin ascent out of the Rio Hondo valley. For the next 12 miles, until we reach Questa, a "dwarf" forest of piñon pine and Rocky Mountain juniper (scalelike "leaves" and blue berries) can be seen growing along the highway. These trees rarely exceed 20 feet in height. Occasionally we'll pass taller trees; these are ponderosa pine. Most of the roadcuts are in alluvial-fan gravels that were transported into this area from the mountains. A few roadcuts expose lava flows of basalt interbedded with gravels. No other rock types are exposed along this stretch of road. The similarity between the geology here and that in the Rio Grande Gorge suggests that during the last 5 million years a large region of the Taos Plateau has had a similar, relatively simple geologic history.

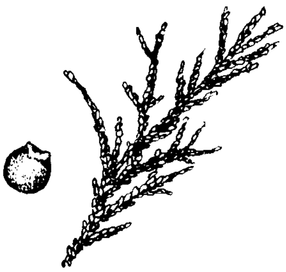
0.7

2.4 Roadcut through alluvial-fan sands and gravels.

1.6

4.0 Entering Carson National Forest.

0.9



Rocky Mountain juniper
Juniperus scopulorum

Piñon pine
Pinus edulis

Ponderosa pine
Pinus ponderosa

4.9 Road to right goes to San Cristobal and the D. H. Lawrence Ranch. Official Scenic Historic Marker reads:

> Lawrence Ranch. University of New Mexico. The Kiowa Ranch, home of novelist D. H. Lawrence and his wife Frieda in 1924-1925, was given to them by Mabel Dodge Lujan. Frieda continued to live at the ranch after his death and later married Angelo Ravagli. In 1934 they built a shrine for Lawrence's ashes. Aldous Huxley was among the many visitors to the ranch.

0.7

5.6 Crossing San Cristobal Creek (Spanish, "St. Christopher").

2.9

8.5 Crossing Garrapata Canyon (Spanish, "sheep and cattle tick").

1.0

9.5 Leaving Carson National Forest.

0.4

9.9 Village of Lama (Spanish, "mud, ooze") to the right.

0.2

10.1 Forest Service Road 9.

0.8

10.9 View ahead of Questa and mouth of the Red River valley.

0.4

11.3 NM-515 on the left leads to the Red River Fish Hatchery.

0.7

12.0 The large round hill to the left at about 9:00 is Cerro de la 011a, a 2million-year-old *shield volcano.* The cluster of angular hills to the right of Cerro de la Olla, from 9:30 to 10:00, is Cerro Chiflo, a 10-millionyear-old lava dome.

0.4

12.4 Slightly to the left, at 11:00, is Guadalupe Mountain. On the distant skyline ahead are the northern Sangre de Cristo Mountains in Colorado. *Tailings* ponds from Molycorp's molybdenum mine are visible in the foreground on the flat plains.

1.3

13.7 Questa village limit. Elevation 7,500 feet.

0.1

13.8 Road crosses the Red River. The trees along the stream are cottonwoods and willows. The community was originally called San Antonio del Rio Colorado but was renamed Questa when the post office opened in 1883. Questa is probably a corruption of the Spanish word "cuesta," which means slope or grade.

0.3

14.1 To the right, at 1:00, on the skyline are piles of mine waste. The angular peak ahead is Pinabete Peak (Spanish, "fir tree"). The high peaks beyond are in Latir Peak Wilderness.

0.9

15.0 Junction with NM-38; **turn right onto NM-38**. We'll be on NM-38 for the next 31 miles until Eagle Nest. NM-522 continues north to Colorado. The U.S. Bureau of Land Management Wild Rivers Recreation

Area, where the Rio Grande and Red River meet, is southwest of Questa; however, to reach the recreation area continue north on NM, 522 and watch for a sign indicating the turnoff on the left. Payment of a nominal camping fee may be required.

Shortly ahead, NM-38 enters Red River Canyon. The Red River, originally called Rio Colorado by the Spanish, was named for the color of its water during flash floods. As we will soon discover, the geology in the mountains is quite different and much more complex than that of the Taos Plateau.

0.3

15.3 Road on the left goes up Cabresto Canyon.

0.5

15.8 Rocks in the steep slopes ahead are Tertiary-age *granitic rocks* of the Bear Canyon *pluton* (24 million years old).

0.5

16.3 Small fishing pond on the right.

0.2

16.5 Entering Red River Canyon. The cliffs along both sides of the canyon for the next mile are Tertiary-age *granite* of the Bear Canyon pluton.

0.2

16.7 Questa Ranger Station, Carson National Forest, on the right. The yellowish-orange roadcut material is altered andesitic lava flows of Tertiary age. We will repeatedly encounter this rock type along the road ahead.

0.4

17.1 On the left, the steep cliffs are part of the Bear Canyon pluton. The high cliffs straight ahead are Amalia Tuff. *Tuff* is a rock composed of compacted, fine-grained volcanic fragments that erupted explosively from a volcano. The Amalia Tuff erupted from the Questa caldera about 25-26 million years ago. Lesser amounts of other volcanic rocks, such as lava flows, *rhyolite*, gray *latite*, and purple *andesite* are also found here.

0.6

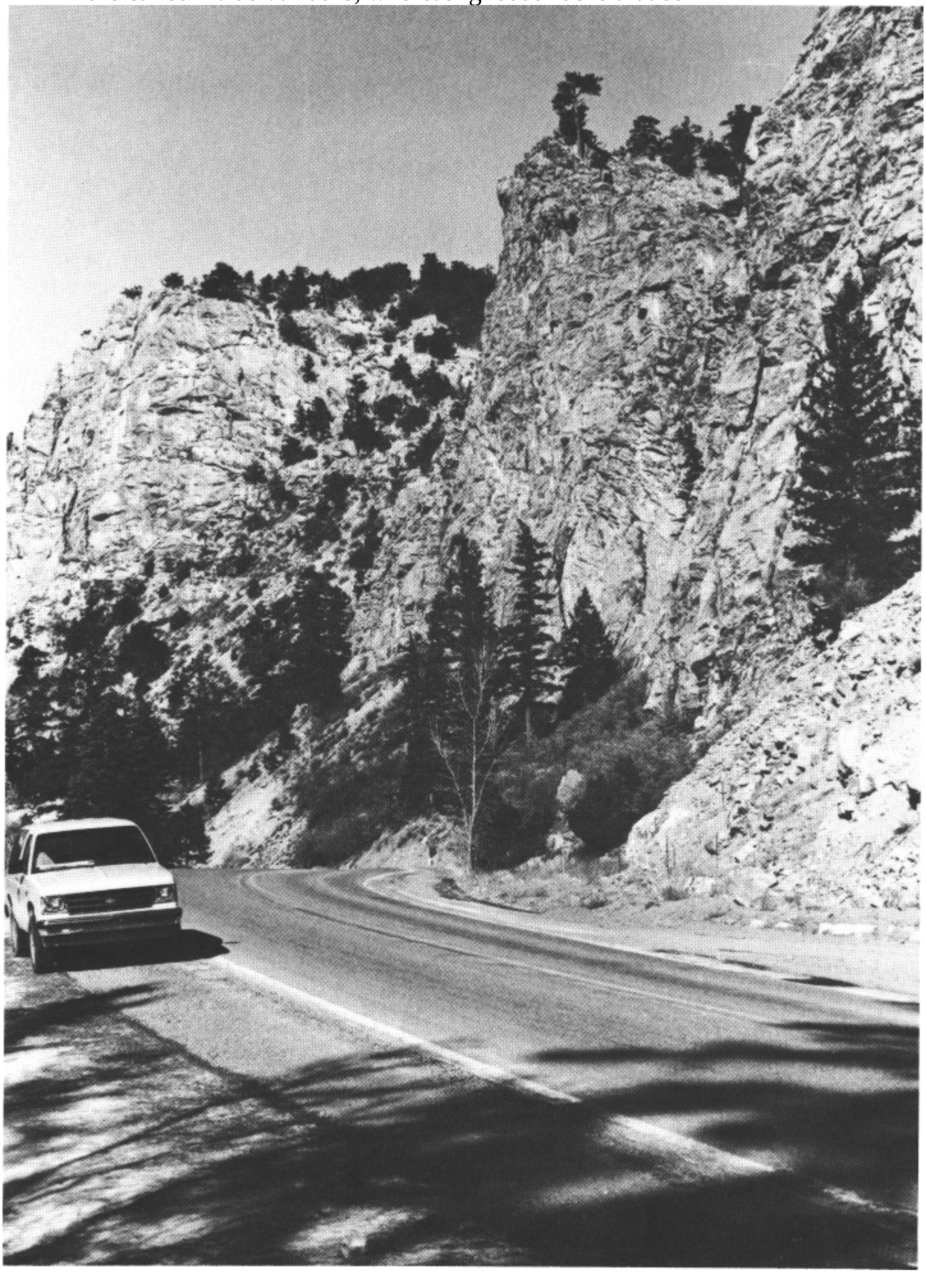
17.7 Road bends sharply to the left. **Stop. Park on wide shoulder to the right.** The purpose of this stop is to examine the Bear Canyon pluton.

Granite is a light-colored, coarse-grained *igneous rock* formed as molten magma slowly cools at depth. The pale-pink granite exposed here in the cliff is composed of grains of *quartz* (clear, glassy), *feldspar* (pink to white), and *biotite mica* (black flakes). The minerals can be seen best by breaking open a chunk of granite and examining the fresh, unweathered surface.

The Bear Canyon pluton is one of many plutonic bodies that have been recognized in this area. Collectively, these granitic rocks, along with other related igneous rocks, make up the "Questa magmatic system."

The pluton was emplaced at depth as a hot mushy mass in the surrounding *country rock* about 24 million years ago, during late Tertiary time. More recently, as the Red River cut down to form Red River Canyon, the pluton was exposed.

Igneous rocks, such as this granite, that solidified before reaching the surface are called *intrusive rocks,* whereas igneous rocks that so-



Tertiary granite of the Bear Canyon pluton forms the cliffs on the north side of Red River Canyon at mile 17.7.

lidified on the surface, such as the lava flows of the Taos Plateau, are called *extrusive rocks.*

The trees along the canyon are cottonwoods, willows, spruce, Douglas fir, and ponderosa pine. The needles of the Douglas fir are flat and soft to the touch, whereas spruce have square, sharp needles.

Douglas fir
Pseudotsuga menziesii

The 14-inch, rubber-lined steel pipelines along the road carry mill tailings (mill waste) from the Molycorp molybdenum mine 9 miles to tailings ponds near Questa. Note the yellow areas along the road that lack vegetation. We will see more of these barren areas farther up the canyon.

Leave stop. Continue up the canyon.

0.9

18.2 Small campground on the right.

0.4

18.6 On the left is the road to the new underground workings of the Molycorp mine. Goat Hill campground is on the right.

0.2

18.8 For the next mile we'll see gravel along the left side of the highway that was washed down Goat Hill Gulch during flash floods and deposited here. Above us on the left are the surface installations of the new, underground mine workings. The Questa molybdenum deposit has been mined in three phases: 1) the original underground mine, which is to the northeast in Sulphur Gulch; 2) the large open pit, which was mined down into the same area of mineralization as the original underground mine; and 3) the new underground mine, which is situated below and extends west of the two older mines. The large concrete tower near Goat Hill on the left (view from road near mile 20.4) is the main service shaft to the underground mine. The lift in the shaft transports miners, equipment, and supplies to the mine workings 2,000 feet below. Ore is moved up a 1½-mile-long conveyor belt in a tunnel, called a decline, to the mill for processing. We will see the mill up ahead. By the time the Goat Hill orebody is mined out, over 125 million tons of ore will have been removed from the mine.

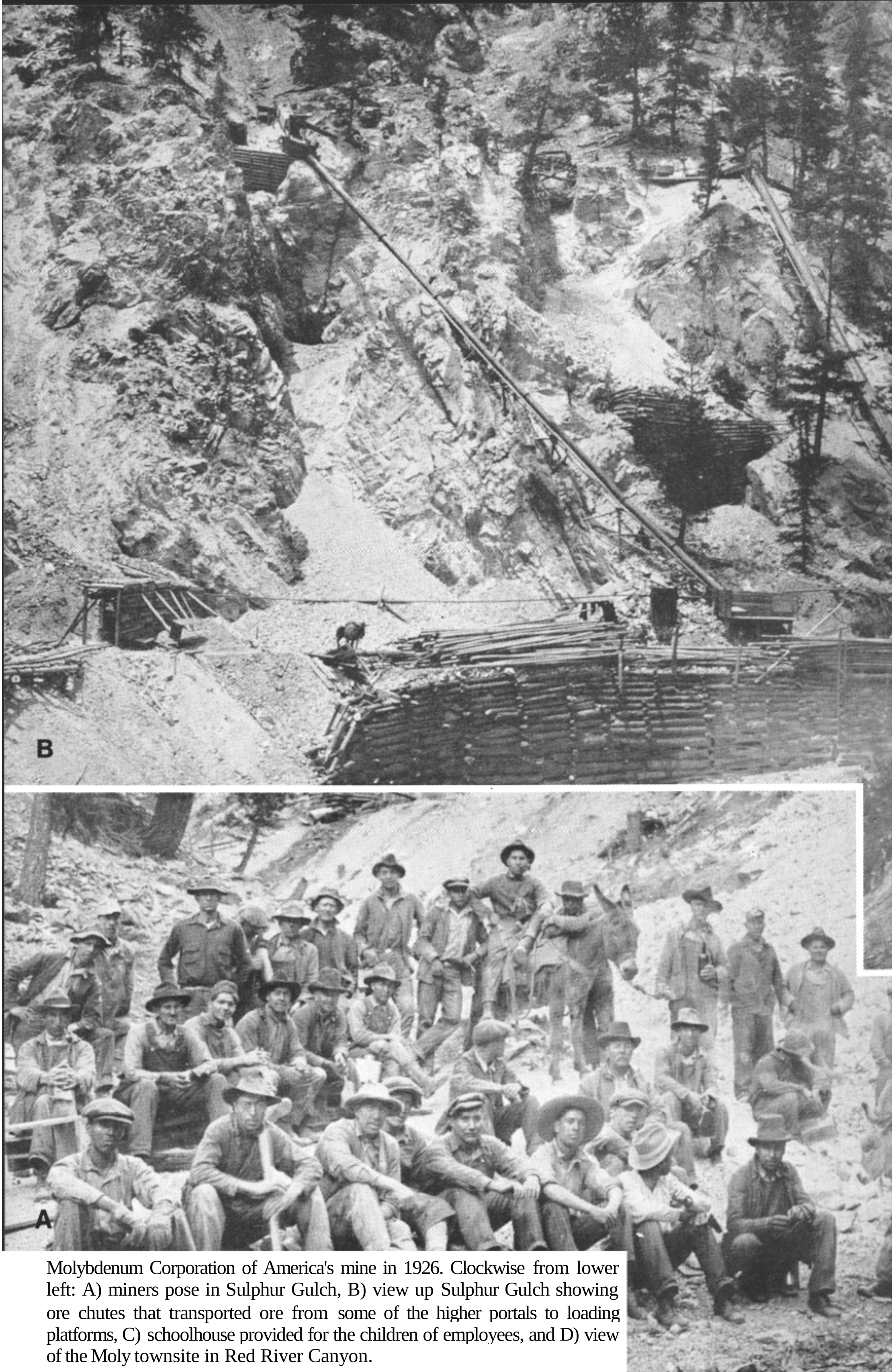
1.0

19.8 Cross bridge over Red River. From about here until we reach the town of Red River the highway follows the southern margin of the Questa caldera.

0.2

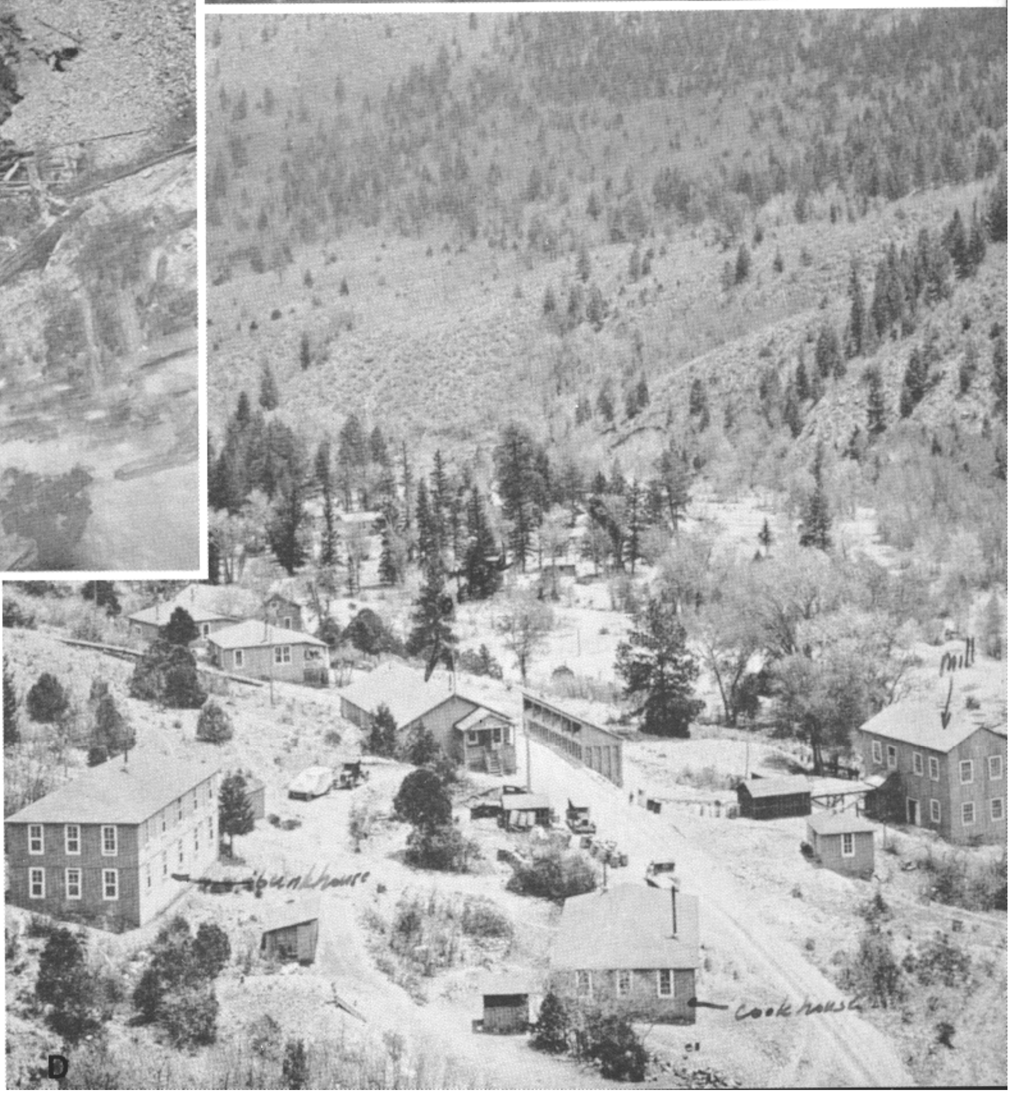
20.0 Precambrian rocks are exposed on the slopes to the right.

0.2



Molybdenum Corporation of America's mine in 1926. Clockwise from lower left: A) miners pose in Sulphur Gulch, B) view up Sulphur Gulch showing ore chutes that transported ore from some of the higher portals to loading platforms, C) schoolhouse provided for the children of employees, and D) view of the Moly townsite in Red River Canyon.


C



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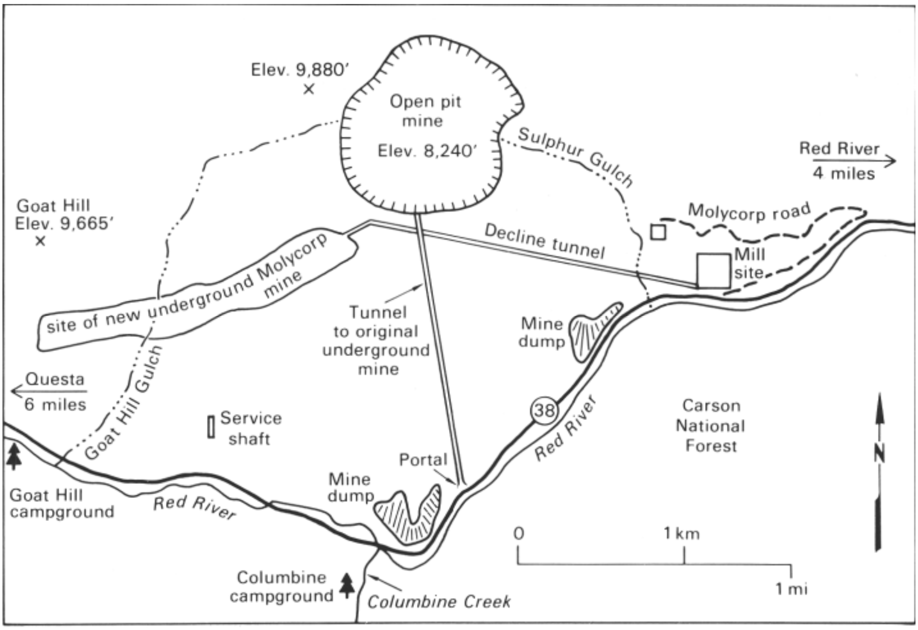


Map of the area around the Molycorp molybdenum mine delineating the three phases of mining. The earliest phase of underground mining (1922-1958) is represented only by the blocked-off, timber-framed portal (mile 20.9) to the mile-long tunnel that was completed in 1945. The large open-pit mine, hidden from view, and the extensive mine dumps along the north side of NM-38 represent the second phase of mining (1964-1985). By the end of this phase of mining the pit was nearly a mile in diameter and 1/3 of a mile deep. The service shaft (mile 18.8) and the new enlarged mill (mile 22.3) are all that is visible of the third phase of mining that began in 1985. The approximate locations of the underground ore deposit, 2,000 feet below the surface, and the new underground "decline" tunnel that carries ore to the mill are outlined on the map.

20.2 Cottonwood Park on the left. Columbine campground on the right. Crossing back over Red River.

0.2

20.4 Road bends sharply left. **Stop on right shoulder.** The light-colored rock at the curve is called the quartz monzonite of Columbine Creek. *Quartz monzonite* is similar to granite but contains a greater proportion of *plagioclase* feldspar. In this rock we can see grains of quartz (clear, glassy) and feldspar (white) and flakes of biotite mica (black). Although the mineralogy of this rock is similar to that of the Tertiary granite at mile 17.7, this rock has a streaked or banded texture. This quartz monzonite may have once looked much like the Tertiary granite; however, it has subsequently been metamorphosed (altered by heat, pressure, and/or chemical action) at great depth. The banding or parallel alignment of mineral grains in such deformed rocks is called *foliation.* Foliated *mica-rich metamorphic rock* is called *schist.* Coarsely banded metamorphic rock is called *gneiss.* This rock could be called either a foliated quartz monzonite or a granitic gneiss. The quartz

Headframe of Molycorp mine's service shaft for the new underground workings near Goat Hill. Photo courtesy of Molycorp, Inc.

monzonite of Columbine Creek has been dated at 1730 million years and is therefore Early Proterozoic in age. The service shaft for the new Molycorp underground mine is visible down canyon.

Leave stop. Proceed up the canyon past a huge dump of waste material from the open-pit mine that is visible to the left. Notice the *rilling* and *gullying* of the dump material. Dumps do not stabilize until a vegetative cover grows.

0.5

20.9 On the left are several buildings. Just past them, at road level, is a blocked-off, timber-framed portal of the original underground Molycorp molybdenum mine. This tunnel extended a mile straight into the mountain before reaching the *veins* of molybdenum ore. All other portals were in Sulphur Gulch, over a mile to the north. The original underground mine contains a network of over 35 miles of tunnels, as well as many vertical shafts and *stopes,* rooms from which the ore was mined. That's a lot of rock removed by the old-time mining techniques!

0.2

The old adit to the original Molycorp underground mine can still be seen today just north of NM-38 (mile 20.9) in Red River Canyon. Figure to the right of the adit for scale.

21.1 Straight ahead, at 12:00, buildings of Molycorp mill visible.
0.4

21.5 More mine waste on the left.
0.3

21.8 On the left beyond the gate, at 11:00, at the west end of the mill area, the upper halves of two large corrugated portal pipes are visible. These pipes mark the top of the 1½-mile-long conveyor belt that brings the ore up nearly 1,000 feet from the underground mine to the mill.
0.5

22.3 On the left is the Molycorp mill. **Stop on the right at the pulloff.** The rocks above the mill are granitic rocks of the 25-million-year-old Sulphur Gulch pluton. The meadow in the mill area was formed when landslides from Sulphur Gulch blocked the Red River. Sulphur Gulch was subsequently filled with mine wastes.

Molycorp molybdenum mine

The mineral molybdenite (molybdenum disulfide), an ore of the metal molybdenum (from the Greek, "molybdos" for "leadlike"), is found in unusually high concentrations in this area. The soft, shiny, black, greasy-feeling molybdenite is in veins and as thin "paint" in cracks along the edge of an igneous intrusion of the same type of granite as the Bear Canyon pluton. During Tertiary time, about 25-26 million years ago, active volcanoes spewed lava and ash over the preexisting landscape. Such a large amount of lava and ash was ejected that the area collapsed along a great circular crack, called a *ring*

In 1951, a battery-powered train transported ore as well as ferried miners to and from Molycorp's old underground míne. Photo courtesy of J. H. Schilling.

fracture. Such collapsed volcanic features, which form huge topographic depressions, are called *calderas.* After the collapse, molten rock continued to intrude along the ring fractures. *Magma* that breached the land surface created volcanoes; magma bodies that solidified underground formed the plutonic bodies that we have seen in Red River Canyon. About 400,000 years after crystallization of the Sulphur Gulch pluton, mineral-rich *hydrothermal fluids* percolated through the rock. Minerals, such as molybdenite, quartz, and *pyrite,* precipitated in small fractures or cracks within the granite and surrounding rocks. These fracture fillings, which are the targets of mineral exploration, are called veins.

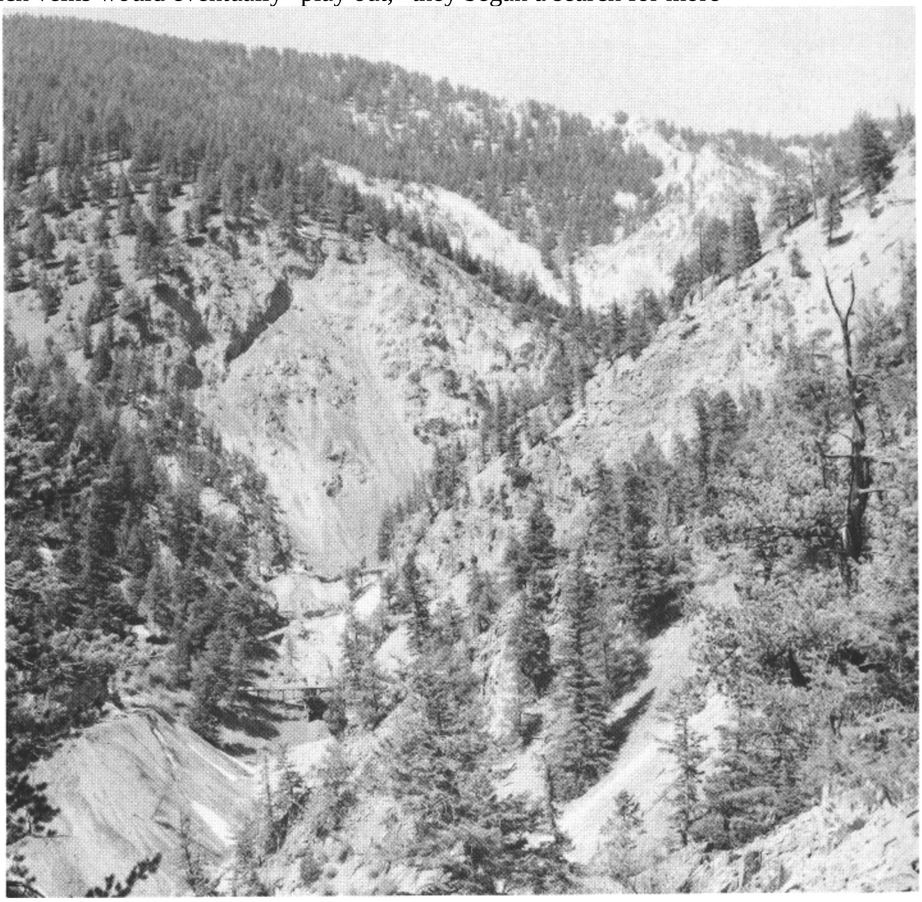
Molybdenite-bearing veins were exposed to the north of Red River Canyon, where Sulphur Gulch cut down into the granite and surrounding rocks. In 1914 a prospector named Fahy, thinking that the molybdenum was silver, sent a sample from one of the veins to an assayer. The sample contained no silver, but the assayer mentioned the presence of molybdenum and its value in making high-strength steel. Fahy staked claims, and attempts were made to mine the veins.

In 1920 the Molybdenum Corporation of America acquired claims in Sulphur Gulch and in 1923 began production, processing ore in an existing 50-ton gold mill near Red River. Tunnels were driven into the high-grade veins, and the molybdenite was extracted. Some of the portals were high on the steep gulch walls, and burros were used to haul the ore. In 1923 production warranted construction of a 50-ton mill closer to the mine.

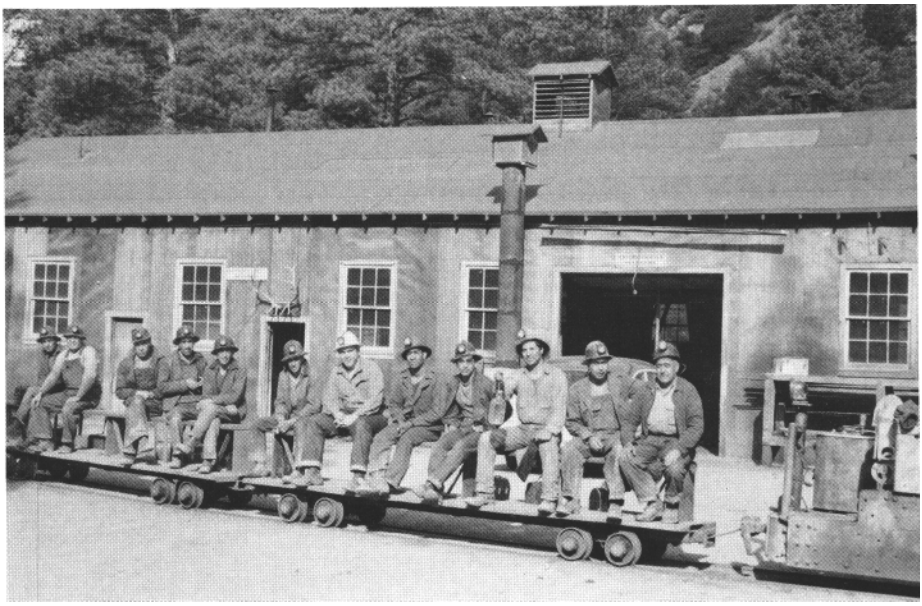
Over time, the uses and demand for molybdenum steadily expanded. As mining continued downward along the veins, the costs of hauling out the ore and pumping out the water increased. In 1945 a mile-long tunnel was driven from Red River Canyon to connect with the lowest level of workings in the mine. This tunnel provided three major advantages: 1) it was cheaper to haul ore out the level tunnel than to haul it up to the old portals; 2) ventilation was improved; and 3) water drained without expensive pumping. Soon, however, mining extended below the level of the tunnel, and the old problems of vertical extraction and water pumps returned.

In those days stope mining was dangerous, hard work. Holes were drilled into the veins with drills powered by compressed air similar to jackhammers. Dynamite was placed in the holes, and the ore was blasted down. Chunks of blasted ore were then loaded into narrow-gauge cars and hauled out the mile-long tunnel and along the surface track to ore bins located down the canyon.

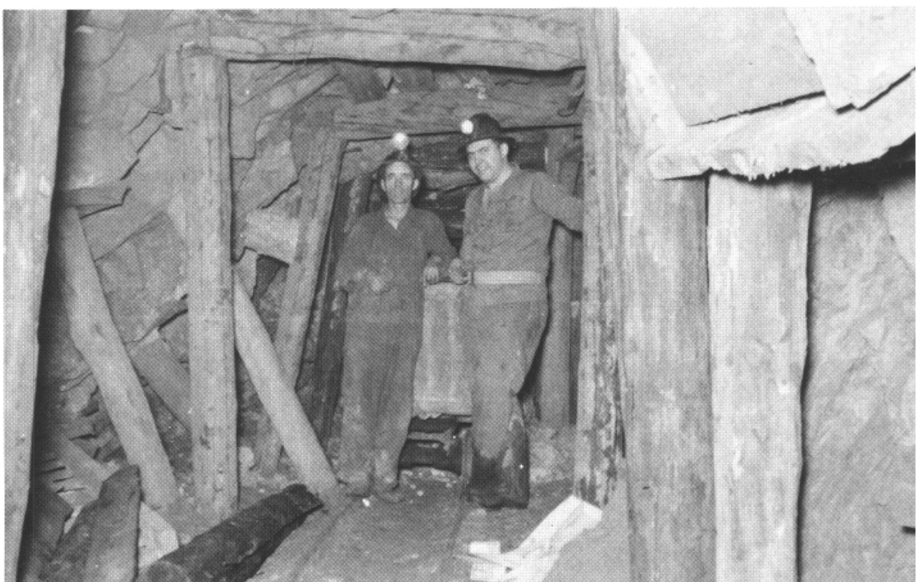
By 1958 the rich veins had been mined out. Earlier, when miners realized that the rich veins would eventually "play out," they began a search for more



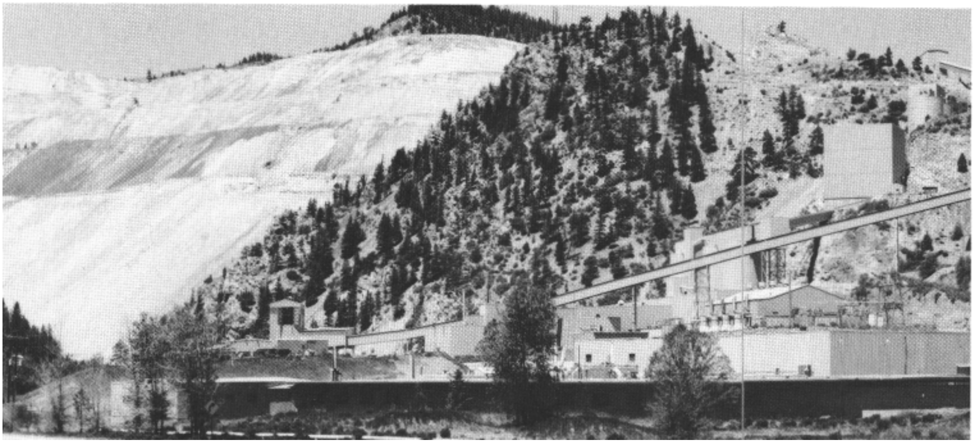
Sulphur Gulch in 1951. Dump (lower left) covers the portal of the early underground workings. The open pit now covers much of the area.



In 1951, miners await the mile-long ride from Red River Canyon into Molycorp's first underground mine. One of the authors, John Schilling, is seventh from the left. Photo courtesy of J. H. Schilling.



One of the authors, John Schilling, and another miner, in 1952, standing in a drift (tunnel) of the old underground molybdenum mine. Photo courtesy of J. H. Schilling.



Molycorp mill in Red River Canyon, on the site of the original camp (see photos on pages 40, 41, and 46). From Bauer et al., 1990. Reproduced by permission of the New Mexico Geological Society.

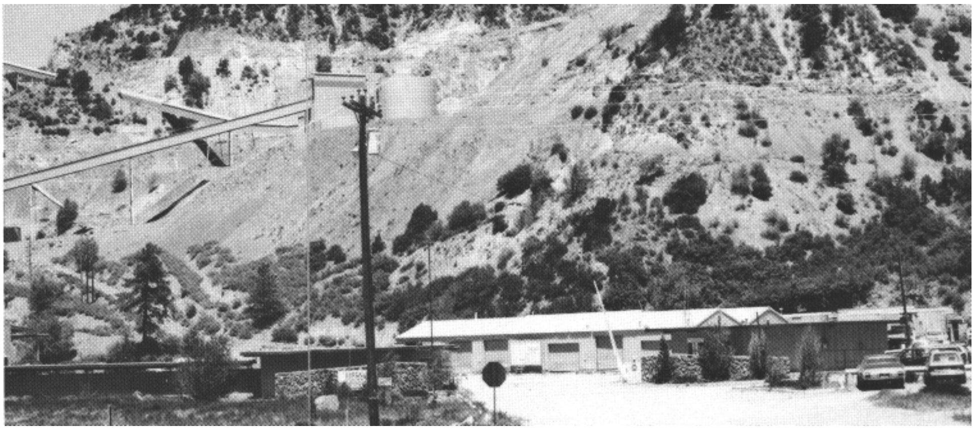
ore. A huge low-grade molybdenum deposit was found in the floor and sides of Sulphur Gulch. Here paint-thin layers (*stockworks*) of molybdenite were found along numerous crisscrossing cracks. By 1964 sufficient reserves had been blocked out to make feasible a new, much larger mill and an expanded operation.

The huge low-grade deposit was mined as an open pit, in contrast to the rich veins, which were mined underground. The pit is north of Red River Canyon and is not visible from the highway (see Plate 5). Mass mining, in which both the ore and waste are dug out of the ground and carried away, was used. Mass, open-pit mining with modern rock-moving machines is much cheaper than selective underground mining, in which ore only is removed by small machines and hand labor. Although the initial investment for mass mining is large, more tons of ore can be mined for the same cost, thus offsetting the lower value of each ton of lower grade ore. Although profits are not necessarily increased, more ore can be mined.

In the open-pit operation, rock was broken by blasting and then loaded into huge trucks by shovels that could scoop up to 10 cubic yards of rock in one bite. Each truck hauled about 90 tons of rock to the mill. Six tons of rock were mined to recover 1 ton of ore; each ton of ore yielded 4 pounds of molybdenite (molybdenum sulfide, MoS_2) containing 2 pounds of molybdenum metal. Over the lifetime of the open-pit operation, over 10 million pounds of molybdenite were mined each year. By 1969 the new modern mill could process 15,000 tons of ore rock per day.

As the deposit was mined downward, more and more waste had to be removed, and open-pit mining became less profitable.

Exploratory drilling led to the discovery of more ore deep underground. This deposit could only be mined economically by underground mining methods, and by 1985 the transition from open-pit to underground mining was completed. The mining is done 2,000 feet below the surface by a technique known as *gravity block caving.* Networks of permanent tunnels or *drifts* are excavated beneath the ore body. Blocks of ore are then shattered by explosives,



[Picture is the right side of what is shown on page 48.]

and the fractured ore "caves" into railroad cars waiting in the drifts below. These cars deliver the ore to a 1½-mile-long underground conveyor belt, which rapidly transports the ore up an inclined tunnel to the mill site. By this method, 18,000 tons of ore are mined daily. When milled and concentrated, 90,000 pounds of molybdenite (MoS_2) are produced.

The ore is processed in the mill. Although ore from the new underground

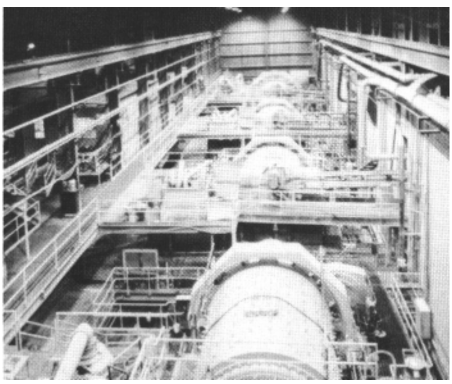
Shovel loading 100-ton truck in the open-pit mine in 1975. Photo courtesy of Molycorp, Inc.

mine averages only 0.3% molybdenite, it is considerably higher grade than the ore mined in the open pit. In the mill as much of the waste material as possible is removed. The flotation process is used. The large chunks of ore are first crushed to thumb-size pieces and then fed into ball mills, large, flat-lying cylinders that contain 3-inch forged steel balls. As the ball mills rotate, the tumbling steel balls grind the ore. As water and ore are fed continuously into one end, powdered ore and water stream from the other end. Any remaining oversize chunks are recycled back into the ball mills by classifiers and reground.

The powdered ore is mixed with small amounts of various oils and then fed into flotation machines, eggbeaterlike devices that churn the mixture into a froth of oil bubbles. The tiny particles of molybdenite, attracted to the oil, stick to these oil bubbles, rise to the surface, and overflow into a gutterlike trough. Particles of other minerals and rock that do not adhere to the bubbles sink to the bottom. Molybdenite particles will stick only to certain kinds of oil; a mixture of several kinds is used here. To separate out a different mineral, a different combination of chemicals and oils would be used.

The waste rock and minerals (tailings) are carried away suspended in water. The water–waste mixture is then moved down the canyon in the 14-inch pipes that parallel the highway. At the tailings ponds near Questa, the waste settles out of the water and slowly builds up a pile of sandlike material. Waste water is reclaimed in a nearby purification complex. Safe transportation and storage of such tailings and the protection of ground water and surface water are important here and throughout the U.S.

The molybdenite–oil-bubble mixture goes through a series of tanks, or flotation cells, where molybdenite settles out, and much of the water can be reclaimed. The molybdenite mixture then passes through thickeners, filters, and dryers where the remaining water is removed. This dry concentrate, containing more than 90% molybdenite, is shipped elsewhere for processing. Much of it is roasted to remove the sulfur and to add oxygen. This molybdenum oxide is used primarily in the steel industry for high-temper alloys



In the Molycorp mill four ball mills (left) grind the ore and flotation cells (right) separate the molybdenite particles from other minerals and rock. Photos courtesy of Molycorp, Inc.

and stainless steels. Very high grade molybdenite, finely divided, is also an important ingredient in lubricants.

Continue up canyon.

0.2

22.5 The fenced area on the left is now a Molycorp storage area, but it and the mill area were formerly the townsite of Moly. Ahead on the left is one of the few remaining large orange dump trucks that were used to haul ore from the open-pit mine to the mill. A diesel engine powers an electric motor in each of the four wheels.

0.4

22.9 For the next 3 or 4 miles the rocks exposed on the left side of the road are complexly faulted. Alteration to the rock along these faults occurred when hydrothermal fluids used them as channels. Rhyolite prophyry *dikes* also intruded along some of the faults.

0.9

23.8 The road begins to climb across loose, yellow-stained gravel. Flash floods carried this loose material down the steep side gulches into Red River Canyon as *mudflows,* mixtures of water, mud, gravel, and boulders having the consistency and appearance of wet concrete. Successive mudflows are gradually burying the trees. During the rainy season in July and August dangerous mudflows often block the highway, and people have been killed trying to drive through the flowing mud and boulders.

Over the next 2.2 miles we will cross several other mudflow deposits and see many barren, yellow-stained areas high on the canyon walls. These barren areas are alteration scars (see Plate 4). The rock is *brecciated,* or highly fractured, and hot water percolated up to the surface through these fractures. These waters deposited several minerals, including pyrite (iron sulfide). When exposed to surface conditions pyrite decomposes to iron oxides. It is these iron oxides, not sulfur, that stain the rocks yellow and brown. Sulphur Gulch was named for the yellow color of its walls in the mistaken belief that the coloring agent was sulfur. The yellow-colored mudflows originate in these areas of brecciated and altered rock. Steep slopes, lack of vegetation, and rapid erosion characteristic of these areas contribute to the reoccurring hazardous landslides and mudflows.

The larger mudflows from the side gulches have formed "dams" across the Red River. Over many years enough mud has collected behind each dam of boulders to create a wide, flat, grassy meadow. Such meadows are the sites for most of the fine campgrounds along NM-38, as well as for the town of Red River.

0.4

24.2 Note large landslide scars straight ahead in high hillslope and on mountainside to the left at 9:00.

0.2

24 4 Fawn Lakes campground on the left.

0.4

24.8 Elephant Rock campground on the right. Elephant Rock on the ridge to the north is a local landmark. It is a large quartz-latite block that slid into Questa caldera from higher on the caldera wall.

0.3

25.1 Red River Water Reclamation Plant on the left is built on a landslide debris apron.

0.4

25.5 June Bug campground on the right. This was the site of the small

Small mudflow in Goat Hill Gulch, circa 1982. Photo courtesy of Molycorp, Inc.

June Bug gold mill where the first molybdenite ore was processed in 1923.

0.4

25.9 Scenic Historic Marker on the right reads:

> Red River Valley. A spectacular scenic drive through Carson National Forest, joining U.S. Highway 64 at Eagle Nest Lake. This popular summer playground offers excellent stream and lake fishing. Guest ranches, hotels and tourist courts serve the visitor. Wheeler Peak to the southeast rises 13,160 ft.

0.2

26.1 Douglas fir trees to the right across the meadow.

0.1

26.2 **Enter Red River,** the highest town in New Mexico at 8,693 feet in elevation. Red River grew to a booming mine town when gold was discovered nearby in 1867. In 1905 Red River had 3,000 residents, 15 saloons, four hotels, two newspapers, a hospital, and a sawmill. Although the gold deposits appeared rich at the surface, most played out rapidly with depth, and the boom collapsed. By the 1920's Red River had become a ghost town.

Today, Red River is a resort town—headquarters for skiing (on slope to the right), hunting, fishing, camping, hiking, pack and jeep trips to the high country, or just relaxing.

0.1

26.3 The rock in the roadcut on the left at the bend is Tertiary-age *quartz latite.* Quartz latite is a fine-grained, extrusive equivalent of quartz monzonite. These quartz latites are actually older than the Tertiary-age igneous rocks associated with the formation of the Questa caldera and probably represent an earlier volcanic center.

0.6

26.9 Entering downtown Red River.

0.1

27.0 **Side trip 1B, Mallette Canyon to Cabresto Canyon.**

Set trip odometer to zero and **turn left on Mallette Road.** This well-graded dirt road climbs into Cabresto Canyon and then loops back to Questa. After crossing the divide Latir Peak comes into view. Latir Peak is the remnant of a cluster of volcanos from which many of the local volcanic rocks erupted during caldera resurgence. The volcanos in the Questa caldera complex and much of the high Sangre de Cristo Mountains were covered by glaciers later during Pleistocene time. The presence of these glaciers is recorded by a number of erosional and depositional features. Several beautiful lakes are nestled high on the slopes of Latir Peak in glacially eroded depressions called cirques. Large stands of aspens make this area particularly beautiful in the fall. Overnight camping is permitted in Mallette campground about 0.25 mile up Mallette Road.

If you wish to take this side trip, turn to page 74.

0.0 **Set trip odometer to zero** and **continue through Red River.**

Straight ahead is the mountain divide that separates the Red River Valley from the Moreno Valley. Red River Ski Area is to the right. The canyon to the right is Pioneer Canyon. Many old gold mines, mining camps, and cabins that date from the boom days can be found along the canyon. The U.S. Forest Service has published a short tour guide to old gold mines in the canyon, and the 1990 New Mexico Geological Society Guidebook 41 contains a geologic road log for the canyon.

0.4

0.4 On the left is Bitter Creek Canyon, site of much of the early mining activity in this region. Most of the rock exposed in the canyon is Tertiary quartz latite.

0.2

0.6 Intersection with NM-578. **Take left fork.** The road to the right winds 9 miles up Red River Canyon. There are beaver dams along this road and good trout fishing! Wilderness trails at the end of the road lead to Wheeler Peak and beautiful timberline lakes. If you drive a little more than a mile up Red River Canyon on NM-578, you'll reach the spot where the old Red River Hill Road forks off to the left and winds up the steep mountainside and over Red River Pass. This road was built by the U.S. Forest Service in 1916 to open up the Red River country to automobile traffic. The extremely narrow, unpaved road has a maximum grade of 7½%, has total southern exposure to minimize winter-snow accumulation, makes six switchbacks, and climbs 1,000 feet; it was considered an engineering marvel of its time. Prior to its construction no roads linked Red River and Eagle Nest. Although the road and its breath-taking views of the Sangre de Cristo Mountains are still accessible, 4-wheel drive vehicles are required.

In contrast, the new paved road, completed in 1966, follows the canyon cut by Bobcat Creek, has multiple lanes, steeper grades, fewer magnificent views, and is less prone to rock falls and avalanches. The new road does not cross Red River Pass but rather crosses what is called Bobcat Pass several hundred feet higher and farther north.

Roadcuts for the next 9 miles expose altered Tertiary volcanic and Precambrian metamorphic rocks and a granitic pluton.

Now is a good time to review the geology we've seen between here and Questa. Precambrian rocks over 1½ billion years old are exposed throughout these mountains. In addition to the foliated quartz monzonite (mile 20.4), many other types of Precambrian metamorphic rocks are exposed. These include gneisses, schists, various intrusive rocks, *quartzite,* and *amphibolite.* In the Red River valley, Tertiary volcanic rocks rest on top of the Precambrian rocks. Late Tertiary volcanic rocks (about 25 million years old) and the Precambrian rocks are intruded by Tertiary granite (about 24-25 million years old). But what of the 1½ billion years of time between the Precambrian and Tertiary? So far, we have seen no rocks from this intervening time. There are three possible explanations for this enormous gap in the geologic record: 1) no rocks were deposited during this time, 2) rocks were deposited but are now covered by the Tertiary rocks, or 3) rocks were deposited but have subsequently been eroded away. As we continue this trip, we will gather some additional clues.

During the ice ages in Pleistocene time, and until about 15,000 years ago, the higher peaks in this area were covered by glaciers. These alpine glaciers scooped out arcuate depressions called *cirques* and carved U-shaped valleys high in the mountains around Wheeler Peak. Extensive continental glaciers covered the Great Lakes region, New England, and much of Canada. Here in northern New Mexico, the warmer and drier climate restricted the glaciers to colder and wetter mountainous areas above 11,000 feet.

Today, snow can be found in shady spots on the higher peaks late into the summer. If the average annual temperature was only slightly cooler, this snow would slowly accumulate, turn to ice, and form small glaciers. Such small glaciers are found in Colorado.

0.2

0.8 Roadcuts ahead expose altered Tertiary and Precambrian rocks.

0.8

1.6 We follow the road to the northeast, leaving Red River valley, and climb to the higher elevation of Bobcat Creek Canyon. For the next several miles roadcuts expose Precambrian quartz monzonite of Old Mike Peak. This rock has an *isotopic age* of 1699 million years.

0.9

2.5 Cross cattle guard.

0.1

2.6 Aspen growing in the canyon to the left.

1.1

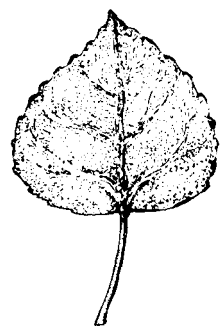
3.7 Leaving Carson National Forest.

0.2

3.9 Cross cattle guard.

0.8

4.7 Entering Colfax County. Bobcat Pass (elevation 9,820 feet) is the highest point on this trip. Road begins descent into Moreno Valley.



Quaking aspen
Populus tremuloides

0.3

5.0 Wheeler Peak (elevation 13,161 feet), the highest point in New Mexico, is visible to the right.

0.4

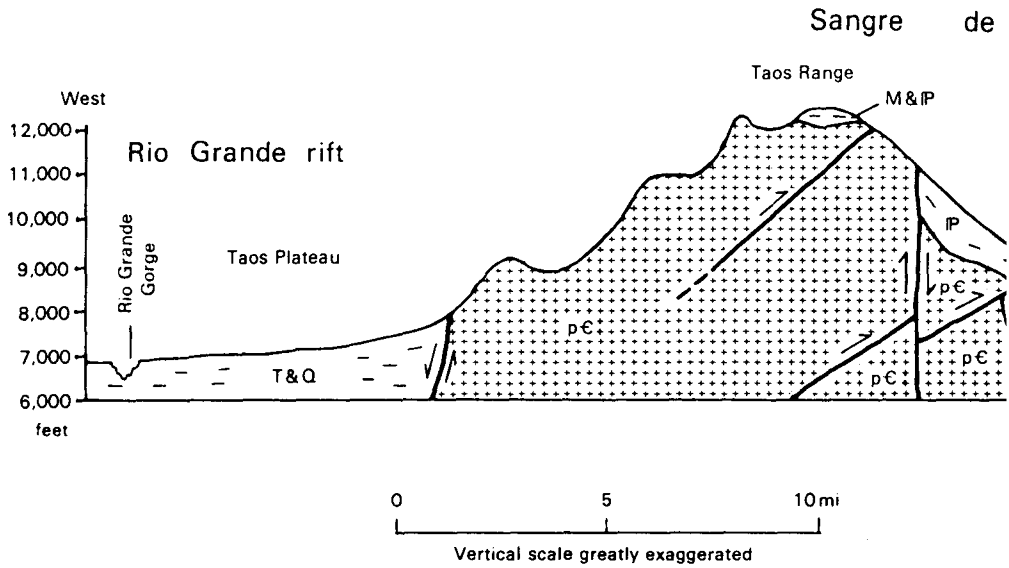
5.4 Outcrop of Precambrian rock on the left.

0.7

6.1 Road swings sharply left. Precambrian rock exposed in the roadcuts.

0.2

6.3 Outcrop of pinkish-tinted white rock in the roadcut to the left. **Optional stop** for mineral collectors; park 0.2 mile down the road at pullout and walk back. Watch for traffic! At this stop we will see an unusual variety of Precambrian foliated metamorphic rock composed of quartz (clear, glassy), feldspar (white), *muscovite* mica (pink flakes), and *magnetite* (black). The mineral collector can find attractive speci-



mens of a rare pink variety of muscovite. Typically, muscovite is transparent and colorless. Here the pink color is due to minor amounts of ferric iron, rather than the manganese, in the crystal structure of the mica.

Continue down the highway. Precambrian rocks are exposed in the roadcuts for the next 3 miles.

1.0

7.3 The high bald peak on the skyline is Baldy Mountain (elevation 12,441 feet) of the Cimarron Range. Baldy Mountain was the site of several gold booms in the late 1800's. In 1897 the town of Baldy, 10,000 feet high on the mountainside, claimed 200 residents, two boarding houses, a school, church services, 12 operating mines, four stamp mills, telephone service to Springer, a blacksmith, tailor, barber, launderer, justice of the peace, livery stable, general stores, and more than one saloon (Sherman and Sherman, 1975).

0.7

8.0 Remnants of an old cabin and outhouse on the left. From the seat in the outhouse, the view of Baldy Mountain is superb.

0.3

8.3 Moreno Valley straight ahead.

0.4

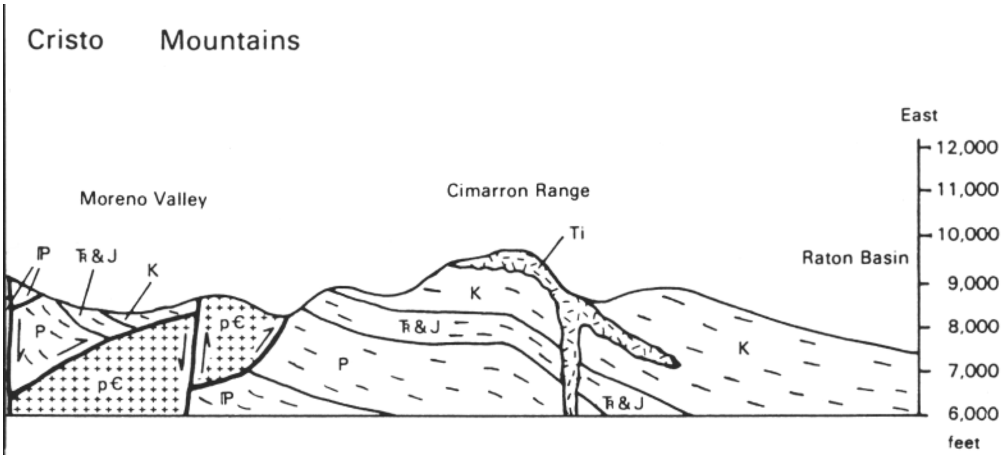
8.7 The high bald peak to the right of Baldy Mountain is Touch-Me-Not Mountain (elevation 12,044 feet).

0.2

8.9 We have left behind Precambrian rocks of the Sangre de Cristo Mountains and are driving now on the Quaternary sediments that fill the Moreno Valley.

0.2

9.1 Crossing approximate trace of the Blue Lake *thrust fault.* The fault is



Schematic west—east geologic cross section through the Sangre de Cristo Mountains north of Taos. **Q** = Quaternary, **T** = Tertiary, **Ti** = Tertiary intrusion, **K** = Cretaceous, **TR** = Triassic, **J** = Jurassic, **P** = Permian, **IP** = Pennsylvanian, **M** = Mississippian, and **p€** = Precambrian. Modified from Clark (p. 63, in Northrop and Read, 1966).

covered here by Cenozoic gravel and sand. To the north, this fault has moved Precambrian rocks over Tertiary *sedimentary rocks.* To the south, the fault has thrust Precambrian granite over Pennsylvanian and Permian sedimentary rocks. Such thrust faults are common along the east flank of the Sangre de Cristo Mountains and are probably related to the *Laramide orogeny.*

0.2

9.3 Peak on the left, at 9:00, is Black Mountain.

0.6

9.9 East Moreno Ranch. We're now heading south down the Moreno Valley. On the right are the Sangre de Cristo Mountains, including Wheeler Peak. On the left, at 1:00, the rounded mountain on the skyline is Skully Mountain (elevation 9,765 feet). Straight ahead in the far distance on the skyline is the southern Cimarron Range. The northern Cimarron Range is to the left, including Baldy Mountain at 9:00.

In October, 1900 the Gold and Copper Deep Tunnel Mining and Milling Company was formed by W. P. McIntyre to drive a prospect tunnel completely through Baldy Mountain. Adits were driven into the east and west sides of the mountain. The two tunnels finally met, within a few inches of one another, 36 years later in 1936. The tunnel failed to intersect any high-grade ore deposits.

Philmont Boy Scout Ranch now owns much of the land on the east side of Baldy Mountain. Although the town of Baldy was razed in 1941, scattered slag piles, foundations, and mine dumps still remain.

2.0

11.9 "Dragon" to the right.

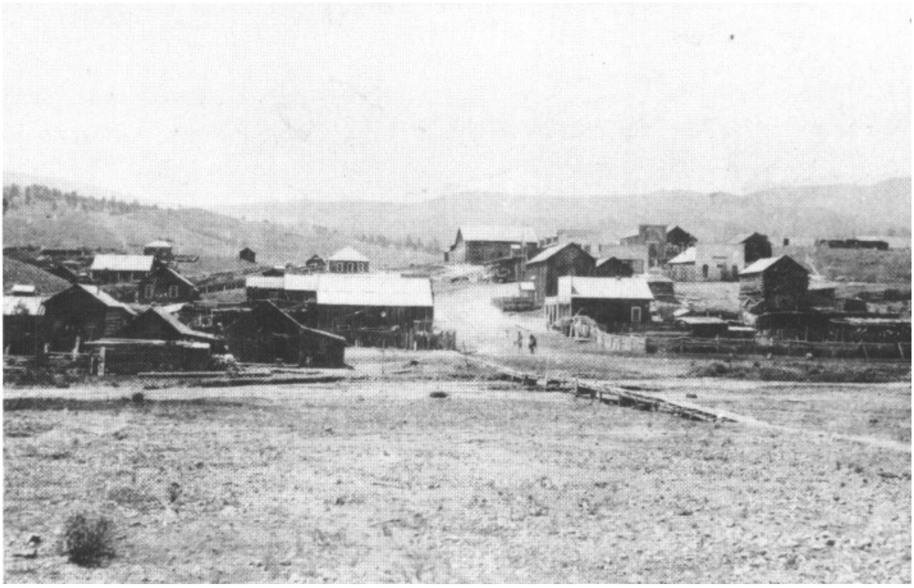
0.5

12.4 To the right is Elizabethtown, now a ghost town but once a rip-roaring mining town of over 5,000 people! The few remaining buildings are on the hill to the right. The skeletal stone structure is what remains of the old Mutz Hotel. Members of the Mutz family still live in the area and now own the townsite of Elizabethtown. The piles of gravel along the road mark the sites of old *placer* mining operations.

In 1866 soldiers found placer gold in this area. The next spring, during a rush to the discovery, gold was also discovered along many of the creeks and in veins on the west side of Baldy Mountain. Prospectors quickly staked claims over all of the paydirt area, and by 1868 E'town bragged of seven saloons, five general mercantiles, two hotels, and three dance halls. In 1870 E'town became the first incorporated town in New Mexico and the county seat of newly formed Colfax County. The town's fortunes began to decline by 1870. In 1872 Cimarron replaced E'town as the county seat, and by 1880 less than 400 residents remained. When a fire roared through in 1903 the town never recovered. In 1956 the old schoolhouse was sold for scrap. Today, only a few families live on the old townsite.

Placer gold deposits are formed when gold, eroded from veins, is concentrated in stream beds. Where the channel of a rapidly flowing stream widens or where the gradient decreases, stream velocity drops. Heavy materials, such as gold, settle out and concentrate in the stream bed. Such concentrations are called placers. In the Elizabethtown min-

Remains of the old Mutz Hotel in Elizabethtown with Baldy Mountain in the background to the east. Spring 1990 photo by C. K. Mawer. From Bauer et al., 1990. Reproduced by permission of the New Mexico Geological Society.



Elizabethtown, circa 1890's. Photo no. 5246 from the Lorin Brown Collection, courtesy of the New Mexico State Records Center and Archives.

ing district, several different methods were used to recover the gold. Most techniques relied on some form of the *sluice box* to concentrate the gold. Gold-bearing stream gravels were washed through the sluice box, which is a wooden trough with spaced cleats, called *riffles*, fastened along the bottom. The gold settled to the bottom and was caught behind the riffles. To keep from losing the finer gold flakes, mercury was placed between the riffles, where the gold and mercury combined to form *amalgam*. The mercury could later be recycled after separation from the gold.

The gold-bearing gravels were dug up and delivered to the sluice box by several different techniques. In the simplest method the gravel was shoveled by hand. Floating *dredges* used an endless chain of buckets to scoop the gravel out of the bank of a pool. Near the turn of the century a large dredge, christened "Eleanor," successfully worked Moreno Creek downstream from Elizabethtown. Eleanor was equipped with 65 large buckets, could process 4,000 cubic yards of gravel per day, and worked around the clock. Although she operated for only four seasons, she recovered approximately $200,000 worth of gold. Eleanor was abandoned near E'town, and by the 1950's all planking had been salvaged, and the metal skeleton had sunk completely from sight beneath the sandy gravels of Moreno Creek.

Hydraulic mining, which used powerful jets of water from giant nozzles to wash down high banks of gravel, was a method successfully used at Elizabethtown.

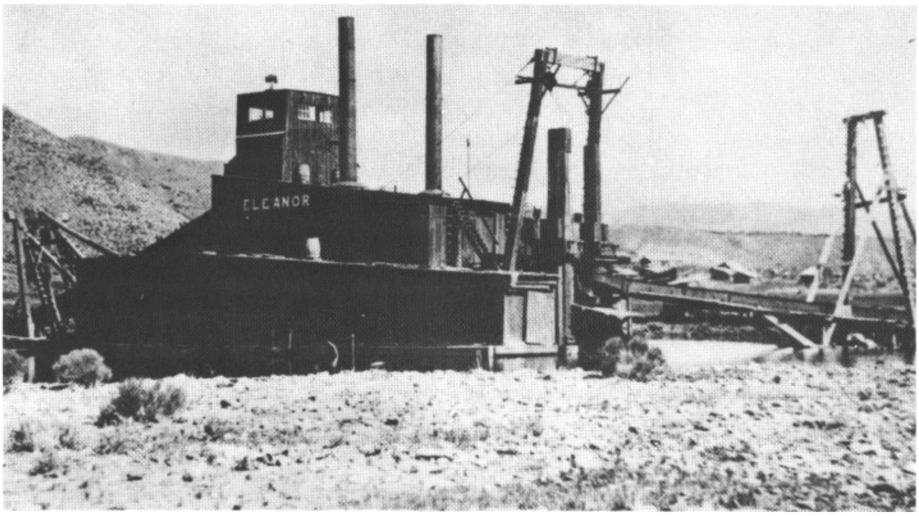
To supply the large amounts of water needed to recover gold, an aqueduct was constructed to bring water from the headwaters of the

Red River across Red River Pass and along the flanks of Baldy Mountain to the goldfields near Elizabethtown. This engineering marvel, known as The Big Ditch, was 41 miles long, even though its ends were only 11 miles apart. The Big Ditch was constructed between May, 1868 and July, 1869 by a force of 420 men and at a cost of about $230,000. The aqueduct leaked so badly that less than 20% of the water reached the placers! In places, remains of the old flumes and ditch can still be found.

The flush production was over by about 1881, although the placers have been worked intermittently ever since. In a conservative estimate, the Elizabethtown mining district produced about $3 million worth of gold. The present day value of this gold would be about $54 million.

0.3

12.7 Old stone retaining wall visible on the hillside on the left. Mounds of gravel are remains of placer operations. Slopes ahead on the right are Tertiary *quartz-diorite* porphyry. Quartz diorite is an igneous rock containing sodium-rich plagioclase feldspar and more than 10% quartz. *Porphyry* refers to the relatively common texture of large crystals (*phe-*



Oro Dredging Company's rig was christened in honor of Miss Eleanor Robinson, visiting New York friend of company manager, R. J. Reiling. "Eleanor" was quite a dredge for her day. Commissioned in 1901, the 65 5-cubic-yard buckets of the $100,000 machine generally processed about 3,000 cubic yards of gravel in a 20-hour period. The bucket elevator could work a 25-foot gravel bank to a depth of 15 feet. Gold was recovered by screening out the oversize material and amalgamating the fine particles in the long-tail sluice seen to the right in this circa 1905 photo. By August 1905 the dredge had worked about half of Oro's holdings and had encountered subgrade gravels above the mouth of Grouse Gulch. Sold in September 1905 the dredge would never work again. Interestingly, Eleanor was not scrapped until 1942 for the war effort. Her skeletal remains slowly sank into the gravels of Moreno Creek where she presumably lies today. Photo courtesy of the Museum of New Mexico, negative no. 128761.

nocrysts) surrounded by a *groundmass* of noticeably finer-grained crystals.

Skully Mountain contains a sequence of Triassic–Jurassic–Cretaceous sedimentary rocks that has been intruded by Tertiary porphyrys. Most of the Moreno Valley south of here is filled with Tertiary–Quaternary sands and gravels that were shed off the mountains.

Somewhere beneath the creekbed on the right lies buried the skeleton of the dredge Eleanor.

1.0

13.7 Straight ahead, at 12:00, are the Cimarron Mountains south of the Cimarron River.

0.1

13.8 To the left, at 10:00, Iron Mountain is composed of Upper Cretaceous *shales* intruded by Tertiary quartz-diorite porphyry *sills.* Dumps and ore bin of the Iron Mountain prospect are visible just below the trees.

0.5

14.3 Eagle Nest Lake visible ahead. Ahead and to the right, at 1:00, on the skyline are the Rincon Mountains. Past the lake, the swaths on the forested slopes of the Cimarron Range are ski runs of the Angel Fire

Hydraulicking on the Lynch placer in either Humbug or Grouse Gulch east of Elizabethtown in the late 1870's. Much of the water used in the placer mines at E'town was delivered by The Big Ditch, a 41-mile-long transmountain aqueduct that originated near the headwaters of the Red River. In hydraulic mining, a firehoselike nozzle, called a monitor, delivers a high-pressure stream of water that washes gravel (and gold) into wooden sluice boxes (visible in the lower center of the photo). Photo by F. C. Warnky, courtesy of the Museum of New Mexico, negative no. 14860.

Ski Area. Tertiary quartz-diorite porphyry is in the slopes on the right.
0.6
14.9 To the left, from 9:00 to 9:30, the high barren peak is Touch-Me-Not Mountain (elevation 12,044 feet).
0.4
15.3 The forested hills on the west side of the valley (1:00-3:00) are underlain by Pennsylvanian–Cretaceous sedimentary rocks. The Pennsylvanian rocks are separated from the younger rocks by the Sixmile Creek thrust fault.
1.0
16.3 Gravel quarries on the left and right.
1.1
17.4 Junction with US-64. The resort town of Eagle Nest (elevation 8,220 feet) is to the left. This community, originally named Therma (Greek, "hot"), was established in 1920. In 1935 the name was changed to Eagle Nest in honor of the golden eagles that inhabit the nearby mountains.

0.0 Turn right onto US-64. Reset trip odometer to zero.
0.1
0.1 Taos Range of the Sangre de Cristo Mountains ahead.
0.1
0.2 Road on the right to the community of Idlewild.
0.5
0.7 To the right, at 3:00, on the hill are green tanks that are used to store drinking water for Eagle Nest.
0.7
1.4 Milepost 284. To the left, at 9:00, is a view of Cimarron Canyon and Eagle Nest Lake. The lake is about 5 miles long and 2 miles wide. The dam that created Eagle Nest Lake was built between 1916 and 1918 at the head of Cimarron Canyon by Charles and Frank Springer. It is thought to be the largest privately constructed dam in the country. The concrete structure stands 140 feet above the creekbed, is 400 feet wide, and 9.5 feet thick at its crest and 45.2 feet thick at its base. Water release is controlled through outlet works at the right abutment. An ungated, 40-foot-wide spillway is cut in the bedrock at the left abutment with a crest elevation 7 feet below the top of the dam. The dam is built in Precambrian gneisses and has remained well sealed for over 70 years. It is owned and operated by the CS Cattle Company of Cimarron. The lake (actually a reservoir) is stocked with rainbow trout, cutthroat trout, and kokanee salmon. In the winter ice thickness on the reservoir may reach 2.5-3.0 feet.
0.6
2.0 The high peaks in the Wheeler Peak Wilderness on the right, at 3:00, were sculpted by glaciers during the Pleistocene ice ages.
1.6
3.6 Official Scenic Historic Marker on the right reads:

> Wheeler Peak. Across Moreno Valley stands Wheeler Peak, 13,161 feet, highest peak in New Mexico. Rocks of Wheeler Peak and the Taos Range

are highly resistant granites and gneisses of Precambrian age. Moreno Valley is underlain by soft sandstones and shales which are covered by stream and glacial deposits. Placer gold was mined at Elizabethtown north of here during the 1860's.

On the left is the entrance to the fishing and recreation area of Eagle Nest Lake.

0.8

4.4 Milepost 281

0.7

5.1 Road on the left to Eagle Nest Lake Recreation Area.

0.8

5.9 Monte Verde Ranch on the left includes a beautiful stone ranchhouse with green roof.

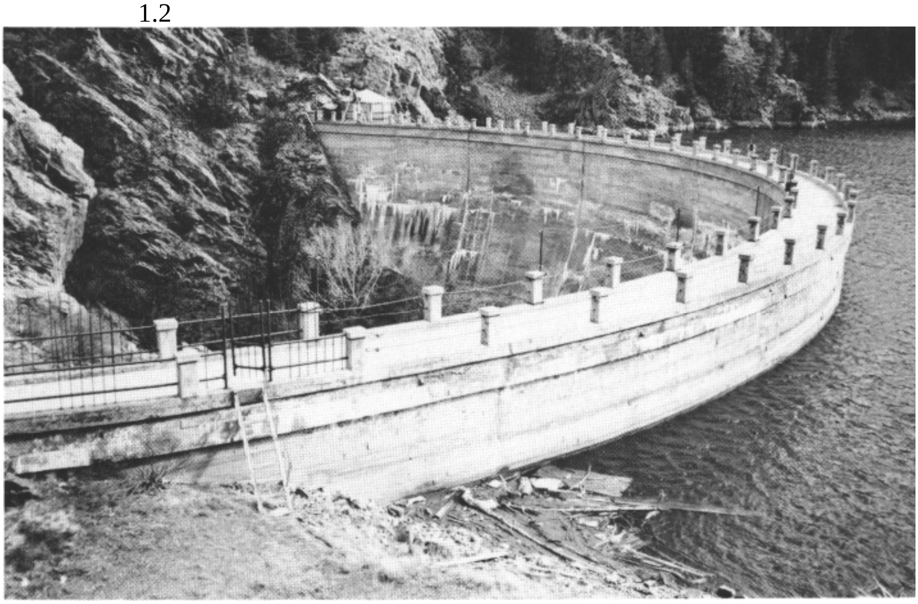
0.6

6.5 To the left, at 9:00, across the creek are exposures of Precambrian rocks that are overlain by Triassic strata. The contact between these different rocks is probably a thrust fault.

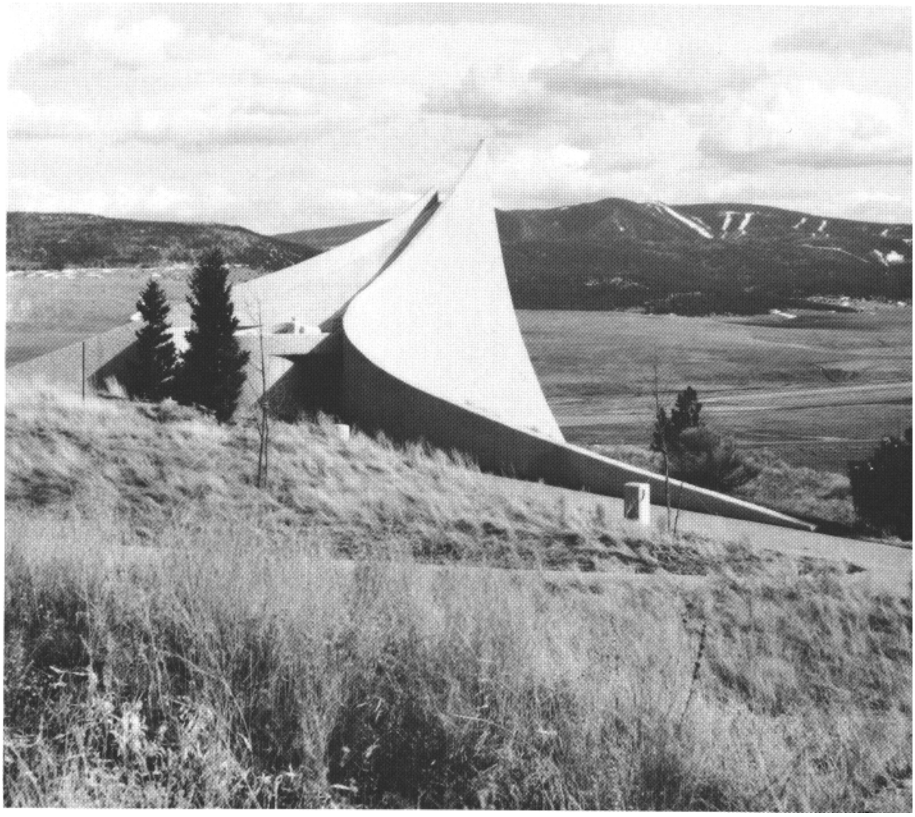
0.9

7.4 Sand and gravel operations to the left.

1.2



Eagle Nest Dam, owned and operated by the CS Cattle Company of Cimarron, is perhaps the largest privately owned dam in the U.S. In addition to its obvious recreational benefits, the dam is currently used for water storage for local irrigation projects, as a municipal water supply for the city of Springer, 43 miles downstream, and as an alternate water source for the city of Raton, which constructed a 42-mile, 14-inch-diameter water pipeline from Cimarron to Raton in 1985. The dam is unsuitable for hydroelectric production because of the highly variable annual runoff. Photo by C. K. Mawer. From Bauer et al., 1990. Reproduced by permission of the New Mexico Geological Society.



DAV Vietnam Veterans National Memorial. Background view to the southeast shows snow-covered ski runs of Angel Fire Ski Area. Photo by C. K. Mawer. From Bauer et al., 1990. Reproduced by permission of the New Mexico Geological Society.

8.6 Turnoff to Vietnam Veterans Memorial. Official Scenic Historic Marker reads:

> DAV Vietnam Veterans National Memorial. This chapel was erected in 1968 by Dr. Victor Westphall in memory of his son and all other U.S. personnel killed in the fighting in Vietnam. It was first dedicated as the Vietnam Veterans Peace and Brotherhood Chapel, and on May 30, 1983, it was rededicated as DAV Vietnam Veterans National Memorial.

On the left is the Angel Fire–Eagle Nest Airport.

0.9

9.5 Junction with NM-434 to Black Lake and Angel Fire Ski Area. **Continue ahead on US-64.**

1.1

10.6 Traces of the old wagon road that went to Black Lake, south of here, are visible on the left from 7:00 to 10:00.

0.1

10.7 Highway begins climb up the Sangre de Cristo Mountains to Palo Flechado Pass. We are leaving the young alluvium of the Moreno Valley for shale, *limestone*, *sandstone*, and *conglomerate* of Pennsylvanian age. These rocks are exposed in the roadcuts for the next 18 miles.

Many different types of marine fossils are found in these rocks, particularly in the shales. The series of disks are the stems of cup-shaped *crinoids* (sea lilies); the shells with ridges are *brachiopods;* the small cones are *cup corals.* These particular fossils are the remains of animals that lived in shallow seas during Pennsylvanian time. Thus, the fossils indicate that these rocks were sediments in a sea about 290-330 million years ago.

0.1

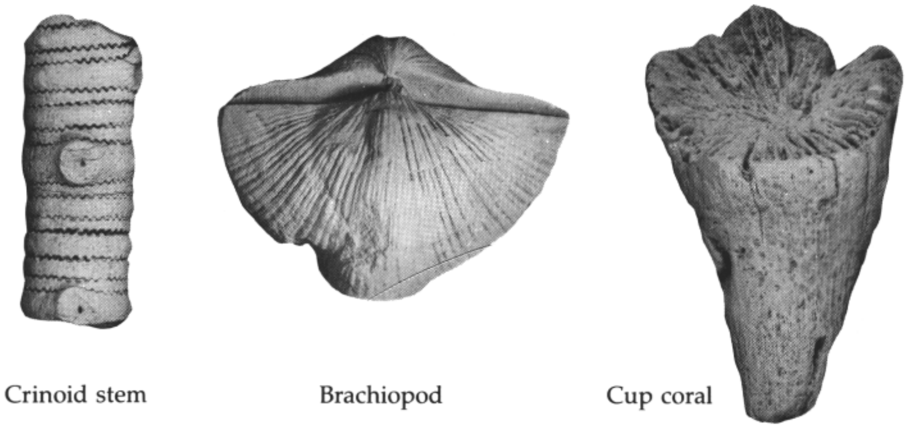
10.8 Entering Carson National Forest. **Caution. The road ahead contains dangerous turns.**

0.1

10.9 Outcrops on the right and ahead are Pennsylvanian-age, coarse-grained sandstones of the Porvenir and Alamitos Formations. They are *cross-bedded* and contain mica and feldspar.

0.1

Pennsylvanian limestone, shale, and sandstone containing marine fossils.



11.0 The trail on the left was the stagecoach road from Cimarron to Taos. It was built sometime in the 1800's.

0.2

11.2 Excellent exposures of Pennsylvanian sandstone on the left. Although sedimentary rocks such as these were deposited on the sea bottom as horizontal layers, here we see the beds dipping at a fairly steep angle. Why? Since the Pennsylvanian Epoch several different great mountain-building events, each taking millions of years to complete, have *folded* and faulted the beds into their present positions.

In the Moreno Valley and in this part of the Sangre de Cristo Mountains we have seen sedimentary rocks that are intermediate in age between the Precambrian and Tertiary rocks of the Red River valley. Thus, rocks were deposited in this region during the Paleozoic and Mesozoic Eras. We have also just discovered that repeated uplift and erosion occurred during these times. Therefore, in the Red River area, if Paleozoic and Mesozoic rocks did overlie the Precambrian strata at one time, they have subsequently been removed by erosion.

0.9

12.1 The rocks here consist predominantly of shale with minor beds of sandstone. If you look carefully at the outcrops on the right side of the road you'll see ancient ripple marks on the bedding surfaces of the shales.

0.2

12.3 We have crossed a fault since mile 12.1. Now we are driving past fossil-bearing limestone.

0.2

12.5 On the right crossbedded sandstone layers are nearly vertical. The limestones, shales, and sandstones in this area are thought to have been deposited along the eastern shelf of a major Pennsylvanian marine basin known as the Taos trough. The source of the sediments was probably a high area to the east known as the Sierra Grande arch. 0.4

12.9 Palo Flechado Pass. County line. Official Scenic Historic Marker reads:

> Palo Flechado Pass. Elevation 9,101 ft. Palo Flechado (tree pierced with arrows) was a pass much used by Indians, Spaniards, and Anglos traveling from the plains by way of the Cimarron River (called La Flecha "the arrow" in 1719). The Flecha de Palo Indians (Apache band) in 1706 inhabited the plains east of the mountains.

One legend has it that the pass is named for the custom of shooting the remaining arrows into a large tree after buffalo hunts. Such a tree was reportedly found on the pass. The old stagecoach road reached the pass to our left, at about 8:00, and descended towards Taos below the modern highway.

Begin descent down the west side of the mountain range along the Rio Fernando de Taos drainage.

0.7

13.6 Hairpin turn. Forest Service Road 5 on the right. Outcrops ahead on the right are interlayered shales and sandstones that dip gently to the east.

0.2

13.8 Here the highway joins the old stagecoach road, visible on the left at 9:00.

0.3

14.1 On the left, from 8:00 to 11:00, the hillslope consists of Precambrian rocks

2.4

16.5 The highway has just crossed a *normal fault* that has brought a Tertiary conglomerate down against Pennsylvanian rocks. The conglomerate contains rounded clasts of tuff, andesite, and basalt; the clasts are Tertiary in age too. This unit is called the Picuris Formation and was probably derived from erosion of volcanic rocks in the area of Latir Peak and Questa caldera.

3.2

16.8 Outcrops of Tertiary-age conglomerate on the right.

0.3

17.1 We have crossed another fault and are now back in Pennsylvanian sedimentary rocks.

0.4

17.5 Destitute Studebaker on the right.

0.6

18.1 Forest Service Road 437 to the left.

0.8

18.9 Dark-colored, flat-lying Pennsylvanian sandstone and shale on the right.

2.2

21.1 Roadcuts for the next few miles contain two types of Pennsylvanian sedimentary rock—thicker, more massive layers of sandstone and thinner, crumbly layers of shale. The sandstone is made up of visible cemented grains, whereas the shale (compacted mud) grains are too small to see.

2.2

23.3 Entering the community of Shady Brook.

0.3

23.6 La Sombra campground. This campground and four others in the next 5 miles have picnic tables, fireplaces, and toilet facilities.

0.5

24.1 Capulin campground. Capulin is Mexican-Spanish for "wild cherry."

0.4

24.5 Forest Service Road 10 on the right.

1.1

25.6 Rancho Canyon.

0.6

26.2 Small lakes on the left.

0.4

26.6 Interbedded sandstone and shale are exposed to the right. Ahead is a sequence of sandstone, shale, and limestone that was deposited as deltas and along the shoreline of the western edge of the Taos trough.

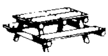
0.2

26.8 Las Petacas campground. Petaca is Spanish for "trunk for clothes." Official Scenic Historic Marker reads:

Taos Canyon. In 1692, after having been driven from New Mexico by the Pueblo Revolt of 1680, the Spanish began to re-establish their rule. In one of the last battles of the reconquest, in September 1696, Governor Diego de Vargas defeated the Indians of Taos Pueblo at nearby Taos Canyon.

1.0

27.8 La Viniteria campground on the left.



0.5

28.3 El Nogal campground on the left. Nogal is Spanish for "walnut tree," but no walnut trees grow here.

0.1

28.4 Leaving Carson National Forest.

0.2

28.6 Intersection with NM-585 on the left. **Stay on US-64 to Taos.**

0.3

28.9 Pennsylvanian sandstone in the roadcuts and in the cliffs. Just ahead is the major fault system that separates the Sangre de Cristo Mountains from the Rio Grande rift.

0.3

29.2 Leaving mountains. Driving on Cenozoic alluvial fans. We are now back in the Rio Grande rift.

0.3

29.5 At 1:00-2:00 on the skyline is the Taos Range.

0.9

30.4 Entering Taos, elevation 6,950 feet.
0.6
31.0 Kit Carson House on the right.
0.1
31.1 Taos plaza—end of trip. Hope you've enjoyed it!

Side trip 1A

(7.8 miles)

Dunn's Crossing

Cumulative mileage

0.0 **Follow dirt road west** from NM-522 (5.4 miles north of US-64 junction) toward Rio Grande Gorge.

0.1

0.1 From 12:00 to 12:30 is Cerro de los Taoses.

0.6

0.7 The Tres Orejas Peaks are visible at 10:00. Big sagebrush (*Artemisia tridentata*) is the bluish-silvery shrub covering these slopes.

0.3

1.0 The Rio Grande Gorge is visible straight ahead.

1.3

2.3 Road forks. **Bear right** and begin winding descent into canyon cut by the Rio Hondo (Spanish, "deep river").

0.1

2.4 Ahead is the village of Arroyo Hondo and the Sangre de Cristo Mountains.

0.4

2.8 Road forks. **Bear left** to descend gorge. Right fork leads to the village of Arroyo Hondo.

0.1

"Long John" Dunn, circa 1925, near Taos. John Dunn ran a passenger stage business between Taos and the train stations at Servilleta and Taos Junction from 1902 to 1928. He carried U.S. mail from 1906 to 1938. The steep, winding road into Rio Hondo Canyon made for an exciting ride whether in a horse-drawn stage or in this Hudson Super Six seven-passenger sedan. Photo by B. G. Randall, courtesy of Las Quince Letras © 1987.

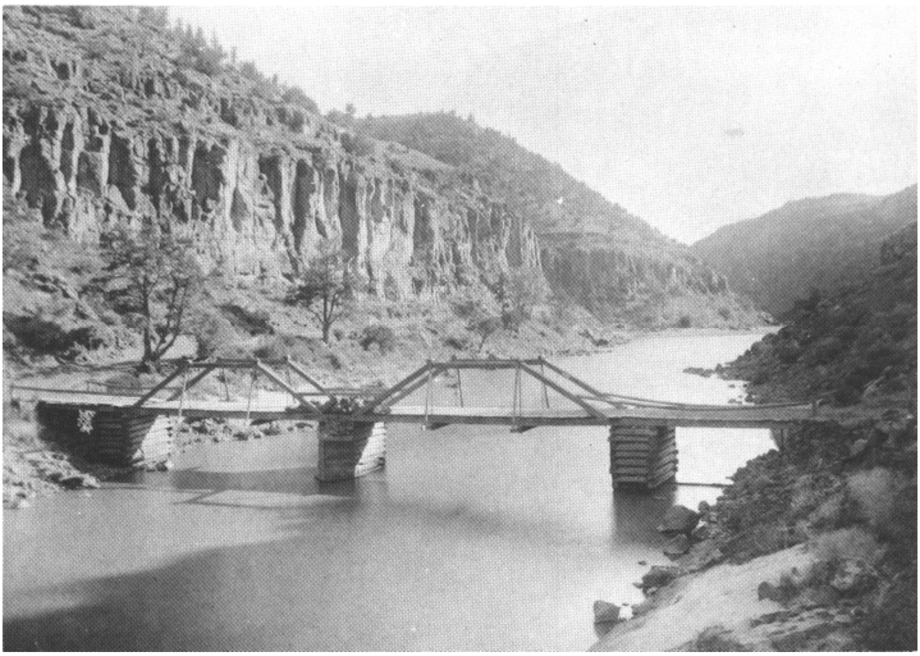
2.9 The black rock along the road and in the opposite wall of the canyon is basalt, part of the same lava flows we saw at the Gorge Bridge. The basalt also forms a layer along the canyon rim. This layer is a lava flow whose source is a series of volcanoes to the west. The basalt contains many small holes, or *vesicles*, formed when gas bubbles were trapped in the hot, molten lava as it cooled. Basalt with this texture is called *vesicular basalt.* The closely spaced, vertical cracks in the lava, *columnar joints,* were formed as the lava cooled, shrank, and cracked. Similar basaltic lava flows accompanied the many recent eruptions in such exciting places as Kilauea on Hawaii, Vesuvius in Italy, and Paricutin in Mexico.

0.8

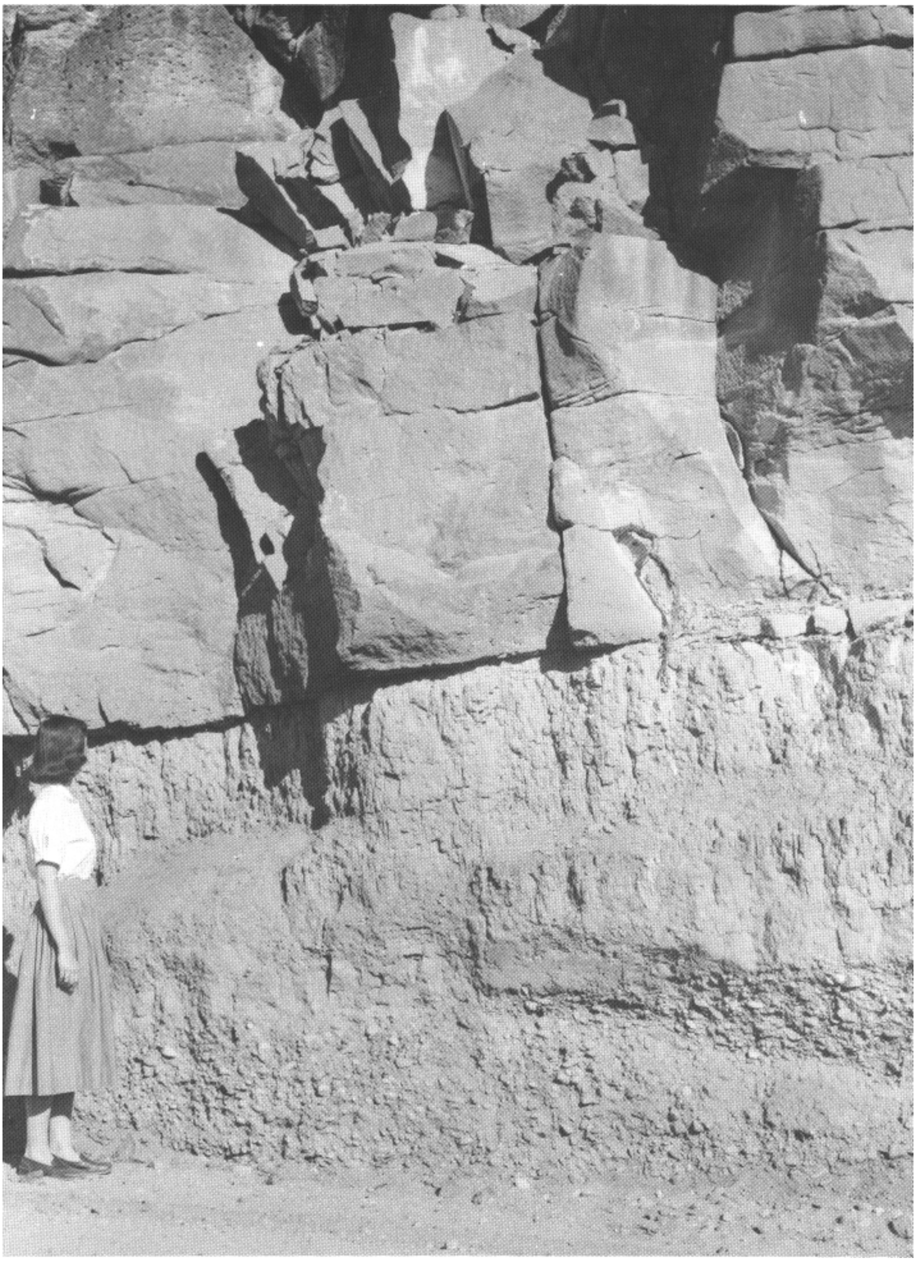
3.7 **Stay right at the fork** as the road crosses the Rio Hondo. Here another lava flow is exposed at a much lower level in the gorge.

0.1

3.8 Bridge. Road crosses the Rio Grande at elevation 6,501 feet (the lowest point on this trip) and climbs out of the gorge on a very steep, narrow grade to the west. This is called Dunn's Crossing, after "Long John" Dunn, who operated a toll bridge here and built the first road. This crossing was used by travelers who were journeying between Taos and the railroad stations to the west. Today, this is one of the most popular boat-launching spots on the river. Rafters who run the rapids of the "Taos Box" start their adventures here. Commercial rafters are



John Dunn's Toll Bridge, circa 1905, Dunn's Crossing. This was one of the few places to cross the Rio Grande in northern New Mexico. Photo by B. G. Randall, courtesy of Las Quince Letras.



On the west side of the gorge, near river level, black basalt lava rests on alluvial-fan gravels. The gravel, once at the land surface, was covered by the molten lava flow and baked brick red.

regulated by the U.S. Bureau of Land Management. Notice the river gauging station just downstream of the bridge. On the west side of the bridge at road height, note the basalt lava flow resting on brick-red gravels. As the hot lava flowed across the gravel plain it baked the gravels brick red.

Notice the boulders in the Rio Grande at the mouth of the Rio Hondo. These boulders, as well as smaller size gravel, have been carried down the Rio Hondo during floods. Probably much of the gravel we see in the walls of the gorge was moved here when flood waters roared down tributaries such as the Rio Hondo.

Turn around and retrace route to NM-522.

1.1

4.9 Fork. The road to the left is an alternate route to NM-522. This road winds through the sleepy village of Arroyo Hondo. The road to the right is the way we came in.

2.9

7.8 Junction with NM-522; **turn left onto highway.**

Side trip 1B

(20.2 miles)

Mallette Canyon to Cabresto Canyon

Cumulative mileage

0.0 From NM-38 in Red River turn left onto Mallette Road.
1 block

0.05 Stop sign. **Continue north on Forest Service Road 597** up Mallette Creek.
0.1

0.1 On the left are exposures of fine-grained Tertiary granite.
0.1

0.2 Mallette Canyon Park. Camping permitted. On the left are cliffs of Precambrian quartzite that have been intruded by Tertiary granitic rocks of the Questa caldera. We are near the eastern margin of the caldera. Ahead on the right are more Precambrian rocks that have been intruded by Tertiary rhyolite and latite.

1.0

1.2 On the left are more fine-grained Tertiary igneous rocks, however, these rocks are darker in color than those below. These rocks are called *monzonite* or *diorite* and contain less quartz and more dark minerals, such as biotite mica and *hornblende.*
0.1

1.3 **Bear left at fork;** leaving Mallette Canyon and beginning the climb into the high country. Red River Ski Area is visible to the left down canyon.
0.2

1.5 More fine-grained Tertiary monzonite on the right.
0.1

1.6 Cross Trail Creek.
0.9

2.5 More Precambrian rocks that have been altered by Tertiary intrusions. 0.1

2.6 Switchback.
1.1

3.7 In this area a rhyolite porphyry is in contact with the Amalia Tuff. We are now driving on Tertiary igneous rocks that accumulated within the Questa caldera.
1.5

5.2 Sawmill Pass; elevation is about 10,300 feet. **Bear left.**
1.5

6.7 We are driving on rhyolite. Bonito Canyon, the deep canyon to the northeast, is the approximate eastern margin of the caldera wall. Just beyond the canyon, outside the caldera, Tertiary andesites overlie Precambrian rocks.
2.0

8.7 The spectacular view to the north includes Pinabete Peak (Spanish, "fir tree") and the Latir Peak Wilderness area. This view is into the core of the Questa caldera.
0.8

9.5 We are now at the outer boundary of the caldera structure. Precambrian quartzite forms the outer wall.

0.6

10.1 Intersection with Forest Service Road 134. Cabresto Creek flows down to Questa where it converges with the Red River. The road upstream leads to several abandoned mining camps.

Retrace route back to Red River on Forest Service Road 597.

Trip 2

(61.5 miles)

Picuris Mountains loop—Taos—Dixon—Peñasco—Vadito—Taos

Trip 2 takes us southwest of Taos along a low-road loop that follows the rivers around the Picuris Mountains. As we travel through ancient, picturesque towns nestled along tranquil river valleys, we will inspect rocks and sediments that range in age from Precambrian (over 1700 million years old) to Holocene (recent). Side trip 2A takes us into the Orilla Verde BLM (U.S. Bureau of Land Management) Recreation Area, formerly Rio Grande Gorge State Park, where we can fish, camp, and pan for gold beneath towering *basalt* cliffs. Payment of a nominal camping fee is required. Side trip 2B is a walking tour of the Harding *pegmatite* mine, a unique location where immense, exotic crystals have been quarried.

The Picuris Mountains form a wedge-shaped prong of Precambrian crystalline rock that extends westward from the Sangre de Cristo Mountains into the Rio Grande rift. As we drive southwest from Taos to Dixon we will parallel the Embudo *fault zone*, a major feature that separates Tertiary strata of the Taos Plateau from Precambrian rocks of the Picuris Mountains. After skirting the western prong of the mountains, we will drive eastward on Quaternary and Tertiary sediments that cover a second fault zone that separates the Precambrian rocks from Tertiary strata of the Espanola Basin. On the final leg of the trip, we drive northward along a third zone of complex faulting and *folding* that separates Precambrian rocks from Paleozoic *sedimentary rocks* of the Sangre de Cristo Mountains to the east.

The first portion of the trip, from Taos to the Dixon turnoff, is covered in detail by an excellent road log in Scenic Trip 13 (Muehlberger and Muehlberger, 1982). For a more technical account of the geology of this loop, see the road logs in the 1984 New Mexico Geological Society Guidebook 35.

Cumulative mileage

0.0 From the northeast corner of the Taos plaza **go east to the stoplight and turn right** onto NM-68.

1.2

1.2 To the left, at 9:00, are the Sangre de Cristo Mountains. Straight ahead are the Picuris Mountains. Picuris Peak, the highest point in the range (elevation 10,801 feet), is a little to the left at 11:30. Cruz Alto Road on the left goes to a Forest Service Office and BLM Office.

0.6

1.8 To the left, at 9:00, are Pennsylvanian sedimentary rocks of the Sangre de Cristo Mountains. At 10:30, the high mountains in the distance are part of the Truchas Peaks area. In the foreground, at 11:00, the low hills are Precambrian *granite*. The canyon to the right of the granite ridge is Arroya Miranda. The Jemez Mountains are on the skyline to the right at 1:30. At 2:30 are the Tres Orejas (Spanish, "three ears"), one of many extinct volcanoes on the Taos Plateau.

0.3

2.1 Junction with NM-585 on the left.

1.2

3.3 Entering Ranchos de Taos (Spanish, "ranches of Taos").

0.2

3.5 On the left, junction with NM-518 to Talpa. **Continue straight on NM-68** and descend into the drainage of the Rio Grande del Rancho, which empties eventually into the Rio Grande.

0.4

3.9 On the left is the famous San Francisco de Asís Church built in 1815. This may be the most painted and photographed church in the country (see page 16). Junction with NM-240 to Los Cordovas, Ranchito, and the Severino Martinez hacienda. Built in 1827, the hacienda is one of the best surviving examples of Spanish Colonial architecture. The Kit Carson Foundation restored the hacienda and maintains it as a public museum. Padre Martinez of Taos was the son of Don Severino Martinez. **Continue straight on NM-68.**

0.2

4.1 Crossing Rio Grande del Rancho.

0.3

4.4 Entering the community of Llano Quemado.

1.2

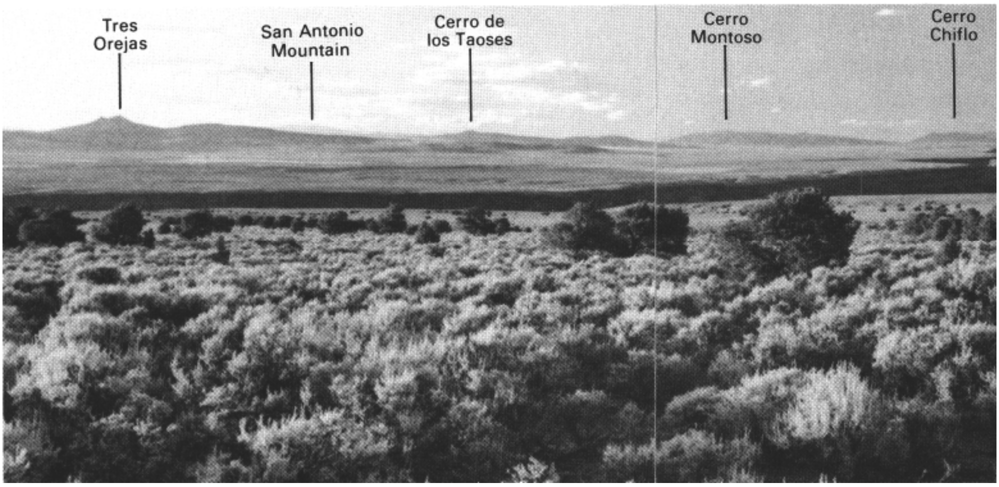
5.6 **Side trip 2A, Panning** for gold in the Rio Grande Gorge.

> If you wish to take Side trip 2A, turn right onto NM-570 towards Taos Junction, **set** trip odometer to zero, and turn to page 104. Because of the steepness of the grade into the gorge, those driving campers or vehicles with unreliable brakes should not take this entrance into the Orilla Verde Recreation Area. For those who decide not to take this route, the beauty of the gorge and the opportunity to pan for gold can be enjoyed by backtracking from Pilar at mile 16.6. Those with campers or tents may want to spend the night in the recreation area. The campgrounds are attractive and reasonably priced, water and restrooms are available, and the fishing can be great!
>
> Panning for gold is a summer and early autumn sport only. In the spring, high water covers the gold-bearing gravel, and in the winter, the water is too cold for pan work.

Those of you not taking the side trip should **continue ahead on NM-68.**

0.3

5.9 We are now driving on the surface of an *alluvial fan* that developed northwestward from the Picuris Mountains. An alluvial fan forms where a rapidly moving mountain stream flows out onto a valley floor. As the stream spreads out and suddenly loses velocity, the coarser sedimentary material is dropped by the stream. This material forms an "apron" that radiates out from the point where the mountain stream enters the valley. Most of this clay, sand, and gravel, called the Santa Fe Group, eroded from the Picuris and Sangre de Cristo Mountains during the past 30 million years. Many thousands of feet of rock were removed from the mountains and transported into the valley as the mountains slowly pushed upward. Measurements in

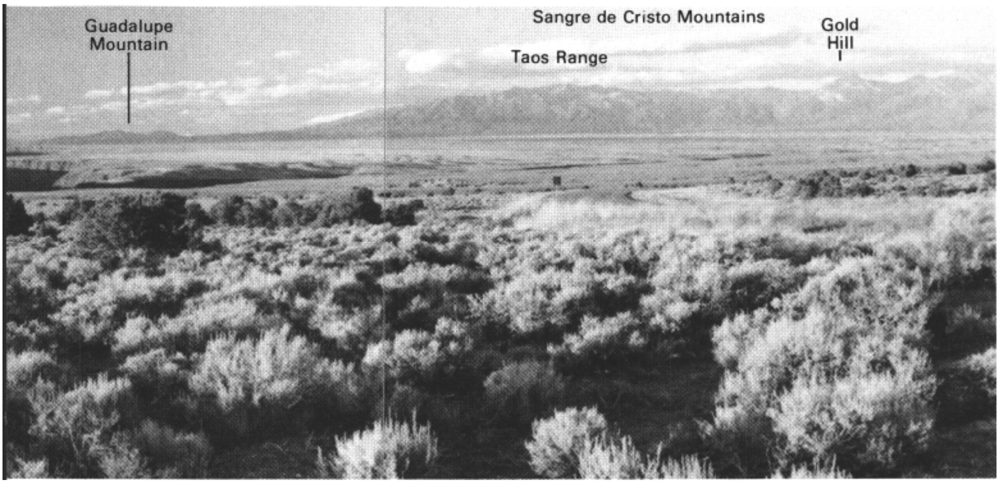


Panoramic view north of the Rio Grande rift from the Rio Grande Gorge overlook south of Taos. The low ocne-shaped mounds on the left are small volcanic eruption centers; the Sangre de Cristo Mountains tower on the right.

areas where mountains are experiencing rapid uplift, such as in the Himalayas, indicate that fast rates of uplift are less than 0.1 inch per year. Such movements are nearly imperceptible over a human life-span.

The climate of the area around the Picuris Mountains is semiarid. This dry climate prohibits growth of most lush, leafy plants characteristic of more humid climates. The prominent vegetation on this alluvial fan is a low, bluish-silvery shrub known as big sagebrush *(Artemisia tridentata).* This plant is common on thick, dry soils. In general, the greater the surface area of a plant, the more moisture it transpires to the air. Consequently, the local vegetation is composed of evergreens with needlelike leaves, a few hardy deciduous trees, such as aspen, and many drought-resistant shrubs and plants. Cacti are the extreme example of minimum surface area. Most cacti have spines rather than leaves and store moisture in stems, which swell with stored water during wet spells and shrink during droughts.

As we travel higher we will notice changes in the vegetation. For every 1,000 feet higher in elevation the average temperature decreases by about 3° F (1.7° C). This increase in elevation is equivalent to traveling 600 miles north. High elevations result in thin air, intense sunlight, and low humidity. Differences between summer and winter, day and night, and sun and shade are more extreme because the thin, light air has less heat-holding capacity. As air moves up the windward side of a mountain it cools. Because cold air cannot hold as much moisture as warm air, the saturation point is reached sooner, and precipitation occurs as rain, snow, or frost. Higher elevations therefore generally receive more precipitation than lower areas. Our present elevation of 7,000 feet receives about 10 inches of precipitation annually, whereas Picuris Peak (elevation 10,800 feet) receives about



(Continued from previous page.)

21 inches per year. Furthermore, because shaded areas have lower temperatures, valleys and north-facing slopes receive more precipitation and experience lower evaporation. As a result, these areas remain wetter and support a more dense vegetative cover than an equivalent south-facing slope. This "climate within a climate" is called a microclimate.

0.3

6.2 Picuris Mountains on the left are composed of Precambrian *metamorphic rocks.*

1.9

8.1 Stakeout Drive on the left.

0.3

8.4 Roadcut through the alluvial-fan deposits of sand and gravel eroded from the Picuris Mountains.

0.3

8.7 Interbedded with the alluvial-fan deposits in the roadcuts to the right and left (but not easy to recognize) is coarse volcanic ash from the most recent caldera-forming eruption in the Jemez Mountains. This eruption, about 1.1 million years ago, produced the Valle Grande depression west of Los Alamos and the upper member of the Bandelier Tuff.

0.5

9.2 Straight ahead in the far distance are the Jemez Mountains. Slightly to the right, at about 12:30, in the middle distance, the group of small pointed hills is Cerro Azul (Spanish, "blue hill"). These hills are composed of Precambrian rocks but are entirely surrounded by Tertiary rocks.

0.9

10.1 To the right, at 3:00, the low dark hills on the Taos Plateau are the

Tres Orejas. From 1:00 to 2:00 on the Taos Plateau are extinct volcanoes. The Tusas Mountains are visible on the skyline. To the right of the highway is the Rio Grande Gorge.

1.6

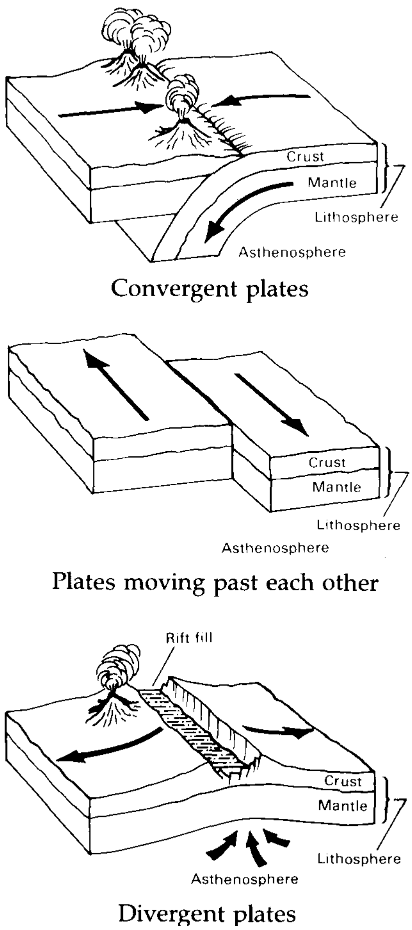
11.7 **Stop at the Rio Grande Gorge overlook. Pull off the right side of the highway, near the picnic tables.** This stop provides us with a superb vista of the Taos area. The extensive, relatively flat valley to the north is called the Taos Plateau. The Rio Grande has cut a deep canyon, called the Rio Grande Gorge, across the plateau. Near-horizontal layers of *tholeiitic basalt* are beautifully exposed in the gorge. Much of the basalt was erupted as *pahoehoe flows* that traveled many miles in thin sheets before solidifying. To the east are the rugged Sangre de Cristo Mountains, which extend 200 miles from Santa Fe to Salida, Colorado. The high mountains on the western skyline, the Tusas Mountains, are composed of Precambrian rocks. To the north notice the isolated, rounded mountains scattered across the Taos Plateau. Most of these mountains are extinct volcanoes of the Taos Plateau volcanic field, and they range in age from 10 to 2 million years. The Tres Orejas are in the middle distance due north. Behind the Tres Orejas, in the far distance, the large gently curved mountain is a volcano called San Antonio Mountain. To the right are several other volcanic mountains.

Although this scene appears solid and calm from our picnic-area vantage point, from a geologic perspective this region is exactly the opposite. We are standing on one of the most dynamic and exciting geologic settings in the world. Buried beneath us is the floor of a huge rent in the Earth's rigid upper surface that is 30 times larger than the "small" scar created by the Rio Grande. This rift is still active, as indicated by the common occurrence of minor earthquakes and the presence of large chambers of molten rock at depth. Fortunately, the *faults* in this area usually release their built-up stress as frequent, small, imperceptible tremors rather than as massive, destructive earthquakes. Notice the *fault scarp* to the south along the highway. Major earth movement must have occurred along the Embudo fault when this scarp developed.

The Rio Grande rift, as it is called, has split from north to south all of New Mexico and part of Colorado for a distance of about 600 miles. The rift is somewhat like a plowed furrow with raised shoulders and half filled with alluvium. In this area, the shoulders are the Sangre de Cristo Mountains to the east and the Tusas Mountains to the west. Just to the north of us, the floor of the rift is estimated to be down-faulted 36,000 feet. Without its fill of alluvium the downdropped *basin,* in places, would be six times as deep as the Grand Canyon!

The obvious question at this point is: "What caused the Rio Grande rift?" The Rio Grande itself did not cause the rift. Instead the river follows a topographic low within the rift. The generally accepted theory is that the Rio Grande rift is part of a system of global fractures that form in order to accommodate relative movements of the Earth's uppermost layer (the *lithosphere)* as rigid plates. This theory of global plate interactions is called *plate tectonics.* The lithosphere is broken into about a dozen major plates that move over an underlying layer of partially molten rocks (the *asthenosphere).*

Diagrams of the three possible types of plate boundaries.

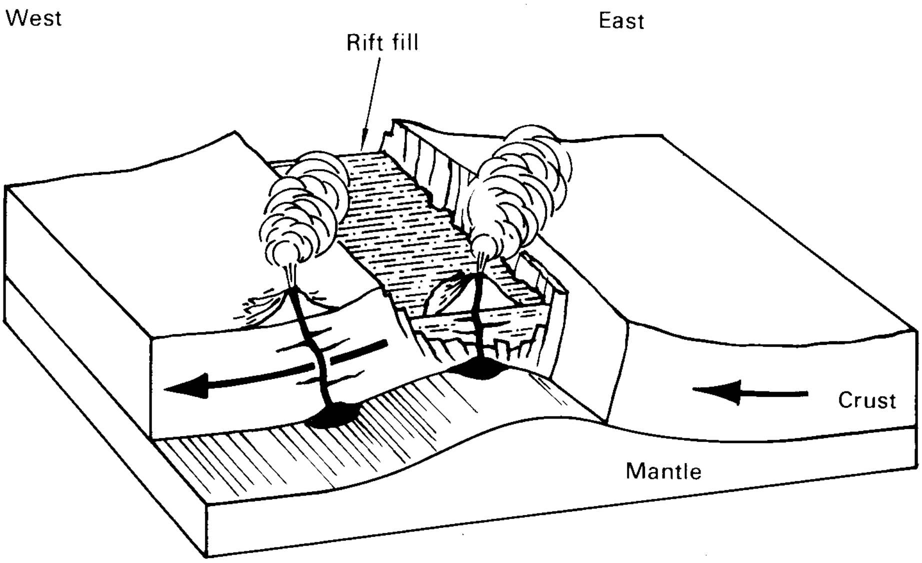


Most of the activity associated with plate tectonics occurs at or near plate margins. Where plates converge, huge mountain systems form (i.e. the Alps, Himalayas) or arcuate (curved) chains of volcanoes develop (i.e. the Japanese and Aleutian Islands). Where plates move horizontally past each other, zones of startlingly energetic faults are present (i.e. the San Andreas fault system). Where oceanic plates diverge, new *crust,* the uppermost layer of lithosphere, is extruded on the ocean bottom in long, narrow, basaltic ridges. Where continental plates or portions of continental plates diverge, rifts evolve (i.e. the Rhine River valley, East African rift valleys, Red Sea). The Rio Grande rift began to form about 30 million years ago as that portion of the North American plate west of the rift began to move faster than the portion east of the rift. Like two loosely linked railroad cars rolling at different speeds, the western portion of the plate has accelerated and is trying to pull away from the slower eastern portion. With this global perspective of rift formation the present panorama takes on new meaning.

Official Scenic Historic Markers read:

Sangre de Cristo ("blood of Christ"). From left to right along the eastern horizon, two of New Mexico's highest mountain ranges are visible—the Truchas Range and the Santa Fe Range. Both are part of the Sangre de Cristo Mountains of the Southern Rockies where glacier carved alpine peaks rise to elevations exceeding 13,000 feet.

Jemez Mountains. Formed from cataclysmic volcanic eruptions some one million years ago, the Jemez Mountains are part of the westernmost New Mexico Rockies that enter the state from Colorado near Chama. Chicoma



Diagrammatic cross section of the Rio Grande rift.

Peak (11,561 feet), prominent on the western horizon, is the highest in the Jemez Mountains. Elevation here is 5,800 feet.

Pueblo Revolt Tricentennial. On August 10, 1680 the Pueblo Indians rose in revolt against Spanish rule. Forced to evacuate Santa Fe by the Tanos, Tewas and Tiwas, Governor Otermin led the retreating colonists south through the lands of the Keres pueblos, whose signal fires could be seen on the mesas, passing through the Pueblo of Santo Domingo on August 24.

Continue southward on NM-68; descend into drainage of Hondo Canyon. Roadcut is through Tertiary-age alluvium.

0.3

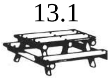
12.0 Roadcut through Tertiary-age sedimentary deposits. Faults have juxtaposed bedded rocks nearly vertically against flat-lying beds.

0.3

12.3 Crossing Hondo Canyon in a tight horseshoe turn. Ahead on the left are roadcut exposures of Santa Fe Group alluvium. These poorly sorted fan deposits of boulders, gravel, sand, and silt are typical of the material that fills the Rio Grande rift.

0.8

13.1 On the left is a small rest area with a picnic table.



0.1

13.2 Begin descent into the Rio Grande valley.

0.7

13.9 **Optional stop at the roadcut on the right.** This outcrop consists of nearly pure *quartz* sand. The curved layering, called *festoon crossbedding,* and the fine, well-sorted sand suggest that these are ancient sand dunes formed by wind.

Most of the sedimentary material in the Santa Fe Group is porous, and therefore water easily passes through. As the water migrates downward, the sand acts as a sieve, filtering out suspended particles to create clean potable water. Such water has been accumulating in the basin fill of the Rio Grande rift for millions of years. Consequently, people, agriculture, and industry are concentrated along the rift and its precious supply of water.

1.3

15.2 Straight ahead at 12:00 the mountain slope of altered Precambrian metamorphosed volcanic rocks is scarred by mines, prospects, and roads.

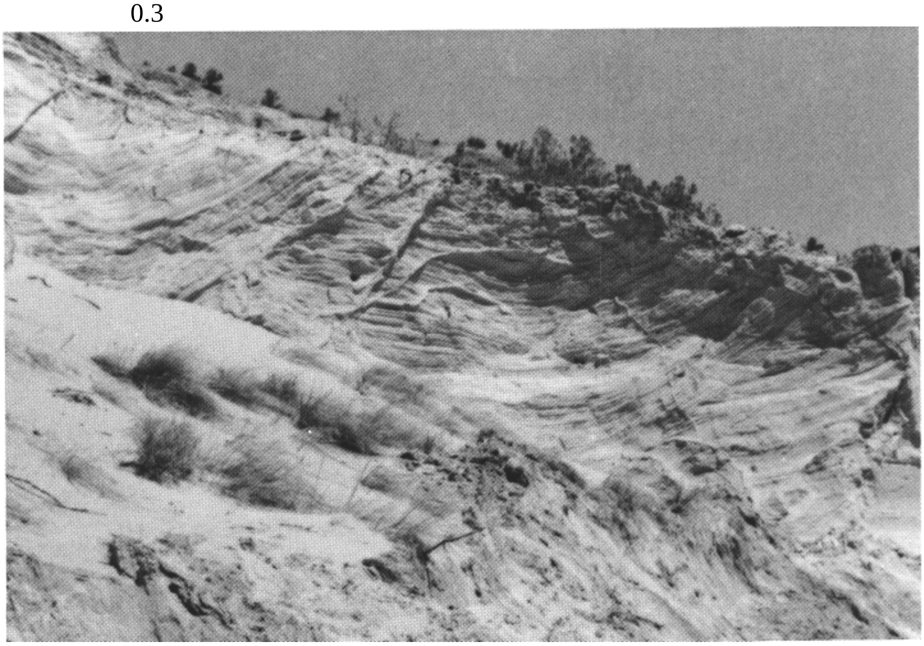
0.9

16.1 Roadcut on the left through Tertiary river *terrace* deposits of sand, gravel, and cobbles. Most of the rounded cobbles are Precambrian *quartzite.*

0.2

16.3 Black basalt *lava* caps the hills straight ahead and to the right. Notice that the basalt is much more resistant to weathering than the underlying Santa Fe Group sediments. In the Southwest, basalt flows commonly form dark, resistant, flat-topped mesas. Vertical crevices, called *joints*, formed as the lava cooled, contracted, and cracked. The dark color, high resistance to weathering, and the vertical joint pattern make the lava flow easy to identify, even from a considerable distance.

0.3



Festoon crossbedding (mile 13.9); this loosely consolidated sand was deposited by wind.

16.6 **Side trip 2A, Panning for gold in the Rio Grande Gorge.**

Village of Pilar (pronounced Pee-lar) and junction with NM-570. **STOP at the Pilar Yacht Club and Cafe.** This is the south and main entrance to the Orilla Verde Recreation Area (formerly Rio Grande Gorge State Park). Pilar, which is Spanish for "pillar," was ceded to settlers in 1795. The origin of the village name is unclear but probably was for either a famous shrine in Spain or an Indian man named Pilar Vigil (Pearce, 1965). Pilar had a post office from 1918 to 1921.

The Pilar Yacht Club and Cafe is the local gathering place for river runners, artists, fisherman, and tourists looking for friendly conversation, a cool drink, and freshly baked apple pie. The Orilla Verde (Spanish, "green bank") Recreation Area, a mile down the road, is worth a visit. As you drive to the recreation area, stop and chat with the local artists and browse through their galleries.

If you are visiting the recreation area to pan for gold, turn now to Side trip 2A on page 104.

0.0 Those of you continuing on the Picuris Mountains loop **reset your trip odometer to zero and resume the drive southwest on NM-68.** For the next 5 miles we will be driving along a projection of metamorphic rocks near the edge of the Rio Grande rift. The road follows a major fault zone, the Embudo fault zone, that separates the uplifted Precambrian metamorphic rocks of the Picuris Mountains from Santa Fe Group sediments and lavas filling the rift.

Official Scenic Historic Marker reads:

> Pilar. In 1795, twenty-five families were granted land along the Rio Grande at Pilar, then known as Cieneguilla. The Battle of Cieneguilla was fought at Embudo Mountain near here in March 1854. A large force of Utes and Jicarilla Apaches inflicted heavy losses on sixty dragoons from Cantonment Burgwin near Taos.

0.3

0.3 The towering cliffs of Precambrian rock on the left are composed predominantly of two rock types. At road level is *quartz–muscovite schist*, called the Glenwoody Formation. This unit probably represents metamorphosed, *rhyolitic tuff* that erupted about 1700 million years ago. A younger example of rhyolitic tuff is the Bandelier Tuff of the Jemez Mountains. The Bandelier Tuff erupted during two enormous volcanic explosions about 1.5 and 1.1 million years ago. Two-thirds of the way up the cliff is a distinctive light-gray quartzite called the Ortega Formation. This 3,000-foot-thick metamorphic rock sequence consists almost entirely of pure quartz sand that accumulated on an ancient coastal beach after eruption of the rhyolitic tuff. The quartzite forms large angular blocks in the *talus* slope near the highway. Out of sight above the Ortega Formation are three other *metasedimentary* formations. These are the Rinconada Formation (schists and quartzites), the Pilar Formation (black *phyllite)*, and the Piedra Lumbre Formation (schist and phyllite).

0.2

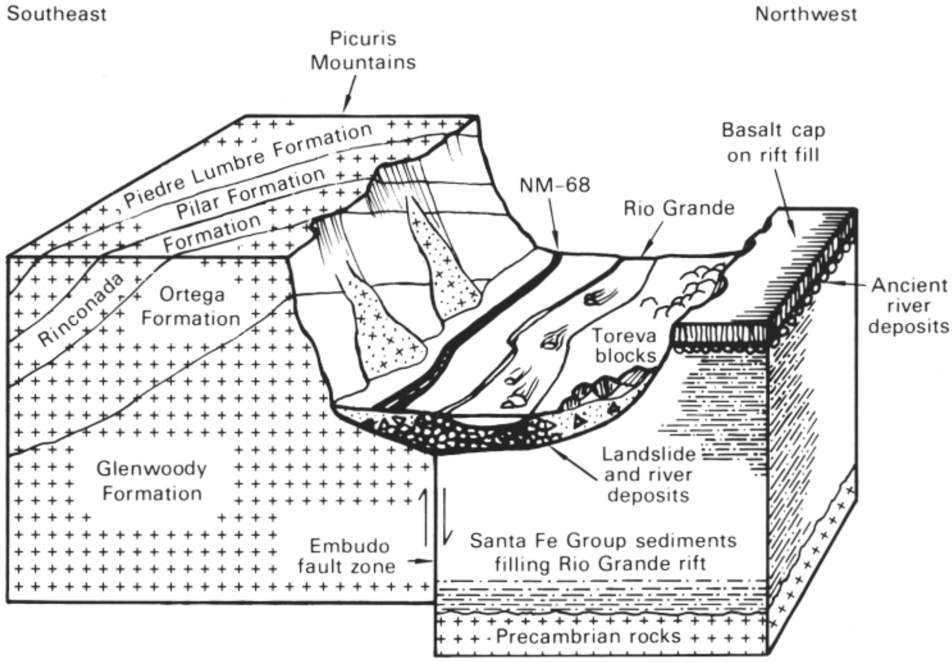


Diagram of the Embudo fault zone.

0.5 Talus slope on the left.

0.4

0.9 Picnic tables and pulloff on the right. Across the river opposite the highway are fairly recent landslide deposits of basalt-flow and alluvial-fan material.

0.5

1.4 Small outcrop of Precambrian rock on the right across the river. These rocks are highly fractured by reoccurring movement along the Embudo fault zone, which is buried by landslide material.

0.6

2.0 Across the river to the right is a flat area with green shrubs and trees. Springs seep from the landslide deposits here. Such areas are called "cienagas," the Spanish word for swamp (see Plate 1). Hillside springs throughout New Mexico are called cienagas.

0.3

2.3 Small pulloff on the right; more cienagas across the river.

0.3

2.6 Glenwoody Bridge on the right was the site of a short-lived gold venture. The bridge was built by the Glen-Woody Mining and Milling Company in 1902 on the piers of an old government bridge that had been burned down in the 1870's. Anticipating riches either from the gold or from selling the stock, the company constructed a water-

Glen-Woody Mining and Milling Company, 1917. Photo no 32055 from the Adella Collier Collection, courtesy of the New Mexico State Records Center and Archives.

powered mill to your left and a town across the river. When gold production did not pan out, the operation was abandoned. All that remains of the old mining camp is the bridge and a few indistinct piles of mill *tailings* on the slope to the left.

0.3

2.9 On the right across the river are highly fractured Precambrian rocks, indicating the proximity of the Embudo fault zone buried by Quaternary landslide material.

0.4

3.3 On the left is the Ortega Formation nearly at road level. Cienaga across the river on landslide.

0.2

3.5 Across the river is a dirt road that was constructed for laying a gas pipeline to Questa.

0.3

3.8 On the left is the contact between the Ortega Formation and schists of the Rinconada Formation.

0.1

3.9 Outcrop of Rinconada Formation schist on the left side of the highway. This quartz—muscovite schist contains small red *garnets* and brown *staurolites.* Certain varieties of *twinned* intergrowths of staurolite are highly valued by collectors. Interpenetrating twins of 90°, called fairy crosses, are collected and sold in mineral shops in Taos and Santa Fe.

0.8

4.7 County line and mile marker 24; entering Rio Arriba County. On the right is one of the major pullouts for the commercial rafting operations in the summer. This is the approximate extent of Precambrian rock exposures along the highway. Landslide material now flanks both sides of the river.

0.3

5.0 Roadcut through landslide material. Notice the enormous variety of poorly sorted rocks.

0.6

5.6 Ahead is a good view of the Santa Fe Group and the town of Rinconada. To the left, from 9:00 to 11:00, in the pinkish cliffs on the skyline are fairly flat-lying beds of the Chama—El Rito Member of the Tesuque Formation of the Santa Fe Group. These rocks form Tertiary-age alluvial fans.

0.2

5.8 Entering the village of Rinconada. During late summer, local apples, fresh cider, and chile ristras can be purchased at roadside stands. Ristras, which consist of braided strings of bright red chile peppers, are a brilliant autumn tradition throughout New Mexico (see Plate 6).

0.8

6.6 To the left, from 10:00 to 11:00, the Embudo fault zone swings southward and disrupts layers of Santa Fe Group sediments.

0.3

6.9 Roadcut through Santa Fe Group sediments.

0.2

7.1 Almost straight ahead, at 12:30, on the skyline, notice a series of stepped basalt blocks that have slumped down from the top of the mesa. Such detached and rotated blocks are called *toreva blocks.*

0.9

8.0 Santa Fe Group sedimentary rocks are exposed in the cliffs ahead on left and right. Here the soil along the river is deep and moist; the environment is protected from the prevailing winds by the surrounding cliffs, and deciduous trees and shrubs thrive.

Notice the chaotic, jumbled nature of basalt blocks, cobbles, and sandy sediment. We are driving on massive landslide deposits of the Santa Fe Group. During Pleistocene time, the river cut down and laterally into the soft sediments of the basalt-capped cliffs. Erosion of the softer underlying sediments oversteepened the cliffs, and they collapsed, perhaps at times triggered by earthquakes. To a lesser

Santa Fe Group sedimentary rocks to the right of NM-68 at mile 8.0.

degree this landslide process continues to occur, with cliff collapse proceeding northward away from the river.

0.2

8.2 **Junction with NM-75. Turn left towards Dixon.**

0.1

8.3 Cross the Rio Embudo. Santa Fe Group sediments in the cliffs to the left.

0.2

8.5 Landslide deposits on the right.

0.4

8.9 To our right is a steep outcrop of Precambrian metamorphic rocks. This outcrop of altered Rinconada Formation is a relatively small, fault-bounded block of Precambrian basement rock surrounded by sediments of the Santa Fe Group.

0.6

9.5 Town of Dixon. Dixon is located along the Rio Embudo (Spanish, "funnel-shaped") in a fertile valley famed for its apples. Five streams flow into the Rio Embudo, which accounts for the name "Embudo" being given to the river and to the original Spanish settlement in the valley. The town was renamed Dixon in 1900 in honor of the first local school teacher Collin Dixon. Dixon sits on Quaternary *alluvial deposits* of the Rio Embudo. Unconsolidated Quaternary sand and gravel de-

Old Dixon store constructed of river-rounded quartzite boulders of the Precambrian Ortega Formation. Corrugated galvanized steel roofing is common in rural northern New Mexico.

posits of older river terraces are along both sides of the valley. The Miocene-age Dixon Member of the Tesuque Formation is exposed in the cliffs south of the valley, whereas the Chama—El Rito Member is exposed to the north. The Dixon Member contains Paleozoic sedimentary clasts that were derived from highlands to the east, whereas the Chama—El Rito Member contains Tertiary volcanic clasts that were derived from highlands to the north (Steinpress, 1981).

0.6

10.1 The building on the left is constructed of river-rounded quartzite boulders of the Precambrian Ortega Formation.

0.1

10.2 Lebeo's General Store on the right. Those planning to take the walking tour of the Harding pegmatite mine, Side trip 2B (page 110), will have to stop at the store to sign a permission-release, unless forms were obtained earlier from the University of New Mexico Department of Geology. We recommend that you carry something to drink on the walking tour. Buy it here.

0.3

10.5 On the left is the entrance to La Chiripada Winery and Pottery, which was written up in the New York Times in 1988. The Johnson family has been producing small volumes of fine wine since 1981. They grow winter-hardy, mainly French-American hybrid grapes in their vineyards. They also make an inexpensive apple wine from local apples. Stop in and sample their vintage, or try their wines in Santa Fe, Albuquerque, or Taos.

0.5

11.0 On the right are exposures of terrace deposits of the Rio Embudo that contain rounded, *imbricated* quartzite cobbles.

0.2

11.2 On the left, at 9:00, is an outcrop of gently dipping Santa Fe Group sedimentary rocks.

0.1

11.3 Straight ahead, at 12:00, the high rounded hill on the skyline is Cerro de los Arboles (Spanish, "hill of trees"); to the left is Cerro Puntiagudo (Spanish, "sharp-pointed hill").

0.1

11.4 Road on the right leads to apple orchards and to the towns of Cañoncito (Spanish, "little canyon") and Las Trampas (Spanish, "the traps"). The church of San Jose de Gracia de Las Trampas is probably the most perfectly preserved Spanish Colonial church in the United States.

0.1

11.5 Highway crosses the Rio Embudo. The creek contains rounded quartzite cobbles and boulders of the Precambrian Ortega Formation. We now begin our climb onto the southern flank of the Picuris Mountains.

0.4

11.9 Precambrian *granitic rocks* form hillside to the right, at 3:00. On the left, at 9:00, are gently dipping Tertiary Santa Fe Group rocks.

1.4

13.3 Taos County line. Santa Fe Group on the left.

0.3

13.6 In the dark-colored hills on the left are exposures of Precambrian rock called the Pilar Formation. This geologic unit is a black, carbon-rich, *slaty* rock that weathers to small, flat plates. The Pilar Formation presumably was ancient black mud that was deposited in a large, stagnant, water-filled basin.

0.4

14.0 Ahead in the roadcut notice light-colored Santa Fe Group rocks overlying the black Pilar Formation.

0.3

14.3 Rocks straight ahead are Piedra Lumbre Formation.

0.1

14.4 Contact between Piedra Lumbre Formation and Marquenas Formation of the Vadito Group is exposed but difficult to see on the left side of the highway. The Marquenas Formation will form the cliffs on the left for several miles.

0.6

15.0 For the next half mile on the left, spectacular roadcuts expose the Marquenas Formation, which consists of metamorphosed and deformed *conglomerate* and quartzite. The conglomerate consists of rounded cobbles of quartzite, schist, and minor amounts of other rock types set in a schistose *matrix*. The cobbles were flattened and elongated by high pressures and temperatures when the rocks were buried from 6 to 7 miles beneath the Earth's surface (see Plate 7). The Marquenas Formation is the uppermost geologic unit of the Vadito Group in the southern Picuris Mountains. The rocks on the right side of the road are Vadito Group schists.

1.0

16.0 Leaving Marquenas Formation; crossing Vadito Group schists again.

0.7

16.7 **Side** trip 2B, Walking **tour of** the Harding pegmatite **mine.**

Turn right onto the dirt road, and **set trip odometer to zero**. Turn now to page 110. A comfortable pair of sturdy shoes is recommended for the walk.

At the turnoff the Jemez Mountains are visible to the southwest, and Pedernal Peak, a high flat-top butte, can be seen north of the Jemez Mountains. The high Truchas Peaks are to the south-southeast.

0.0 **Reset trip odometer at zero** and **resume drive on highway.**

0.1

0.1 We have now climbed 1,400 feet to an elevation of 7,400 feet since crossing the Rio Embudo at mile 11.5. Notice the difference in vegetation. This floristic zone, known as the piñon-juniper woodland, is characterized by piñon pine, scrub juniper, and stands of perennial grasses and scattered shrubs. The piñon pine's short needles grow in pairs. The small cones produce nuts that are delicious to people and animals. Their harvest in the fall is a tradition. The juniper has scalelike leaves; its bluish-purple berries are another important source of winter food for animals.

1.1

1.2 Straight ahead is the highest part of the Picuris Mountains, Picuris Peak (elevation 10,800 feet). Picuris Peak is difficult to distinguish from surrounding peaks, although binoculars show that it is topped by a white fire lookout tower. Forest Service Roads 469 (mile 9.2) and 114 (mile 15.7) lead to the summit, and the view is superb.

0.1

1.3 To the right, at 2:00, is the Truchas Peaks area of the southern Sangre de Cristo Mountains. Many of the tallest peaks in New Mexico are in this range. Several of these peaks retain their snowpack on north-facing slopes well into the summer. The summits of the highest peaks, those above 12,000 feet in elevation, lie in the alpine tundra zone in which only grasses, sedges, and dwarf shrubs grow.

0.2

1.5 Begin descent into the valley of the Picuris Pueblo.

0.4

1.9 Cattle guard. Entering Picuris Pueblo land.

0.5

2.4 Straight ahead is a cluster of buildings in the Picuris Pueblo. The

Sangre de Cristo Mountains are on the skyline to the right, at 2:00.

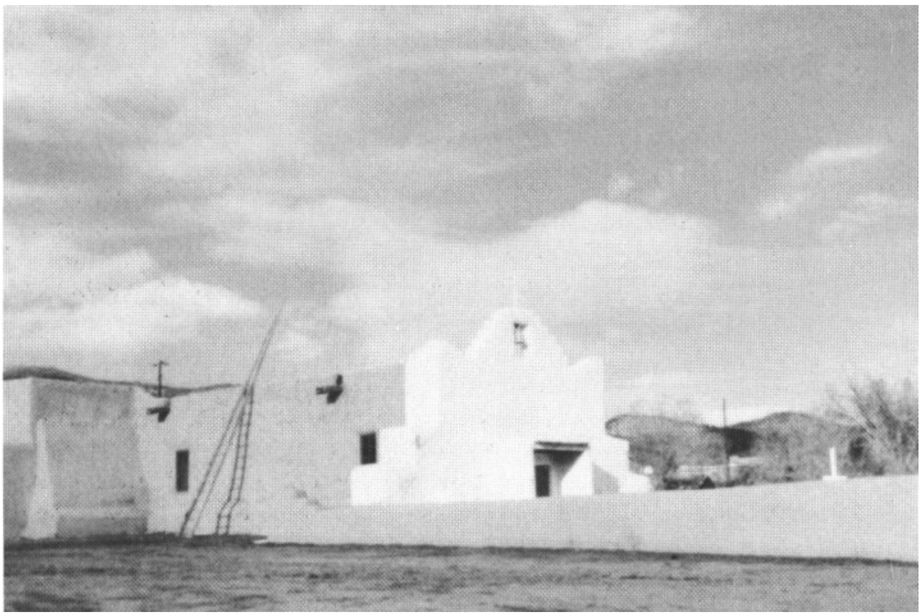
0.9

3.3 Road on the left leads to Picuris Pueblo. The pueblo, also called San Lorenzo Pueblo after its patron saint, is located about a mile down the road and is open to visitors. This area was originally settled around 1300 and is one of the most isolated pueblos. The pueblo was from seven to eight stories high when first visited by the Spanish in 1591. The Picuris Pueblo is one of the original 16 pueblo groups in New Mexico to receive a land grant from Spanish Governor Cruzate in 1689. Construction of the first pueblo church began in 1621. The new San Lorenzo church was completed by 1776; total reconstruction of this structure was begun in 1988. This pueblo contains a 400-yearold, above-ground kiva--the only one of its kind to survive in a modern pueblo. The Picuris Indians are noted for their distinctive pottery, which uses a mica-rich clay slip to give the finished pieces a shiny golden color. This *mica* is collected by Indian women from highly altered, Precambrian quartz–muscovite schist in the Picuris Mountains. The tribal visitor center has a shop where one can purchase this pottery, a restaurant, and a museum that displays ancient artifacts and relates Pueblo history.

0.1

3.4 Crossing the Rio Pueblo.

0.2



The church at Picuris Pueblo, San Lorenzo de Picuris, was constructed in the 1770's. In 1988, 13 years after this photograph was taken, the pueblo began an ambitious restoration project. Photo no. 10236 from the Sallie Wagner Collection, courtesy of the New Mexico State Records Center and Archives.

Flooding along the Rio Santa Barbara in Peñasco, 1973. Photo no. 34373 of the State Planning Office Collection, courtesy of the New Mexico State Records Center and Archives.

3.6 Entering the community of Rio Lucio. The Rio Santa Barbara flows through the valley to the right.

1.2

4.8 Road on the left to Picuris Pueblo. Scenic Historic Marker reads:

> Pueblo of Picurís. The pueblo of Picurís, first visited by Spaniards in 1591, was described as being 7 to 8 stories high. In the 18th century Picurís cooperated with the Spaniards against the raids of the Plains Indians. The church, the third at this pueblo, dates from the 1770s.

0.2

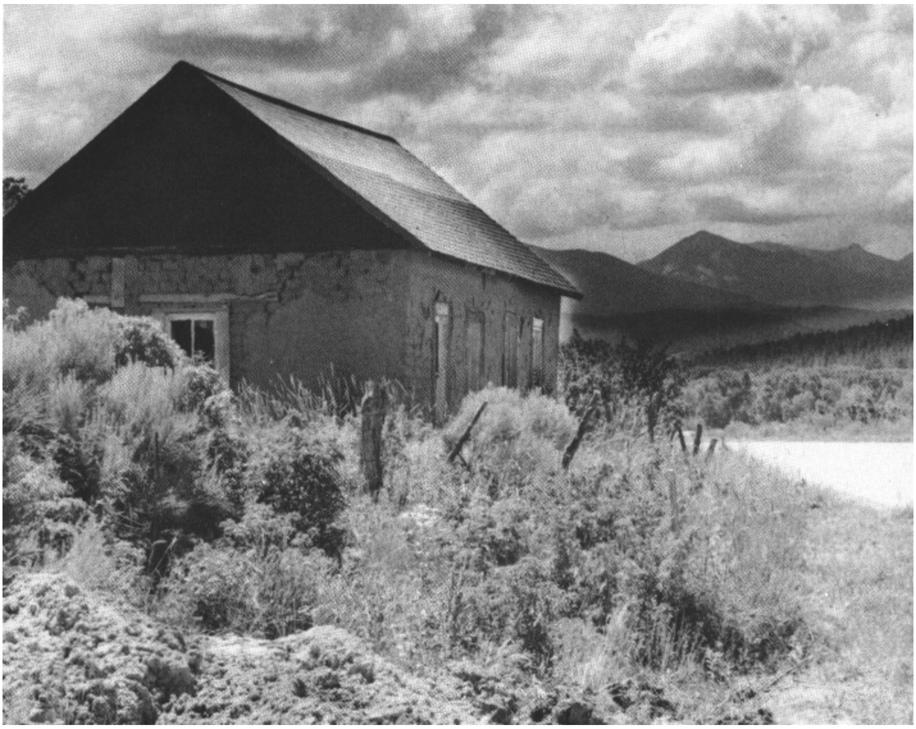
5.0 The Truchas Peaks are visible ahead on the far skyline.

0.3

5.3 Junction with NM-76 on the right. **Continue straight ahead on NM-75**. NM-76 south to Santa Fe passes through small farming communities, including the towns of Las Trampas, Truchas (Spanish, "trout"), where Robert Redford filmed "The Milagro Beanfield War," and Chimayo (the name is a derivative of the Tewa Indian word "tsimayo," which means "good flaking stone"). Towns in this area are well known for their traditional wool rugs and wood carvings.

0.3

5.6 Road turns left; entering the town of Peñasco (Spanish, "rocky"). On the left are outcrops of Precambrian granitic rock called Peñasco quartz monzonite. *Quartz monzonite* is a coarse-grained *intrusive igneous rock*



Truchas Peaks are visible straight ahead as we enter Peñasco (near mile 5.0).

that contains potassium *feldspar, plagioclase* (sodium—calcium) feldspar, and more than 10% quartz.

0.4

6.0 Peñasco Post Office on the right.

0.9

6.9 Junction with NM-73. **Take left fork; continue on NM-75**. The right fork continues through the valley of the Rio Santa Barbara to Rodarte and Llano.

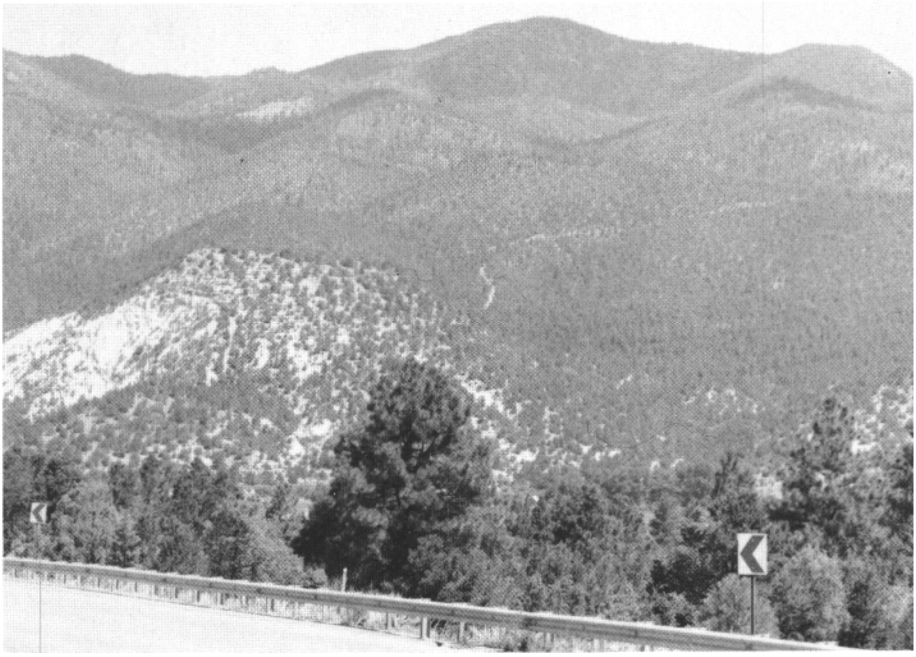
0.3

7.2 On the left is the Camino Real Ranger Station, Carson National Forest. Stop here for inexpensive maps and free brochures. The Carson National Forest map shows places to drive, picnic, camp, and hike. Beyond the ranger station is a cliff of Santa Fe Group sediments.

0.3

7.5 We are now at 7,700 feet in elevation and are in the lower part of the vegetative zone known as the mixed conifer zone. The forest consists mainly of ponderosa pine, Rocky Mountain juniper, and Gambels oak. The ponderosa pine is a tall straight pine and is an important timber crop in the Southwest. Its long needles grow in bundles of three. Mature ponderosa pines have orange-brown bark that smells like vanilla.

0.4



Cerro Blanco (mile 7.9) and the Picuris Formation.

7.9 **Pull into the small parking area on the right.** Looking north we see a large white hill with a cross erected on the top. Called Cerro Blanco (Spanish, "white hill"), this hill has one of the best exposures of the Picuris Formation that we will see on our trip. The Picuris Formation, which is part of the lower Santa Fe Group, consists of alluvial-fan deposits, *flow breccias*, and sediments composed of volcanic debris. Deposition of this formation began in response to the volcanic activity that accompanied early extension along the Rio Grande rift about 30 million years ago. The volcanic debris probably came from the Latir volcanic field, which lies 40 miles to the north, near Questa, New Mexico.

In the distance to the east is a flat-topped mesa with a black strip running around its edge. Notice the vertical lines on the black rock. This is a Tertiary basalt flow called the Vadito basalt.

0.7

8.6 Entering the town of Vadito. To the left is a good view of Cerro Blanco.

0.4

9.0 Crossing the Rio Pueblo.

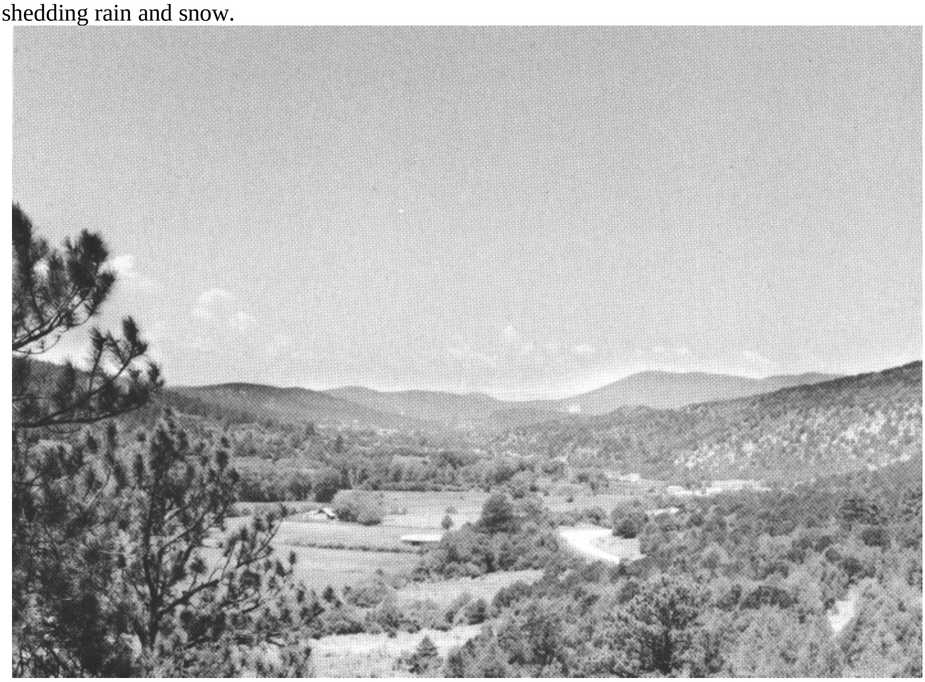
0.2

9.2 On the left is Forest Service Road 469, which goes to the summit of Picuris Peak.

0.2

Gambels oak
Quercus gambelii

Rural home in the Rio Pueblo valley illustrates the traditional Spanish Colonial floor plan with rooms in a single line. Near 7,700 feet in elevation, the pitched metal roof becomes important for shedding rain and snow.



Valley of the Rio Pueblo as seen from NM-518. Mesa at the far right is capped with Vadito basalt.

Junction of NM-75 and NM-518. The west-dipping bedded rocks on the right side of the photo are Pennsylvanian shales of La Pasada Formation. Farther left is the Picuris Formation.

9.4 Roadcuts in the Picuris Formation sands and gravels on the left. 2.9

12.3 Junction with NM-518. **Turn left onto NM-518 towards Taos**. The road to the right goes to Sipapu Ski Area, Tres Ritos, Holman, and over the Sangre de Cristo Mountains to Las Vegas, New Mexico. The outcrop on our right contains *shale* of the Pennsylvanian La Pasada Formation. The shales and *limestones* of this age contain abundant fossils of salt-water creatures, such as *trilobites,* corals, *crinoids, brachiopods,* and *pelecypods.* It is because of this assemblage of species that geologists were able to determine that these fossil-bearing rocks formed from sediments that accumulated in a sea about 300 million years ago, during the Pennsylvanian Period. Shallow seas covered 80% of what is now New Mexico at that time.

Outcrop of Tertiary Picuris Formation sand and gravel is to the left and above the Pennsylvanian rocks.

0.4

12.7 Outcrop of the Picuris Formation on the right.

0.1

12.8 Straight ahead, at 12:00, on the skyline is a basalt-capped ridge.

0.3

13.1 On the right is a spectacular roadcut through a Tertiary-age sand and gravel deposit containing rounded quartzite cobbles and boulders.

0.5

13.6 On the right the roadcut exposes bedded Pennsylvanian sedimentary rocks. More exposures ahead on the left.

0.3

13.9 On the right is Forest Service Road 4 to Amole Canyon. The dirt road on the left leads to an active mica mine in Precambrian schist. This is the only major mica mine west of the Appalachian Mountains. Mica is used in plasterboard joint cements and paints.

Ponderosa pine and Rocky Mountain juniper are present; piñon pine is absent, and aspen is becoming more common. As we climb higher we will see larger groves of aspen. Aspen, requiring light and an open area to become established, predictably move into areas destroyed by fire and logging. If you take this trip during the fall you will be in for a treat. The aspen fall colors are some of the loveliest in the Southwest.

Engelmann spruce
Picea engelmannii

0.8

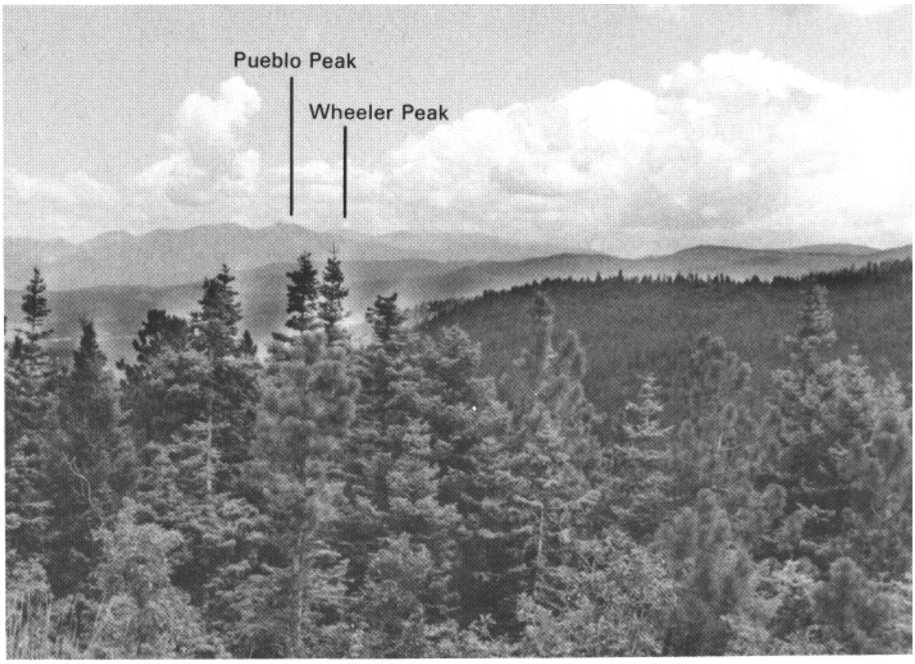
14.7 Pennsylvanian sedimentary rocks here are faulted and folded.

1.0

15.7 Forest Service Road 114 on the left winds up to the fire lookout tower on Picuris Peak.

0.2

Rudolph's camp, 1910, about 30 miles southeast of Peñasco, near Holman, on the east side of the Sangre de Cristo Mountains. Note the spare wheel on the back of the wagon. Photo courtesy of Las Quince Letras.



View from U.S. Hill.

15.9 **Stop at the U.S. Hill vista on the right. Pull into the parking lot on the right side of the** road. The U.S. Hill scenic overlook presents a splendid view of mountain scenery. We are now at the highest elevation (8,600 feet) we will reach on our drive. We are in the uppermost part of the mixed conifer woodland. The trees are predominantly Douglas fir, white fir, ponderosa pine, and aspen. In the spring and summer months this area is alive with wild flowers.

To the north, in the rugged Taos Range, are some of the higher peaks of New Mexico, including Wheeler Peak, the highest point in the state at 13,161 feet. The Enchanted circle (Trip 1) is a 100-mile drive around the Wheeler Peak region. Above about 9,000 feet in elevation is the spruce–fir woodland vegetative zone. These areas are composed of dense forests of Engelmann spruce, subalpine fir, limber pine, blue spruce, aspen, and local growths of Douglas fir and white fir. Both spruce and fir have short needles, but the needles of the spruce are square and sharp, whereas those of the fir are flat and soft. Above 12,000 feet, the forests thin dramatically, and flora of the alpine–tundra are predominant.

To the east are the Sangre de Cristo Mountains. Most of what we can see is composed of fossiliferous Pennsylvanian sedimentary rocks, such as limestone, shale, and *sandstone.* **Continue north on NM-518.**

0.4

16.3 Outcrop of Pennsylvanian *mudstones* and sandstones on the left. These rocks are highly deformed, due to a combination of *soft-sediment deformation* and later tectonism.

1.7

18.0 White Picuris Formation and some underlying Pennsylvanian rocks can be seen in the roadcuts on both sides of the highway for the next mile.

2.1

20.1 Forest Service Road 439 on the right parallels the Rio Grande del Rancho. Conglomerate in the roadcut on the left.

0.6

20.7 Highway crosses Rio Grande del Rancho.

0.3

21.0 Taos Range is visible straight ahead on the skyline. The low hills ahead are mainly Pennsylvanian limestone.

0.3

21.3 Forest Service Road 438 on the right follows the Rito de la Olla.

0.1

21.4 Here, at 7,600 feet in elevation, the fir, spruce, and aspen have disappeared; they are replaced by piñon pine and some ponderosa pine.

0.3

21.7 Fort Burgwin Research Center on the left. Scenic Historic Marker reads:

> Cantonment Burgwin 1852-1860. Never officially designated a fort, this post was built to protect the Taos valley from Utes and Jicarilla Apaches. It is named for Captain John H. A. K. Burgwin who was killed in the Taos uprising of 1847. It was abandoned in 1860, and is the site of the Fort Burgwin Research Center.

The structures of the fort have been restored and now house the Fort Burgwin Research Center, a branch of Southern Methodist University. A museum is open to the public during the summer months.

0.3

22.0 High ridge to the left is composed mainly of Precambrian granitic rocks.

1.1

23.1 On the left is the Carson National Forest Tierra Azul picnic area. Restrooms are provided.

0.1

23.2 To the left is the Rio Grande del Rancho, a slow-moving, mature mountain stream that meanders through green meadows. On occasion, one can see beaver dams and beaver swimming in the pools. The area is a favorite spot with fishermen.

0.6

23.8 Roadcuts on the right display dark-colored Pennsylvanian shales.

1.1

24.9 Leaving Carson National Forest.

0.8

25.7 Roadcut in landslide debris.

0.2

25.9 Driving out of the river valley onto the alluvial fans of the Sangre de Cristo Mountains.

0.2

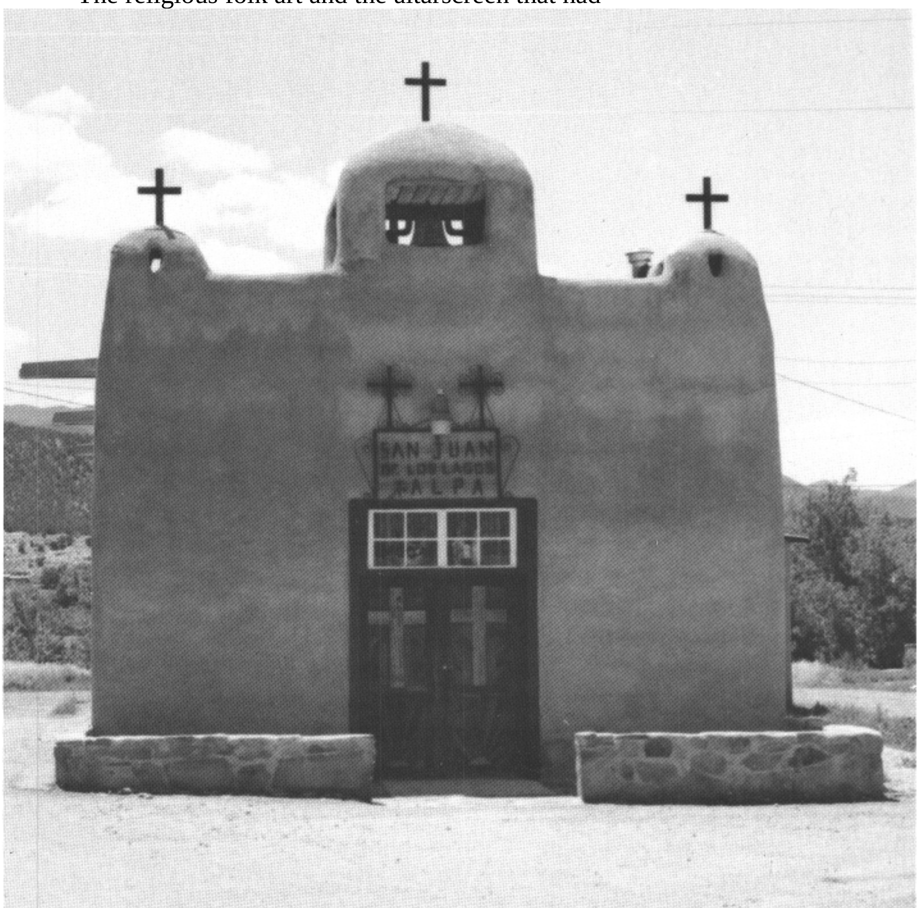
26.1 Forest Service Road 437 on the right follows the Rio Chiquito. Entering the village of Talpa (Spanish, "knob"), which contains picturesque, traditional adobe homes and churches. This area probably was settled in the 1780's. It is now a community favored by artists, many of whom sell their work in Ranchos de Taos and Taos.

0.5

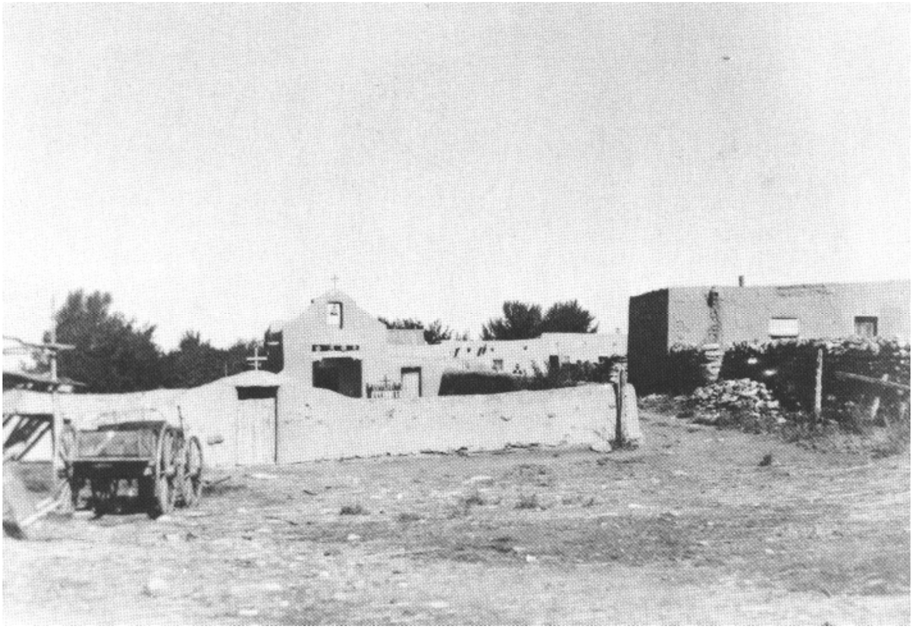
26.6 Chapel of Our Lady of San Juan de los Lagos in the small plaza on the left.

0.4

27.0 Off the highway to the left are the remains of the private chapel, Our Lady of Talpa, and 19th-century hacienda and a Campo Santo (Spanish, "cemetery"). The religious folk art and the altarscreen that had



Church of Our Lady of San Juan de los Lagos, built in 1828, in the plaza of Rio Chiquito (now Talpa).



Chapel of Our Lady of Talpa, also known as the Duran family chapel, circa 1917, was built as a private oratory in 1838 by Don Nicolas Sandoval of Rio Chiquito, 6 miles south of Taos. When a post office was established in 1904 the town took the name "Talpa" because of a U.S. Postal Service requirement for simpler village names. Photo no. 32000 from the Adella Collier Collection courtesy of the New Mexico State Records Center and Archives.

The adobe torreón (Spanish, "large defense tower") on the left, circa 1917, originally built for protection and defense against attacks by nomadic Indians, suffers from obsolescence and neglect. Photo no 32014 from the Adella Collier Collection courtesy of the New Mexico State Records Center and Archives. Plastered adobe torreón near Talpa (right) may be the only one remaining today in New Mexico. It reputedly had a hexagonal second story constructed of logs. During Indian attacks the women and children were sheltered in the windowless, circular adobe room while the men defended the tower from the second level.

been housed in the chapel are now on permanent display in the Taylor Museum of Colorado Springs.

0.5

27.5 Campo Santo and morada to the right. The morada (Spanish, "meeting house") was the meeting place of the village chapter of a Catholic confraternity called the Brotherhood of Our Father Jesus the Nazarene, also known as the Penitente Brotherhood. The Brotherhood originated around 1800 at a time when the number of Catholic priests in New Mexico began to dwindle and the Spanish population began to increase and spread to new, isolated villages that were beyond the reaches of the few remaining priests. Without the services of priests, the Penitente Brotherhood dealt with poverty and sickness, took care of burials and the bereaved, and maintained civil law and order within the village, as well as enacting the Good Friday passion and death of Christ during Holy Week, one of the principal sacred periods of Christianity. The male-dominated Brotherhood provided both religious and communal leadership for individual villages.

0.1

27.6 Torreón (Spanish, "large tower of a fortress") on the left where Spanish settlers defended themselves against attacking nomadic Indians.

0.6

28.2 Junction with US-68. **Turn right to Taos.** We hope that you enjoyed this tour, and perhaps you even found some gold to take home.

Side trip 2A

(12.3 miles)

Panning for gold in the Rio Grande Gorge

Those of you joining us on this side trip will need some basic gold-panning equipment. The well-equipped panner will have a gold pan, a 1/8"-3/16" sieve or screen, shovel, eyedropper, vial, and a pair of hip boots if the weather is cool. If you lack some of these items, don't panic. Substitutes for a gold pan can include a frying pan, a frisbee, a hubcap, and even an old coffee can. A colander or just picking out the large pieces of rock with your fingers can substitute for the sieve. Nearly anything can substitute for the shovel, even your bare hands. We will explain panning techniques in detail when we get to the spot where the gold is located.

WARNING: NM-570 (mile 5.6 of Trip 2) is a precipitous, partially unpaved route with steep grades and hairpin turns. If you feel that your vehicle may have difficulty negotiating this road, use NM-570 north from Pilar (mile 16.6 of Trip 2) as an alternate route into the gorge.

Cumulative mileage

0.0 Begin at the intersection of NM-570 and NM-68 (mile 5.6 of Trip 2).

0.1

0.1 To the left, at 10:30, in the near distance the low, dark, pointed hills are Tres Orejas. On the far skyline, past Tres Orejas, are the Tusas Mountains. At about 11:30 is the volcanic field of Cerro de los Taoses. To the right, the high volcano on the skyline is San Antonio Mountain. Farther to the right the low, dark hills in the distance are Cerro Montoso. Behind Cerro Montoso on the skyline is Cerro de la 011a; both are *shield volcanoes.* In the far distance at 12:30 is Ute Mountain. To the right of Ute Mountain is Guadalupe Mountain. Finally, the Taos Range begins at 1:00 on the right, and at 2:30 is the Wheeler Peak Wilderness area.

0.4

0.5 Crossing a small draw.

0.3

0.8 Picuris Mountains are on the left at 9:00.

1.4

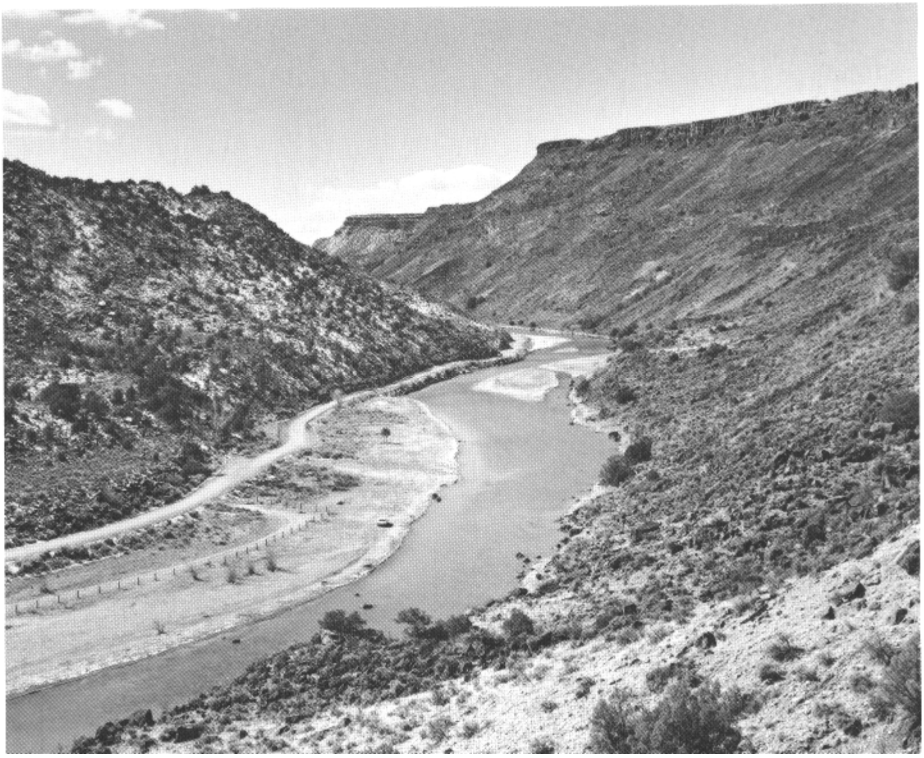
2.2 Crossing roadcuts in alluvial-fan deposits.

1.8

4.0 On the left, at 11:00, the low angular hill that sits in the middle of the flat plateau is Cerro Azul. Cerro Azul is Precambrian quartzite but is surrounded by Tertiary lava flows and rift-filling sediments. On the skyline to the left, at 10:00, are the Jemez Mountains.

0.5

4.5 Sign reads: "Orilla Verde Recreation Area, Rio Grande Wild and Scenic River." Orilla verde is Spanish for green banks. End of paved road. We now begin our descent into the gorge; use low gear. The Rio Pueblo de Taos flows through this canyon before emptying into the Rio Grande near the Taos Junction Bridge.



View of the Rio Grande Gorge just downstream from the Taos Junction Bridge. Late winter snow lingers on the slopes above NM-570 on the left. Black basalt lava flow caps the mesa to the right of the Rio Grande. Photo by W. Lambert, 1978.

Basalt cliffs are visible on the far side of the gorge. Roadcuts ahead on the left are in basalt.

0.3

4.8 Spectacular basalt flows are exposed along the far side of the gorge. These flows can be traced across to this side, indicating that no major faults separate the gorge walls. Areas covered by rock debris are sand and gravel deposits. One of these sand and gravel layers is exposed in the roadcut on the left.

0.4

5.2 Sand and gravel deposits on the left. Large landslide deposit on the right.

0.5

5.7 We are now at the level of the river. Notice the variety of plants that grow near the water.

0.3

6.0 Fork in the road. Stay right. Confluence of Rio Pueblo de Taos and Rio Grande.

0.1

6.1 Paved road resumes.

0.2

6.3 Junction with NM-567. **Stop and park on this side of the river,** just downstream of the Taos Junction Bridge. Across the river is the Taos Junction campground of the Orilla Verde Recreation Area. Restroom facilities and drinking water are available. NM-567 crosses the Rio Grande and connects with US-285 8 miles to the west at Taos Junction, once an important trading center on the Denver and Rio Grande Railway's "Chili Line." This was the main route over the gorge before completion of the Rio Grande Gorge Bridge on US-64 in 1965.

The best gold-panning location is about 300 feet farther downstream. Although the exact source of the gold is unknown, it is probably many miles upstream in Precambrian and Tertiary *lode* deposits of the Taos Range. Upstream from here the Rio Grande and the Rio Pueblo de Taos flow through steep, narrow gorges, in which the water is deep and turbulent during the spring runoff. Here however, the canyon is wider, and the river is more placid. As a result, much of the gold that is being transported by the river settles out and concentrates to form a *placer* deposit.

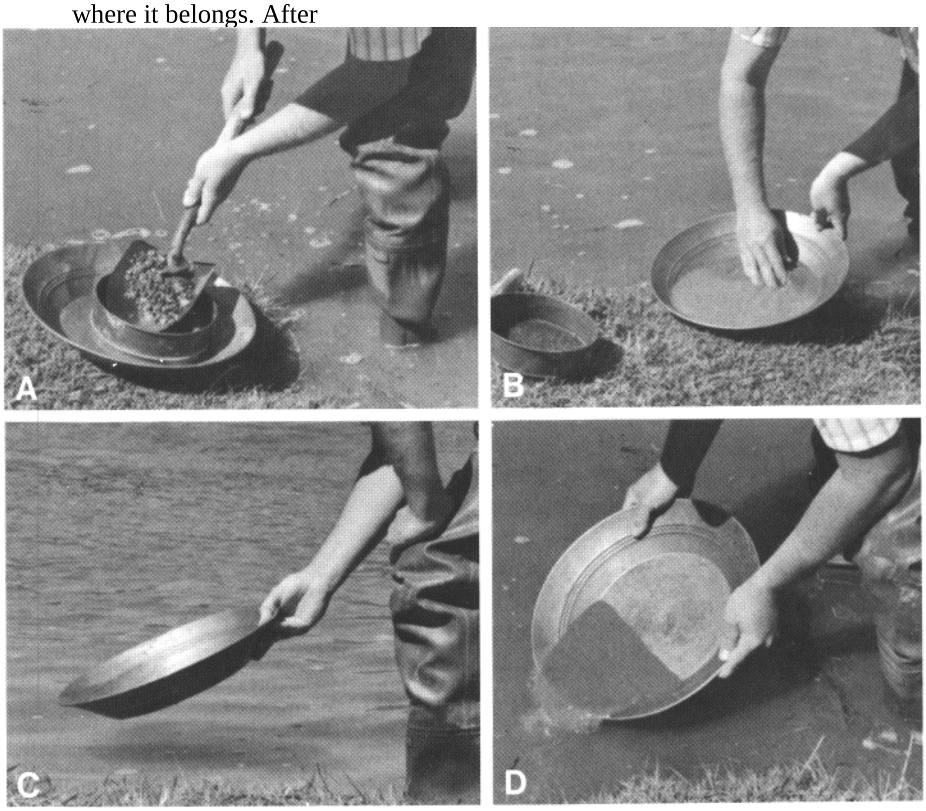
This area was worked commercially for gold around the turn of the century. Piles of gravel from the old operation still remain on the west bank of the river. However, *dredges* could not operate efficiently among the large basalt boulders in the river, and because these boulders could not be removed economically, the operation failed. This placer deposit is small compared to a deposit such as at Elizabethtown, and it is doubtful that there is enough gold here for a profitable operation, even without the boulders.

As we walk along the river bank we can see three types of sedimentary deposits. The first is the dirt that covers the river bank and the parking area and is characterized by fine clay and silt. If placed in water, it gets sticky and muddies the water. This material, which has been washed down from the surrounding cliffs, contains no gold. The second is the sand—gravel—cobble sediment in the deeper, rapidly flowing part of the river. This material is currently being washed downstream, and although it does contain gold, shoveling in fast-moving water is difficult. The third is silt, sand, and gravel located in the shallow part of the river and under the layer of soil along the bank. This river sediment was deposited and then partially covered with soil washed down from the cliffs. Here is where we will prospect for placer gold.

As soon as you locate a slowly flowing area in the river where the water is about 6 inches deep we can begin panning. Put the screen on the pan and load the screen with a shovelful of sand and gravel. Refer to the sequence of photos showing proper panning technique. Sieve the fine material into the pan. Discard the coarse material remaining on the screen. If you do not have a screen, pick out the large rocks by hand. Now put the pan in the water and run your fingers through the gravel to wash away any mud. You should now have several pounds of clean sand in the pan.

The next step separates the heavier minerals from the lighter waste.

The method we will use, gravity settling by panning, concentrates any material that is denser than the sand or gravel. In other localities, this method is also used for finding diamonds, rubies, sapphires, and cassiterite (commonly called stream tin). With a small amount of water in the pan, tilt the pan away from you and grasp it with one hand near the top edge. Now shake the pan from side to side with your wrist. The sand and gravel will settle in the depression of the pan. Continue shaking the pan for a few seconds more so that the heavy minerals will settle to the bottom. Now put the pan into the water and tilt the far edge up and out of the water with your wrist. As the water washes out of the pan it takes some of the light-colored sand with it. Do this a few times and then shake the pan from side to side to ensure that the gold is still at the bottom where it belongs. After



Sequence of photos showing proper panning technique.

A) Shovel gravel through screen into pan.

B) Put pan into water and stir contents to dislodge dirt.

C) Using wrist action, shake pan from side to side to settle gold at the bottom of the pan.

D) Lower side of pan containing sand into the water. Tilt pan upward allowing water to slosh over the edge, carrying some of the upper deposit of sand over the rim. Repeat this action a few times and then start again from C. Repeat C and D as many times as required to concentrate the darker, heavier minerals (and the gold) at the bottom of the pan.

a few minutes of shaking and washing, most of the light-colored sand will have been washed out of the pan. Most of the black sand remaining in the pan is *magnetite,* a common iron-bearing mineral in the sediment of most streams. There should also be some large dark-colored minerals in the pan. The round, dark reddish-brown, buckshot-size minerals are garnets. Most of the very dark brown, rectangular grains are staurolites. Both of these heavy minerals weathered out of the Precambrian rocks in the Picuris and Taos Mountains. You may also find some man-made surprises. When we tested this spot, we found a fisherman's lead sinker in the pan. Fragments of bullets and scrap metal might show up also.

Your pan now contains lots of black sand but probably no visible gold. Put a cupful of water in the pan and slosh all the black sand to the side farthest from you. Picture the pan as the face of a clock. The black sand is at 12:00, and you are at 6:00. Tilt the pan gently so that 12:00 is the lowest; now tilt it so that 1:00 is the lowest; now 2:00, 3:00, 4:00, 5:00, and so on. As you tilt the pan, the water will spread the black sand around the rim extending from 12:00 to about 6:00. Take your time doing this part of the procedure. Most of the gold at this location is found as small pinhead-size flakes. When you find a flake, remove it with the tip of a pocket knife or with an eyedropper. If you find that it's too much trouble to pick out each fleck of gold while you are panning, dump all of the black sand into a bottle. When

Heavier, dark minerals remaining in the gold pan after washing out most of the light-colored sand include magnetite, garnets, staurolites, and possibly a little gold.

you get home, dry the sand and use a magnet to remove the magnetite. Put the remainder back in a gold pan, add water, and swirl it around to uncover the gold. You should be able to see more gold flakes with the magnetite sand removed.

You may find that the first panful takes 5 minutes or more to concentrate. Hopefully, with practice, you will learn to pan more rapidly. Most beginners worry about going too fast and washing the gold out of the pan. Just remember, if black sand, garnets, and staurolites are found in the bottom of the pan, then you are also getting the gold. If you are concerned about the loss of gold, test your technique by dropping a small piece of metal into the pan before you start. It should still be in the pan when you are done. You can work fast at the beginning of each pan and slow down for the final steps. How fast is top speed? An accomplished panner can do a pan in a minute or so.

When you have all of the gold that you can carry, leave the parking area and **continue downstream along the river on NM-570** towards the village of Pilar.

0.5

6.8 Rio Grande Spring on the left. Landslide deposits of basalt blocks and sand and gravel are present all along the left side of the road for several miles.

1.2

8.0 River gauging station on the right.

1.1

9.1 Petaca Recreation Site.

0.9

10.0 Arroyo Hondo Recreation Site on the right.

0.7

10.7 Orilla Verde Recreation Site and park headquarters.

0.4

11.1 Pilar Recreation Site on the left.

1.2

12.3 Entering the village of Pilar. Junction with NM-68. **Turn right onto NM-68 and continue on the main road log,** starting at mile 16.6 on page 84.

Side trip 2B

(1.2 miles)

Walking tour of the Harding pegmatite mine

A permission—release form from the University of New Mexico Geology Department in Albuquerque is required before entering the Harding mine property.

The Harding pegmatite mine is a unique occurrence of unusual minerals. In 1974 Dr. Arthur Montgomery, Professor Emeritus of Geology at Lafayette College in Pennsylvania and owner of the property, offered to donate the mine to the University of New Mexico in order that it be preserved as one of New Mexico's unusual natural assets. Because the mine property included both patented and unpatented claims the transfer of title required the transfer of federal lands to state lands. This literally required an "Act of Congress" (Senate Bill 1403), which was signed by President Carter as part of Public Law 95-550 on October 30, 1978.

Its mineral resources first discovered in about 1910, the property was mined during the early 1920's for lepidolite, a mineral used in the manufacture of heat-resistant glass. The mine was presumably named after Warren G. Harding, U.S. President from 1911 to 1923. During World War II the War Production Board encouraged active mining of the *strategic minerals* found here. These included microlite, tantalite-columbite, beryl, and spodumene. Even though most of the rock was mined and sorted by hand, the Harding set production records. This was the only mine in the world to yield substantial amounts of microlite. Between 1950 and 1955, 752 tons of beryl were produced. This amounted to more than 20% of total U.S. production, ranking New Mexico number one beryllium-producing state.

Cumulative mileage

0.0 From Trip 2, mile 16.7 (page 91) **turn right onto dirt road.**

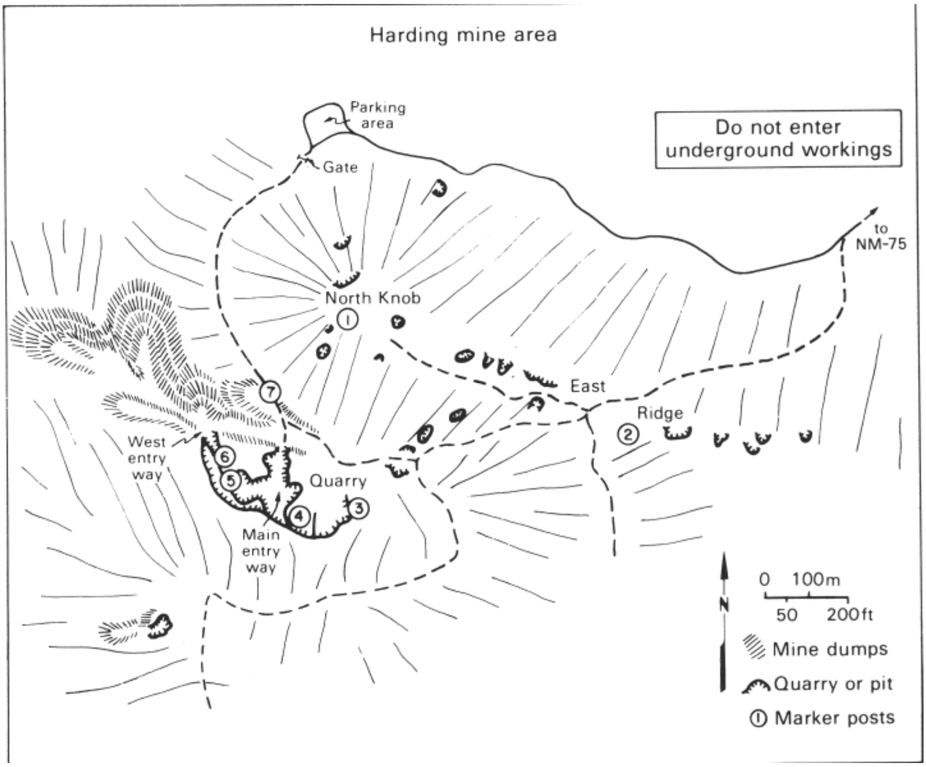
0.4

0.4 At fork, **bear right.**

0.2

0.6 Parking area. The gate has been placed across the mine road entrance to prevent wholesale mining of specimens. Please take only what you can use for your own collection or a maximum weight limit of 10 pounds. Collect only loose rock and never hammer on the quarry walls near the mine entrances. The caretaker lives in the area and visits the mine frequently. Persons who violate these rules will be prosecuted.

Every year hundreds of people with many different backgrounds visit the Harding mine. Our walking tour is designed for the non-geologist and is less technical than the tour available from the University of New Mexico Geology Department in Albuquerque. If you do have a background in geology, you will want to get a copy of the more technical tour, *The Harding pegmatite mine,* by Bryan Chakoumakos. Both tours use the same map with stops at seven locations



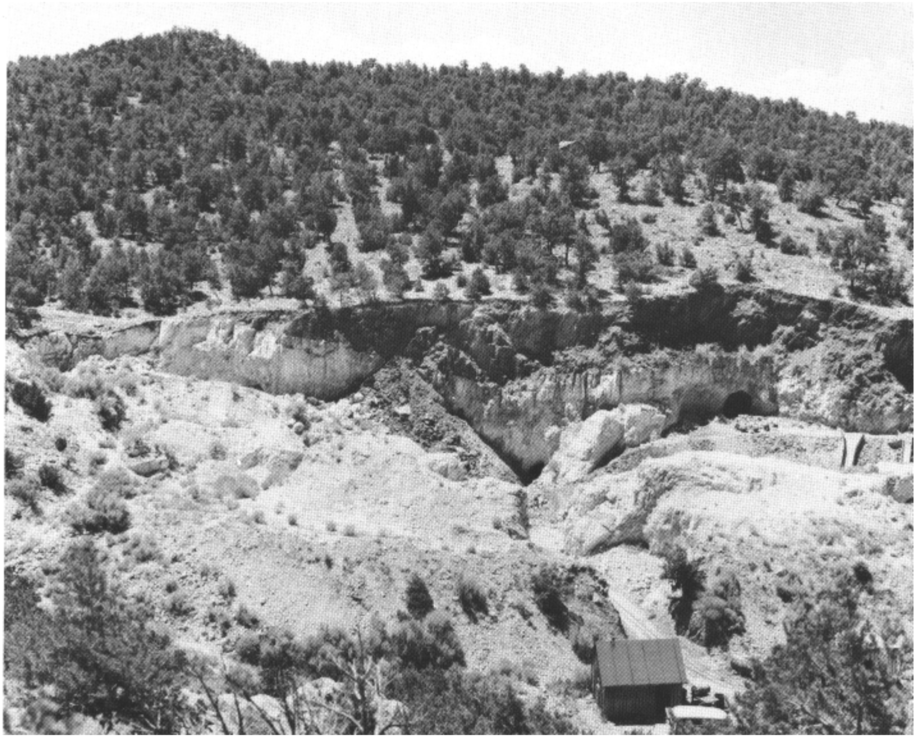
Map of the Harding pegmatite mine (from Chakoumakos, 1977). Courtesy of the University of New Mexico Geology Department.

marked with numbered posts. **Please keep track of where you are at all times and keep youngsters under close supervision. This mine is dangerous, so do not enter the underground workings.**

Stop 1 is on top of North Knob, the hill to your left as you face the gate. If you feel that you should not attempt the climb, continue along the road to Stop 7. Although your view will not be as good from there, you should be able to see most of the sights. The best mineral-collecting areas are in the quarry and on the mine dumps. To go directly to these sites, proceed around the gate and down the road. **Otherwise, climb to the top of North Knob.**

Stop 1 On North Knob. The pegmatite body is exposed in the quarry wall. The upper contact of the pegmatite with the blackish-green, Precambrian, metamorphic *country rock* is clearly visible.

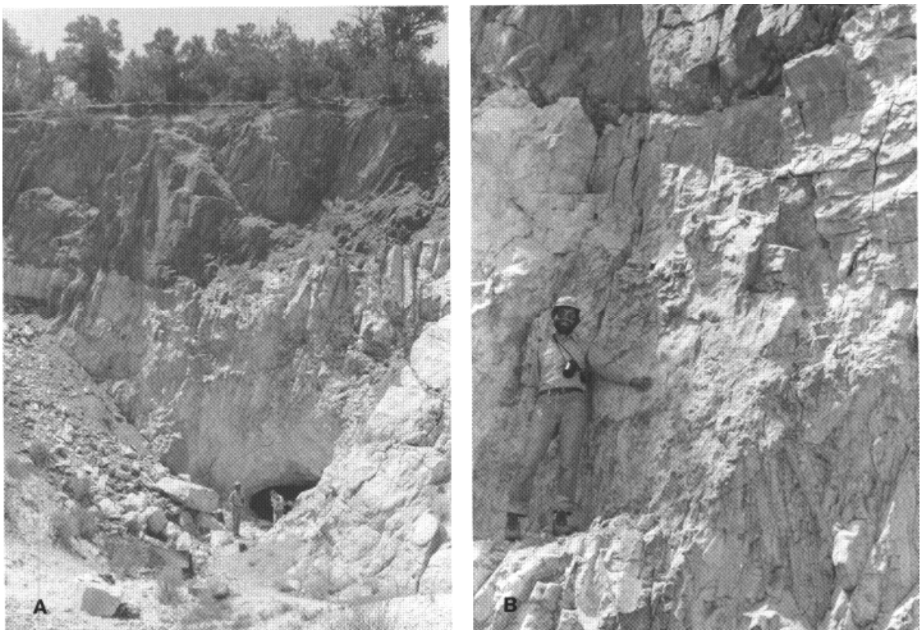
Pegmatites form when bodies of *magma* crystallize deep within the Earth's crust. As the magma cools minerals crystallize, leaving residual liquids and gases, called *volatiles.* Due to high confining pressures these volatiles are extremely mobile and can travel great distances before crystallizing as pegmatites. The Harding pegmatite is the main body of a series of pegmatites in the Precambrian rocks of this area.



Southwest view in 1953 of the main quarry of the Harding pegmatite mine from North Knob. The upper contact of the pegmatite with the darker Precambrian metamorphic country rock can be easily identified. Three underground entrances to the mine are visible. The lowest tunnel at the end of the road is the entrance to the large lepidolite room. To the left and upslope is the entrance to the microlite tunnel, and upslope to the right is the tunnel to the beryl workings. If you have a keen eye you'll see five men sorting beryl at the tunnel entrance. Ore also was dumped down the wooden chutes for sorting. The buildings in the foreground are mine buildings; the building on the wooded slope behind the mine is a temporary structure of the U.S. Bureau of Mines. © 1981 Laura Gilpin Collection, Amon Carter Museum, Fort Worth, Texas.

The Harding pegmatite has the shape of a large watermelon seed and ranges in thickness from 3 feet at its east end to over 80 feet in the quarry. The flattened shape dips at 10°-15° to the south.

From radioactive age-dating techniques we know that the Harding pegmatite formed over a billion years ago in Precambrian time. As a pegmatite magma cools, generally from the rim to the core, different minerals crystallize. Likewise, as the Harding pegmatite cooled successive shells or layers developed around the walls of the magma chamber. As crystallization progressed distinct zones of different compositions formed; thus, this body is a zoned pegmatite. However, because of gravitational settling of crystals during cooling, the mineralogical–compositional zones in the lowermost portion are not identical to those of the top portion. To further complicate matters, *replacement bodies* or *reaction zones* commonly cut across the primary zones. The



The Harding quarry where years of open-cut mining have exposed the main pegmatite body.

A) The large opening is the entrance to the lepidolite room. Directly above the entrance are large laths of spodumene in the quartz–lath spodumene zone. The dark Precambrian country rock appears in stark contrast to the pegmatite body.

B) Detail of large laths of spodumene in the quarry wall below and to the right of the figure. The sharp contact between the pegmatite and the overlying dark country rock is at the top of the photo.

replacement is due to the chemically corrosive, reactive nature of the residual volatile liquids. These liquids reacted with and replaced earlier-formed crystals. Eight different zones have been identified in the Harding pegmatite (see Plate 8).

Because pegmatite magmas are volatile rich and cool very slowly deep underground, the world's largest crystals are found in pegmatites. Above the lower left mine entrance, we can see a "picket fence" of large, dull-white spodumene crystals nearly 5 feet long. Spodumene crystals up to 47 feet long and 5 feet in diameter have been mined from pegmatites in the Black Hills of South Dakota. Approximately 50 additional minerals have been identified in the Harding pegmatite. This large number of minerals is not unusual because over 100 pegmatitic minerals exist. Some of the minerals found in the Harding pegmatite, however, are rare. **Follow the old jeep trail to your left for about 350 feet to post 2.**

Stop 2 **Walk to the edge of the small prospect pit near the upper contact of the pegmatite body.** Look carefully into the pit; the uppermost inch of the white rock, known as a *border rind,* consists of fine-grained

Quartz-albite-muscovite pegmatite. This rind probably represents a *chill zone,* along which cooler country rock caused rapid crystallization of the pegmatite magma. Beneath the rind is a 2-foot-thick continuous layer of a slightly coarser aggregate of the same minerals. At other locations, *accessory minerals,* such as microcline, apatite, lepidolite, tantalite-columbite, and spectacular pods of coarse beryl, are found in this layer. This layer is called the wall zone, and together with the border rind has been grouped into the **beryl zone.** A similar layer, which contains less beryl, is present along the bottom of the pegmatite body. We will see this basal layer on the walk between Stops 6 and 7.

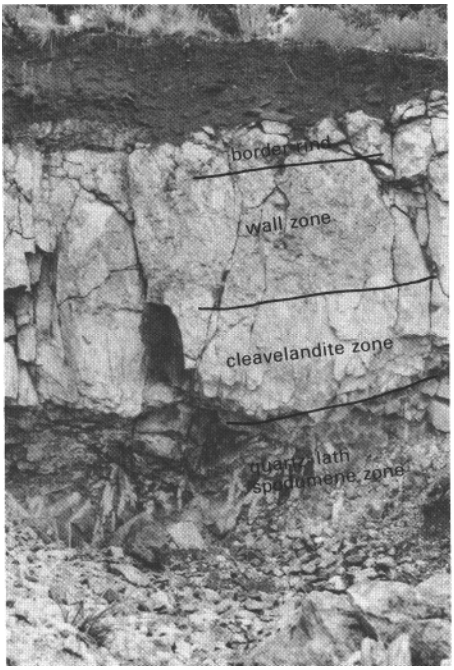
Immediately under the beryl zone is the 3-foot-thick **cleavelandite zone.** Here cleavelandite, a variety of albite feldspar, forms radiating masses of white- or cream-colored, curved plates. This is a reaction zone; it formed from the interaction between corrosive liquids and the nearly completely crystallized pegmatite. As we move towards the core of the pegmatite reaction zones of various types are more common. In the core of the pegmatite, most original material has been destroyed by secondary reactions.

Beneath the cleavelandite zone is the **quartz-lath spodumene zone,** which consists of coarse laths of dull-white spodumene in a quartz matrix. This zone contains the 5-foot-long crystals that we could see on the quarry wall at Stop 1.

Walk downhill into the core of the pegmatite. Notice the zone of pure quartz that we are walking through. This is part of a 2-8-footthick continuous layer of massive quartz called the **quartz zone.** Muscovite, microcline, and cleavelandite are present in local concentrations. The marker post for Stop 3 overlooks the east end of the quarry.

Stop 3 We are standing on top of the massive quartz zone and can see the face of the quarry and several lower zones and replacement bodies. The beryl zone is above the quartz zone. Where it extends across the quarry face the quartz zone is thin. Beneath the quartz zone is the spectacular quartz-lath spodumene zone. This widespread unit is 640 feet thick. In places it fills the entire core of the pegmatite. The spodumene crystals are bladelike and up to 5 feet long. Although the crystals here are crudely oriented in the pattern of a picket fence, in many locations the orientation tends to be more random. White beryl, dark blue-green apatite, white to pale-green microcline, and black to brown tantalum—niobium minerals also are present in the lower part of the quartz-lath spodumene zone.

From here we have a good view of the quarry, and we can reconstruct the history of the various phases of mining. At first glance, the operations appear to be uncoordinated. However, we must remember that although the minerals are in zones, large replacement bodies crosscut the zones. During the history of mining in the Harding pegmatite, three different minerals were mined, each from a different zone.



View of the southern face of the prospect pit at Stop 2. Four zones of the pegmatite are exposed here: border rind, wall zone, cleavelandite zone, and quartz–lath spodumene zone.

Exposure to the left of the tunnel entrance at Stop 4 is in the quartz–lath spodumene zone but shows alteration of the white spodumene laths to rose muscovite (outlined in black) and the quartz to cleavelandite; this area of alteration is the rose muscovite–cleavelandite zone.

Lepidolite period, 1919-1930

Quartz outcrops, similar to the massive quartz we are standing on, first attracted gold prospectors in the late 1800's. It wasn't until 1918 that Joseph Peyer of Taos recognized the significance of appreciable quantities of lithium mineralization in large masses of lilac-colored lepidolite. Beginning in 1919 Peyer and his partners mined lepidolite by blasting loose boulders and working the open cut. They hand sorted the ore and hauled it by wagon to Dixon. From Dixon the ore was shipped by rail to Wheeling, West Virginia, where it was ground and sold to the ceramics industry. Lepidolite served as a *flux*, *opacifier*, and toughener in the manufacture of opaque white glass for jar tops and lighting fixtures. For 10 years the mining operation experienced ups and downs under several owners. As the large pods of lepidolite were extracted, the main quarry evolved. By 1929 the large body of rich lepidolite had been mined out, and efforts turned to the more expensive selective extraction of smaller irregularly shaped pods. Miners made several undercuts in the south face of the quarry, ultimately resulting in the large, roomlike opening located down and to your left as you face west. In 1930 the mine shut down. Although this first period of mining was generally unprofitable for the mine operators, it provided some of the world's finest exposures of a complex zoned pegmatite.

Microlite period, 1942-1947

The Harding mine was reopened in 1942. World War II created a demand for tantalum because of its use in airplane radio sets, in vacuum tubes, in making synthetic rubber, and for making extremely hard and strong alloys. A relatively rare calcium tantalate called microlite was known to be present in the main quarry. Arthur Montgomery first identified the Harding property as a potentially mineable source of tantalum. The mine was sampled, and favorable results led Montgomery to enter a lease–purchase agreement for the property in 1942. The richest portion of the microlite ore was mined by hand without explosives so that no ore would be lost by blasting. The highest grade ore was located at the bottom of the quartz–lath spodumene zone in the rose muscovite–cleavelandite replacement zone on the east side of the quarry face (Stop 4). By the time production ceased in 1947 the eastern parts of the main quarry face had been considerably modified, and a labyrinth of tunnels and small rooms had been made south of this face. The entrance to

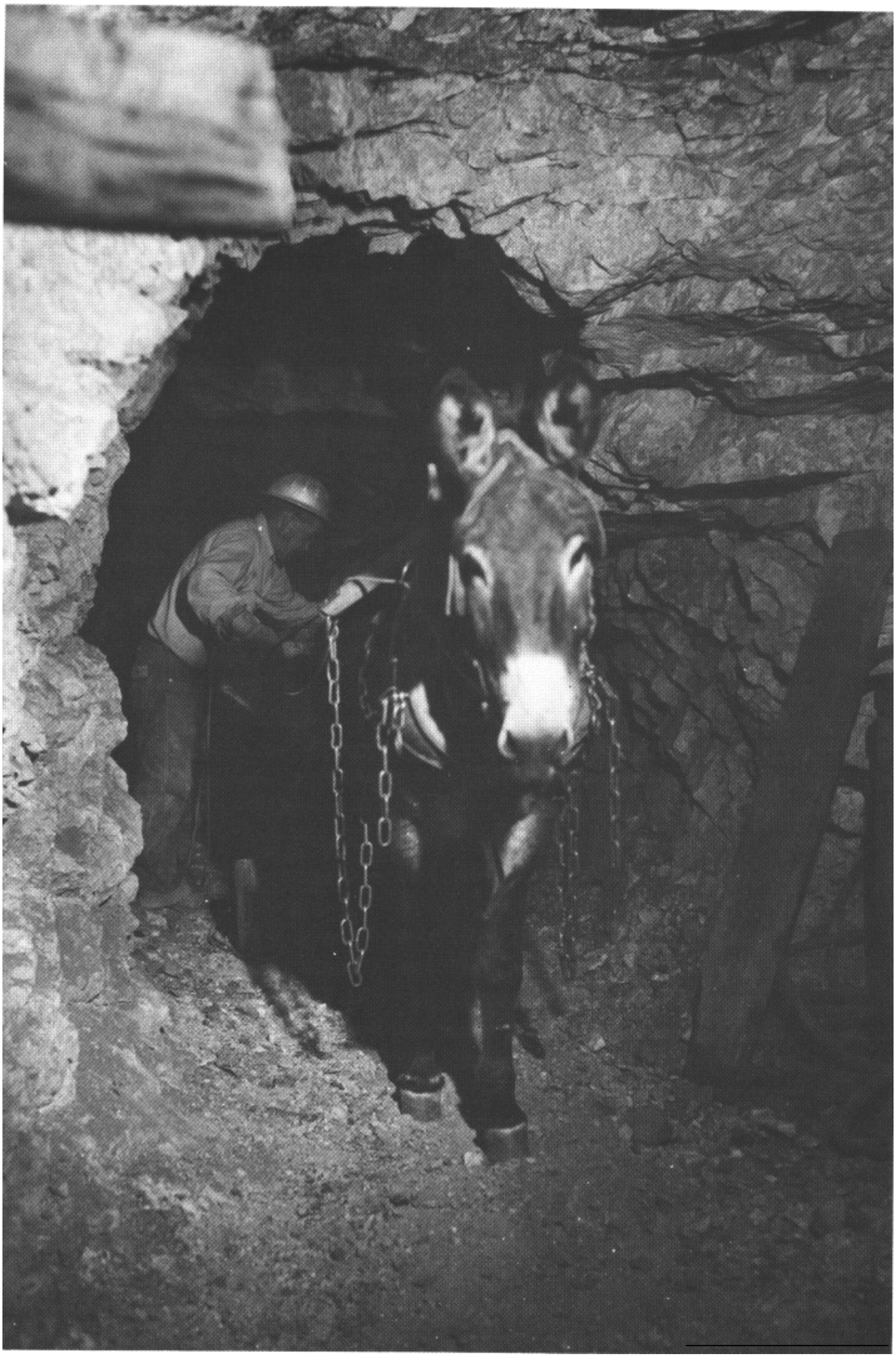
Sorting beryl in 1953 at the entrance to the beryl tunnel. From left to right: Arthur Montgomery, Flaudio Griego, A. E. Archuleta, Beryl, the mule, Juan Romero, Eliseo Griego, and Pablo Rendon. © 1981 Laura Gilpin Collection, Amon Carter Museum, Fort Worth, Texas.

these tunnels is covered with rubble and is barely visible to the left of the opening to the large room excavated during the lepidolite period. Between 1942 and 1947 the Harding mine produced 41 tons of spodumene, 558 tons of lepidolite ore, nearly 500 pounds of tantalite—columbite, and over 22,000 pounds of microlite concentrate averaging 68% tantalum oxide and 7% niobium oxide. Diamond drilling in the area to the south of the quarry documented a considerable reserve of spodumene and tantalum—niobium ore.

Beryl period, 1950-1958

The abundant beryl in the Harding mine was overlooked for many years. In 1944 Arthur Montgomery discovered a thick, elongate lens of nearly pure beryl along the upper surface of the west side of the pegmatite. A 23-ton shipment of ore from this lens contained nearly 11% beryllium oxide (pure beryl would yield about 13%). Beryllium is a light-weight metal. Alloys with other metals are light, strong, and resistant to metal fatigue. By early 1950 the working face of the west tunnel displayed solid beryl for days at a time. Four men and a mule named Beryl, extracting from 500 to 2,000 pounds per day, made the Harding mine the leading U.S. beryl producer in 1950 and 1951. Total production was 690 tons of ore containing 11.2% beryllium oxide and 184 tons containing 5.5% beryllium oxide. When we reach Stop 5 the tunnels driven during this period will be visible.

Dumping a small cartload of beryl ore down wooden chute for sorting, 1953. © 1981 Laura Gilpin Collection, Amon Carter Museum, Fort Worth, Texas.



The mule Beryl and Juan Romero emerging from the main beryl tunnel, 1953. © 1981 Laura Gilpin Collection, Amon Carter Museum, Fort Worth, Texas.

Stop 4 may be difficult to locate. As you face the quarry, **climb down the slope to your right onto the large flat bench in front of you.** This bench is the lowest level before descent to the main mine entrance. **Follow the cliff to your left until you reach a small mine entrance into the face of the quarry.** The wooden post for Stop 4 is in front of this entrance.

Stay away from cliffs, especially during wet weather. Please be extra careful with children from here to Stop 7; we are now entering a hazardous area.

Stop 4 At entrance to small mine. The lavender-pink color of the spodumene lath in front of you is attributed to replacement of spodumene by fine scales of rose muscovite (see Plate 7). This reaction zone, the **rose muscovite–cleavelandite zone,** contains the richest concentrations of microlite.

As we progressed from the border rind to the inner core, crystal size increased from a fraction of an inch to over 5 feet. We also saw two cross-cutting reaction zones, the cleavelandite zone and the rose muscovite–cleavelandite zone. As we move from Stop 4 to Stop 5, we will cut across the core of the pegmatite. In the core we will see an increase in late-stage reaction products, so much so that the original composition of the pegmatite has almost been completely obliterated. On our way from Stop 4 to Stop 5 we will pass the microlite tunnels and the large lepidolite room.

With the main quarry face to your left, **walk down into the main quarry area. Continue straight ahead across the quarry to the wooden post at Stop 5.**

Stop 5 We are at the base of a pinnacle that extends up from the core to the wall zone. Here we see only three zones because the country rock, border rind, and part of the wall zone have been removed. A thin portion of the wall zone remains, followed by the massive quartz zone, and then a new zone of pinkish rock dotted with white blotches. This is the **spotted-rock zone.** The white blotches in this outcrop are spodumene and microcline in a fine-grained matrix of feldspar, muscovite, and lepidolite. The spodumene and microcline have been extensively corroded and replaced by mica. In some places the microcline is light rose pink, probably because of inclusions of rose muscovite. Other minerals, including microlite, beryl, and quartz, are present in smaller amounts.

We have a very good opportunity to look at some of the ore minerals of the Harding mine at this location. Four minerals are difficult to distinguish; these are beryl, feldspar, spodumene, and quartz. The spodumene crystals are fairly easy to identify in the quartz–lath spodumene zone because of their lath shape. In the spotted-rock zone identification is a bit more difficult, but spodumene can be recognized as the dull white, silver-dollar-size spots that give the spotted-rock zone its name. Also notice that on weathered exposures the spodu-

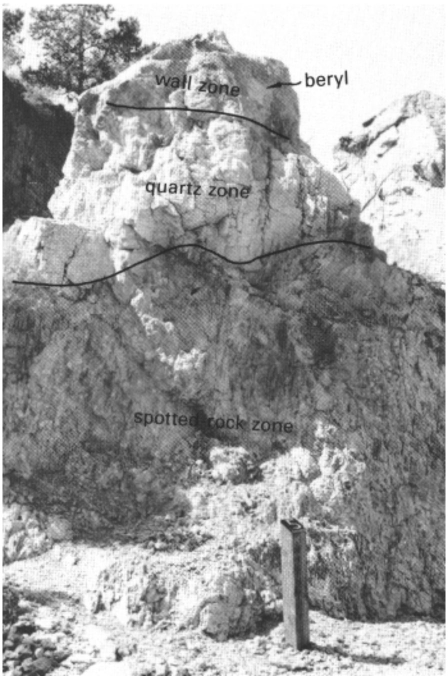
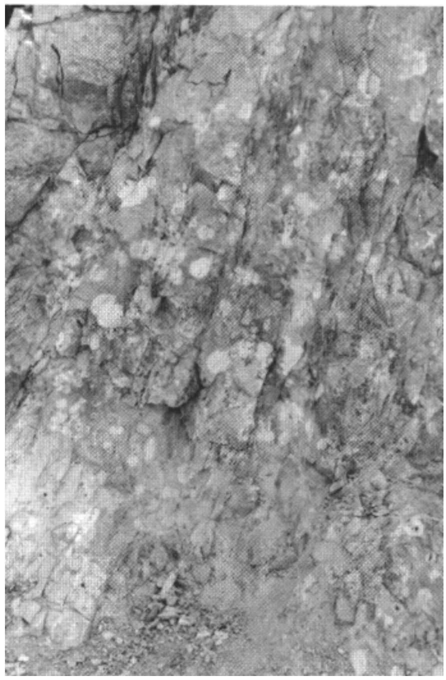


Photo showing the location of Stop 5 at the base of a pinnacle that exposes a thin portion of the wall zone, the massive quartz zone, and the spotted-rock zone.



Closeup of the spotted-rock zone. The white spots are spodumene or microcline feldspar in a fine-grained matrix that consists principally of feldspar, muscovite, and lepidolite.

mene "spots" are very slightly depressed and have dull surfaces, illustrating the relative ease with which spodumene weathers. The quartz and beryl, which are so difficult to identify in hand specimen, can be distinguished here by the tendency of the beryl to form discrete sharp-edged round spots, while the quartz tends to "blend in." In hand specimen the beryl has a resinous or greasy luster, which, with some practice, can be distinguished from the glassy luster of the quartz. The beryl commonly has a slight pinkish color, which the quartz does not have. Near the top of the pillar, in the wall zone, are a couple of spots of beryl about 1½ feet across. Feldspar also tends to form discrete sharp-edged round spots and may commonly be pink because of inclusions of rose muscovite. It can, however, be identified by its flat luster. Rose muscovite and lepidolite also may be impossible to distinguish, but, in general, the rose muscovite is rose pink and forms small flakes. The lepidolite is more purple and forms larger masses of almost indiscernible flakes. The dark glassy specks in the spotted rock are microlite crystals (you'll have to look closely for these; the microlite crystals are less than 1/8 inch across). Economic concentrations of this mineral, however, were found at the base of the quartz–lath spodumene zone, where the microlite was lighter in color, in some cases almost a honey color.

The tunnel to the upper left contains the beryl workings described at Stop 3.

Proceed to post 6 located 20 feet to your right.

Stop 6 **Turn to the north** and look at the rib of the outcrop, keeping the main quarry face behind you. We have seen the units that make up the pegmatite core (rose muscovite–cleavelandite zone at Stop 4 and spotted-rock zone at Stop 5), and we now begin examining those units that form the lower portion of the pegmatite. The lower zones are very different from the upper zones. Because of this the Harding pegmatite is known as an asymmetrically zoned pegmatite. As the pegmatite magma crystallized, those minerals that had densities greater than the magma tended to sink, whereas lighter minerals floated to the top. Therefore, even though the zones formed concurrently, the lower zones are mineralogically and texturally different from the upper zones.

Exposed at Stop 6 are masses of salmon-pink perthitic microcline. *Perthite* refers to the microscopic intergrowths of potassium and sodium feldspars. This **perthite zone** occupies much of the lower portion of the pegmatite body.

Walk back to the main quarry area and leave the mine through the main entryway. Here we pass the best exposure of pegmatite with the underlying country rock. The lowermost unit here is a mixture of the perthite zone and white *aplite,* a sugary-grained rock composed of quartz and albite.

Common minerals in the Harding pegmatite

quartz—(silicon dioxide) white to smoky in color; glassy luster; breaks along rough surfaces.

beryl—(beryllium–aluminum silicate) very difficult to tell from quartz (beryl is less transparent); white to pinkish in color; resinous or greasy luster; breaks in rough fragments; forms roundish, sharp-edged masses with the other minerals.

microcline feldspar—(potassium–aluminum silicate) white to pinkish in color; porcelainlike luster; breaks in blocky chunks.

albite feldspar (variety **cleavelandite**)—(sodium–aluminum silicate) white in color; pearly luster; consists of interlocking curved plates.

spodumene—(lithium–aluminum silicate) white in color; porcelainlike luster; large, flat crystals.

apatite—(calcium–fluorine–chlorine phosphate) dark blue in color.

muscovite mica—(potassium–aluminum silicate) rose pink in color; small flakes; may be mistaken for lepidolite, which has a fairly dark purplish color and forms smaller flakes; rose pink color from minor manganese.

lepidolite mica—(potassium–lithium–aluminum silicate) fine-grained; purplish color; very small flakes.

almandine garnet—(manganese–iron–aluminum silicate) easily distinguished by wine-red color.

microlite—(complex oxide containing various amounts of sodium, calcium, uranium, tantalum, niobium, and fluorine) sand-size, yellow to brown crystals.

View of the west entryway with Stop 5 on the left and Stop 6 20 feet beyond on the right.

The wooden post for Stop 7 is located on the right side of the main road, at the base of North Knob.

Stop 7 Here we can trace the sharp lower contact of the pegmatite as a curved plane that extends from the main entry to North Knob. To the west are mine dumps containing waste rock from the mining operations. These dumps make good collection sites.

On our tour we saw eight units. The upper portion of the pegmatite body is composed of: 1) the **beryl zone,** which is made up of the contact zone (border rind) and the wall zone; 2) the massive **quartz zone;** and 3) the **quartz-lath spodumene zone.** The core and lower portion of the body are composed of reaction zones: 4) the **spotted-rock zone,** 5) the **rose muscovite-cleavelandite zone,** and 6) the **cleavelandite zone.** The lowermost pegmatite consists of 7) the **perthite zone** and 8) the **aplite zone.**

Continue on the road to the parking area. Return to the highway and rejoin the main road log at mile 16.7 (page 91).

Glossary

accessory minerals—minerals found in very small amounts in a rock.

alluvial deposits—alluvium; a general term for clay, silt, sand, gravel, or other unconsolidated material deposited relatively recently by flowing water.

alluvial fan—a low, gently sloping, fan-shaped mass of loose rock material deposited by flowing water or debris flows where they exit a narrow mountain canyon and flow out onto a broad plain.

amalgam—a general term for an alloy of mercury with another metal, especially gold. Typically used to recover gold from sluices and mill plates.

amphibole—a group of common, dark, rock-forming iron-magnesium silicate minerals. Examples are hornblende, tremolite, and glaucophane. Similar in composition to a pyroxene but containing water (hydroxyls, OH_2). Amphibole cleavage fragments have elongate diamond-shaped cross sections.

amphibolite—a metamorphic rock composed predominantly of amphibole and plagioclase feldspar, with little or no quartz.

andesite—a medium- or dark-colored, fine-grained extrusive igneous rock that typically contains phenocrysts of plagioclase feldspar and additional phenocrysts of biotite, hornblende, or pyroxene in a groundmass of the same minerals plus quartz. Diorite is the intrusive equivalent.

asthenosphere—the layer of the Earth below the lithosphere, which is soft and probably partially molten. Equivalent, in part, to the upper mantle. Rigid lithospheric plates float on the asthenosphere.

basalt—a fine-grained, dark- or medium-colored, generally extrusive mafic igneous rock composed of calcium plagioclase feldspar and pyroxene (± olivine). Vesicular basalt often has a clinkerlike texture. Small holes, called vesicles, form as gases rising through the lava flow are trapped in the cooling lava. Basalt is the most abundant extrusive igneous rock and is particularly common along rifts in the Earth's lithosphere. Most of the bedrock beneath our oceans is basalt. Gabbro is the intrusive equivalent.

basin—a regional-scale, topographically low, downwarped area of the Earth's crust in which sediments accumulate.

bedrock—a general term for the solid rock that underlies unconsolidated surficial material.

biotite—see mica.

border rind—the margin of an igneous intrusion, which differs in texture and composition from the main body of the íntrusion. *See* chill zone.

brachiopod—a bivalved marine invertebrate resembling a clam but with bilaterally symmetrical valves. Lived from the Early Cambrian Period to the present.

brecciated—composed of large, angular, broken rock fragments that are cemented together in a finer-grained matrix. Such rocks are commonly located along faults.

caldera—a large, generally rounded volcanic depression usually caused by the collapse of the roof of a magma chamber following eruption of magma.

chill zone—the border of an igneous intrusion characterized by a relatively fine grain size because of more rapid cooling near the intruded host rock. *See* border rind and country rock.

cirque—a deep, steep-walled, half-bowl-shaped depression located high on the side of a mountain and typically at the head of a glacial valley. Cirques are formed by mountain glaciers and commonly contain small alpine lakes.

columnar jointing—parallel, vertícal cracks caused by the contraction of cooling volcanic rock, such as basalt, give the appearance of several-sided prismatic columns.

conglomerate—a sedimentary rock composed of rounded pebbles and cobbles cemented in a fine-grained matrix of sand or silt. The lithified (cemented) equivalent of gravel.

country rock—the rock surrounding and intruded by an igneous body.

crinoid—a flowerlike marine invertebrate. Most forms lived attached by a "stem" to the ocean floor. Also called sea lilies. Lived from the Ordovician Period to the present.

crossbedding—an internal arrangement of layers in a stratified rock that are an expression of rapid local changes in air or water currents as sand and silt are being deposited. Often inclined at an angle to the primary bedding planes. Typical of alluvial and eolian wind-blown dune deposits.

crust—the outer shell of the Earth. The outermost layer of the lithosphere. The continental crust is mostly granite, and the oceanic crust is mostly basalt.

cup coral—solitary cone-shaped coral that did not live in a colony. Also called horn coral. Lived from the Ordovician Period through the Permian Period.

dike—a tabular intrusive igneous rock that cuts across older surrounding rocks.

diorite—a medium- to dark-colored, coarse-grained intrusive igneous rock composed of plagioclase feldspar, hornblende, pyroxene, and minor quartz (less than 5%). Quartz diorite contains from 5% to 20% quartz. Andesite is the extrusive equivalent.

dredge—a large floating machine designed for scooping up unconsolidated sediments from a river bed. Used in placer mining.

drift—a mining term that refers to a horizontal tunnel that is driven along a vein.

extrusive (volcanic) rock—igneous rock that has been ejected onto the surface of the Earth. Includes lava flows and volcanic ash.

fault—a fracture in rocks along which there has been movement. Movement can range from inches to miles. A normal fault is a type of fault where rocks above the fault plane move down. A thrust fault is a type of fault where rocks above the fault plane move up, and older rocks are pushed over younger rocks. A strike-slip fault is a type of fault where rocks slip horizontally past each other.

fault scarp—a steep slope or cliff representing the exposed surface of a fault.

fault zone—a faulted region that is expressed as a zone of numerous small faults. May be hundreds to more than a thousand feet wide.

feldspar—a group of abundant rock-forming aluminum–silicate minerals containing potassium, sodium, or calcium. They are the most common minerals, being found in all kinds of rocks and constituting 60% of the Earth's crust. Plagioclase is a sodium-and/or calcium-bearing feldspar. Orthoclase is a potassium feldspar

felsic minerals—light-colored minerals rich in silica and/or aluminum, such as quartz and feldspar.

festoon crossbedding—a variety of trough crossbedding with scooplike scours that are filled with thinly laminated curved layers. The scours are, in turn, overlain by crosscutting layers. *See* photo on page 83.

flow breccia—a breccia that forms as a lava flow moves. Fragments of cooled crust are incorporated in the lava as the flow advances.

flux—the lowest-melting mineral in a glass, which combines easily with silica and helps higher-melting aluminum–silicate minerals form a glass.

fold—deformation of flat, layered beds of rock into arcuate forms (when seen in cross section). Flat-lying rocks can literally bend in response to great forces within the Earth's crust.

foliation—general term for a planar alignment or texture of platy minerals and cleavage, especially in metamorphic rocks. Foliation can be parallel mica grains in a schist, alternating layers of dark- and light-colored minerals in a gneiss, or aligned tabular feldspars in a granite.

garnet—a group of hard, aluminum–silicate minerals containing iron, magnesium, manganese, and calcium. They are most commonly found as red or reddish-brown crystals in metamorphic rock. Pure crystalline forms are considered semiprecious stones and used in jewelry.

gneiss—foliated metamorphic rock in which bands of light-colored minerals (i.e., feldspar, quartz) alternate with bands of dark-colored minerals (i.e., hornblende, mica). Commonly quartz and feldspar rich.

granite—a light-colored, coarse-grained intrusive igneous rock containing quartz, plagioclase feldspar, and potassium-rich feldspar. Dark-colored accessory minerals include biotite and hornblende. Rhyolite is the fine-grained equivalent.

granitic rock—a term loosely applied to any light-colored, coarse-grained intrusive rock containing quartz, feldspar, and minor mafic minerals.

gravity block caving—method of underground mining that undercuts the ore before blasting so that it can fall directly into waiting haulage cars.

groundmass—fine-grained or glassy material surrounding phenocrysts in a porphyritic igneous rock.

gullying (gully erosion)—erosion of soil or soft rock by running water to form narrow channels. Gullies typically contain water only during and after rainstorms and in the spring during melting of snow or ice.

hornblende—the most common amphibole mineral. Hornblende forms long, dark-colored crystals in igneous and metamorphic rocks.

hydraulic mining—the extraction of ore by means of forceful jets of water. Typically used in placer deposits.

hydrothermal fluid—hot subsurface solution (commonly water but also other gases) that may contain high concentations of dissolved minerals.

igneous rock—a rock that solidified from molten or partially molten magma.

imbricated—describes the orientation and stacking of pebbles and cobbles in a river deposit. The pebbles lean against each other and their flat surfaces dip upstream so that the current is unable to tumble them farther.

intrusive (plutonic) rock—igneous rock that solidified below the surface of the Earth within preexisting rocks. Intrusive rocks that cooled slowly have large crystals. Includes granite, diorite, and monzonite.

isotopic age—a rock or mineral age given in years, calculated from the rates of decay or disintegration of "parent" atoms of certain unstable radioactive elemental isotopes into "daughter" atoms of more stable elements. The rates of decay for many isotopes have been experimentally determined. Commonly used in isotopic dating are an isotope of potassium decaying to argon, an isotope of rubidium decaying to strontium, and an isotope of uranium decaying to lead.

joint—a fracture or crack in rock along which no movement has occurred.

Laramide orogeny—a period of deformation, well-documented in the Rocky Mountains, that lasted from Late Cretaceous to early Tertiary time. The Rocky Mountains and adjacent basins formed at this time. Structures such as folds and thrust faults characterize this event. Named for the Laramie Formation of Wyoming and Colorado.

latite—a porphyritic extrusive igneous rock containing about equal amounts of plagioclase-feldspar and potassium-feldspar phenocrysts and little or no quartz in a fine-grained groundmass. Quartz latite is a quartz-bearing latite. Monzonite is the extrusive equivalent.

lava—general term for magma or molten rock that has reached the Earth's surface and has solidified.

limestone—a sedimentary rock consisting chiefly of calcium carbonate, primarily as the mineral calcite.

lithosphere—the rigid, outer layer of the Earth, comprising the crust and upper mantle. Overlies the plastic asthenosphere.

lode—a mineral deposit in the form of an unusually large vein or a zone of veins in consolidated rock, as opposed to a placer deposit.

mafic minerals—dark-colored minerals rich in iron and magnesium, such as amphibole, pyroxene, or olivine.

magma—molten rock produced within the Earth, from which intrusive and extrusive igneous rocks form.

magnetite—a black, strongly magnetic iron oxide mineral. Found as an accessory mineral in rocks of all kinds and as a placer deposit. A major iron ore.

mantle—the zone of the Earth below the crust and above the core.

marble—a metamorphic rock consisting primarily of recrystallized calcite and/or dolomite. Metamorphosed equivalent of limestone.

matrix—the fine sand and silt grains surrounding larger grains, pebbles, or cobbles in a sedimentary rock.

metamorphic rock—any rock formed from preexisting rocks by heat, pressure, and the chemical actions of fluids deep within the Earth. Metamorphism can include chemical and structural changes in minerals and the creation of new minerals.

metasedimentary rock—metamorphosed sedimentary rock.

mica—a group of aluminum-silicate minerals of variable composition that are characterized by a sheetlike crystal structure. Micas are soft and readily split into thin, flexible sheets. Common in igneous and metamorphic rocks. Biotite is a dark-colored potassium-magnesium-iron mica. Muscovite is a light-colored potassium mica.

monzonite—a group of intrusive igneous rocks containing about equal amounts of potassium feldspar and plagioclase feldspar, little or no quartz, and pyroxene. Latite is the extrusive equivalent. In a quartz monzonite, quartz accounts for 10-50% of the light-colored minerals.

mudflow—a flowing mass of water, clay, and rock debris. If more than half of the solid material in the mass is larger than sand size the term "debris flow" is used.

mudstone—a very fine grained, blocky sedimentary rock composed of compacted (lithified) mud. Similar to shale but lacking shale's fine platy structure when weathered.

muscovite—*see* mica.

normal fault—*see* fault.

opacifier—in a glass an opacifier is a mineral whose crystals prevent light from penetrating the glass and thus give the glass a white color.

orogeny—the process by which mountains are formed. Large areas of the Earth's crust are compressed, folded, thrust faulted, and metamorphosed.

pahoehoe flows—an Hawaiian term for a basalt lava flow that has a glassy, smooth, undulating surface.

pegmatite—a very coarse grained granitic intrusive rock, commonly crystallized in podlike bodies. The composition may include rare minerals rich in lithium, boron, fluorine, niobium, tantalum, and uranium.

pelecypods—bivalved marine and freshwater mollusks commonly called clams. Lived from the Ordovician Period to the present.

perthite—a variety of feldspar consisting of intergrowths of pink potassium-rich feldspar (orthoclase or microcline) and white sodium-rich feldspar (albite).

phenocryst—conspicuous, relatively large crystal in a porphyritic igneous rock.

phyllite—a layered metamorphic rock intermediate in texture between slate and schist. Typically displays a silky sheen on surface because of small crystals of mica.

placer—a surficial mineral deposit formed by erosion and concentration of heavy minerals from weathered rock. Placers are usually alluvial, although they may also be marine, eolian, lacustrine, or glacial.

plate tectonics—the theory that the Earth's lithosphere consists of a number of thin, rigid plates that move over the aesthenosphere. Areas where plate boundaries meet are subject to earthquakes and volcanic activity.

plagioclase—*see* feldspar.

pluton—a general term for an igneous intrusion formed at depth in the Earth's crust.

porphyry—an igneous rock of any composition that contains conspicuous phenocrysts in a finer-grained groundmass. The rock name descriptive of the groundmass composition precedes the term porphyry (i.e., diorite porphyry).

pyrite—iron sulfide; a common pale-bronze or brass-yellow metallic mineral with the composition FeS_2. Commonly forms perfect cubic crystals. Also known as fool's gold, but gold is softer and heavier. Pyrite is the most common sulfide mineral and is found in all kinds of rocks. An important ore of sulfur.

pyroxene—a group of dark, complex rock-forming silicate minerals that are analogous in chemical composition to the amphiboles but lack the water (hydroxyls). Examples are augite, hypersthene, diopside, and jadeite. Pyroxene cleavage fragments commonly have almost rectangular or square cross sections.

quartz—silicon dioxide; SiO_2. The second most common mineral in the Earth's crust. A major constituent of many sedimentary, igneous, and metamorphic rocks. Exists as colorless (or sometimes colored yellow, brown, purple, red, green, blue, or black by impurities) hexagonal crystals or crystalline aggregates.

quartz diorite—*see* diorite.

quartz latite—*see* latite.

quartz monzonite—see monzonite.

quartzite—a metamorphic rock composed principally of quartz and formed by recrystallization of sandstone.

reaction zone—see replacement body.

replacement body—new minerals deposited by fluids that have partially or wholly dissolved older minerals. Found in pegmatites.

rhyolite—a fine-grained igneous rock, generally porphyritic, consisting of quartz and potassium feldspar phenocrysts in a fine-grained or glassy groundmass. Rhyolite magmas are viscous and slow moving compared with basalt lava flows (pahoehoe). They are fine grained because they cooled quickly at or near the surface of the Earth. Granite is the coarse-grained intrusive equivalent.

rhyolitic tuff—*see* tuff.

riffles—series of laths on the bottom of a sluice box or flume that traps heavy minerals, such as gold.

filling (rill erosion)—the development of many small, closely spaced channels from uneven runoff of surface water on soil. Typically leads to gully erosion.

ring fracture—a cylindrical pattern of steep faults that is associated with subsidence of a caldera.

rock cycle—a sequence of events leading to the formation, alteration, destruction, and reformation of rocks, as when sedimentary rocks are buried, heated, and recrystallized to form metamorphic rocks or melted to form igneous rocks or when the eroded remains of older rocks become lithified (hardened) into sedimentary rocks.

sandstone—a medium-grained sedimentary rock composed of abundant sand-size fragments cemented by silica, iron oxide, or calcium carbonate. The sand-size fragments are predominantly quartz, but feldspar and other minerals can be present. Sandstones form in beach, river-channel, and desert environments.

schist—a well-foliated metamorphic rock characterized by a parallel arrangement of relatively large crystals of platy minerals, such as mica and hornblende. Schists have a rather homogeneous appearance because they are not layered like gneisses, and schists usually can be easily split into thin flakes or slabs.

sedimentary rock—a rock formed from the consolidation of loose erosional debris of other rocks, from the remains of plants and animals, or from the precipitation of chemicals from water.

shale—a fine-grained sedimentary rock formed by the consolidation of clay, silt, or mud, and characterized by fine layers that readily split apart. Shales form in quiet-water environments, such as sea floors, lagoons, lakes, and on flood plains. 80% of exposed sedimentary rocks are shales.

shield volcano—a broad and low volcano, like a flattened dome, built by flows of very fluid basalt lava. Mauna Loa, on the Island of Hawaii, is a typical shield volcano. Cerro de la Olla is an extinct shield volcano.

sill—a horizontal, tabular igneous intrusion.

slate—a compact, fine-grained metamorphic rock that possesses a type of foliation called slaty cleavage or fissility—breaks into thin slabs along parallel planes independent of original bedding. Metamorphosed equivalent of shale.

sluice box—a rectangular box through which water and soil are washed in order to separate heavy minerals, such as gold, from gravel of a placer deposit. Heavy minerals accumulate on the bottom of the box behind laths, called riffles.

soft-sediment deformation—disturbance of horizontal sediment layers into folded or contorted beds before lithification (consolidation into sedimentary rock).

staurolite—brown iron–magnesium aluminum–silicate mineral that is commonly found in metamorphic rocks, such as schist and gneiss. Commonly grows as twin crystals.

Twins that grow at 90° are informally called fairy crosses. Found in placer deposits.

stockwork—a mineral deposit in the form of a network of veinlets scattered within the country rock.

stope—in a mine, the underground excavation formed by removing ore in a series of horizontal levels or steps above or below a drift.

strategic minerals—essential minerals for which the U.S. supply is inadequate or potentially inadequate.

tailings—the pulverized rock material remaining after the extraction of ore.

talus—large, angular rock fragments weathered from bedrock and found at the base of a steep rocky slope or cliff.

tectonic event—general term for related large-scale movements and deformation of the Earth's crust, commonly to form mountains and adjacent sedimentary basins. *See* Laramide orogeny.

terrace—any long, narrow, gently sloping surface bounded along one side by a steeper descending slope, and along the other by a steeper ascending slope. Commonly found along the margin and above the level of some body of water (stream terrace), denoting a former level of the water.

tholeiitic basalt—a silica-rich basalt composed mainly of plagioclase feldspar, pyroxene, and iron-oxide phenocrysts in a finer-grained groundmass.

thrust fault—*see* fault.

toreva blocks—large landslide blocks that rotate backwards toward the parent cliff as they break and fall free of the cliff.

trilobite—an extinct marine arthropod characterized by a three-lobed exterior skeleton. Attained lengths from ¼ inch to 27 inches. Lived from the Early Cambrian Period through the Permian Period.

tuff—a compacted deposit of fine volcanic ash and fragmented volcanic rock that was transported through the air during an enormously destructive explosive eruption. May contain up to 50% sediments, such as sand and clay. A welded tuff has been hardened by heat, the weight of overlying tuff, and hot gases; typically contains pumice and streaky banding. Rhyolitic tuff originates from an explosive eruption of fluids trapped in viscous rhyolitic magma.

veins—minerals in a tabular or sheetlike deposit along a fault or fracture in an older host rock.

vesicles—small generally rounded holes in igneous rocks that formed when gas bubbles became trapped ín coolíng lava.

vesicular basalt—see basalt.

volatiles—liquids and gases, such as water or carbon dioxide, which are dissolved in a magma but may escape in a fluid form.

volcanic rock—a general term for an igneous rock formed at or near the Earth's surface.

Suggested reading

Architecture

Bunting, Bainbridge, 1962, Architecture of the Embudo watershed: New Mexico Architecture, v. 4, nos. 5-6, pp. 19-27.

The evolution of New Mexico architecture as documented in the surviving churches and houses in Dixon, Peñasco, Las Trampas, and other rural villages in the Embudo watershed south of Taos. Very informative text.

Bunting, Bainbridge, 1974, Of earth and timbers made—New Mexico architecture: Albuquerque, University of New Mexico Press.

A collection of photographs by Arthur LaZar, with text by Bainbridge Bunting, captures the beauty of architectural detail.

Bunting, Bainbridge, 1970, Take a trip with *New Mexico Architecture*—an architectural guide to northern New Mexico: New Mexico Architecture, v. 12, nos. 9-10, pp. 1351.

A collection of six car tours and two walking tours of the Taos and Santa Fe areas. Excellent guide to the history—not just architectural history—of the Santa Fe and Taos areas and Las Trampas.

Bunting, Bainbridge, 1964, Taos adobes—Spanish Colonial and Territorial architecture of the Taos Valley: Santa Fe, Fort Burgwin Research Center and Museum of New Mexico Press.

A valuable architectural study of 12 adobe buildings in the Taos area; beautifully illustrated with historic photographs, photographs by the author, and drawings by Jean Lee Booth and William R. Sims, Jr. Several of the buildings have been destroyed.

Bunting, Bainbridge, Thomas R. Lyons, and Margil Lyons, 1983, Penitente Brotherhood moradas and their architecture, *in* Hispanic arts and ethnohistory in the Southwest, edited by Marta Weigle: Santa Fe, Ancient City Press, pp. 31-80.

Studies the architecture of meeting places (moradas) of the Penitente Brotherhood.

Iowa, Jerome, 1985, Ageless adobe—history and preservation in southwestern architecture: Santa Fe, Sunstone Press.

Outlines the history of southwestern architecture with many historic photographs. Also includes valuable information on historic preservation, adobe additions, and solar retrofitting.

Kessell, John L., 1980, The missions of New Mexico since 1776: Albuquerque, University of New Mexico Press.

Includes information on the architecture of the mission churches.

Kubler, George, 1940 (reprinted 1962), The religious architecture of New Mexico in the Colonial period and since the American occupation: Colorado Springs, The Taylor Museum of the Colorado Springs Fine Arts Center (a fifth edition was published in 1990 by the School of American Research and University of New Mexico Press, Albuquerque).

Comprehensive study of 17th century early missions and 18th–mid 19th century missions and parish churches. Includes a convenient alphabetical chronological table of the churches, although recent researchers have revised some of the dates. Also includes over 150 historic black-and-white photographs.

Spears, Beverley, 1986, American adobes—rural houses of northern New Mexico: Albuquerque, University of New Mexico Press.

Chronicles the distinct architectural style that evolved from Spanish Colonial origins in the remote villages in north-central New Mexico—known as the New Mexico Vernacular style, Mountain Gabled style, or Rural style.

Wroth, William, 1979, The Chapel of Our Lady of Talpa: Colorado Springs, The Taylor Museum of the Colorado Springs Fine Arts Center.

A small, well-researched volume about the history of a family chapel in Talpa; its collection of "santos," images of saints, is a permanent exhibit in the Taylor Museum.

Also documents Spanish settlement of the Taos area, traditional village life, and religious architecture and folk art in northern New Mexico.

Fossils

Arduini, Paolo, and Giorgio Teruzzi, 1986, Simon & Schuster's guide to fossils: New York, Simon & Schuster, Inc.
Excellent color guide to the identification of fossils.
Casanova, Richard, and Ronald P. Ratkevich, 1981, An illustrated guide to fossil collecting (third revised edition): Happy Camp, California, Naturegraph Publishers, Inc.
A good introduction to collecting and identifying fossils.
Kues, Barry S., 1982 (reprinted 1986), Fossils of New Mexico: Albuquerque, University of New Mexico Press.
Well-illustrated chapters organize fossils into major groups and by age. Outcrops of rocks of each age are plotted on maps of the state. Fossil-bearing Pennsylvanian rocks can be found east of Taos.
McAlester, A. Lee, 1977, The history of life (second edition): Englewood Cliffs, New Jersey, Prentice–Hall, Inc.
This book from Prentice–Hall's Foundations of Earth Science Series chronicles the origins and history of life on Earth.
Rhodes, Frank H. T., Herbert S. Zim, and Paul R. Shaffer, 1962, Fossils—a guide to prehistoric life: New York, Golden Press. A division of Western Publishing Company, Inc., Racine, Wisconsin.
From the series of Golden Nature Guides, this pocket-size book is a good introduction to fossil collecting.
Thompson, Ida, 1982, The Audubon Society field guide to North American fossils: New York, Alfred A. Knopf.
Excellent color guide to the identification of fossils.
Trimble, Stephen, 1980, From out of the rocks—discovering ancient life in New Mexico: New Mexico Office of Cultural Affairs, Life History Program Advisory Committee and the Museum of Northern Arizona.
A short but well-written, beautifully illustrated introduction to New Mexico fossils.

General

Burdett, William, 1990, The roads of New Mexico: Fredericksburg, Texas, Shearer Publishing.
The State of New Mexico divided into 55 sections, mapped in great detail (1 inch = 2.9 miles), and bound into a convenient-to-use road atlas. Also lists geographic names, state and national recreation areas, ghost towns, pueblos, museums, and other attractions and includes colorful illustrations of plants and animals.
Christiansen, Paige W., and Frank E. Kottlowski, editors, 1972, Mosaic of New Mexico's scenery, rocks, and history: Socorro, New Mexico Bureau of Mines and Mineral Resources, Scenic Trips to the Geologic Past, No. 8.
Introduces New Mexico's geologic history, varied landscapes and vegetation, the histories of its culturally diverse inhabitants, and national and state parks, forests, and monuments.
Delgado, Deane, compiler, 1990, Historical markers in New Mexico (revised edition): Santa Fe, Ancient City Press.
The complete text on all 80 current (fall 1989) historical markers and each sign in New Mexico's 40 state parks. The roadside historical signs are numbered and keyed to maps of five regions of the state.
Pearce, T. M., editor, 1965, New Mexico place names—a geographical dictionary: Albuquerque, University of New Mexico Press.
Contains the history of over 5,000 names. Information for this unique compilation

was first collected between 1936 and 1940 by workers of the New Mexico Writers' Project. The first compilation, containing 334 names, was published in 1949.

Geology

Baldridge, W. Scott, Patricia Wood Dickerson, Robert E. Riecker, and Jiri Zidek, editors, 1984, Rio Grande rift—northern New Mexico: Socorro, New Mexico, New Mexico Geological Society, Guidebook to 35th Field Conference.

Includes many technical articles on the geology of the northern Rio Grande rift and Taos area. Three road logs cover parts of the routes in this volume as well as routes farther northwest and southeast.

Bauer, Paul W., Christopher K. Mawer, and Spencer G. Lucas, editors, 1990, Tectonic development of the southern Sangre de Cristo Mountains, New Mexico: Socorro, New Mexico, New Mexico Geological Society, Guidebook to 41st Field Conference.

Includes many technical articles on the geology of the Taos and Red River areas and the Moreno Valley. Three road logs cover parts of the routes in this volume as well as routes farther north and east to Cimarron.

Bennison, A. P., compiler, 1990, Geological highway map of the southern Rocky Mountain region—Utah, Colorado, Arizona, New Mexico (revised edition): Tulsa, American Association of Petroleum Geologists, Map No. 2.

Geology of a four-state area with interstate, U.S., and state highways superimposed. Smaller maps of the area's physiography; bedrock geology and major structural features; and mineral, gemstone, and fossil localities and other places of geologic interest.

Brookins, Douglas G., Bryan C. Chakoumakos, Clarence W. Cook, Rodney C. Ewing, Gary P. Landis, and Marcia E. Register, 1979, The Harding pegmatite—summary of recent research: Socorro, New Mexico, New Mexico Geological Society, Guidebook to 30th Field Conference, pp. 127-133.

This technical article summarizes research on isotopic dating of muscovites, cleavelandites, lepidolites, perthites, microclines, and albites; more than 500 fluid inclusions taken from all lithologic zones; and microlite mineralogy.

Chakoumakos, Bryan C., 1977, The Harding pegmatite mine: Albuquerque, University of New Mexico, Department of Geology.

More technical walking tour of the Harding pegmatite mine; written for the geologist or student of geology.

Chronic, Halka, 1987, Roadside geology of New Mexico: Missoula, Mountain Press Publishing Company.

One of a series of roadside geology guides designed for readers with little or no geologic training. Road logs describe geology along interstate, U.S., and state highways; specific geologic features are keyed to highway mileposts.

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Detailed technical study of approximately 300 square miles that include Red River, Elizabethtown, Eagle Nest, and Wheeler Peak.

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Audubon's small format field guide organizes 725 photographs by flower color and shape.

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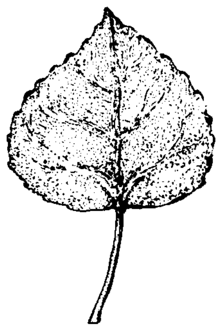
Sangre de Cristo Mountains, Taos Plateau, Rio Grande Gorge—the geology of north-central New Mexico is as diverse and spectacular as any place on Earth. Just as there are contrasts between strikingly different landscapes, diversity also is found in the region's history and in its American Indian, Spanish, and Anglo American cultures. This guidebook's two main tours follow major highways north and south of Taos, incorporating descriptions of roadside geology with highlights on history, architecture, and vegetation along the routes and with notes on places to picnic, fish, and camp. One road log makes a 100-mile loop north of Taos through Questa, Red River, and Eagle Nest, a route familiarly known as the "enchanted circle." A second, 62-mile road log follows tranquil river valleys through the picturesque towns of Dixon, Peñasco, and Vadito while circling the Picuris Mountains. Explore these routes and four shorter side trips on less-traveled roads into the Rio Grande Gorge, into the high country northwest of Red River, and to the Harding pegmatite mine. Discover what geological processes have been at work for millions of years shaping the landscape and directing the course of human history as well.



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