

Manzano Mountains – Fourth of July Trail

Overview: A nature walk into a subalpine woodland in the heart of the picturesque east side of the Manzano Mountains, central New Mexico. Students examined plants, wildlife, mostly birds, and geology along a three mile “out and back” stretch of the Fourth of July trail (Figure 1), which is famous for large groves of big tooth maple trees.

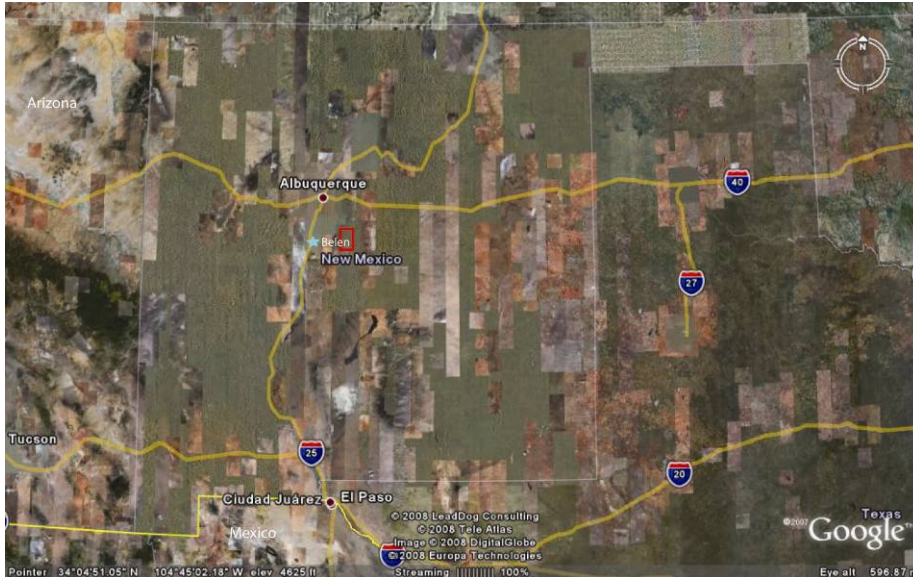


Figure 1: Top: Index satellite map of New Mexico showing major cities and roads and the approximate location and area traveled as part of this trip (red rectangle).

Left: Inset satellite image map of area shown in red square. Location of Fourth of July Campground, starting point for this trip, is shown as blue teardrop. Images courtesy of Google Earth ©.

Access: From Belen, head southeast on NM 47 to where it dead-ends at US 60. Turn left on US 60 and head east to Mountainair. At Mountainair, turn left and head north on NM 55 for 21.4 miles to Forest Road (F.R.) 55. Turn left and head west on F.R. 55 for 7 miles to the campground, which will be on the right.

Topography and terrain: The trail climbs at a gentle to moderate grade up the eastern flanks of the Manzano Mountains until Upper Fourth of July Spring. After this point, the trail follows a rugged canyon up to the crest of the range. The Manzano Mountains (manzano means “apple tree” in Spanish) are rugged “fault block” mountain range that trends roughly north-south through central New Mexico. The name Manzano comes from

apple tree orchards planted by Spaniards in the 17th Century near the town of Manzano on the east side of the mountains. The range is bounded in the north by Tijeras Canyon, which separates the Manzano from the Sandia Mountains, in the south by Abo Pass, in the west by the Albuquerque Basin and Rio Grande valley, and in the east by the Estancia Basin. The mountains rise abruptly almost 5000 feet from floor of the Rio Grande valley to a high point of 10,098 feet above sea level at Manzano Peak.

Average elevation along the trail is approximately 7700 feet above sea level. The east side of the Manzano Mountains is characterized by gentle to moderately sloping terrain and dense groves of ponderosa pine, big tooth maple, and gambel oak tree forest. This is in contrast with the rugged, steeply sloping western flank of the range, which mostly consists of sparse stands of juniper trees, cacti, and other high desert plants. The highest elevation reached on our transect was approximately 8100 feet above sea level; our route gained approximately 700 feet over 1.5 miles. Water could be found at Lower and Upper Fourth of July Springs.

Geology: The Manzano Mountains are a north-south elongated “fault block” range that formed as the east flank of the Rio Grande Rift during Miocene time (20-15 Ma). The range consists of a diverse suite of rocks that span in age from 1.7 billion years to recent surface deposits (Figure 2). The oldest rocks in the Manzano Mountains are highly deformed and metamorphosed igneous rocks of Early Proterozoic (1750-1650 Ma (*mega annum* = million years)) age. These rocks are found mostly on the rugged west side of the range below the crest, though the high peaks of the southern part of the crest are comprised of these rocks. These rocks are the remains of the early assembly of this part of the North American continent. Early Proterozoic rocks are intruded by plutonic rocks of Early and Middle Proterozoic (1650-1420 Ma) age. Together, these Early and Middle Proterozoic rocks are a part of what is regionally known as the “crystalline basement” of southwestern North America.

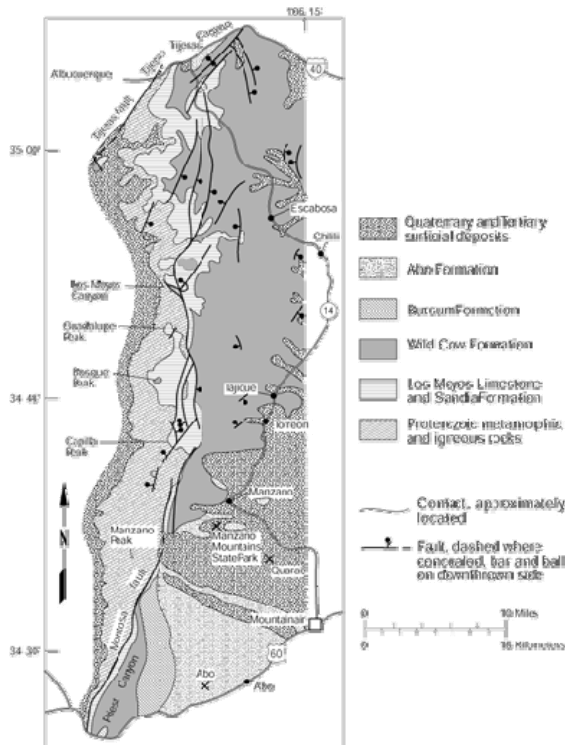


Figure 2: Geologic map of the Manzano Mountains and vicinity. From New Mexico Bureau of Geology and Mineral Resources website, modified from McLemore, V.T., 2000, Manzano State Park and Abo and Quarai units of the Salinas Pueblo Missions National Monument, New Mexico Geology, vol. 22, p. 108-122.

Proterozoic rocks are overlain by tilted and faulted beds of limestone, sandstone, and shale of Mississippian (363-323 Ma), Pennsylvanian (323-290 Ma) and Permian (290-245 Ma) age. The contact between the overlying Pennsylvanian and Permian sedimentary rocks and the underlying Proterozoic rocks is recognized as an unconformity, a gap in the rock record. In this case, the unconformity represents over one billion years of missing time! This unconformity is widespread throughout the southwestern U.S. and is recognized at the Grand Canyon as the “Great Unconformity”. These sedimentary rocks contain abundant fossils and were deposited mostly when present day New Mexico was at or near sea level and was close to the equator.

The present day Manzano Mountains were uplifted during formation of the Rio Grande Rift (RGR) during Miocene time (20-15 Ma). The RGR is a long, north-south trending valley that stretches from Socorro in the south to central Colorado in the north and formed as the result of extension of the Earth’s crust. This extension was accompanied by mountain block uplift, formation of sedimentary basins, earthquakes, and volcanism. Initial extension of the RGR began at approximately 30 Ma and has been ongoing to the present time as evidenced by recent seismic and magmatic activity.

Recent history: The Manzano Mountains are flanked in the east by a closed sedimentary basin named the Estancia Basin. In Pleistocene time, the basin was filled in by water forming a vast lake. After the lake dried up at the end of the last ice age (~12,000 years ago), evaporite deposits, such as halite and gypsum, were left behind and became economically important to the various groups of human settlers that came to inhabit the area.

Among the first of these were early Native Americans. Although the exact date of settlement is uncertain, clearly they were there long before the Spanish first explored New Mexico in the late 16th Century, as there were already well established settlements. These Native Americans were pueblo people, descendants of an ancient civilization known as Anasazi (Navajo for “ancestor of our enemies”), who are recognized as the best example of a complex society in the southwestern US.

The first Spaniards arrived here in the 17th Century. These were Franciscan missionaries, who established missions at Abo, Quarai, and Gran Quivira. This is one of the first and best preserved examples of early contact between Spanish and pueblo people. The remains of this early contact can be viewed at Salinas Pueblo National Monument, located near the present town of Mountainair at the south end of the Manzano Mountains.

Spanish colonial settlers began to establish permanent settlements in the Rio Grande valley to the west, including the towns of Belen and Los Lunas, and in the forests on the east flank of the mountains, including the villages of Manzano, Tajiue, and Torreon, in the late 17th Century.

New Mexico was a colony of the Spanish Empire and was part of New Spain until the Mexican War of Independence with Spain ended in 1821, and the territory became a province of Mexico. New Mexico remained a part of Mexico until the territory was conquered by the United States following the Mexican-American War, which ended in 1848. New Mexico remained a territory until 1912 when it became the 47th state of the US.

White Sands National Monument and Valley of Fires State Park

Overview: Two day scientific field excursion to White Sands National Monument and Valley of Fires State Park, both located in the harsh yet beautiful Tularosa Valley in southern New Mexico (Figure 1). White Sands is named for the famous white sand dune field, the largest gypsum dune field in the world. Valley of Fires is noted for tens of square miles of young dark lava flows, known as the Carrizozo malpais, which are some of the youngest continental lava flows in the United States. Participants camped in the nearby Organ Mountains, east of Las Cruces.

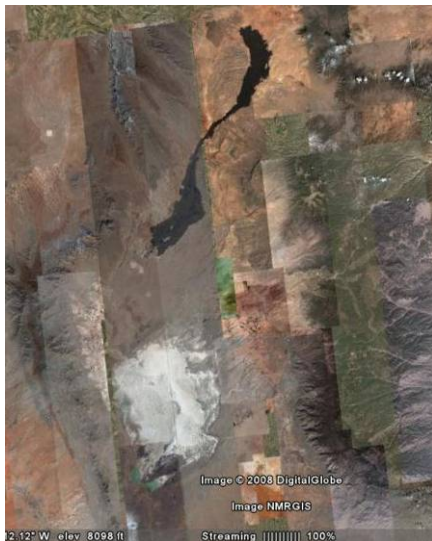
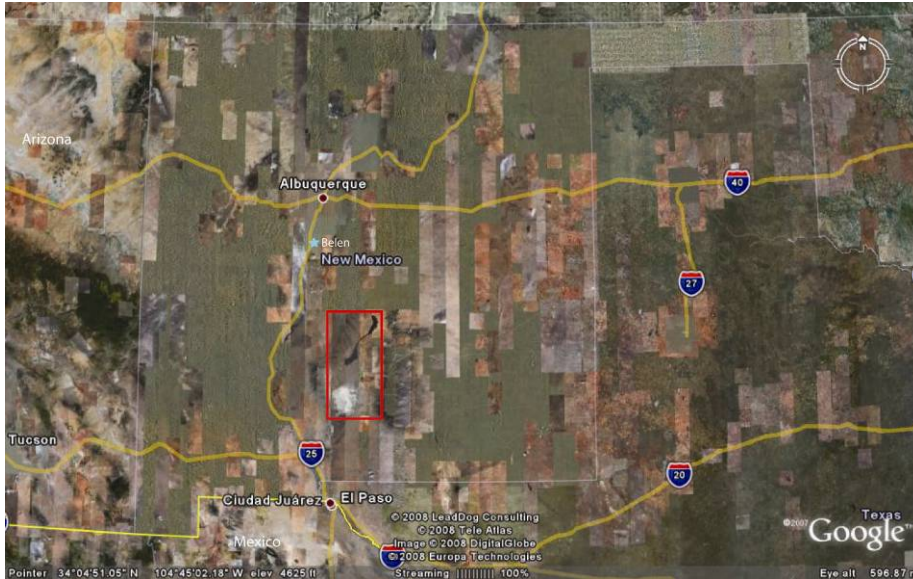


Figure 1: Top: Satellite image of New Mexico showing location of Valley of Fires, White Sands National Monument, and the surrounding Tularosa Valley (enclosed by red rectangle). **Left:** Inset map of area enclosed by red rectangle. Note the striking contrast between the Carrizozo lava flows (black) and the white sands. Sacramento Mountains are to the east, San Andres Mountains are to the west. Images courtesy of Google Earth ©.

Access: From Belen, head south on I-25 to US 380. Head east on US 380 for about 60 miles. The Valley of Fires Recreation Area is about 4 miles west of the town of Carrizozo. From there, to get to White Sands, proceed east to Carrizozo and then head south on US 54 to Alamogordo. From there, head southwest on US 70 approximately 15

miles to White Sands National Monument. To reach the campsite at the Aguirre Springs, continue southwest on US 70 for about 35 miles. The turnoff to the campsite is marked on the left side of the highway.

Topography and terrain: The Tularosa Valley, better known as the Tularosa Basin (Figure 1), is an area of rugged, extreme, and contrasting landscapes. The valley trends roughly north-south for 150 miles and is approximately 60 miles east-west at its widest point. The valley is bounded to the west by the San Andres Mountains, which rise to an elevation of 8965 feet above sea level at Salinas Peak. The Sacramento Mountains bound the valley to the east, and rise to an elevation of 9695 feet at the crest. A transect from the bottom of the basin to the crests of either of these ranges allows the observer to witness a dramatic transition from the sparsely vegetated desert lowland of the valley floor, through piñon-juniper woodland, and then into subalpine forests. Both the Sacramento and San Andres Mountains are examples of “sky islands”, mountain ranges that contain a high concentration of plant and animal species unique to those ranges due to geographic isolation.

The basin is bounded by Chupadera Mesa in the north and by the Franklin and Hueco Mountains to the south. The lowest point in the valley is Lake Lucero, at an elevation of 3891 feet above sea level. The Tularosa Basin is internally drained, which means all water that flows into the basin remains in the basin. Runoff drains into Lake Lucero, becomes groundwater, or is evaporated away.

At White Sands, the valley floor is essentially flat, except for the dune field, and sits at about 4000 feet above sea level. Vegetation is extremely sparse in the dune field itself, occurring mostly at the edges, and is almost non-existent in the surrounding flats. The area surrounding Valley of Fires is characterized by nearly flat, but extremely rugged, terrain. This rugged terrain is the result of jagged surfaces and deep fractures, and collapsed caverns above lava tubes. The dark volcanic surface is difficult to negotiate, even on foot, and is virtually unsuitable for farming or settling. For these reasons, the Spanish gave this land, along with several other volcanic areas in New Mexico, the name “malpais”, which literally means “bad land” in English. Again, vegetation is sparse and mostly consists of high desert plants. On a satellite image, such as in Figure 1, the contrast between the black volcanic lava flows and the white dune field is quite striking.

Geology: Both White Sands and Valley of Fires lie in the Tularosa Basin, which is considered part of the Rio Grande Rift geologic province. Figure 2 shows a general geologic map of the Tularosa Basin. Pre-Tertiary (rocks older than 30 Ma) are only exposed in the mountains flanking the valley. The basin is known as graben, i.e., a valley that forms between two fault block mountain ranges during extension of the Earth’s crust (Figure 3). The formation of the Tularosa Basin is related to formation of the Rio Grande Rift, which began at approximately 30 Ma and has been ongoing to the present time. Although the white sands themselves are relatively young (geochronologic evidence suggests major dune building began between approximately 7000-6500 years ago), the gypsum sands represent sediment derived from limestone deposited during the Permian Period (290-245 Ma). Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is an example of an evaporite, a mineral

formed as a precipitate from the evaporation of water. When sea level fell during Permian time, gypsum was formed as the water evaporated. Potential sources for Permian limestone and gypsum are in the nearby San Andres and Sacramento Mountains. This limestone was deposited as what is now New Mexico was covered by a shallow sea and was situated near the equator.

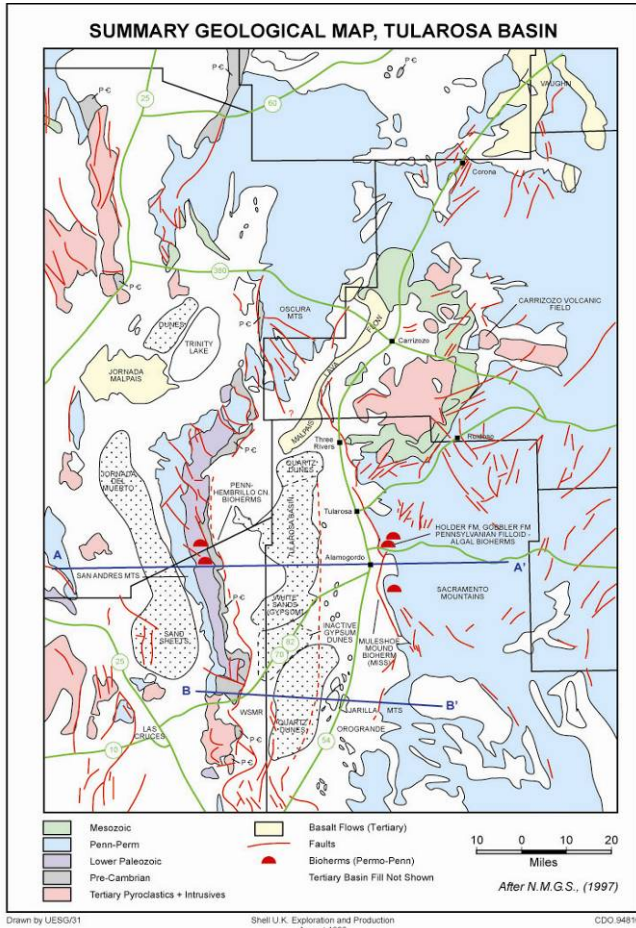


Figure 2: Geologic map of the Tularosa Basin.

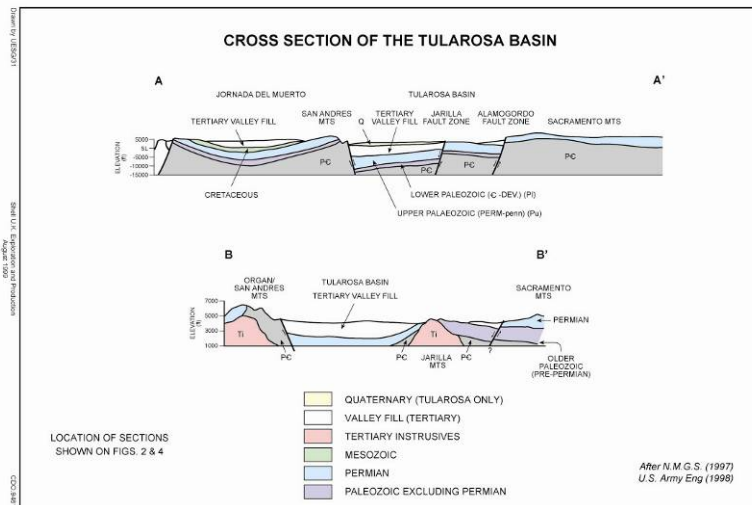


Figure 3: Geologic cross section of the Tularosa Basin, corresponding to lines A-A' and B-B' on geologic map in Figure 2.

The Sacramento and San Andres Mountains, which were once part of a single uplift that formed during the Laramide Orogeny (~80-40 Ma), the mountain building event responsible for uplift of the modern Rocky Mountains, were then separated from each other by a regional extension event. This event formed the Rio Grande Rift and the Tularosa Basin. Extension began ~30 Ma and is ongoing to the present day. This extension was accompanied by widespread uplift, erosion, earthquakes and volcanism.

The Carrizozo lava flow at Valley of Fires is a very young example of this volcanism. The Carrizozo flows consist of an upper and lower flow; the lower flow is the longer of the two and traveled a distance of ~75 km (see satellite image in Figure 1). Both the upper and lower flow sourced from Little Black Peak, a cinder cone located near the north end of the flow. The Carrizozo lava flow consists entirely of basalt, a mafic, volcanic, igneous rock. The term mafic refers to the chemical composition of the rock, and means that the rock consists mostly of minerals containing iron and magnesium. An example where basalt is being formed right now is at Kilauea volcano in Hawaii. Because of the relative youth of the Carrizozo flow (recent data suggests the flows are ~5200 years old), it provides a great opportunity to see primary igneous textures, such as pahoehoe (Figure 4), a ropy texture that forms on the surface as molten lava still flows underneath. Also apparent are tumescent areas, large cooling cracks and fissures, as well as lava tubes, which are caves left behind by lava flowing underground.



Figure 4: Pahoehoe lava texture from the Carrizozo lava flow at Valley of Fires. Image courtesy of NMGS.

Prior to the Carrizozo eruption event, in late Pleistocene time during the most recent ice age, what is now Lake Lucero was part of larger lake known as Lake Otero, which filled up most of the Tularosa Basin. Gypsum from the San Andres and Sacramento Mountains would be carried by water down into Lake Otero (Figure 5). As Lake Otero dried up at the end of the last ice age, dissolved gypsum, and other evaporites, such as halite, would precipitate out of solution. Alkali Flats, which flanks the dune field to the west, is composed of gypsum and other evaporites left behind from the old lake. Therefore, sources of gypsum that make up the White Sands dune field are either gypsum being

weathered from the nearby mountain ranges or gypsum particles being picked up from deposits left behind by the former Lake Otero.



Figure 5: Map showing the extent of the Pleistocene Lake Otero, the location of the present dune field and Lake Lucero, and the prevailing wind direction.

Recent history: Human history in the area goes back to approximately 10,000 years ago, when “paleo Indians” reached the shores of Lake Lucero. These people lived primarily as hunter-gatherers. Although there were some efforts at agriculture at about 4000 years ago, major efforts at farming and establish permanent settlements are not evident until ~ AD 700. Settlements grew and progression towards more “complex” civilization is evident until ~ AD 1100. A major drought that affected most of the Southwest towards the end of the 13th Century and, for reasons not entirely understood, by 1350 all major settlements in the Tularosa Basin had been abandoned.

Spanish colonists coming into New Mexico must have found this area undesirable for settlement. The Tularosa Basin is the heart of what the Spaniards named the Jornada del Muerto (literally translated “Journey of the Dead”), which refers to the stretch of the Camino Real (“the Royal Road”, the route from Mexico City to Santa Fe) from Las Cruces to Socorro. This name still appears on maps today. The presence of Mescalero Apache Indians, combined with the harsh environment, probably discouraged the Spanish from establishing permanent settlements.

The end of the Civil War, combined with the establishment of the Mescalero Indian Reservation, opened up the Tularosa Basin to settlement by colonists from Texas and other parts of the US. Major settlements in the area today include Alamogordo and Carrizozo. Industry in the region primarily includes sheep and cattle ranching, mining, and agriculture. Colorful characters roamed the area in the late 19th and early 20th Century including Pat Garrett, Billy the Kid, and Oliver Lee.

When the US military set aside land for the White Sands Missile Range in the 1930’s, defense research also became a major industry. The area has notoriety for the Trinity Site, where the world’s first atomic bomb was detonated. Today, the missile range is still used for weapons research, development, and testing.

Carlsbad Caverns National Park – The Big Room and Slaughter Canyon Cave

Overview: A two day scientific field trip to Carlsbad Cavern National Park, located in the beautiful and rugged Guadalupe Mountains of southeastern New Mexico and westernmost Texas (Figure 1). The trip featured tours of the world famous Big Room of Carlsbad Caverns, the largest cave chamber in North America, and Slaughter Canyon Cave, a “wild cave” featuring amazing cave formations including the “Christmas Tree”, a 89 foot tall column known as “The Monarch” and much more. Participants camped at Pine Springs Campground just south of the New Mexico border in Texas.

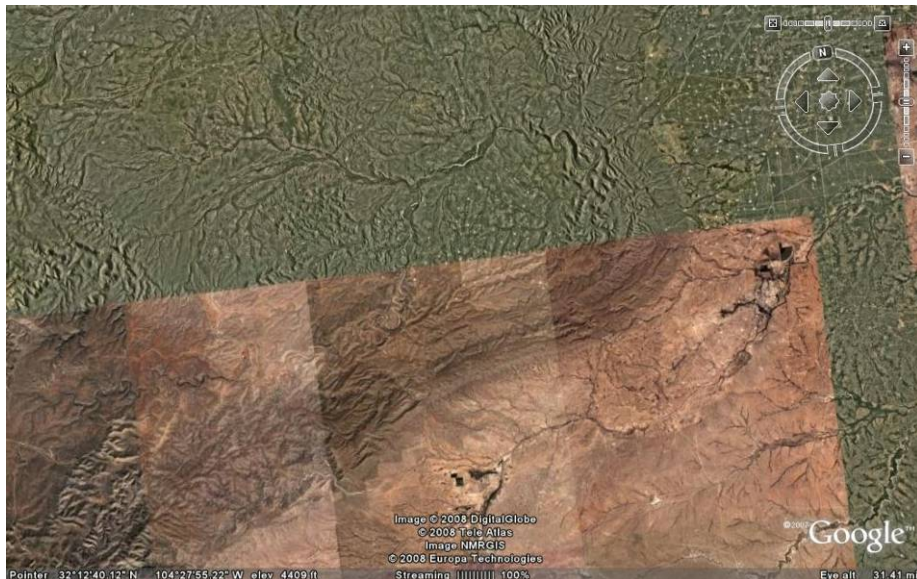
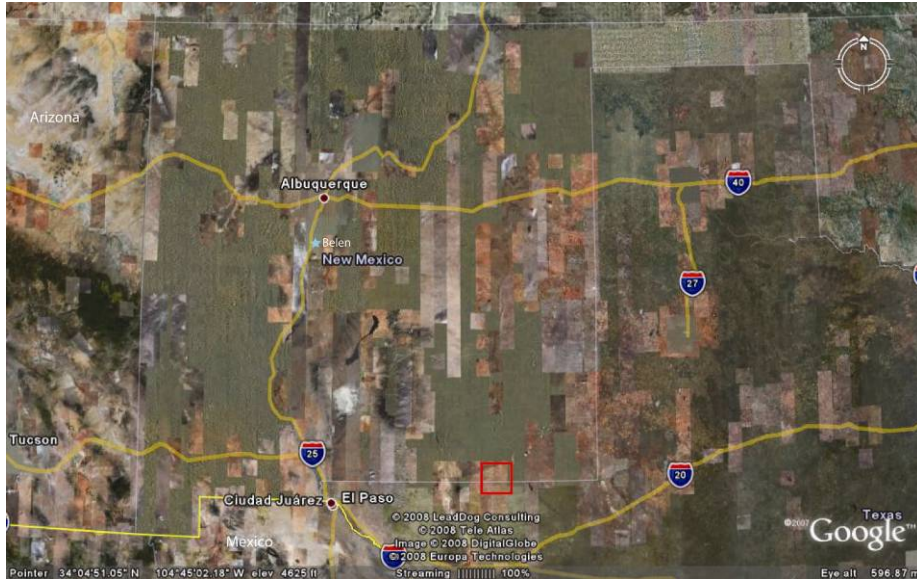


Figure 1: Top: Satellite image showing the location of Carlsbad Caverns and Guadalupe Mountains National Parks (enclosed by red rectangle). **Bottom:** Inset map of area enclosed in red rectangle. Note the prominence of the southern face of the Guadalupe Mountains. This prominent escarpment is the Capitán Reef.

Access: From Belen, south on I-25 to US 380 and head east to Roswell. From Roswell, head south on US 285 to Carlsbad. At Carlsbad, turn right and head southwest on US 62/180 toward Whites City. At Whites City, turn right on Carlsbad Caverns Highway and head west 7 miles into the park. To reach our campground at Pine Springs, continue heading southwest on US 62/180 to Pine Springs Campground, the campground entrance is on the right.

Topography and terrain: The Guadalupe Mountains have a bifurcated shape; from Guadalupe Peak, the range extends north-northwest and northeast into New Mexico. The northeast extension is a geologic feature known as the Capitán Reef, which ends near Whites City (Figure 1). Carlsbad Caverns and most of the nearby caves are found in the limestone of the Capitán Reef. The NNW extension is fault block bounded by a dramatic escarpment known as “The Rim” that is separated from the Sacramento Mountains to the west. The mountains rise from approximately 4000 feet above sea level at the valley floor to the highest point in the state of Texas, Guadalupe Peak, at 8749 feet above sea level. Most of the range is characterized by Chihuahuan high desert plants, such as mescal, agave, and ocotillo, though at higher elevations piñon-juniper woodland dominates. Only at the highest elevations at the along the crest are ponderosa pine forest observed. Surface water is sparse here, found perennially only at McKittrick Canyon. Runoff from this range either drains into the Pecos Mountains to the east or Linda Lake to the west.

Geology: The geology of the area consists chiefly of Permian (290-245 Ma) age limestone forming the Capitán Reef complex. The mountains are a classic example of an older structure governing the geometry of later structures. The ancient reef escarpment is the present day southeastern front of the mountain range. The reef limestone contains abundant marine fossils such as sponges, algae, ammonites, crinoids, brachiopods, bivalves, and more. When this limestone was deposited, it would have been a barrier reef like the Great Barrier Reef of today. Adjacent to the Capitán Reef complex, and now presently situated to the south and east, are the limestones and organic-rich shales of the Delaware Basin, which contains vast deposits of economically important oil and natural gas (Figure 2). The Delaware Basin deposits are the remains of a great equatorial inland sea, that the Capitán Reef fringed during Permian time.

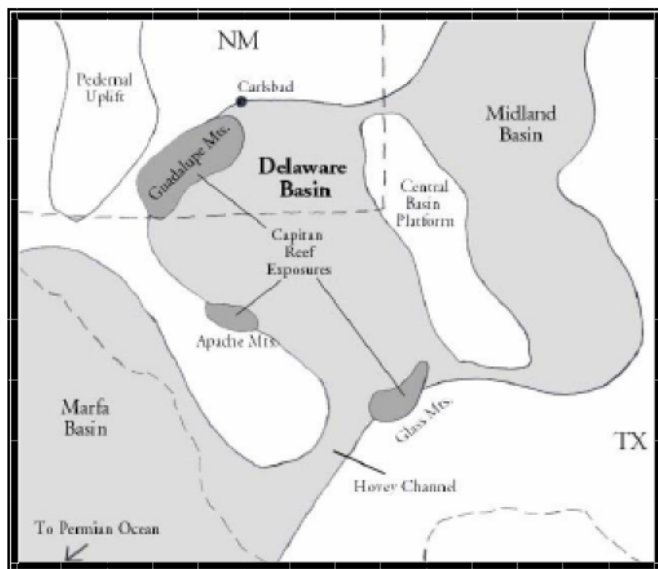


Figure 2: Generalized tectonic map showing the location of Permian uplifts and Basins. Remnants of the Permian Capitán Reef are exposed in the Guadalupe, Apache and Glass Mountains (shown in dark gray). The reef fringes the Delaware Basin of SE New Mexico and NW Texas (shown in light gray).

Like much of New Mexico, the present day high elevation of the Guadalupe Mountains can be accounted for by the Laramide Orogeny (~80-40 Ma), the mountain building event that uplifted the Rocky Mountains. The Guadalupe Mountains were then probably detached from the Sacramento Mountains to the west as a result of Basin and Range extension, the same extension event that formed the Rio Grande Rift. The extensive faulting and fracturing of the limestone would provide excellent conduits for acidic groundwater to interact with limestone and thus would help initiate the process of cave formation.

The caves of Carlsbad Caverns were likely carved out as the result of sulfuric acid dissolution of limestone. The chief constituent of limestone is the mineral calcite, CaCO_3 , which is readily soluble in acid. Most caves are formed by dissolution of limestone by carbonic acid, a weak acid that forms from the interaction of CO_2 in the air and in soil with rainwater. This is what makes the formation of the caves at Carlsbad so unique. At approximately 15-12 Ma, during Miocene time (not coincidentally about the time Basin and Range extension was taking place) hydrogen sulfide (H_2S) migrated up from underground reservoirs of oil and gas interacted with ground water and formed sulfuric acid (H_2SO_4). The acidic water would dissolve and form caves. As the water table lowered, newer caves would be formed deeper underground (Figure 3). Evidence for sulfuric acid dissolution of the caves at Carlsbad are 1) the immense size of the main chambers of the cave, and 2) the large amounts of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) present. Gypsum can be formed by the interaction of calcite with sulfur-bearing groundwater. Another potential source for sulfuric acid are sulfur reducing bacteria that live in the cave. A byproduct of these microorganisms is hydrogen sulfide. The role of bacteria in cave formation and growth has only recently begun to be understood.

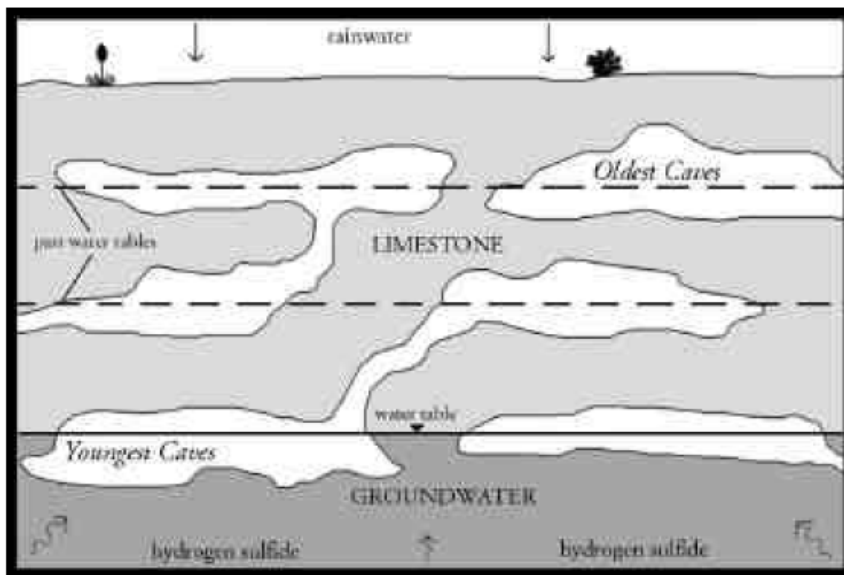


Figure 3: Schematic drawing illustrating the hypothesis for cave formation at Carlsbad Caverns. Hydrogen sulfide originating from oil and gas reservoirs, moves up fractures to interact with ground water forming sulfuric acid, which dissolves caverns in the limestone. As the water table moves down, new caves are formed at lower levels. In caves where the water table has abandoned the cave, speleothems will begin to form.

If sulfuric acid dissolution accounts for the formation of the caves of Carlsbad, what accounts for the beautiful cave formations, or speleothems, that form there? The basic idea is that once the water table starts to lower and thus leave the cave after initial formation, then weakly acidic groundwater, originating from up near the surface, interacts with limestone, dissolving some of it on the way down, and then slowly precipitates calcite drip by drip. The result: the reason so many people like caves – speleothems! Amazing structures like stalactites, stalagmites and columns, soda straws, draperies, helictites and popcorn (Figure 4). Speleothems not only are really cool to look at, but new methods now allow scientists to calculate the growth rate and ages of speleothems. Furthermore, speleothem growth is heavily influenced by climate change, such as varying amounts of rainfall. Therefore, by characterizing speleothem growth and combining it with growth rate and ages, scientists can begin to estimate length of periods of greater or lesser precipitation and when these periods took place.



Figure 4: Some of the world class speleothems exhibited at Carlsbad. You can see lots of stalactites and an impressive column (where a stalactite and stalagmite grow together).

Recent history: The first people who likely came to the Guadalupe Mountains were “paleo Indians.” These people were tribes of hunters and gatherers who probably migrated here from Asia via the Bering Strait toward the end of the last ice age. Although Native American tribes, followed by Spaniards, and later Texans came through this area, there is very little evidence of

any permanent settlements in this area. This is probably due the vast distances and the harsh environment of this region. Water is scarce in these parts, and there is very little land here suitable for agriculture.

Following the Civil War, homesteaders came here to raise cattle. In addition to this, Guadalupe Pass became an important stop on the southern overland wagon route from St. Louis to San Francisco. The Butterfield Station at the pass was the only stop for miles in this harsh and sometimes hostile country. The discovery of large oil and natural gas reservoirs toward the end of the 19th Century in the Delaware Basin transformed the region and opened it up to unprecedented settlement and development. Towns like Carlsbad, Hobbs, and Artesia sprang up overnight. In the 20th Century, tourism became big business as well, as people from around the world began to flock to the Guadalupe Mountains to visit Carlsbad Caverns National Park and to recreate in the beautiful mountains themselves. However, the area still has a very wild and rugged feel to it. Even small towns are separated by many miles of desolate and unpopulated country.

Jemez Mountains – Soda Dam, Spence Hot Springs, Valles Caldera and Bandelier National Monument

Overview: A two day scientific field trip to one of the most picturesque mountain ranges in the Southwestern US, the Jemez Mountains of northern New Mexico (Figure 1). Highlights include a natural dam made from travertine from a deep underground spring, a geothermal (hot) spring, a drive through a more than million year old “supervolcano” and an ancient pueblo settlement at Bandelier. Participants camped at the Juniper Campground in Bandelier National Monument.

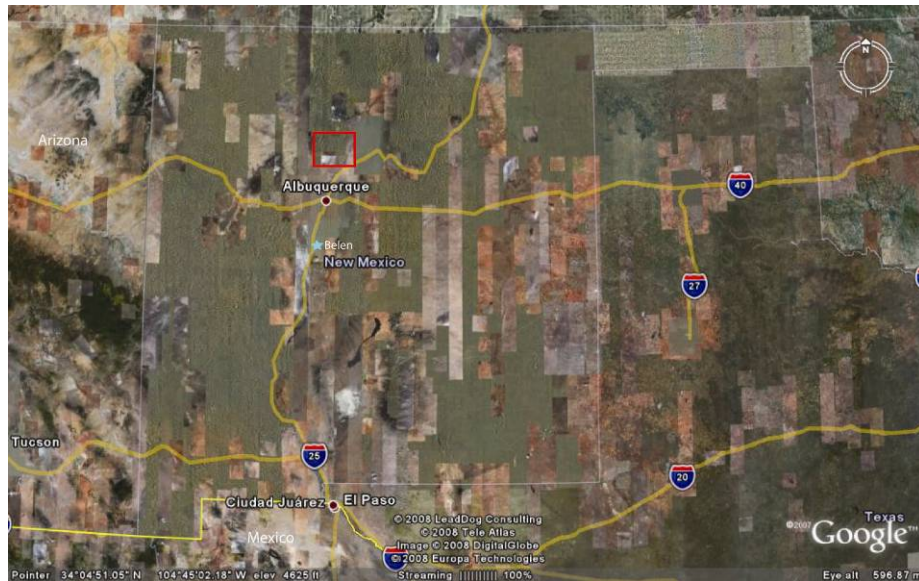


Figure 1: Top: Index satellite image map showing the location of the Jemez Mountains and surrounding vicinity (enclosed in red rectangle. **Bottom:** Inset map showing satellite image of the Jemez Mountains. The large ring shaped feature near the center of the image is the Valles Caldera, the remnants of ancient caldera that erupted approximately 1.4 million years ago.

Access: From Belen, head north on I-25 to Bernalillo. From Bernalillo, head northwest on US 550 to San Ysidro. From San Ysidro, drive north on NM 4 29 miles to Soda Dam, located on the Jemez River just north of Jemez Springs. To reach Spence Springs from here, continue north on NM 4 for about 7 miles to a large parking area on the right hand side of the road. There is a hiking trail that goes down to the spring. To get to Bandelier, continue north then head east on NM 4. This route takes you right through the Valles Caldera National Preserve. Continue east on NM 4 to the park entrance for Bandelier, which is on the right side of the road. Turn south on this road to head into the park. Camping is available at Juniper Campground just off the main entrance road.

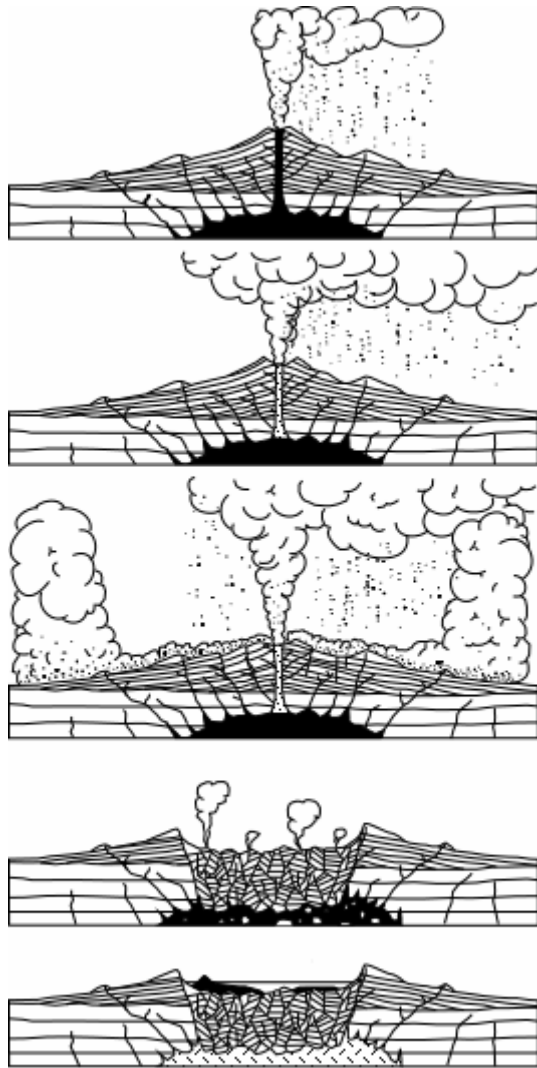
Topography and terrain: The Jemez Mountains of northern New Mexico are a rugged mountain range characterized by high elevation, steep canyons and volcanic formations. Elevations in the area range from about 6000 feet above sea level in the foothills to 11,528 feet at Redondo Peak, the high point of the Jemez Mountains. The range is roughly circular in shape, characterized by steep flanks leading up the crest of the range. In the center of the range is the floor of the Valles Caldera, which is characterized by grassy meadows and subalpine woodland. The steep sides of the range are characterized by deeply incised canyons, piñon-juniper woodland in the low foothills, and ponderosa pine forest at higher elevations.

Several drainages radiate from the Jemez Mountains, all of which eventually flow into the Rio Grande, which bounds the range to the east. The Sierra Nacimiento is adjacent to the Jemez Mountains to the east. To the south are volcanic plateaus where several present day Indian pueblos are built on. To the north of the range are the rugged highlands of northernmost New Mexico, including the Tusas Mountains. In addition to the rivers, lakes, and streams in the vicinity, the range also has an abundance of geothermal springs, which are popular for tourists to soak in. Also of interest for the tourists are numerous Indian ruins and archaeological sites.

Geology: The Jemez Mountains are a volcanic feature, both in terms of rock types present and structure. The central highlands of the mountains represent volcanic deposits superimposed over a geologic substrate similar in both composition and history with that exposed in the in the Manzano Mountains. The Jemez Mountains volcanic complex is located at the junction of two major structures in the Earth's crust: 1) the Rio Grande Rift, a long, roughly north-south valley formed due to extension of the Earth's crust, and 2) the Jemez Lineament, a roughly northeast-trending tectonic element along which volcanic centers in Arizona, New Mexico and Colorado are concentrated. The Rio Grande Rift is relatively young tectonic feature, that began forming at ~30 Ma and is still active at the present time. The Jemez Lineament is an ancient feature and represents a suture between two Proterozoic tectonic terranes.

Figure 2 shows a stratigraphic column for the western Jemez Mountains; a stratigraphic column shows how rocks are stacked on top of each other in a given area. Prior to formation of the Jemez Mountains volcanic complex, the region shared a similar history to that of the Manzano Mountains area. Like all of New Mexico, this area was uplifted to high elevations during the Laramide Orogeny (~80-40 Ma), the mountain building event that formed the Rocky Mountains of New Mexico, Colorado, Wyoming and Montana. A major Laramide structure, the Nacimiento Fault, lies just to the west of the the Sierra Nacimiento. After the Laramide Orogeny, widespread

magma chamber in the subsurface is depleted. As a result, the rocks above the magma chamber collapse, forming a large ring-shaped landform, called a caldera. Caldera formation is accompanied by high volumes of widespread explosive volcanic products, such as pyroclastic flows, base surge deposits, volcanic glass, and pumice, which get preserved as welded tuff.



After H. Williams, 1951

The Valles Caldera finished forming at about 1.4 Ma, based on the age of the Bandelier Tuff, the youngest volcanic deposits related to the forming of the caldera. Volcanism persisted in the area after Valles formed; the most recent volcanic deposits are ~ 60,000 years old. In fact, most of the distinctive peaks in Valles, like Redondo Peak, are resurgent volcanic domes that formed after the caldera formed. After formation of the caldera, the magma chamber underneath the caldera crystallizes to form granite. Meanwhile, on the surface, the caldera may be filled in with water forming a lake, as a caldera is usually an internally drained basin. An example of this kind of lake is Crater Lake in Oregon, which is a relatively young caldera. In the case of Valles, the caldera was in fact filled in by a lake during the last ice age. Lake deposits can be found throughout the valley.

The Jemez Mountains are an area of ongoing geologic activity. For instance, Soda Dam is a natural dam of the Jemez River that is formed of travertine, which has the same composition as limestone (i.e., the principal mineral is calcite). However, unlike limestone, which is deposited in shallow marine settings, travertine is formed through the interaction of water with CO₂. In the case of Soda Dam, travertine is formed as CO₂ is outgassed through springs along the Jemez Fault, a major RGR structure. Recent evidence suggests that this CO₂ comes from the Earth's mantle deep below the surface. Based on the available data, travertine formation began 5000-6000 years ago.

There are also abundant geothermal springs in the area, which are evidence of ongoing volcanic activity in the area. There are a variety of hot springs, warm springs, and cold springs. These springs have unusual chemistry, including high amounts of arsenic.

Recent history: Human beings have continuously inhabited the Jemez Mountains for thousands of years. Settlement of the foothills around the Jemez Mountains near Bandelier began approximately 10,000 years ago, when nomadic hunters and gathers roamed this part of New Mexico. Permanent settlement of the area began in the 12th Century, when the Ancestral Pueblo people (also known as Anasazi) carved cliff dwellings out of the volcanic rocks. The reason these people chose to live in cliff dwellings was probably for protection and safety during times of drought and resource scarcity. Over the next few centuries, people began to abandon these cliff dwellings and migrated out into the Rio Grande valley. By the middle 16th Century, these native people established permanent settlements in the valley. Inhabitants of the modern pueblo of Cochiti are the descendants of the people who inhabited these cliff dwellings at Bandelier.

Spaniards reached these mountains in the early 17th Century. The Spanish established many settlements in the area including Los Alamos, Santa Fe, Espanola, and numerous other smaller settlements. Incidentally, Santa Fe was founded in 1598 and became the capital of New Mexico in 1610. This gives the city the distinction of being the oldest state capital in the United States. The Spanish maintained rule over the pueblo people until 1680, the year of the famous Pueblo Revolt. The Pueblo Revolt was the most singularly successful rebellion by native people in the Americas against a European power. The pueblo people united against the Spaniards and drove them out of Santa Fe all the way south to El Paso. In 1692, the Spaniards reconquered New Mexico and maintained control of the province until 1810, when Mexico defeated Spain in the Mexican War of Independence. The territory remained under Mexican control until 1848, when it was conquered by the US after the Mexican-American War. The territory of New Mexico was granted statehood in 1912, with the capital remaining at Santa Fe.

Unlike many other tribes of native people in the US, the pueblo people of New Mexico were allowed to remain on their native lands. There are 19 separate pueblos in the state of New Mexico, each one of which has its own lands and government, and are considered sovereign nations. Although there are umbrella organizations, such as the Eight Northern Indian Pueblos Council, which pueblos may belong to, each pueblo governs itself and is independent from other pueblos. Pueblos near to the Jemez Mountains include Cochiti, Zia, and Jemez Pueblo. Many pueblos are open to the public, and on feast days and many Sundays there are dances and festivals that visitors may attend.