



# Ghost Ranch and Vicinity

CARSON NATIONAL FOREST

113

The area around Abiquiu and Tierra Amarilla preserves a wide variety of geologic features and vistas in a small geographic area. The majestic multihued cliffs near Ghost Ranch inspired the artistry of Georgia O'Keefe, and the stark, bare cliffs of the Brazos Box near Tierra Amarilla are the focus of many photographs. Flat-topped Cerro Pedernal is a landmark that can be seen for miles. Although much of this area is not public land, many of the most spectacular features are visible from US 84 and NM-96.

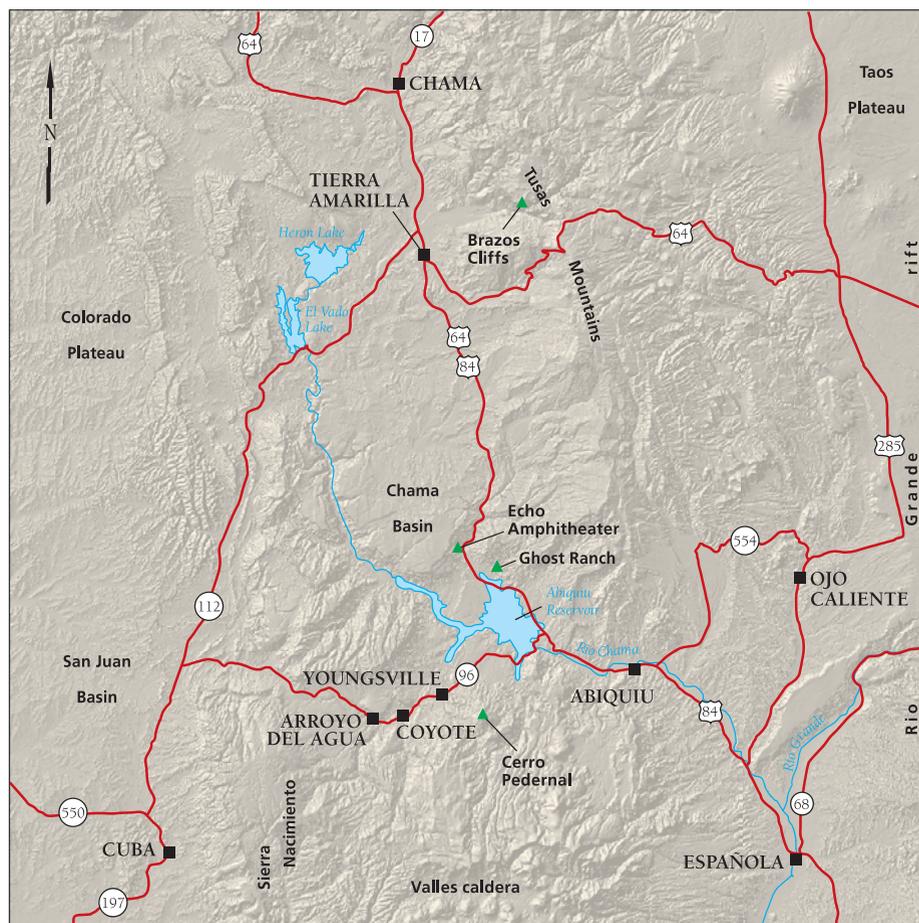
## Regional Setting

The Abiquiu–Tierra Amarilla area is geologically complex. It sits at the boundary between the Rio Grande rift (to the east) and the Colorado Plateau (to the west). The middle part of the area includes the Chama Basin, which roughly follows the valley of the Rio Chama. This basin is a geological depression that formed during the Laramide orogeny, a compressional basin-forming and mountain-building event. To the west is the San Juan Basin, a bigger version of the Chama Basin, which also formed during the Laramide orogeny. The Chama and San Juan Basins are on the Colorado Plateau, which has been a relatively stable block in the earth's crust for at least 600 million years. Consequently, the rocks around Ghost Ranch are relatively flat-lying and are only mildly deformed by broad-scale folding and localized faulting with offsets of less than 120 feet. To the east and south is the Española Basin, which is part of the Rio Grande rift, a large and complex trench of Tertiary age that runs down the center of New Mexico. To the south is the enormous volcanic complex of the Jemez Mountains and the Valles caldera. To the north and east are the Tusas Mountains, a mass of ancient Precambrian rocks with a veneer of Tertiary volcanic rocks. To the west is the Sierra Nacimiento, which is also composed of Precambrian rocks partially covered with Pennsylvanian to Permian sedimentary rocks. These mountainous areas formed partly during Laramide time and partly at the same time as the Rio Grande rift.

## The Rock Record

The Tusas Mountains include a variety of Precambrian rocks that were deposited or placed 1,760 to 1,650 million years ago. These rocks include quartzite, a low-grade metamorphic rock that is made up primarily of quartz sand grains that were later recrystallized as the rock

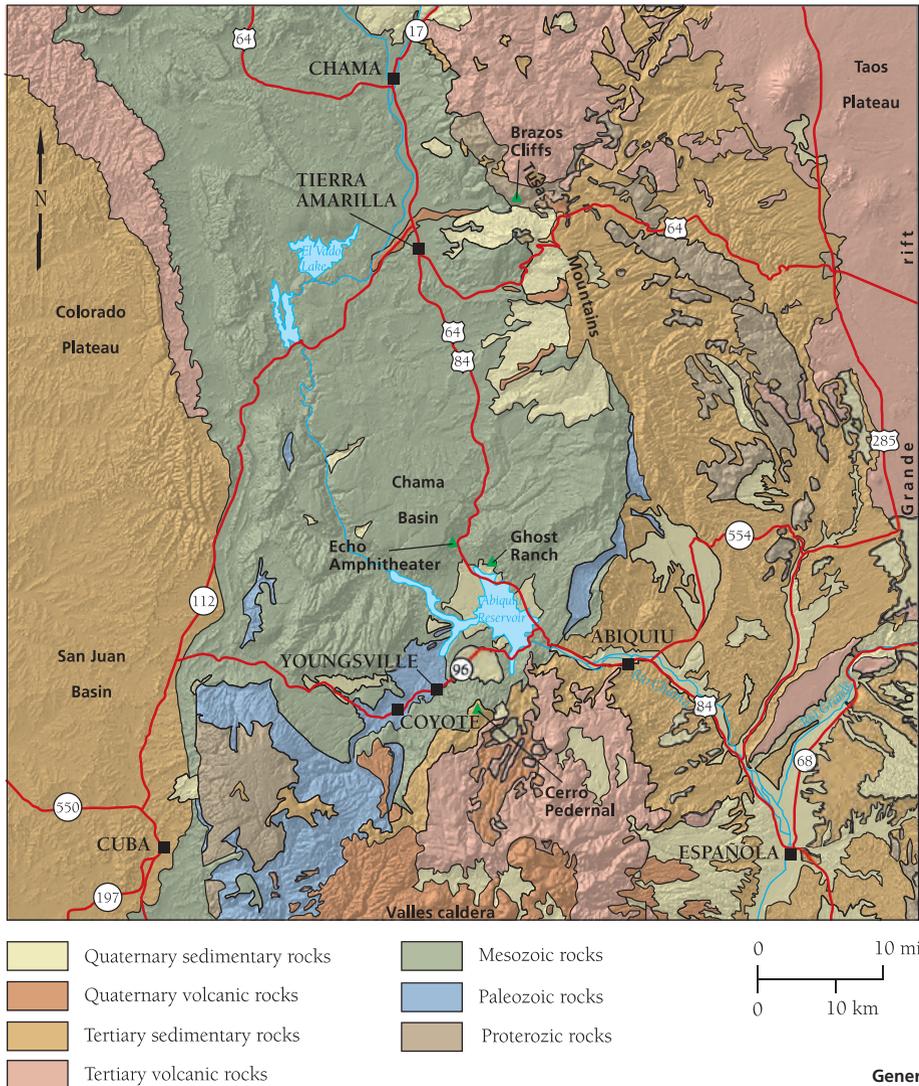
OPPOSITE: The Rio Chama, at the boundary between the Colorado Plateau and the Rio Grande rift. Capping the hills on the skyline are volcanic deposits from the Jemez volcanic field. The colorful sediments of the Chinle Group are visible at the base of those hills.



Geographic overview of the Abiquiu region.

was buried and heated. The distinctive grayish-white Ortega Quartzite forms the bold cliffs of the Brazos Box. There is also a range of ancient sedimentary rocks that were metamorphosed in the middle of the crust to form schist and phyllite, as well as basaltic-to-rhyolitic volcanic rocks that were metamorphosed to form amphibolite and metarhyolite.

The scenic red rocks that surround Abiquiu Reservoir and extend off to the west toward Arroyo del Agua and Gallina are sedimentary rocks of Permian and Triassic age. These rocks include the Permian Cutler Group and the Triassic Chinle Group, both of which formed by rivers flowing during times of semi-arid climate. Both of these rock units are well known throughout the Southwest. The Permian Cutler Group is well exposed at Canyonlands National Park in Utah. The Chinle Group is the unit that forms the Painted Desert in Arizona. Both units consist



Generalized geologic map of the Abiquiu region.

of thick packages of red siltstone and mudstone and white-to-tan sandstone and conglomerate. These rocks have yielded significant fossils that document the rise of primitive reptiles and subsequently dinosaurs. The most famous are *Limnoscelis*, which is close to being the ancestor of reptiles, found in the 1870s near Abiquiu, and *Coelophysis*, a small meat-eating dinosaur that is the state fossil of New Mexico. The first pieces of *Coelophysis* were found in 1876, but the animal did not become well known until Edwin Colbert of the American Museum of Natural History found a mother lode of hundreds of skeletons at Ghost Ranch in 1947.

The cliffs above Ghost Ranch and the rocks visible along US 84 as it climbs north of Abiquiu Reservoir represent younger Mesozoic rocks,



Jurassic bivalves (in cross section) from basal sandstones of the Summerville Formation on Kitchen Mesa at Ghost Ranch.

including a sequence of Jurassic and Cretaceous strata. The most prominent Jurassic rocks are the massive red, white, and yellow cliffs of Entrada Sandstone, which formed in a large desert during middle Jurassic time. The Entrada Sandstone contains impressive crossbeds that are several feet high. On top of these cliffs is a thin interval of limestone and a thick pile of soft white gypsum, both part of the Todilto Formation that formed in a large shallow body of saline water that once covered northern New Mexico. Colorful slopes of the maroon Summerville Formation and green Morrison Formation are above the Entrada/Todilto cliffs. The basal 25-to-40 feet of the Summerville Formation is laminated white-to-tan sandstone with ripple marks and casts of gypsum crystals, interbedded with green-to-red mudstone and shale. The basal sandstone unit is overlain by a thick section of maroon mudstone and pinkish-tan, poorly cemented, crossbedded sandstone (Bluff Sandstone) deposited in an arid environment. The Brushy Basin Member, the only member of the Morrison Formation present at Ghost Ranch, consists of pistachio green-to-salmon pink mudstone with a few interbedded tan and green sandstone beds deposited in a slightly more humid setting. Rounded, highly polished stones often interpreted to be *gastroliths* from the digestive tracts of dinosaurs are common in the Morrison Formation in this region.

Cretaceous rocks, including the Burro Canyon Formation, the Dakota Sandstone, and the Mancos Shale, cap the tall cliffs behind Ghost Ranch and are easily visible as US 84 snakes up past Echo Amphitheater. The Burro Canyon Formation consists of crossbedded medium-to-fine-grained sandstone, quartz and chert pebble conglomerate, and pale-green to pale-red mudstones. The Dakota Sandstone is composed of tan-to-yellow-brown sandstone and interbedded dark gray carbonaceous shale and siltstone (Mancos Shale). Ripple marks on tops of sandstone beds are common. The Cretaceous rocks all formed close to or in the Western Interior Seaway, a shallow sea that split North America north to south during this time period.

Younger strata including basal conglomerates of the Eocene El Rito Formation are visible in a road cut on the north side of US 84 between Abiquiu and Abiquiu Reservoir just as the highway starts to climb out of the white to tan sedimentary rocks deposited in the Rio Grande rift onto the red Permian and Triassic rocks of the Colorado Plateau. The basal conglomerate consists of well-rounded Ortega Quartzite boulders and cobbles derived from the Tusas Mountains to the north during

AGE	UNIT	ROCK TYPE	ENVIRONMENT OF DEPOSITION OR DEFORMATION	BEST SEEN
Pleistocene	Bandelier Tuff	Tuff	Caldera eruption	South of Coyote
Pliocene	Jemez volcanic field lava flows	Andesite basalt dacite	Volcanic eruption	Cerro Pedernal
Miocene	Ojo Caliente Sandstone	Crossbedded sandstone	Dune field	Abiquiu
	Chama-El Rito Member	Sandstone, siltstone, conglomerate	River	
Oligocene	Abiquiu Formation	Sandstone, conglomerate	Braided streams	Abiquiu
	Pedernal Chert	Chert, limestone	Silica-rich groundwater	Cerro Pedernal
	Ritito Conglomerate	Conglomerate, Sandstone	River	Abiquiu
Eocene	El Rito Formation	Sandstone, conglomerate	River	West of Abiquiu
Cretaceous	Mancos Shale	Shale, siltstone	Marine	US 84 west of Ghost Ranch
	Dakota Sandstone	Sandstone, shale	Marine to marginal marine	
	Burro Canyon Member	Conglomerate, Sandstone	River	
Jurassic	Morrison Formation (Brushy Basin Member)	Siltstone, sandstone	River and floodplain	Ghost Ranch
	Bluff Sandstone	Crossbedded sandstone	Dune field	
	Summerville Formation	Siltstone, sandstone	Alluvial flat	
	Todilto Formation	Gypsum, limestone	Salina	
	Entrada Sandstone	Crossbedded sandstone	Dune field	
Triassic	Chinle Group	Mudstone, sandstone conglomerate	River	
Permian	Yeso Formation	Crossbedded sandstone	Dune field	South of Coyote
Pennsylvanian	Cutler Group	Sandstone, siltstone	River	Arroyo del Agua
	Madera Group	Limestone, shale, sandstone	Marine	Southern Sierra Nacimiento
Precambrian	Igneous and metamorphic rocks	Quartzite, schist, metavolcanics, amphibolite	Island arc caught up in mountain building	Brazos Cliffs

Laramide uplift of that mountain range. The basal unit is overlain by reddish-orange fine-grained sandstone.

An early Rio Grande rift conglomerate, which contains cobbles of a variety of Precambrian rock types derived from the Tusas Mountains, forms low hills near the village of Abiquiu. The conglomerate is overlain by the Abiquiu Formation, a very distinctive unit that contains volcanic rock fragments and thin beds of volcanic ash derived from the Latir volcanic field north of Taos. The Abiquiu Formation forms the dazzling white ribbed cliffs just west of the town of Abiquiu on both sides of US 84. The Abiquiu Formation is also exposed on Cerro

**Generalized stratigraphic record in the vicinity of Ghost Ranch (not to scale).**

Pedernal and on highlands as far west as the Sierra Nacimiento. One interesting unit just below the base and within the Abiquiu Formation on the flanks of Cerro Pedernal and on nearby highlands is the Pedernal Chert. Chert is a hard, fine-grained silica-rich rock, often called flint when it is black or dark gray. Prehistoric arrowheads, spear points, and hand axes made from Pedernal Chert have been found hundreds of miles away, and there are several ancient quarries high on Cerro Pedernal.

The prominent cliffs on the west edge of the village of Abiquiu are composed of the Miocene Chama–El Rito Member and the Ojo Caliente Sandstone of the Santa Fe Group. Normally these units are quite soft and form slopes, but fluids that came up along a major fault on the west side of the village, the Cerrito Blanca fault, provided abundant calcium carbonate to cement the rocks. The Chama–El Rito Member is an ancestral Rio Chama deposit containing small rounded pebbles of volcanic rocks derived from San Juan volcanic field near the New Mexico–Colorado state line to the north. The crossbedded Ojo Caliente Sandstone formed a sand dune field that once covered the area between the Sierra Nacimineto and Española.

The majority of younger rocks are volcanic in origin, or are sedimentary rocks eroded from volcanoes. Cerro Pedernal, the high mountain with a distinctive flat top just south of Abiquiu Reservoir, is capped by 8-million-year-old andesite flows from the Jemez volcanic field. The mesas south and west of Abiquiu are also capped by basaltic-to-andesitic rocks from the Jemez volcanic field that are as young as 3 million years old.

## Geologic History

The geologic history of the area is delightfully complicated. The oldest Precambrian rocks in the Tusas Mountains are 1,693 to 1,760 million-year-old basaltic-to-rhyolitic volcanic rocks and associated intrusions that formed in a volcanic arc setting. These rocks were buried, deformed, and then eroded to be exposed at the earth's surface. Sedimentary rocks of the Vadito Group and the Ortega Quartzite overlie these deformed volcanic rocks. Although deposition of sediment continued until 1,650 million years ago, this whole package was buried and deformed starting 1,690 million years ago. The Precambrian rocks did not come back up to the earth's surface until middle Pennsylvanian time, 315 million years ago during Ancestral Rocky Mountain deformation, when the Tusas Mountains were part of the Uncompahgre/San Luis uplift that occupied much of north-central New Mexico.

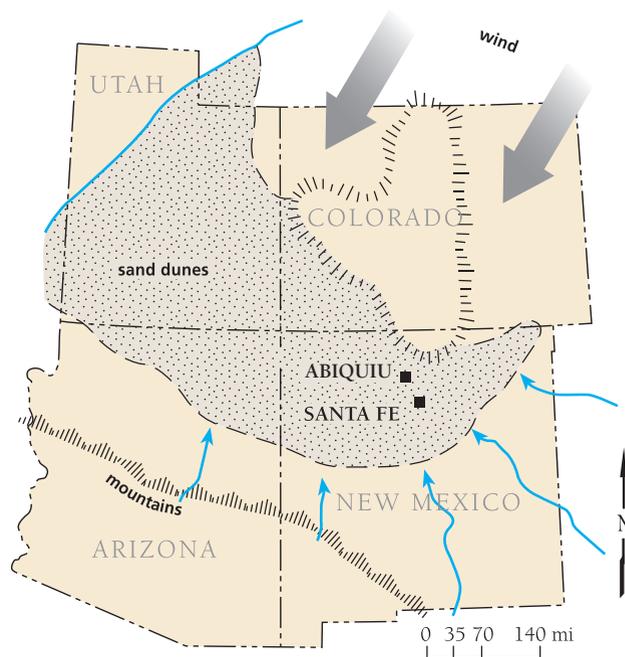
Rocks with ages between 1,650 and 300 million years are not exposed in the immediate vicinity of Ghost Ranch, although the Madera Limestone of Pennsylvanian age is present in the subsurface and is exposed on the flanks of Sierra Nacimiento to the west. Starting 300 million years ago, the ocean shoreline retreated toward the south, and a south-flowing river system drained the region. The lower part of the Cutler Group contains abundant cobbles and pebbles of Proterozoic quartzite and granite likely derived from areas to the northeast, off of the Ancestral Rocky Mountain Uncompahgre/San Luis uplift. As time went on we know the climate started to dry out because channel sandstones in the upper part of the Cutler Group are much less common than they are in the older part.

Seventy-two million years of geologic history is missing at the contact between the Cutler Group and the Chinle Group. The Late Triassic Chinle Group was deposited by large Mississippi River-scale river systems flowing from central Texas toward the northwest between 205 and 228 million years ago. At that time the Ghost Ranch area was located about 10 degrees north of the equator.

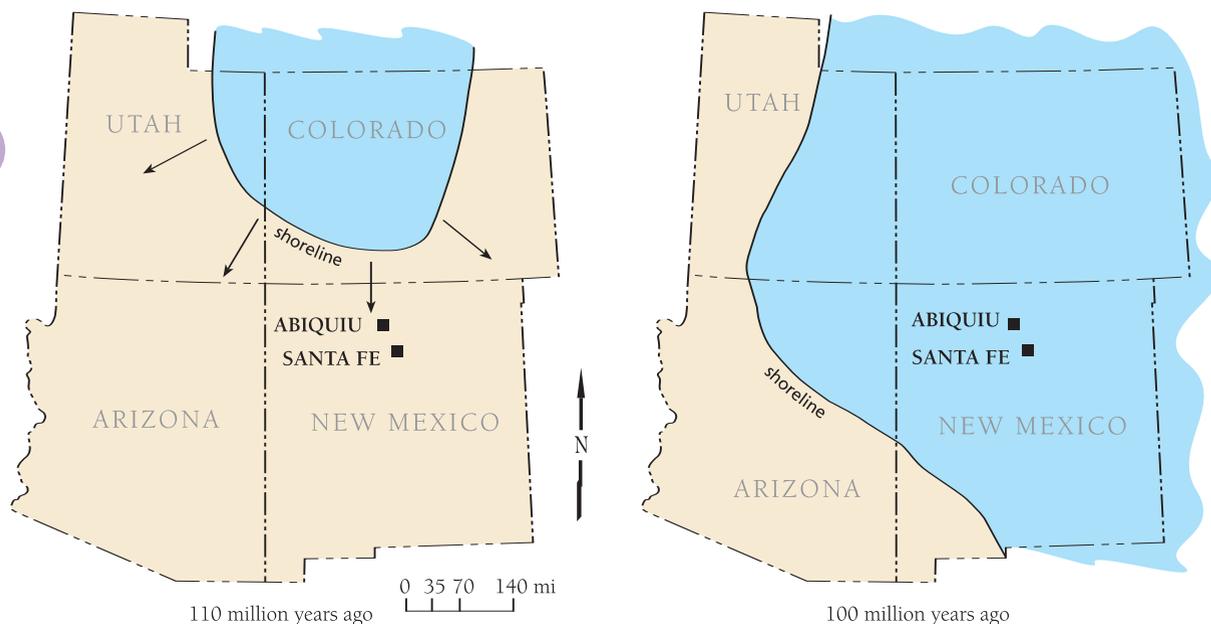
A significant unconformity representing a gap of 44 million years is present between the late Triassic rocks and the middle Jurassic rocks at Ghost Ranch.

The eroded, muddy top of the Chinle Group was desiccated when sands of the Entrada first moved across this region, as evidenced by the sand-filled mud cracks on top of the Chinle Group. The Entrada Sandstone deposits at Ghost Ranch are remnants of a vast sand dune field that covered much of northern New Mexico, southwestern Colorado, southeastern Utah, and northeastern Arizona. The dip of crossbeds in the Entrada Sandstone has been used to determine that the sand was transported by wind blowing toward the south to southwest.

The Entrada dune field may have been flooded catastrophically, with very little reworking of the sand dunes, by an arm of the Jurassic Sundance Sea, which was in east-central Utah during this time period. The resulting Todilto Formation was most likely deposited during evaporation of a *salina*, a moderately deep, oxygen-poor, body of saline water that was isolated from the main body of the Jurassic ocean by a



**The Jurassic Entrada Sandstone dune field extended hundreds of miles to the northwest.**



The Dakota Sandstone was deposited as seas advanced from the north/northwest in the late Cretaceous in response to worldwide changes in sea level. This was the first advance of the Western Interior Seaway.

Burrows of marine organisms on the base of a block of Dakota Sandstone near Ghost Ranch.



barrier. The Todilto grades into the Summerville Formation, which was deposited on an arid coastal plain. The Bluff Sandstone, exposed near the top of the Summerville Formation, represents a return to eolian deposition in this area. Crossbeds in the Bluff Sandstone record winds blowing toward the east during this time interval.

An unconformity between the Summerville Formation and the overlying Morrison Formation marks a major plate tectonic reorganization of the southwestern United States and a shift from an arid to a more humid environment in this region. The Jurassic Morrison Formation was deposited by rivers flowing northeast across a broad, low-gradient muddy floodplain that dipped toward the north to northeast away from the developing Mogollon highlands in southwestern New Mexico and southeastern Arizona. Radiometric dating of ash beds in the Brushy Basin Member in Utah and Colorado yields ages of 148 to 150 million years for this unit.

The mesas around Ghost Ranch are capped by Cretaceous coastal plain, shoreline, and marine units that were deposited along the western edge of the Western Interior Seaway 93 to 125 million years ago. Twenty-five million years of earth history is missing across the contact between the Late Jurassic Morrison Formation and the Early Cretaceous Burro Canyon Formation, deposited by braided streams flowing north/northeast across a coastal plain. This unit is 100 to 125 million years old. The Dakota Sandstone records the alternating rise (shale) and fall (sandstones) of sea level as the shoreline moved back and forth across the area 98 to 100 million years ago. The sandstones of the

Dakota Sandstone are locally crossbedded, but in general the sandstones were intensely burrowed by marine organisms living in the shallow water along the shores of the Western Interior Seaway. A gradual, long-term rise in sea level deposited rocks of the Mancos Shale on a shallow ocean floor 98 million years ago.

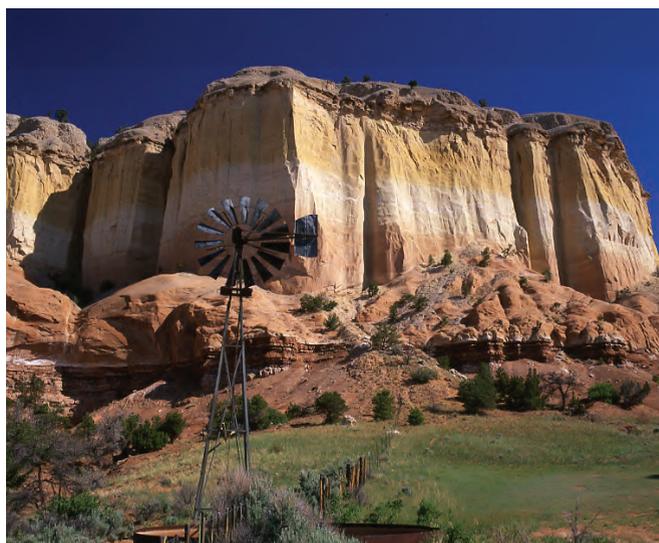
Starting 75 million years ago, compressional Laramide deformation delineated the major basins (Chama and San Juan) and uplifts (Tusas and Sierra Nacimiento) of the region. Several small monoclines, including those visible from NM-96 north of Coyote and near Arroyo del Agua, formed during this time frame. The Eocene El Rito Formation was deposited in the low spot between the Tusas Mountains and Sierra Nacimiento.

A broad basin developed between the Sierra Nacimiento and the Sangre de Cristo Mountains starting 30 to 35 million years ago and accumulated first sediments of the Abiquiu Formation and later Santa Fe Group sediments. Normal faulting associated with the Rio Grande rift began to disrupt the basin 25 million years ago. The basaltic dikes that can be seen along US 84 west of Abiquiu were emplaced 18 to 20 million years ago, signaling the onset of volcanic activity in the vicinity of the Jemez Mountains. The main phase of volcanism in the Jemez Mountains started at about ten million years ago. The Rio Grande rift, accommodated by normal faults with hundreds of feet of displacement, mainly formed in this area between 13 and 3 million years ago.

The youngest units around Ghost Ranch and Abiquiu are Quaternary terrace and pediment gravels exposed along the drainages, especially the Rio Chama, and extensive landslide and colluvial deposits along the escarpments. Many of the terrace gravels contain quartzite that is likely derived from the Tusas Mountains to the northeast of Ghost Ranch, either directly from the Precambrian Ortega Quartzite, or from quartzite clasts recycled from the Eocene El Rito Formation on the west flank of the mountain range.

## Geologic Features

**GHOST RANCH**—Privately owned and run by the Presbyterian Church, Ghost Ranch includes two public museums. The Ruth Hall Museum of



Triassic and Jurassic sedimentary rocks form this cliff near the Box Canyon trail at Ghost Ranch. The brick-red Chinle Group at the base of the cliff is overlain by red, white, and yellow-banded Jurassic Entrada Formation. The banding is caused by variable chemical reactions with iron within the sandstone. The cliff is capped by gray Todilto Formation.

Paleontology focuses on the Triassic fossils of the area, notably *Coelophysis*. There is a trail up to the quarry where the skeletons of this dinosaur were excavated. The scenic red cliffs behind Ghost Ranch and Georgia O'Keefe's house, which is adjacent to the ranch, are formed by the uppermost part of the Chinle Group, capped by the Entrada Sandstone and the prominent white gypsum of the Todilto Formation. Several trails, including the Chimney Rock, the Kitchen Mesa, and the Box Canyon trails, allow visitors to more closely examine the upper parts of the Triassic and lower portions of the Jurassic sections at Ghost Ranch. The lower part of the Chinle Group can be seen a few miles away at Abiquiu Dam.



Cerro Pedernal on the horizon, with Triassic Chinle sandstone and siltstone along the shore of Abiquiu Reservoir in the foreground.

**CERRO PEDERNAL**—Located in the Santa Fe National Forest, Cerro Pedernal is a popular climbing destination. Late Triassic to Early Cretaceous sedimentary rocks are exposed around the northern and eastern base of Cerro Pedernal, while younger Cenozoic basin fill sediments underlie the shoulders of the peak. The Pedernal Chert occurs just below the base of the Abiquiu Formation, where it is locally interlayered with thin beds of the underlying arkosic sandstone and conglomerate. The unit, a conspicuous ledge former, can be massive

chert, limy chert, or limestone containing nodular chert. The chert can be red, yellow, black, white, gray, or bluish gray. Cerro Pedernal, which means “flint mountain,” derives its name from this unit. South and west of Cerro Pedernal, the Pedernal Chert is present at several intervals within the Abiquiu Formation, and the chert is totally absent near the village of Abiquiu. The distribution of the unit indicates that it formed sometime after the Abiquiu Formation was deposited and is likely a diagenetic unit that formed as silica-enriched ground water moved through and precipitated in the sediment. The andesite flows capping Cerro Pedernal give the mountain its distinctive flat top and were erupted from the northern Jemez volcanic field about 8 million years ago.

**ECHO AMPHITHEATER**—A few miles north of Ghost Ranch on US 84 is the Echo Amphitheater, on the Carson National Forest. Here high cliffs of Entrada Sandstone form a natural amphitheater. Look closely at the Entrada Sandstone and you can see inclined lines of stratification running at angles to one another through the cliffs. These are called cross-beds, and they outline the faces of ancient sand dunes. The red rocks at



Echo Amphitheater is cut into the Jurassic Entrada Formation. This rock unit is underlain by brick-red Chinle (lower right) and overlain by Todilto Formation.

the base of the cliff are the Triassic Chinle Group. The thinly bedded gray rocks and white soft rocks on top of the Entrada Sandstone cliffs are the Todilto Formation.

**THE BRAZOS BOX**—East of Tierra Amarilla on US 64 there are great views to the north of the feature known as the Brazos Box. Here extremely tall cliffs of Precambrian Ortega Quartzite rise above the trees. The Rio Brazos has cut a 2,000-foot-deep gorge through the quartzite. Rivers do not cut slots through rocks unless the rock slowly rises. Raise a piece of cheese up through a cheese wire and you will end up with a slot. Imagine the wire is the Rio Brazos and the cheese is the quartzite, to get some idea of how the Brazos Box formed.



The Ortega Quartzite exposed in the Brazos Box was deposited along the ancient southern margin of the North American continent 1.7 billion years ago.

**HOPEWELL LAKE**—Traveling farther east on US 64 you will reach Hopewell Lake on the Carson National Forest. If you hike around this area you will see Precambrian rocks. The rocks in this area are metamorphosed igneous rocks and include altered volcanic rocks that are now hornblende schist as well as a 1.7 billion-year-old intrusive granodiorite. Placer gold mining is part of the history of the Hopewell Lake area. Modern-day gold panners still work the main drainage below the lake.

—Adrian P. Hunt and Shari A. Kelley

## Additional Reading

*The Little Dinosaurs of Ghost Ranch* by E. H. Colbert. Columbia University Press, 1995.

*Ghost Ranch* by Lesley Poling-Kempes. University of Arizona Press, 2005.

*Geology of the Chama Basin* edited by Spencer Lucas, Kate Zeigler, Virgil Lueth, and Donald Owen. New Mexico Geological Society 56th Annual Field Conference Guidebook, 2005.

## If You Plan to Visit

The Abiquiu–Tierra Amarilla area is most easily accessed by taking US 84 north from Española. An alternate, more scenic route is by way of NM–96 west from US 550 just north of Cuba. Not all of this is public land, although much of the geology is visible from the highway. Portions of it are included in the Carson National Forest, including Hopewell Lake. Abiquiu Reservoir is managed by the U.S. Army Corps of Engineers. Ghost Ranch is privately owned, though the museums and trails there are open to the public.

Cerro Pedernal can be accessed by driving 27 miles northwest from Española on US 84, then turning west (left) onto NM–96 toward Youngsville. Travel 11.5 miles west and watch carefully for a small brown sign marking Forest Road 100, a gravel road on the south side of the highway, and turn left. The left turn into Temoline Canyon (Forest Road 160) on the south side of Cerro Pedernal is located 5.7 miles south along Forest Road 100. You can park your car here and walk about 3 miles up the road to an open meadow at the base of the steep slope near the top of Cerro Pedernal, or you can drive a high clearance four-wheel-drive vehicle to the meadow. For more information:

Carson National Forest  
208 Cruz Alta Road  
Taos, NM 87571  
(575) 758-6200  
[www.fs.fed.us/r3/carson/](http://www.fs.fed.us/r3/carson/)

Ghost Ranch Conference Center  
HC 77, Box 11  
Abiquiu, NM 87510-9601  
(505) 685-4333  
[www.ghostranch.org](http://www.ghostranch.org)

