New Mexico
EARTH
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WINTER 2021

New Mexico's Volcanic Hazards: A Matter of Time

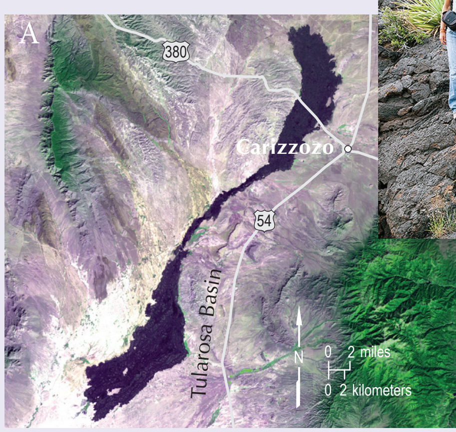
New Mexico's world-renowned landscapes reflect the vigorous geologic activity of the region. For those who live here, we see—and sometimes even feel—this Earth energy. However, such geologic vigor comes with a price in the form of geologic hazards. Reports on the evening news about earthquakes in eastern New Mexico are increasingly common. Driving over mountain passes and through deep gorges of northern New Mexico may require dodging boulders on the road—evidence of recent rock falls and landslides. Floods from the summer monsoons frequently reshape our neighborhood arroyos, and redesign the rapids in our rivers. One of the greatest potential hazards in New Mexico, one not experienced by any humans in recent history, is a volcanic eruption from the many young volcanic fields found in the state. In this article, we explore the history of young volcanoes in New Mexico, describe recent research to better understand these hazards, and ponder the likely events during a future eruption.

A Brief History of New Mexico Volcanism

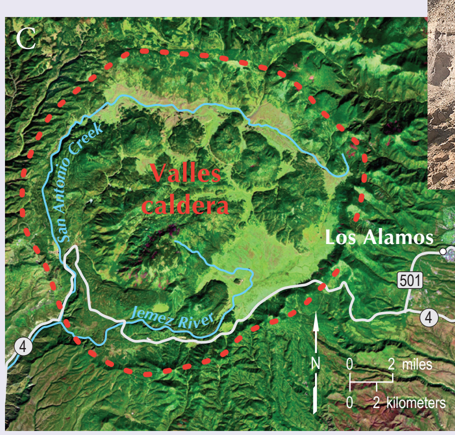
Pick nearly any place in New Mexico and you are likely to find some evidence for past volcanic activity. Most volcanism in the state has occurred in just the last 35 million years. This is when the Rio Grande rift, a continental-scale feature related to extension of the crust, began to form. Rifting triggered two major geologic processes, volcanism and faulting. Extension causes Earth's crust to thin, allowing the molten mantle to either rise toward the surface, or to melt overlying rocks, both of which can produce volcanic eruptions. During faulting, the crust on one side of the fault moves upward, forming mountains, while the other side of the fault moves downward, producing a basin. The Sandia Mountains and the Albuquerque basin are a textbook example of this process.

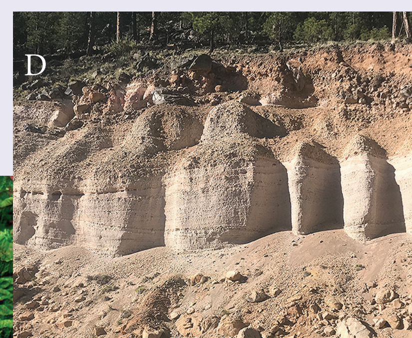
Recent volcanism in New Mexico can be divided into two broad periods of activity, each with their own distinctive traits. Between about 37 and 25 million years ago, a cluster of about twenty supervolcanoes (known as calderas to volcanologists, because of their resemblance to large caldrons) erupted in southwestern New Mexico, each of which injected dozens to hundreds of cubic miles of ash into the atmosphere, and spilled hot, incandescent ash-flows across the landscape. Before and after the colossal supereruptions, numerous "small" volcanoes erupted, producing explosions similar to the famous May 18, 1980 eruption of Mt.

Maps and photographs showing the two different styles of recent eruptions in New Mexico.



A) *Basaltic lava flows, such as the 5,200-year-old flow near Carrizozo (the second youngest eruption in New Mexico), are common. The lava flowed 45 miles south down the Tularosa Basin.* B) *Young flows, such as in Valley of Fires State Park, typically have very little vegetation and a well-preserved flow surface.*





C) *Young, explosive rhyolitic eruptions in New Mexico are rare and are found only in the Jemez Mountains.* D) *Ash-rich deposits are common during rhyolitic eruptions. This outcrop, along NM 4, exposes a 40-foot sequence of ash ejected during a 74,000-year-old eruption. Photo by Nick Meszaros.*

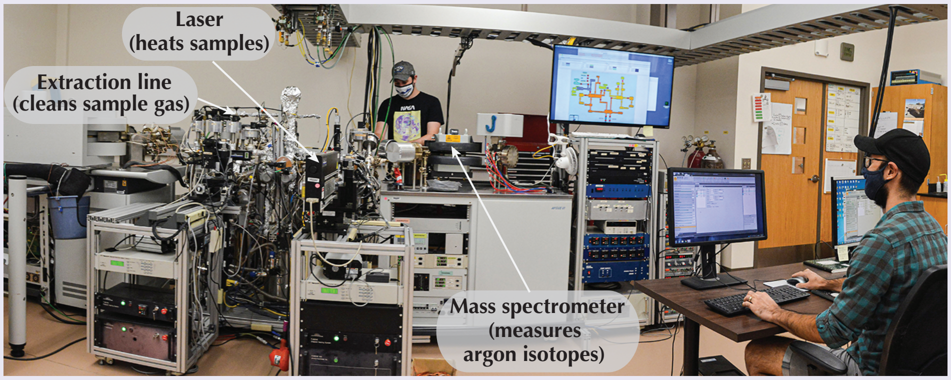


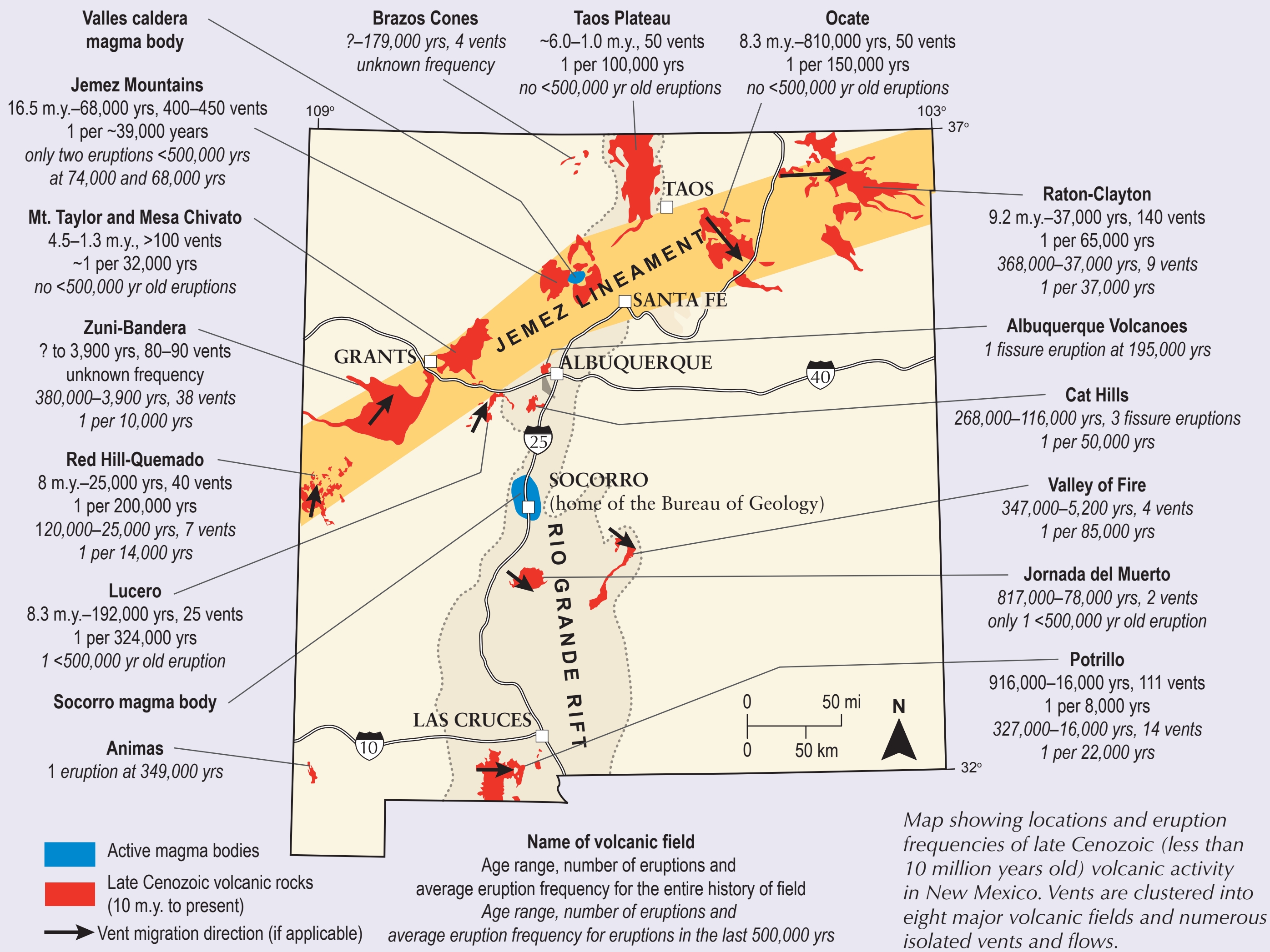
Photo of students working in the New Mexico Geochronology Research Laboratory. The lab has supported hundreds of projects from around the world, many led by New Mexico Tech students.

St. Helens. Thankfully, this field of New Mexico's supervolcanoes is now extinct, and is beautifully exposed in the Gila Mountains and surrounding areas.

Beginning about 12 million years ago and continuing until about 3,900 years ago, the style of volcanic activity in New Mexico dramatically changed. Instead of the cataclysmic, caldera-forming eruptions, the younger volcanoes produced smaller eruptions of lava with very little ash. Some examples of these small volcanoes include cinder cones (steep-sided cones built from the accumulation of small, cooled fragments of lava called cinders), shield volcanoes (volcanoes with very shallow slopes formed by many lava flows), fissure vents (lines of small volcanoes that erupt along a fracture), and maar craters (formed when rising magma meets groundwater, causing a violent steam explosion).

This younger pulse of activity is clustered into eight major volcanic fields and a few isolated vents and related flows. Some of these volcanic fields are located in the Rio Grande rift. Others are located along a feature called the Jemez lineament, a zone of crustal weakness that has focused volcanic activity along a northeast-trending line. Although most eruptions in New Mexico in the last 10 million years are small, the Valles caldera, also known as "New Mexico's supervolcano," produced two immense, explosive eruptions at 1.6 and 1.2 million years ago, generating widespread ash falls.

Why did the style of eruptions shift between the older and younger volcanoes? Geologists have determined that the shift was related to a change in the composition of the magma. The older calderas typically erupted rhyolite composition magma, which contains large amounts of silica, making the magmas more viscous (less likely to flow). When magmas rise through the crust, the decrease in pressure allows dissolved gases to be released. However, the viscous rhyolite prevents gas expansion, and causes pressure to build,



Map showing locations and eruption frequencies of late Cenozoic (less than 10 million years old) volcanic activity in New Mexico. Vents are clustered into eight major volcanic fields and numerous isolated vents and flows.

resulting in a highly explosive eruption. The rapid release of pressure during the eruption causes bubbles to quickly expand and burst, fracturing the rapidly solidified magma into small fragments called ash. However, most of the younger volcanoes in New Mexico (Valles caldera is the exception) erupted basalt, a type of magma that is low in silica and rich in iron and magnesium. These types of magmas have low viscosity (more likely to flow). The gases in the rising basaltic magmas can easily escape, preventing the extreme build-up of pressure, and thus typically producing lava flows with only mild explosive activity.

Will There be Future Volcanic Activity in New Mexico?

Although there hasn't been an eruption in New Mexico in almost 4,000 years, there are three lines of evidence that suggest future volcanic activity is likely.

1) Two places in New Mexico are underlain by relatively shallow magma that could erupt. The Socorro magma body exists at a depth of about 12 miles. The other is located beneath the Valles caldera at depths of 3 to 9 miles.
2) Thousands of volcanoes have erupted during the last 10 million years, including 700+ in the last 5 million years, and 350 in the last 2 million years.
3) There have been at least four eruptions in the last 11,000 years, suggesting the long episode of activity that began 10 million years ago is not over.

These aspects of New Mexico volcanism suggest that future activity is not a question of if, but when!

Understanding Past Volcanism to Prepare for Future Volcanism

One of the fundamental components in hazards assessment is establishing the ages and locations of past events. For volcanic hazards, this means answering three questions.

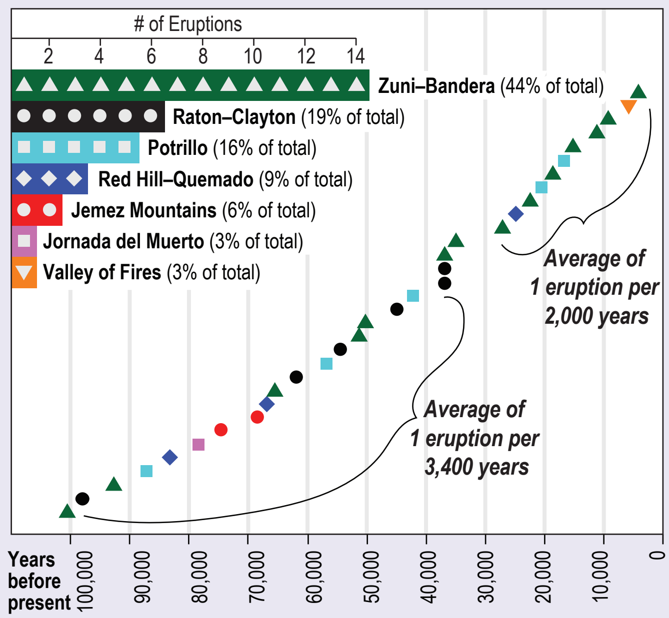
1) What is the eruption frequency, and is it increasing or decreasing?
2) How much time passed between eruptions (known as the repose period)?
3) Are the vents randomly dispersed, or have they migrated through time?

The first two questions help address the overall threat of a volcanic field. For example, a field that erupts once every 1,000 years poses a much greater threat than a field that erupts once every 100,000 years. The third question helps volcanologists assess where to expect future activity.

Despite the recognition that New Mexico is susceptible to future volcanic eruptions, a key element in understanding this threat was missing until recently. To answer any of the three questions we must know the precise ages and locations of past eruptions. Although many studies have investigated aspects of eruptive behavior in the state, no study existed that addressed state-wide eruptive time patterns. This data gap began to close in 2013, when researchers at the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) at New Mexico Tech were awarded a National Science Foundation (NSF) grant to study volcanic hazards. Since then, nearly 200 new ages from almost 100 volcanic deposits have been generated for eruptions that took place in the last 500,000 years.

Before revealing the results of our study, let's discuss how the ages of volcanic rocks are determined. The NMBGMR is home to the New Mexico Geochronology Research Laboratory, a world-renowned facility that specializes in a rock-dating technique called $^{40}Ar/^{39}Ar$ dating. The method relies on the radioactive decay of isotopes of potassium to isotopes of argon. The technique is particularly useful for dating volcanic rocks for two reasons. First, potassium is the eighth most abundant element in Earth's crust and thus exists in nearly every volcanic rock. Second, the half-life (the amount of time it takes for half of the potassium to decay to argon) is about 1.25 billion years, and so is useful for dating rocks in all of Earth's 4.56-billion-year history. In the lab, the isotopes of argon are released from the sample by heating with a laser at progressively higher temperatures to remove more and more gas. The extracted gases are then cleaned so that only argon is delivered to the mass spectrometer (an instrument that measures the abundances of isotopes) for the age determination. A major upgrade to the lab in 2011 improved our precision for dating young volcanic rocks to less than a few thousand years, allowing volcanologists to detect patterns in eruptive activity that were previously unresolvable.

Summary of New Mexico volcanic eruptions in the last 100,000 years



Graphical summary of eruptions in the last 100,000 years in New Mexico. Symbols represent the age of a dated volcanic rock, coded to their respective volcanic fields (upper left).

Eruption Frequency

With the new ages, eruption frequency is now better known for all the volcanic fields in New Mexico. As expected, the frequency of activity differs among volcanic fields and varies throughout the lifespan of each individual field. For example, the most rapid eruption frequency is found in the Zuni–Bandera volcanic field, located just south of Grants, where the average eruption frequency is about one eruption every 3,800 years during the last 65,000 years, and one event every 14,000 years between 350,000 and 100,000 years ago. This suggests that eruptive activity has increased during the field's lifespan. In contrast, other fields show a decrease in activity. In the Potrillo field, near Las Cruces, an estimated 100 vents erupted between 916,000 and 262,000 years ago, an eruption frequency of one per 6,500 years. However, between 190,000 and 21,000 years ago, only 10 volcanoes erupted for a frequency of one event per 16,900 years, a rate that is 2.5 times slower than the earlier history of the field.

Another way to characterize volcanic activity is to calculate eruption frequency for the entire state. One challenge is that the geologic evidence of older volcanic eruptions is commonly lost to erosion or covered by younger lava flows, thus skewing the calculations. Therefore, the most recent activity provides the best information to use for our calculations. Between 100,000 and 3,900 years ago, there were 32 eruptions in New Mexico, for an average frequency of one eruption per 3,000 years. Although the average frequency (3,000 years) is less than the amount of time since the last eruption (3,900 years), this does not indicate that New Mexico is "due" for an eruption. Instead, it means that the current period of inactivity is typical for New Mexico volcanism and we should consider the region to be dormant, rather than extinct.

Eruption Repose Periods

Further complicating the ability to predict future volcanism is the erratic timing between eruptions. There is evidence that consecutive eruptions can happen rapidly. For example, a repose period of approximately 1,000 years separates the two youngest eruptions in the state. Alternatively, there are long, inactive periods of tens of thousands of years, both within individual fields and across the entire state. For example, between 400,000 and 300,000 years ago, only three eruptions have been discovered. The inconsistent repose period between volcanic eruptions makes predicting future activity impossible.

Vent Migration Patterns

By combining the new ages with the locations of volcanoes, we can examine how activity in New Mexico migrates, geographically, through time. In general, the locations of most volcanic vents have migrated eastward. That is, older vents are found on the western parts of the fields and the youngest vents are located to the east. For example, in the Zuni-Bandera field, the older volcanoes in the southwestern part of the field are covered by windblown dust and mature vegetation, whereas younger parts of the field lack vegetation because plants have not had time to grow on the youngest flows. The important implication to the vent migration pattern is that future volcanic activity within each of the volcanic fields may be located near the most recent eruptive sites or perhaps just east. This vent migration pattern should only be used as a guide, not a rule, for assessing future activity, as there are plenty of exceptions to the pattern.

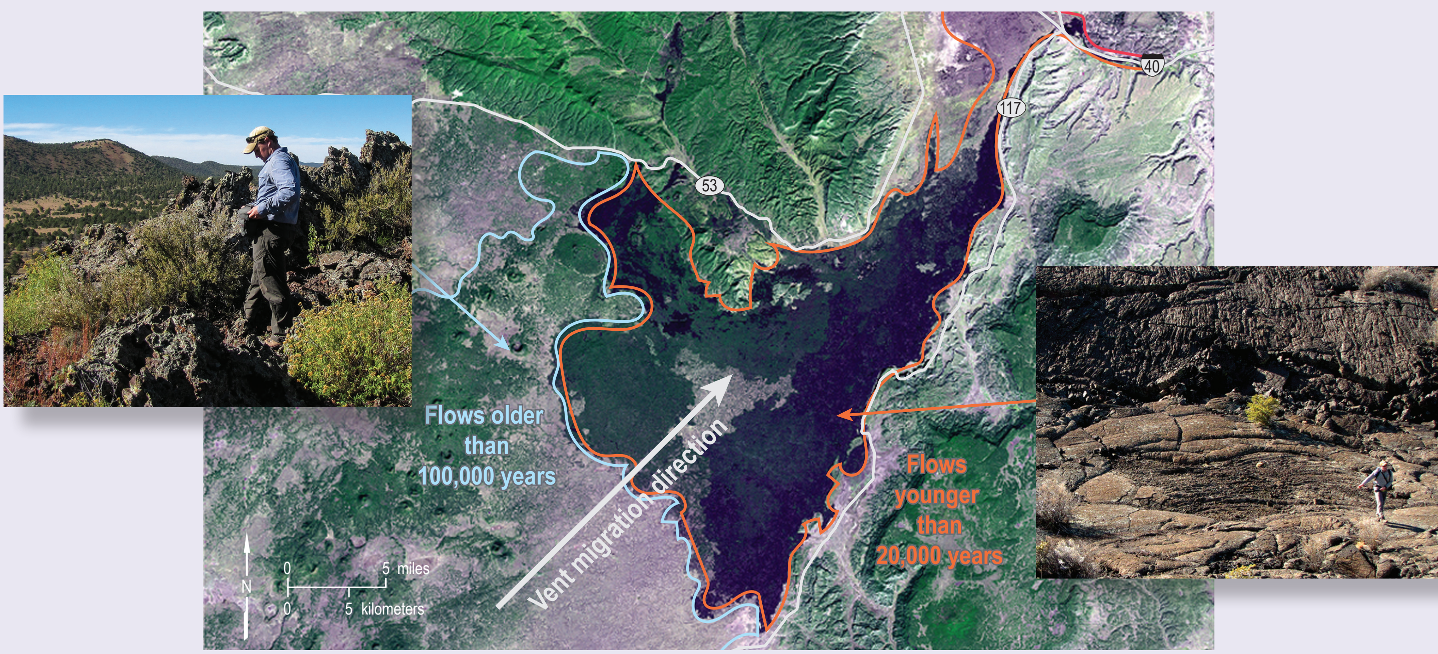
There are two other interesting aspects to the newly discovered vent migration patterns in New Mexico. First, other volcanic fields in the southwest, such as the San Francisco and Springerville volcanic fields in neighboring Arizona, show similar eastward vent migration. Second, in all of these fields, the eastern migration rate is a few inches per year, which is a similar rate, but opposite, to the southwestern movement of the North American Plate. This suggests that the migration of volcanism in the Southwest is, in part, related to movement of tectonic plates.

What Would a Future Eruption Look Like?

Although the new ages and spatial analyses allow us to understand past volcanic eruptions, they do not allow us to predict when or where the next volcano will appear. Instead, a useful exercise is to envision what a future eruption in New Mexico might look like, and what hazards to expect based on past volcanism in the state and around the world.

A Small Basaltic Eruption

The most common type of volcanism in New Mexico during the last 500,000 years are small basaltic eruptions that produce cinder cones and lava flows. These eruptions typically start with mild, gas-rich explosions that produce some ash and cinders (small fragments of cooled lava). Ash-rich eruptive columns can range from a few hundred feet to more than a mile high, possibly impacting air traffic and downwind airports. Finer ejected material would be carried downwind and could accumulate to many feet thick near the volcano and perhaps a few inches thick miles away. If ash and cinders accumulates on homes and other infrastructure, it may collapse roofs and power lines. The gases released in these types of eruptions are typically rich in sulfur dioxide, which can kill vegetation and cause respiratory problems for people and animals. As the gas-rich phase of the eruption wanes, a lava flow might emanate from the cone. Basalt flows can travel many miles downslope, so downhill communities would likely need to evacuate. Likewise, infrastructure might be at risk. During the 2018 lower Puna eruption in Hawaii, lava flows travelled through Leilani Estates, forcing evacuations and causing an estimated $800 million in damage. Most of the basaltic volcanoes in New Mexico are in rural areas where damage due to lava flows



Example of vent migration in the Zuni-Bandera volcanic field. Older flows and vents in the southwestern part of the field (upper left photo) are more eroded and have more vegetation. In contrast, younger flows and vents to the east and northeast (lower right photo) have little erosion and less vegetation. Photos from Kelsey McNamara.

Examples of eruptions that resemble past and potentially future volcanism in New Mexico.

A and B) *Photos of the 2018 lower Puna Hawaii eruption. This four-month long eruption produced many small cones and extensive lava flows that consumed homes, roads, and infrastructure. Most recent activity at Zuni-Bandera and near Carrizozo in New Mexico resembles this type of eruption.*

C) *Photo of the June 12, 1991 eruption of Mt. Pinatubo in the Philippines. Future rhyolitic volcanism in the Jemez Mountains may produce a similar highly explosive, ash-rich eruption.* D) *Photograph showing buildings that collapsed on the Clark Air Force base due to the weight of ash from the cataclysmic eruption of Mt. Pinatubo on June 15, 1991. All photos courtesy of the United States Geologic Survey.*

would be minimal, but the ash deposits could impact local communities. Based on historical events, this type of eruption could last a few weeks to many years, potentially posing both short-term and long-term hazards.

A Larger Rhyolitic Eruption

The only location in New Mexico to experience explosive rhyolitic eruptions in the last million years is the Jemez Mountains, and any future eruptions there would likely follow the same trend. Such eruptions produce much more ash than their basaltic cousins, thus a far larger part of the state and southwestern U.S. air space would be affected. For example, ash from a 74,000-year-old Valles caldera eruption is found 125 miles south in Socorro. Some of our largest cities, such as Albuquerque, Santa Fe, and Taos are near Valles caldera, and could be at risk. Pyroclastic flows (a dense mixture of ash and hot gases that travels downslope at rapid speeds) and ash falls could decimate the dozens of communities that occupy the valleys surrounding the caldera. In contrast to basaltic eruptions, the viscous rhyolitic flows do not typically travel far from the vent and are likely not major hazards. Fortunately, eruptions at Valles caldera are infrequent (2 in the last 100,000 years), and recent dating suggests increasing repose periods between eruptions.

Summary

Although there is no indication that New Mexico will experience an eruption any time in the near future, volcanic activity in our state is certainly not over. Periods of inactivity of several thousands of years, such as the one we are in now, are common, having happened many times in recent geologic history. Nevertheless, volcanic eruptions pose a real and perhaps underappreciated threat to New Mexicans. Hence, geologists remain vigilant to quickly identify any signs of a volcanic awakening, such as increased seismicity due to moving magma, changes to gas emissions, changes to hot and cold springs, changes to geothermal features above magma chambers, and ground uplift that might indicate magma moving closer to the surface. Additional studies to understand past eruptions are underway and will help us prepare for an eruption scenario in the future, when volcanic activity returns to The Land of Enchantment.

—Matthew Zimmerer

Matthew Zimmerer is a field geologist with the New Mexico Bureau of Geology and Mineral Resources. His research focuses on volcanism in the southwestern U.S. and Antarctica.

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Bureau News

State Water Data Initiative Online

The NM Water Data Initiative was established by the state legislature in 2019. This collaborative initiative will make statewide water data accessible, openly shared, and interoperable. The expanding data catalog and gallery of maps are found at newmexicowaterdata.org.

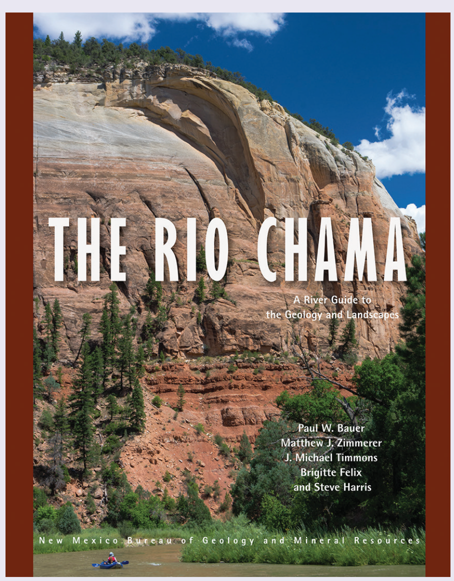
Research Group Lands Major DOE Grant

Bureau of Geology and NM Tech Economic Geologist Dr. Alexander Gysi was granted $895,603 from the U.S. Department of Energy to study fundamental chemical properties of rare earth elements (REE) in hydrothermal fluids using lab experiments and numerical modeling. The project will support two NM Tech Ph.D. students and two post-doctoral researchers.

Rare earth elements are critical metals that are essential components of high-tech and green-tech devices, such as smart phones, efficient lights, and permanent magnets used in wind turbines and hybrid cars. REE exist in only trace amounts in Earth's crust, but can be concentrated in ore deposits by hydrothermal processes. However, the energy processes involved in the formation of these deposits are poorly understood, so thermodynamic modeling can predict REE mobility in fluids, and can help explain field observations and mineral assemblages of ore deposits. The project's experiments will focus on how slight differences in molecular properties such as ionic radius, ion size, and ionic charge affect the behavior of REE in aqueous fluids. The investigators will create a database, called the MINES thermodynamic database, which researchers can use to model the behavior of REE in hydrothermal systems.

Upcoming Publication

The Rio Chama: A River Guide to the Geology and Landscapes



The 135-mile Rio Chama of northern New Mexico is a major tributary of the Rio Grande. From its alpine headwaters at the Continental Divide of the glaciated San Juan Mountains in southern Colorado, this hidden gem flows across the Colorado Plateau in a spectacular canyon cut into Mesozoic sedimentary rocks, in places up to 1,500 feet deep. Towering, vibrant, sandstone cliffs, heavily wooded side canyons, superb camping, and a diversity of historical sites offer an outstanding wild river backdrop for the boater, angler, hiker, or camper.

This book contains detailed river maps of the seven sections of the Rio Chama, plus its three resplendent reservoirs, from the Colorado headwaters to its confluence with the Rio Grande near Española. The Chama Canyon section, below El Vado Dam and through the Chama Canyon Wilderness, is one of the finest, multi-day, whitewater trips in the Southwest. *The Rio Chama* will be printed in early 2021.

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