View from the top of Vulcan at the Albuquerque volcanic field. *Photo courtesy of Linda Brown.*

Lite Geology

Fall 2018
Issue 43

In this issue...

This edition of Lite Geology highlights several places described in the New Mexico Bureau of Geology publication: *The Geology of Northern New Mexico's Parks, Monuments, and Public Lands*. L. Greer Price, featured "Through the Hand Lens" geoscientist, edited *The Geology of Northern New Mexico's Parks, Monuments, and Public Lands* book. This issue of *Lite Geology* also details research, hikes, historical geology, and even a movie, framed by these settings. By spotlighting "The *Northern Parks Book*" we hope to inform our readers of the many beautiful landscapes and natural resources in our state that have shaped our history and culture. We also seek to get readers excited about the upcoming New Mexico Bureau of Geology publication: *The Geology of Southern New Mexico's Parks, Monuments, and Public Lands*, scheduled to be released in 2019.

Earth Briefs: The Valles Caldera National Preserve

Shari A. Kelley

The Valles Caldera National Preserve, which became a part of the National Park System in 2015, features a 13 mile wide caldera that formed during the eruption of a supervolcano 1.25 million years ago, and a world-class, post-eruption resurgent dome. The Preserve is located in north-central New Mexico about 18 miles west of Los Alamos in the middle of the Jemez Mountains. Visitors flock to the Preserve to see the exceptional volcanic landscapes, enjoy the beautiful vistas across grassy meadows, and view the abundant wildlife that includes large elk herds. Scientists from a wide variety of technical fields (aside from the geological sciences) are also drawn to the Preserve because of its unique ecology, hydrology, and upland setting. One group of scientists from the University of Arizona has created a collaborative network called the Jemez River Basin Critical Zone Observatory in order to study "the thin veneer of Earth that extends from the top of the forest canopy to the base of weathered bedrock." This area was chosen as an observatory because Redondo Peak, the resurgent dome in the center of the caldera, creates a "unique situation where headwater streams of the Jemez River originate on different aspects [hillslope orientations] of the same mountain, providing the opportunity to probe contrasting microclimates on a uniform parent material with a common precipitation regime." Study of the Jemez River watershed in the Rio Grande basin is paired with study of a second watershed in the Santa Catalina Mountains northeast of Tucson, Arizona, in the Colorado River basin. The National Science Foundation provides funding for these investigations.

Most of the geoscience-related critical zone research in the Valles caldera focuses on determining the thickness of soil and weathered rock (regolith) on volcanic features in the Jemez Mountains using reflection seismology, calculation of rates of regolith production and erosion in this mountainous setting, and measurements of the rate of erosion of regolith after wildfires. These studies have documented that soil and regolith in watersheds on Redondo Peak are generally thicker on ridgelines and slopes and are thinner beneath the valley bottoms; this pattern mimics the depth to the groundwater table observed beneath the topography of mountain ranges. Furthermore, soil and regolith are thicker on north-facing slopes.

Measurements of the thickness of regolith deposits on hillslopes have at least two practical applications. First, this information can be used to properly design the capacity of manmade dams and retention ponds that mitigate the effects of debris flows that form in the aftermath of devastating forest fires, such as the 2000 Cerro Grande and 2011 Las Conchas fires that scorched large parts of the Jemez Mountains. Second, thick regolith deposits profoundly influence groundwater/surface water interactions in high-elevation settings by storing snow-melt water that later provides summer base-flow to mountain streams. Isotopic studies of groundwater show that the water residence times in mountain watersheds that face north are longer than those that face south.

View of the Valle Grande from Los Griegos on the southern rim of the Valles Caldera. The dead trees in the foreground were burned in the 2011 Las Conchas fire. This area is near the origin of that fire. *Photo by Shari Kelley.*

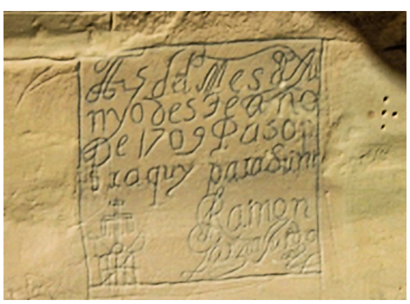
For more information about this project, go to
criticalzone.org/catalina-jemez/about/

View from Los Griegos on the south side of Redondo Peak, a resurgent dome that formed when the floor of the Valles Caldera was pushed upward by rising magma after the caldera-forming eruption 1.25 million years ago. The Jemez River Basin Critical Zone Observatory focuses its investigations on this mountain. *Photo by Shari Kelley.*

How Water affects inscriptions at El Morro National Monument, New Mexico

Talon Newton

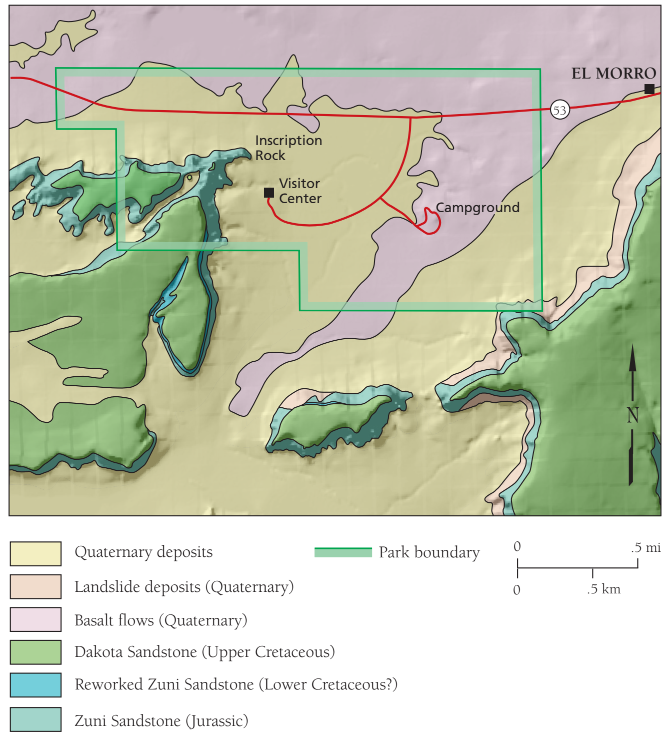
El Morro National Monument is located in Cibola County in western New Mexico and features the 200 to 145 million year old, Zuni Sandstone cliffs of El Morro, which served as a prominent landmark and water source (a perennial pool lies at the base of the cliff) for Puebloan people, Spanish explorers and American settlers for hundreds of years. Inscription Rock, a 70-meter-high sandstone monolith, documents a long history of human activity featuring the Atsinna Pueblo ruins, petroglyphs, and thousands of signatures carved into the cliff walls by Spanish explorers and American emigrants. One of the primary goals of El Morro National Monument, established in 1906, is the preservation of these historic inscriptions that are deteriorating due to both natural and anthropogenic processes. Much research has been conducted to understand the natural erosional processes that contribute to the deterioration of the inscriptions in order to identify possible methods to mitigate their eventual loss. Geochemical reactions between water and minerals and the freezing and thawing of water are the primary drivers of these weathering processes. Therefore, it is important to understand how water comes in contact with the sandstone in areas where there are inscriptions.



Top: Inscription Rock at El Morro National Monument.

Bottom: Example of an inscription on Inscription Rock dated 1709.
Photos by Shari Kelley.

Researchers at the New Mexico Bureau of Geology and Mineral Resources have recently conducted a study that aimed to understand the different travel pathways that bring water in contact with the inscriptions. Of the many scientific techniques used for this study, the measurement of soil moisture at different areas throughout the Monument provided insight to the process by which rain and snow-melt at the top of the cliff moves downward through the subsurface. Instruments that recorded hourly measurements of the amount of water present in the top 12 inches of soil were installed at different distances from Inscription Rock. For areas located out in the open, away from the cliff, rain storms resulted in small increases in soil moisture in the top 4 inches, which quickly decreased within a few days due to evaporation and transpiration (water used by plants) if no other storms occurred. This pattern in post-storm soil moisture loss was also detected in some areas next to the cliff, indicating that precipitation was the only source of soil moisture in these areas. However, in some areas near the cliff, it appeared that extra water entered the soil during these storms, resulting in much higher increases in soil moisture in the top 12 inches below the surface. In addition, the soil moisture in these areas did not decrease as quickly as was observed at points away from the cliff. These data indicate that when it rains or snow melts on top of the cliff, some



Generalized geologic map for El Morro and vicinity. From *The Geology of Northern New Mexico's Parks, Monuments, and Public Lands* book, p.42.

water flows through northeast-trending joints downward to the bottom of the cliff. These joints are fractures that began to form between 35 and 80 million years ago during the Laramide orogeny, a period of heightened tectonic activity that formed the mountains in western North America. Researchers have found that water traveling along these joints may be the contributing to the deterioration of some of the inscriptions.

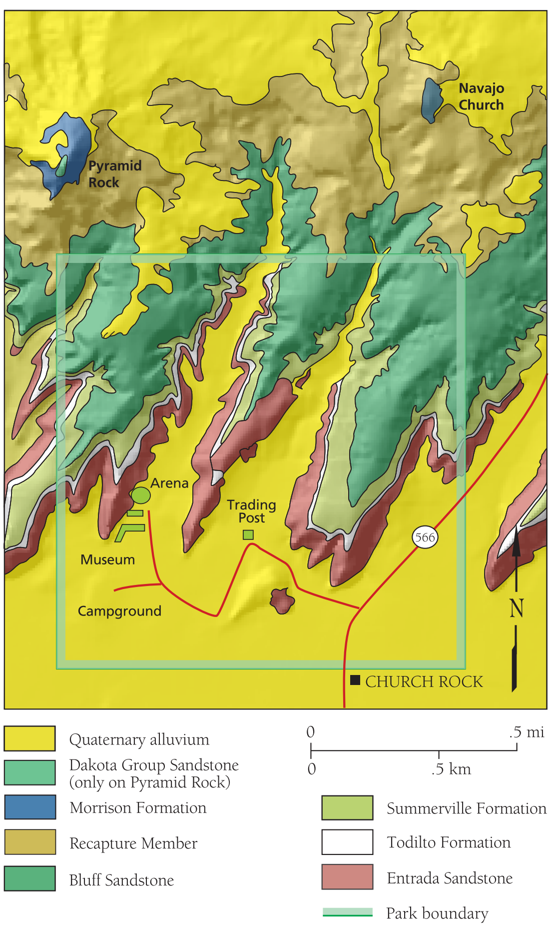
Aerial view of Inscription Rock shows prominent linear joints that provide pathways for water to move through the cliff. Pinion and Juniper trees for scale. *Photo courtesy of Google Earth.*

A Geology Guide to Red Rock Park

Virginia T. McLemore

Red Rock Park, east of Gallup, New Mexico, takes its name from the spectacular red sandstone cliffs surrounding an impressive array of public facilities, including a rodeo arena, convention center, museum, and camp grounds. The 640 acre park offers excellent scenery for balloonists, hikers, campers, and other visitors. Red Rock Park opened in 1972 as a state park and was turned over to the Navajo Indian Tribe in 1989. Hiking along the one mile nature trail north of the Outlaw Trading Post takes the visitor into undeveloped portions of the park.

In Red Rock Park, exposed Jurassic rocks date from 175 to 145 million years old and Quaternary rocks less than one million years old. The oldest and most prominent rocks within Red Rock Park are the red sandstones belonging to the Jurassic Entrada Sandstone. The spectacular cliffs forming the background for the public facilities in the park belong to this unit. The Entrada Sandstone is divided into three members: Iyanbito Member (oldest), a middle siltstone member, and an upper sandstone member. (youngest).



Generalized geologic map of Red Rock Park and vicinity. Navajo Church and Pyramid Rock are two most prominent topographic features visible from the park. From *The Geology of Northern New Mexico's Parks, Monuments, and Public Lands*, p.46.

Impressive Jurassic Entrada Sandstone cliffs border museum facilities at Red Rock Park. *Photo by Cynthia Connolly.*

The basal Iyanbito Member is not exposed at Red Rock Park. The middle siltstone member consists of 40 to 60 feet of reddish-brown to reddish-orange silty sandstone and siltstone that form slopes at the base of the massive cliffs. The upper sandstone member forms the amazing cliffs and consists of 100 to 400 feet of reddish-orange, well-cemented, thick-bedded, well-rounded sandstones, typical of ancient sand dunes. High-angle cross-beds or layers are seen in the sandstone. The sand dunes were cemented by silica and calcite from groundwater and compacted to form the massive rock cliffs seen today.

The Todilto Formation overlies the Entrada Sandstone and forms a white to gray, resistant cap on top of the Entrada Sandstone. It consists of as much as 20 feet of fine-grained limestone that was deposited in either a marine bay or a saline lake. Topping the Todilto are slopes of interbedded white, pink, and reddish-brown sandstone, siltstone, and shale belonging to the Summerville Formation. The Summerville is as much as 50 feet thick and was deposited in a shallow-water coastal plain environment, marginal to the Todilto marine embayment or saline lake.

Jurassic Bluff Sandstone sits on the Summerville Formation and consists of 190 feet of green-gray to pink, well-cemented sandstone. This unit was deposited in an arid environment as sand dunes. The Jurassic Morrison Formation is located above the Summerville Formation and consists of three members: Recapture (oldest), Westwater Canyon, and Brushy Basin (youngest). Only the Recapture Member is present in the park and consists of 100 feet of reddish-brown to brick-red siltstone interbedded with white to green to yellow sandstone. The Recapture Member is well exposed at the base of Navajo Church, seen from the Outlaw Trading Post. The Recapture Member was deposited in both fluvial (river) and eolian (wind-blown), sand-dune environments.

The Westwater Canyon Member is not exposed within the park boundaries, but it is visible on some of the mesas north of the park and at the top of Navajo Church. This unit consists of 130 to 230 feet of red to orange sandstone with thin lenses of siltstone and shale. The Westwater Canyon Member was deposited in a fluvial environment. It is host to most of the uranium resources in the Gallup–Grants area. The Brushy Basin Member also is not exposed within the park boundaries but crops out north of the park. It consists of green to purple to gray shale, siltstone, and sandstone. These rocks were subsequently eroded, mainly by wind and rain, to form mesas and spires such as Navajo Church. Erosion of the rock continues today and contributes to Quaternary alluvium and unconsolidated eolian sand and silt deposits in the park.

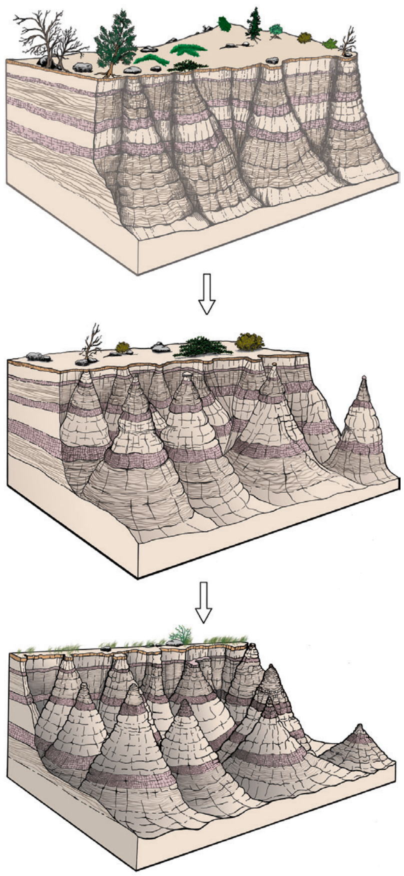
Volcanology of Kasha-Katuwe Tent Rocks National Monument

Cynthia Connolly and Nelia Dunbar

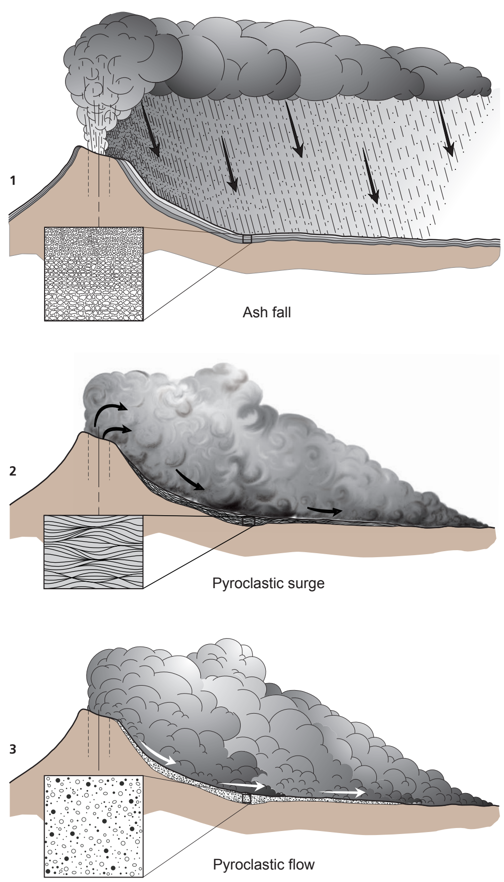
Kasha-Katuwe hoodoos with Cerrillos Hills to the left and Ortiz Mountains on the right, in the background. *Photo by Cynthia Connolly.*

Kasha-Katuwe Tent Rocks National Monument is a unique and spectacular geologic marvel located about 40 miles southwest of Santa Fe on the flanks of the Jemez Mountains. Kasha-Katuwe, which means "white cliff" in Keresan, the traditional language of the people of Cochiti Pueblo, was created approximately 7 million years ago as part of pyroclastic activity from Jemez Mountain volcanic field eruptions. Conical tent-shaped rocks (called hoodoos), some with capstones, were formed through preferential erosion of the Peralta Tuff, mostly by water. Rocks more resistant to erosion protect the softer material beneath to form hoodoos.

The various rock textures seen at Kasha-Katuwe tell the story of several different styles of pyroclastic deposition. Some layers were formed directly from volcanic eruption deposition (pyroclastic) and other layers were deposited and reworked by wind or water (epiclastic). Deposits from several pyroclastic eruption styles can be seen. Ash-fall deposits commonly exhibit layered, planar bedding. Cross-bedding is indicative of pyroclastic surge deposits, where ash and pumice are transported in a cloud of hot, volcanic gas. Pyroclastic flows produce rock with indistinct bedding consisting of a various grain sizes, and also result directly from volcanic eruption.



Following the deposition of thick layers of Peralta Tuff, erosion has shaped the receding cliff faces into "tents." Large rocks more resistant to erosion protect the softer material underneath, resulting in the conical shapes we see today. From *The Geology of Northern New Mexico's Parks, Monuments, and Public Lands*, p. 157.



Several different lithologies are represented within the Peralta Tuff. From *The Geology of Northern New Mexico's Parks, Monuments, and Public Lands*, p. 154.

After the deposition and lithification (process by which loose sediment is converted into rock) of pyroclastic and epiclastic material, several earthquake events produced a 350 foot offset of pyroclastic layers along a secondary fault associated with the Pajarito fault. The main Pajarito fault zone, located to the east of Kasha-Katuwe, has off set the 1.2-million-year old Bandelier Tuff by hundreds of feet indicating that some of these earthquakes must be younger than 1.2 million years. The presence of capstones on tent structures shows that there has been no major seismic activity recently, since earthquake motion would cause many of these balanced capstones to fall.

Another fascinating item that can be found at Kasha-Katuwe are "Apache Tears," composed of dark- colored volcanic glass called obsidian. Obsidian is a product of rapid cooling of rhyolitic lava, probably close to the volcano. Fractures in the obsidian facilitate break-down of the larger lava flow into smaller pieces of obsidian, which are then transported by water and deposited alongside sand in sedimentary beds. The name Apache Tear, is derived from a story about a band of Apaches that were killed by the U.S. Calvary. The women of the tribe cried for their dead and their tears became immortalized as the Apache Tear obsidian fragments. When visiting Kasha-Katuwe, please do not take Apache Tears.

Rio Grande del Norte National Monument: Where volcanoes and rivers collide!

Matt Zimmerer

To many people, New Mexico is one of the best places on Earth to study and explore geologic processes. From the picturesque sedimentary rocks and related fossils of the Colorado Plateau to the uplifted granites and the Great Unconformity of the Sandia Mountains, New Mexico seems to have it all. But if you are interested in the combination of young volcanoes and the relentless power of flowing water, perhaps no place is better than Rio Grande del Norte National Monument of northern New Mexico. The monument, designated on March 25th, 2013, is one of the newest public lands in the state—second only to Organ Mountain and Desert Peaks National Monument outside of Las Cruces. Located directly south of the New Mexico–Colorado border and with much of the land elevation near or above 7,000 feet, the monument is a great place to escape the summer heat.

Aerial image (facing south) of the confluence of the Red River (gorge on the left) and Rio Grande (gorge on the right) at Wild Rivers Recreational Area. Layers of lava flows are well exposed in the gorge walls. All of the topographic high points on the mesa are extinct volcanoes.

Two world-renowned New Mexico geologic features are on spectacular display in the monument, the Taos Plateau volcanic field and the Rio Grande gorge. Within the monument nearly every peak or mountain that towers over the high plateau is an extinct volcano. For example, San Antonio Mountain and Ute Mountain are both extinct volcanoes. The volcanic field is located in the Rio Grande rift, where the Earth's crust is spreading and thinning. Similar to other rift zones around the world (such as the East African rift or the West Antarctic rift), this process results in widespread volcanism and faulting. Eruptions of the Taos Plateau volcanic field began around 10 million years ago. The youngest eruption occurred approximately 1 million years ago, originating from the Mesita vent in south-central Colorado. The current hiatus in eruptions indicates that the field is probably extinct or, alternatively, in a very long dormant period. The volcanoes erupted a wide-range of lava types, from rhyolite to basalt, although the latter seems to be the most abundant. To the east of the volcanic field, the uplifted flank of this part of the Rio Grande rift forms the Sangre de Cristo or "Blood of Christ" Mountains. Light from a typical sunset turn the mountains a deep reddish color, which is the inspiration for their name.

View of Big Arsenic Spring as it enters the Rio Grande. For more information on the springs of the area check out this article (www.geoinfo.nmt.edu/publications/periodicals/nmg/32/n1/nmg_v32_n1_p26.pdf) or follow this link to an informative slideshow of the unique hydrogeology of the area (www.geoinfo.nmt.edu/repository/index.cfml?rid=20100001).

Slicing through the heart of the volcanic field (and the monument) is the Rio Grande gorge. The gorge varies in depth throughout the monument from a couple hundred feet deep in the north to almost a thousand feet deep near the confluence of the Rio Grande and Red River. Exposed within the walls of the gorge are layered lava flows from the volcanic field. If you look closely you will find lenses of sediments between the flows that were deposited in between eruptions. The sediments are commonly an orange-red color, which is due to the intense heat the sediments experienced when the overlying flows were emplaced. Numerous hot and cold springs are located throughout the gorge, commonly found along faults or where groundwater seeps out along the top or bottom of lava flows.

In addition to the spectacular geology, the monument is occasionally the site for geologic training of NASA astronaut candidates (also known as ASCANs). The volcanoes and erosional features found within the monument are similar to what we think might exist on other planets. For a week in June 2018, four bureau geologists (Paul Bauer, Mike Timmons, Adam Read, and Matt Zimmerer), along with instructors from the University of Texas at El Paso and at Austin, Hamilton College, the USGS, and NASA participated in training the 2017 astronaut candidates. The 14 members of the 2017 ASCAN class are from a variety of backgrounds, including

Photo of the 2017 astronaut candidate group after completing the 2018 geologic mapping exercise at Wild Rivers Recreational Area. *Photo by Paul Bauer.*

aviation, military, medicine, biology, engineering, and even geology. Prior to their arrival at the monument, the ASCAN class spent a week reviewing satellite and remote sensing images of the field area, imagery similar to what they might see and acquire from the International Space Station. After developing hypotheses related to the geologic history of the area, their time in the monument was spent making field-based observations to test their hypotheses and constructing geologic maps and cross-sections. The training helps the future astronauts understand fundamental geologic processes and may even play a role in mission planning for future trips to the Moon, and possibly even Mars.

You don't have to be an astronaut, however, to explore this wonderful monument. Much of the monument can be accessed by car, such as the Wild Rivers Recreational Area and the Rio Grande Gorge Bridge. Numerous trails, which lead to both the highest peaks and the bottom of the gorge, provide hiking and horse-back riding opportunities. Arguably one of the best ways to explore the monument, particularly in the summer, is by rafting or kayaking down the Rio Grande.

More information can be found following these links:

Information about the monument, including hiking, camping, and alerts.
www.blm.gov/visit/rgdnnm

Geology and River Guide for the upper Rio Grande.
geoinfo.nmt.edu/publications/guides riogrande/home.cfml

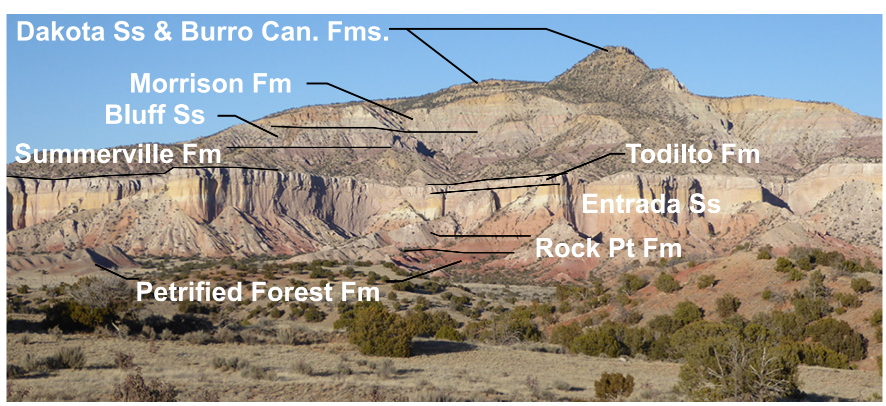
The colorful geologic wonder of Ghost Ranch

Daniel Koning and Shari Kelley

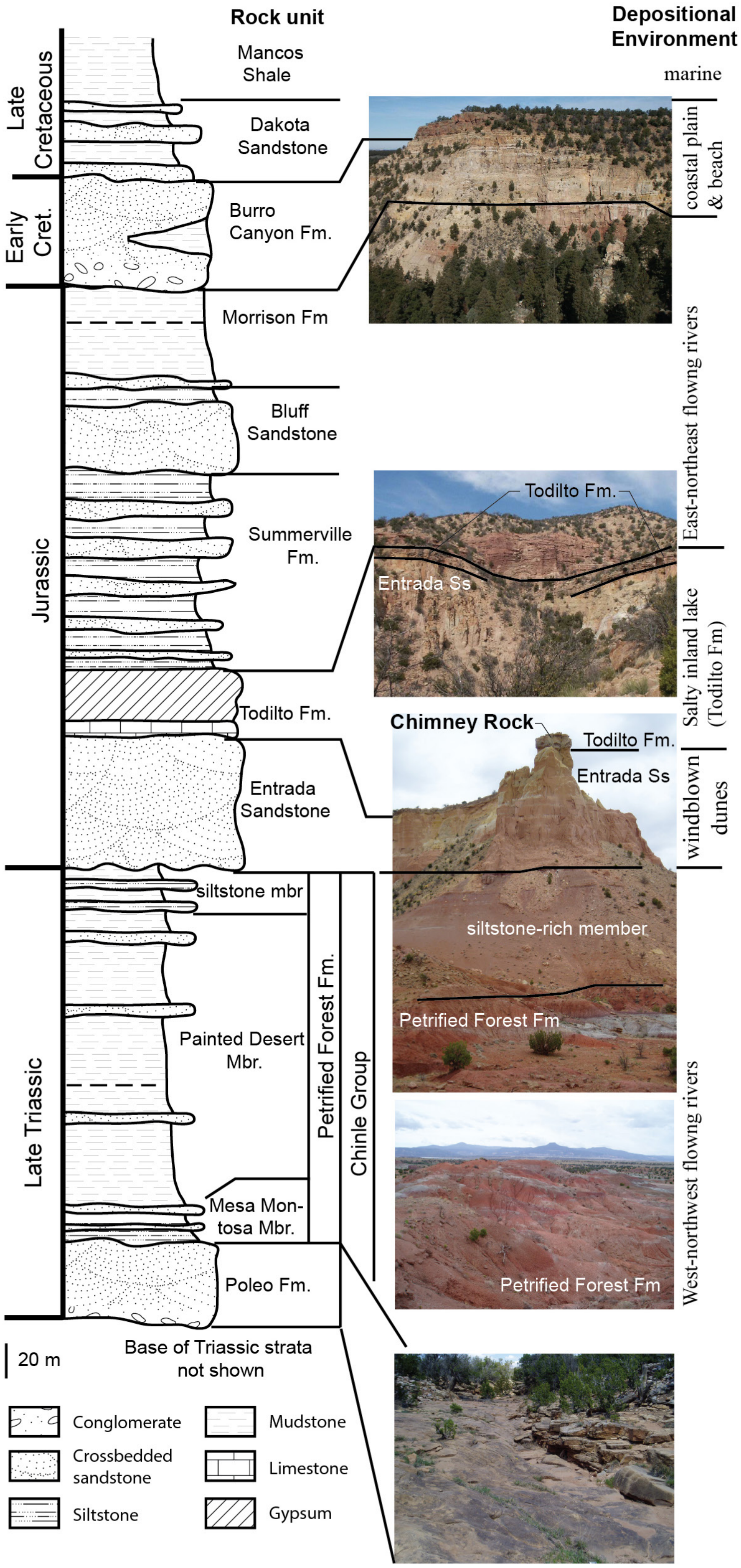
The drive between Santa Fe and Chama is one of the most scenic in New Mexico. A highlight of the drive is the wide Chama Valley, where Abiquiu Lake is framed by gorgeous, colorful cliffs to the north. Nestled in those picturesque cliffs is Ghost Ranch, which makes a nice midway stop in the drive. Operated by the Presbyterian Church, for a nominal fee of $5 one can hike several trails that either wind through narrow canyons or climb adjoining mesas for an even-better view than seen in the car. One can readily appreciate why Georgia O'Keeffe was so eager to capture this landscape in her paintings! We had the privilege of mapping the geology of the Ghost Ranch area about 13 years ago. In this article, we'd like to discuss the rock layers seen near Ghost Ranch and share the story of how they came to be.

Deposition

Let's start with the story first, and then relate the exposed rocks at Ghost Ranch to the story. This story has three episodes. The first happened 220 to 100 million years ago, when none of the landscape you see now was present and dinosaurs were stomping around. Over time scales of millions of years, difficult for the human brain to fathom, layers of sediment were laid down by either water or wind (creating distinctive layers called formations). Back then, this land was relatively flat and witnessed a progression of dramatic changes in environment. First, at 220 to 200 million years ago (Late Triassic), there were large rivers flowing west-northwestward in an environment that resembled the lower Amazon River Basin. Sand deposited in the channels of the rivers make up most of the Poleo Formation, while the overlying Petrified Forest and Rock Point formations mostly contain sediment from the muddy swamp-lands. Jump forward about 30 to 40 million years, across a time gap in the geologic record (called an unconformity), and one would see a desert landscape. Wind-blown sand dunes stretched as far as the eye could see, á la the Sahara Desert, and their lithified remnants constitute the Entrada Sandstone. The dunes were followed by



Annotated photograph of the cliffs and steep slopes found west of Ghost Ranch. (Fm is an abbreviation for formation.) *Photo by Shari Kelley*, and *annotated by Dan Koning.*



A stratigraphic column (left) showing the stacking order of formations at Ghost Ranch. The composition of rock in these formations is shown by various graphic patterns, explained at the bottom of the column. Geologic photographs on the right side are tied to particular formations by black lines. *Courtesy of Spencer Lucas* and *Kate Zeigler*, *modified by Dan Koning*.

establishment of a large, salty lake or bay—like the Dead Sea in Israel. Gypsum and limestone laid down in this lake form the Todilto Formation. After that, rivers began flowing here again, but this time to the east-northeast, and sequentially laid down the Summerville, Bluff Sandstone, and Morrison formations between 165 and 148 million years ago. Over this time period, the environment progressively became less arid and more humid. Jump forward tens of millions of years in time, across another unconformity, and one would see rivers depositing sediment (Burro Canyon and lower Dakota Sandstone Formations) on a coastal plain on the lee side of a mountain range located to the southwest (in Arizona). Sea levels were progressively rising so that by 95 to 96 million years ago, a marine beach was here (middle to upper Dakota Sandstone), followed by submersion under a shallow ocean. This ocean laid down muds that geologists refer to as the Mancos Shale.

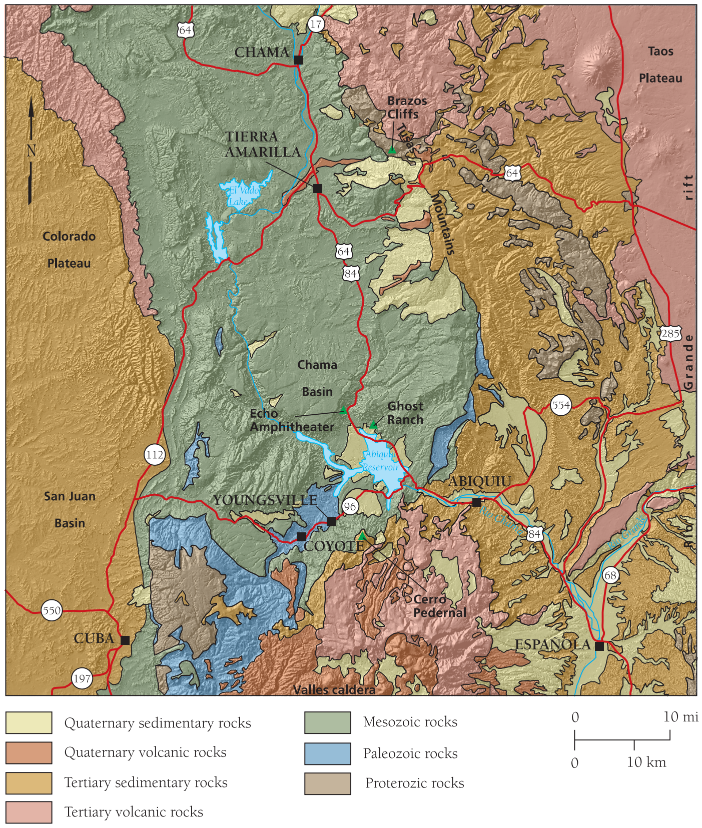
Tectonic activity and erosion

The second episode in the geologic story involves a two-part narration of Earth tectonic activity. It is not evidenced in the deposition of the sediment layers, but by what happened to the first episode layers after they were deposited. The first part of tectonic deformation happened 70 to 40 million years ago, when the earth's crust was being pushed together. The second part happened 30 to 5 million years ago, when the earth's crust was being pulled apart. The pushing locally folded the rock layers (not too much, because most of the sediment layers are flat). The later pulling formed faults, where layers slide past each other along extensive, planar cracks. During 30 to 5 million years ago, the area was being uplifted, probably in pulses, and sediment was not able to accumulate like it did in the first episode.

Canyon-carving

Canyon-carving is the theme of the third episode.
This canyon-carving began 7 or 8 million years ago, but probably accelerated during glacial-interglacial paleoclimate cycles that characterized the last 700,000 years of the Earth's history. Down-cutting of the Rio Chama and its tributaries, including the ones near Ghost Ranch, incised into the Triassic-Jurassic sedimentary layers deposited in the first episode. Steep slopes and cliffs created during this incision facilitated landslides and rockfalls that widened the stream valleys. Landslides were more active prior to the relatively dry climate we are in now, because higher precipitation primes steep slopes, (especially slopes underlain by mudstones), for catastrophic failure. But rockfalls still occur and locally modify the landscape, as observed several years ago on a jutting cliff (of Todilto-Entrada Sandstone) about 1.5 mi west of Ghost Ranch.

For a brief visual narration of the geology, let's start near the intersection of the Highway 84 and the dirt road that leads north to Ghost Ranch. One thousand feet west of this intersection, Highway 84 crosses a canyon carved by Arroyo Seco, which is a tributary to the Rio Chama. The light gray sandstone forming the walls of the canyon belong to the Poleo Formation, laid down by rivers flowing northwest about 215 million years ago.



Generalized geologic map of the Abiquiu region. From *The Geology of Northern New Mexico's Parks, Monuments, and Public Lands*, p. 115.

The flat surface on the west side of the canyon is a river terrace formed during a brief pause in the landscape incision that characterized the third episode of the geology story. Driving the dirt road north of the intersection, one crosses a flat, grassy surface formed on alluvium (a few hundred thousands of years old) laid down by local side-streams. On the right, is a log cabin that once was used as a movie prop. The road crosses Arroyo del Yeso and then continues to Ghost Ranch headquarters on a wide valley floor underlain mainly by unconsolidated sand only a few to several thousand years old—geologically young! To the left, is a beautiful, smooth landscape underlain by reddish and purplish mudstones of the Petrified Forest Formation. Ahead are looming cliffs that effectively wall the canyon. These belong to the Entrada Sandstone, and bear evidence of the Sahara-like conditions that used to exist here. Capping the Entrada is a white, somewhat "crusty" layer of rock that belongs to the Todilto Formation.

Two trails from Ghost Ranch headquarters ascend the Entrada-Todilto cliff. The one to the west climbs up a landslide to allow views of Chimney Rock, a spire of Todilto on top of Entrada Sandstone. The Kitchen Mesa Trail takes advantage of stacked-up rockfalls and a notch to ascend the cliff. Once on top, one has a wonderful vista of the reddish-orange Triassic rocks below. To the northeast, one can see grayish red rock layers (Summerville Formation) that transition upwards to light gray sandstone (Bluff Sandstones) and greenish-pastel layers (Morrison Formation). In most areas above the Entrada-Todilto cliff, these upper rock layers are not exposed because of landslide activity over the past 700,000 years, which effectively create a "mushy", tree-covered landscape rather than the well-exposed badlands seen below. However, at the top of the landslide-dominated, upper slopes one sees a continuous, capping rock layer corresponding to the Dakota Sandstone underlain by the Burro Canyon Formation. Another trail leads up Arroyo del Yeso to the Box, which is incised into cliffs of Entrada Sandstone. Numerous waterfalls fed by several fault-controlled springs cascade over large blocks of sandstone that have fallen off of the cliff.

Knowing the geology story adds an intriguing time dimension for enjoying the three-dimensional wonder of the beautiful rocks near Ghost Ranch—a colorful landscape that Georgia O'Keeffe loved to capture in her paintings. More information about the Ghost Ranch area, including its geology, can be found on their website:
www.ghostranch.org

Teacher Hike: Albuquerque Volcanoes Field Trip

Linda Brown

The Albuquerque Volcanoes, located on Albuquerque's west side, make for an easy two-hour field trip in which students can learn about volcanic features and the Rio Grande rift. The field trip includes several stops in which teachers can instruct students about these features. I have students take notes and make drawings during the field trip. The field trip can be done without climbing Vulcan, but if you do wish to climb to the top of Vulcan, you need to get an educational permit to do so. You can get this permit by calling the Petroglyph National Monument at (505) 899-0205.

There are two maps that I give students on the field trip. The first is a segment of the USGS Volcano Ranch quadrangle. This map can be found at the following link:
www.yellowmaps.com/usgs/quad/35106b7.htm

The second is a simplified map from the paper titled "Basaltic near-vent facies of Vulcan Cone, Albuquerque Volcanoes, New Mexico" by Gary A. Smith, Patrick S. Florence, Alex D. Castrounis, Mark Luongo, Jessica D. Moore, John Throne, and Karin Zelley, 1999.

The map can be found on the 4th page of the pdf (listed as page 212) at this link:
nmgs.nmt.edu/publications/guidebooks/downloads/50/50_p0211_p0219.pdf

I also use an enlarged cross-section of the Rio Grande rift in order to explain the rift features. I constructed this based on a cross-section created by Sarah Wilson at Sandia Prep (see accompanying photo).

Teacher Notes for each stop:

Parking Lot: Safety and Guidelines

- Instruct students to watch their footing as the trail becomes rocky, and, if climbing Vulcan, becomes steep.
- Keep an eye out for snakes and be careful of where you step and place your hands.
- You are in a National Monument, so you need to leave things as you find them and pack out any trash.

Thank you, Linda Brown

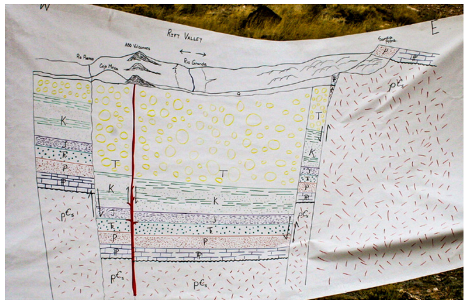
"Teacher Hike" a new *Lite Geology* feature, aims to get teachers and students outside the classroom and into exploring the amazing geology of New Mexico. This segment is written by guest writers, who have field-tested these hikes. Linda Brown, a master teacher at Eldorado High School in Albuquerque, New Mexico, is a veteran of many "Rockin' Around New Mexico" geology workshops and definitely knows how to rock out! Linda has taken her classes to the Albuquerque Volcanic Field multiple times and uses a plan modified from Sandia Prep teacher Sarah Wilson. *Lite Geology* is looking for educators to share their geology field experiences with other teachers. If you would like to submit a field trip piece to our publication, please email Cynthia Connolly: cynthia.connolly@nmt.edu. Thank you Linda Brown for contributing this well written and informative article!

- Do not walk on any trails that are being treated for erosion control (covered in jute fiber, or obliterated).

Map: Volcano Ranch Quadrangle

- discuss how topographic maps are used. This can be in-depth or a review if students have already learned about maps in class.
- I have students orient themselves on the map and label the three main cones with their names. The south most cone on the map is JA, the middle one is Black and the northern one is Vulcan.

From here, we walk the trail to the east and then to the north around the east side of Black. Our first stop is where the trail curves to the west and there is a good view of Vulcan.



Enlarged cross-section of Rio Grande rift. *Photo courtesy of Linda Brown.*

Stop 1: North Side of Black

I start out here with a general overview of the volcanoes.

- They are cinder cones that erupted approximately 150,000 years ago (the age estimate ranges anywhere from 140,000 to 200,000 years depending on the dating technique used).
- These volcanoes formed because of faults and thinning of Earth's crust in the Rio Grande rift.
- The eruption occurred along two fissures that are slightly offset from each other and trend from north to south. JA, Black and Vulcan are located on the southern fissure and Bond and Butte are located on the northern fissure. Eventually the lava cooled and solidified along the fissures except for a few points, where lava continued to erupt and the existing cones are located. At these points, lava and spatter (blobs of lava thrown into the air) built up the cones.
- The lava is basalt, and in particular is tholeiite, which is a type of basalt that is low in sodium and potassium.
- 23 square miles of land were covered by lava flows.
- There are six lava flows that have been mapped.
- There is another cone just to the north of Black, called Cinder. It is no longer prominent as it was mined away in the past.

I have students make a sketch of Vulcan, the most prominent cone to the north.

From this stop, we continue along the trail to the base of Vulcan. If you have obtained a permit, you may proceed past the gate to the north. I take students to a flat spot to the right of the trail at the base of Vulcan (just above the borrow pit, which is marked on the map of Vulcan). If you do not have an educational permit, continue to follow the trail to the west and then around to the north and then east into the crater/quarried area, which is stop 4.

Stop 2: Above Borrow Pit on South Side of Vulcan

I take out my enlarged cross-section of the Rio Grande rift and talk about the rift features and types of rock and point them out on the cross-section. Students take notes and draw a simplified version of the cross-section.

- The Rio Grande rift is a continental rift, which is where the continental crust is being pulled apart. The rift is being pulled apart at a rate of 2.5 cm every 40 years.
- The rift begins in Colorado and extends down into Mexico.
- The center of the rift is dropping down and the margins are rising up along normal faults (I point out the Madera limestone on top of the Sandia Mountains and show where this is on the cross-section. I compare this to where it is located thousands of feet beneath Albuquerque).
- At Albuquerque, the east margin of the rift is located along the Sandia Mountains and the west margin of the rift is located along the Rio Puerco.
- The volcanoes formed along a fracture that was caused by rifting, which allowed magma to rise up through the crust.

View of Vulcan at the Albuquerque volcanic field. *Photo courtesy of Linda Brown.*

I point out Mt. Taylor to the west and discuss that it is a composite volcano.

- This type of volcano has magma that is rich in silica, making it more viscous

Linda Brown on top of the world with her students and a small helper. *Photo courtesy of Brian Baker.*

and thus the eruptions more explosive.

At this location, I also have students collect different rocks from the nearby area (and put them back before leaving).

- The rocks are basalt and scoria with vesicles (holes formed from escaping gas).
- The color of the basalt and scoria is controlled by the condition of the iron in the rock. The more oxidized the iron is, the redder the rock.
- Some rocks are covered in a white coating called caliche. This is calcium carbonate, which is common in the soils of arid environments.

As we get ready to leave and climb Vulcan, I talk about the composition of the cones.

- The cones are made up of lava flows that are coated in ash & cinders—small particles of dried lava, and spatter—thin sheets and blobs of magma that cooled rapidly and coated the sides of the cone in a hard crust.
- I also remind students about safety when climbing Vulcan and tell them to take their time getting to the top.

Continue north on the trail to climb Vulcan.

Stop 3: Top of Vulcan

At the top of Vulcan is a great spot for a group photo. After photos, I have students take out their map of Vulcan and I talk about some of the different lava flows shown on the map.

- Clastogenic lava – basalt that formed in close proximity to fountains of lava
- Lava pond basalt – with columnar joints (four to six sided columns that form in basalt)
- Shelly pahoehoe – basalt with a smooth or ropy surface

From here, I have students follow the trail down the southwest side of Vulcan. Once down, continue to follow the trail to the west, then north and then east into the quarried part of the crater.

Stop 4: Crater/Quarry of Vulcan

At this stop, students observe the north and south sides of the crater, where we discuss the differences and students sketch the two sides.

- North: the sides are layered–this is due to differing levels of the lava within the lava pond.
- South: this side is blocky and contains poorly formed columnar joints.

I then describe lava tubes and gutters and tell students that we will be looking for them as we hike around the eastern and northern sides of Vulcan (you may only do this if you have an educational permit. If you do not have a permit, turn around and hike the trail back out and around the base of Vulcan. When you get the large dirt road, follow it back to the parking lot).

- Lava tubes form as lava is flowing along the surface of the ground. The outside of the lava flow cools and solidifies before the inside. The inside remains molten and empties out from the lava tube, leaving behind a hollow cavity. The lava tubes on Vulcan are small. One is hollow and students are able to look through it. There are also small gutters where the lava flowed. The most recent flows can be seen on the bottom of the gutters.
- I again remind students of safety, as we will be walking off trail through rocks and scrub brush. Remind them again to watch out for snakes.

From here, follow the trail to the east. I take students about ten to twenty feet down and then move around the outside of Vulcan to the north. I point out the differences between pahoehoe (smooth, ropy lava) and aa (rough, jagged lava). I point out examples of lava tubes and gutters and have students look for more. I take students to the hollow lava tube, which is located along the northeast part of Vulcan. We then continue around to the west of Vulcan and back to the trail. From here, follow the trail around the base of Vulcan until you come to the large dirt road. Follow this road to the south and it will take you back to the parking lot.

Earth Science Movie Review—Cowboys & Aliens (2011)

Andy Jochems

PG-13

1 hour, 59 minutes

Director: Jon Favreau

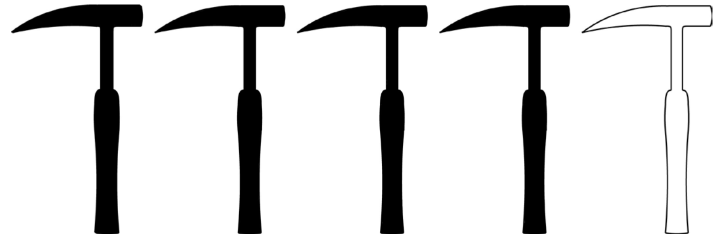
Cast: Daniel Craig, Harrison Ford, Olivia Wilde

Have you ever wondered what a cross-over between The Magnificent Seven and Men in Black would be like? No? Well you're not alone, but we got it anyway in 2011's Cowboys & Aliens from director Jon Favreau. If the western-meets-sci-fi mashup wasn't enough, the movie features an outstanding backdrop of the country between Abiquiu and Santa Fe. It's not an earth science flick by any stretch, but this movie provides excellent optics of northern New Mexico geology.

There's…aliens in them there hills? Triassic through Cretaceous rocks in the Ghost Ranch area provide stunning backdrops for Cowboys & Aliens. *Photo by Matthew Zimmerer.*

In the opening scene, a dazed and memory-less Jake Lonergan (Daniel Craig) awakens among the piñons and junipers of the high desert, complete with vistas of the Jemez Mountains and Cerro Pedernal. This is Ghost Ranch, known as Georgia O'Keeffe's home and, among geologists, for dinosaur-bearing rocks found at the intersection of the southern Rocky Mountains, Colorado Plateau, and Rio Grande rift.

Lonergan finds a futuristic metal bracelet strapped to his wrist—definitely not the work of the local blacksmith. He makes his way to the fictional town of Absolution, set in mid–1870s New Mexico Territory. The town site was filmed on the famous Bonanza Creek Ranch south of Santa Fe, long-time home to dusty, windswept western movie sets. The theatrical appeal of this spot is no doubt due to sweeping views of rangeland backed by the southern Sangre de Cristo Mountains. Much of this area is underlain by gently sloping Santa Fe Group basin-fill sediment less than 3 to 5 million years in age.



4/5 "picks"

Lonergan is soon thrown in jail by Sheriff Taggart (Keith Carradine) and local cattle-boss Colonel Dolarhyde (Harrison Ford) shows up to demand some good ol' vigilante justice. Turns out Lonergan, still suffering amnesia, recently relieved the Colonel of his precious gold. But justice must wait as Absolution comes under fire from mysterious, fast-flying ships that kidnap townsfolk via Inspector Gadget-like cables. The good sheriff and Dolarhyde's son Percy (Paul Dano) are among those snatched up. But things aren't quite hopeless—Lonergan's wrist contraption can track and shoot down these Reconstruction-era extraterrestrials.

It wouldn't be a western without a posse so Dolarhyde and Lonergan set aside their differences and the survivors set out in search of the missing humans. With them is Ella (Olivia Wilde), ostensibly an Old West courtesan but perhaps possessing deeper knowledge of the otherworldly antagonists. A series of misfortunes awaits the posse, including a holdup by Lonergan's old gang in a narrow canyon. This is Diablo (or Ancha) Canyon, formed by 2.5 million year old basalt lava flows interbedded with Santa Fe Group sediment across the Rio Grande from White Rock.

The action continues as a fight between the gang and posse is interrupted by those pesky aliens below the cliffs of Ghost Ranch. Favreau struck gold with this filming locale, where the deep reddish hues of the Triassic Chinle Group contrast with light tan Jurassic Entrada Sandstone and Todilto and Summerville Formations on the skyline. Lonergan attempts to rescue Ella as she's yanked away by an alien craft, forcing it to crash into a lake (Abiquiu Reservoir). An alien emerges from the water and a paleontologist might be struck by the missed opportunity to style the invader after Coelophysis, the dinosaur and state fossil recovered from Triassic beds near Ghost Ranch.

Our snakebit heroes are captured by Apaches, but form a quick alliance, as Ella's extra-human nature is explained and Lonergan regains his memory of being abducted along with his wife. In a small twist that would make George Hearst smile, the aliens are after gold, including the stash Lonergan took from the Colonel.

So valuable is gold to the aliens that they've established an imposing mining base/mothership in a white-cliffed amphitheater. The posse, Apaches, and (after some persuasion) Lonergan's gang hatch a plan to attack the base, set in Plaza Blanca north of Abiquiu. New Mexicans could be forgiven for confusing this location with the better-known Kasha-Katuwe Tent Rocks National Monument. The whitish, tuffaceous sediment of the 19 to 27 million year old Abiquiu Formation forming the Plaza Blanca cliffs sure looks like the 7 million year old Peralta Tuff of Tent Rocks.

We've leaked enough spoilers, but suffice it to say that the ensuing fight would make The Duke and Clint Eastwood proud. From a theatrical perspective, Cowboys & Aliens is an admirable attempt at bridging two very different genres and the movie is just plain fun. The gorgeous backdrops of northern New Mexico are a most pleasant bonus for scientists and action-buffs alike.

More information on parks depicted in Cowboys & Aliens:

- Abiquiu Dam & Lake Recreation Area (US Army Corps of Engineers)
- Diablo Canyon Recreation Area (Bureau of Land Management)
- Ghost Ranch Education & Retreat Center
- Plaza Blanca hiking area

Geologic maps covering select movie locations:

- Abiquiu quadrangle by Maldonado (USGS): Plaza Blanca
- Ghost Ranch quadrangle by Koning and others (NMBGMR)
- Turquoise Hill quadrangle by Dethier & Koning (NMBGMR): Diablo (Ancha) Canyon

Through the Hand Lens: Profile of a Geoscientist and Editor

L. Greer Price served as the Director and State Geologist from 2011 to 2015 and edited our featured publication: *The Geology of Northern New Mexico's Parks, Monuments, and Public Lands* in 2010. Greer started working at the Bureau in 2001 as the chief editor, and associate director from 2001 to 2011, then director after that until his retirement in 2015. In 1974, he graduated from Washington University with a B.A and M.A. in geology and completed his Master's thesis on the paleontological evidence for Holocene lake-level fluctuations at Lake Chichancanab in the Yucatan. After teaching at the University of Missouri, his interest in fieldwork and sedimentary geology motivated him to work as an exploration geologist for Exxon and then as a production geologist for Sohio. Over the next ten years, Greer worked for the National Park Service with assignments from Guam to the Grand Canyon. Greer's love of the printed word inspired him to become the managing editor at the Grand Canyon Association, which then led to him to work at the Bureau. For more information about L. Greer Price, his professional contributions, and publications visit: **www.geoinfo.nmt.edu/staff/price/home.html**

Greer Price and four-legged friend. *Photo courtesy of Sara Stebbins.*

What is your professional background?

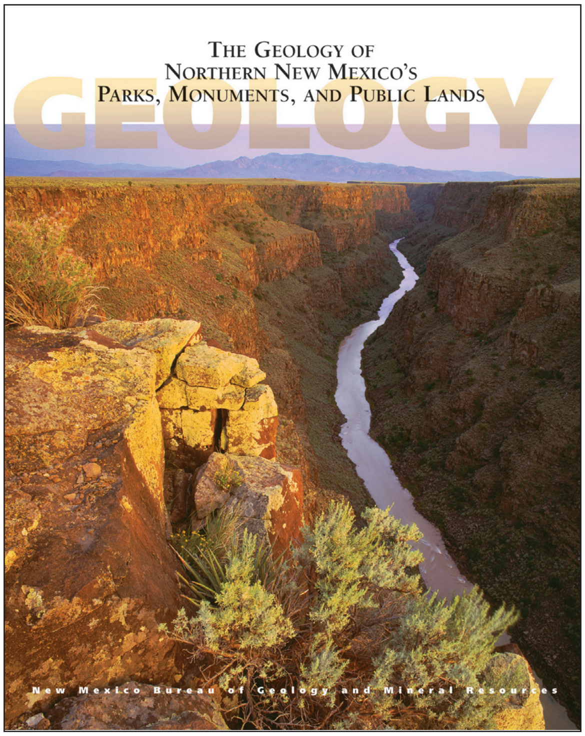
A native of NYC, I received my bachelor's and master's degrees from Washington University in St. Louis, and spent a year and a half doing work toward a doctorate at the University of Michigan. After a brief stint of teaching, I went to work in the oil patch, first doing stratigraphic micropaleontology in the Gulf of Mexico, then development geology in the frontier fields of northern Alaska. I spent ten-plus years with the National Park Service, much of it at Grand Canyon, and four-plus years working at Grand Canyon Association. I came to the New Mexico Bureau of Geology in January 2001.

How did you decide to work at the Bureau of Geology and Mineral Resources?

I was familiar with the work of the bureau, since I had spent many vacations in New Mexico. Through an odd bit of serendipity, I met both Chuck Chapin and Shari Kelley at a conference on Grand Canyon geology in June 2000. One thing led to another, and I felt that the bureau could use my unique set of talents. And, last but not least, I came along at a time when they were looking for someone with my background.

What accomplishments are you most proud of in your work?

I'm proudest of the work I've done that speaks to the general public about the glories and intricacies—and importance—of the earth sciences. That would include my work in publications and exhibits, my on-site years of doing personal interpretation with the National Park Service, and my varied teaching experience.



The Geology of Northern New Mexico's Parks, Monuments, and Public Lands, L. Greer Price, editor, New Mexico Bureau of Geology & Mineral Resources, 2010.

Where are some of the places that your work has taken you?

My early education in the field took me to southeast Missouri, southern Illinois, and Wyoming. My Master's fieldwork was done in the central Yucatan. I spent a summer on the island of Majorca exploring the possibility of working with Pleistocene cave sediments. As an undergraduate, I spent hundreds of hours working in central Kentucky, primarily with the Cave Research Foundation, of which I am a proud lifetime member. My experience in the oil patch took me offshore in the deep-water Gulf of Mexico and northern Alaska (the Beaufort Sea). My park service years took me to Mammoth Cave, Grand Canyon, Point Reyes National Seashore, Petrified Forest National Park, eastern Nevada, and the Marin Headlands.

Why is it important to inform the public about earth science?

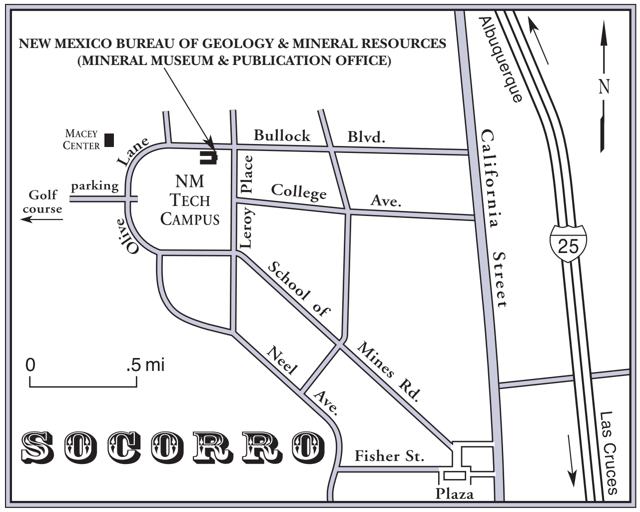
Geology is about understanding the planet on which we live. Now, more than ever, this understanding is important to all of us, whether it's related to the search for natural resources (water being perhaps the most important of those) and energy resources, or an understanding of natural hazards—just ask the folks who live in Hawaii. We ignore these things at our peril, and a well-informed public is much more likely to make wise decisions, decisions that ultimately affect us all.

How do you think that teachers can best convey the importance of geology and geologic processes to their students?

In many ways the Earth Sciences are the most accessible of all the sciences, because we live with them, intimately, every day of our lives. Teachers need only remind their students of this fact. I also feel strongly that teachers should emphasize that geology is not just about the past, but very much about the present and the future. Finally, the tools teachers need to remind their students of the dynamic nature of geology are around us everywhere: volcanoes, earthquakes, the glorious landscapes that we live in, and so forth.

What would you like to say about the featured publication, *The Geology of Northern New Mexico's Parks, Monuments, and Public Lands*?

It's one of the efforts that I am proudest of. It was a collaborative effort in every sense of the word—many different authors, photographers, designers and editors, federal and state agencies, etc. We worked with a world-class publication designer, and our own bureau staff devoted a great deal of time and energy to it. As far as I know, it's still one of the best-selling publications at the bureau, and I continue to get compliments on it. It was an enormous amount of work, but I think it paid off.



The Mineral Museum is on the campus of New Mexico Tech in Socorro, New Mexico

Monday through Friday 9 a.m. to 5 p.m.
Saturday and Sunday 10 a.m. to 3 p.m.
Closed on New Mexico Tech holidays

Bureau of Geology building is located at the corner of Leroy Place and Bullock Blvd. on the campus of New Mexico Tech in Socorro. Visitor parking on the east side of the building provides convenient access to the Mineral Museum and Publications Sales office.

Mineral Museum

The bureau's mineralogical collection contains more than 16,000 specimens of minerals from New Mexico, the United States, and around the world, along with mining artifacts and fossils. About 5,000 minerals are on display at a time.

For teachers, students, and other groups, we offer free tours of the museum. We like to show off our home state minerals, as well as give students an idea of how minerals end up in products we use every day. Museum staff can also identify rocks or minerals for visitors. Please call ahead to ensure someone will be available. For more information on the museum, please visit our website at: geoinfo.nmt.edu/museum/

Dr. Virgil W. Lueth: Senior Mineralogist and Museum Director

575-835-5140; virgil.lueth@nmt.edu

Kelsey McNamara: Museum Curator

To schedule a museum tour, contact:
575-835-5418; kelsey.mcnamara@nmt.edu

Cynthia Connolly: Education Outreach

575-835-5264; cynthia.connolly@nmt.edu

Publication Sales Office

A wide selection of resources for teachers is available, including publications on New Mexico's geology. Many are written for the amateur geologist and general public.

We offer:

- Popular and educational geologic publications
- Topographic maps for the entire state of New Mexico
- Geologic maps for selected areas of New Mexico
- U.S. Forest Service maps
- Jewelry and children's science exploration kits

20% Teachers Discount on Bureau of Geology and New Mexico Geological Society publications

Call 575-835-5490 for phone orders or information,
or visit our website at: geoinfo.nmt.edu/publications

Email address: nmbg.publications@nmt.edu

April Brunson: Publications Sales Manager 575-835-5145

Adam Roybal: Resource Specialist 575-835-5490

Credits

Managing editor: *Cynthia Connolly*

Editorial assistance: *Susan Welch, Brigitte Felix, Gina D'Ambrosio*

Layout & web design: *Stephanie Chavez*

Graphics & cartography: *Stephanie Chavez*

Web support: *Adam Read*