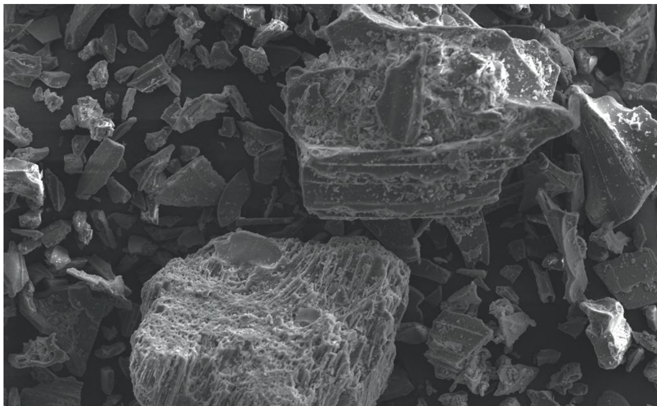

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New Mexico EARTH MATTERS

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Micro New Mexico

NEW MEXICO IS KNOWN FOR ITS VAST OPEN SPACES showcasing some of the world's most unique landscapes and geologic features. Our state's natural wonders come in all shapes and sizes, but they are all built from a framework at the microscale that is just as awe-inspiring and critical to understanding our geologic past.

For instance, the Rio Grande flows for nearly 1,900 miles in total, beginning at its source in the Rocky Mountains of Colorado. It bisects New Mexico for 465 miles before reaching Texas, forming the U.S.-Mexico border. From there, it flows for another 1,200 miles to the Gulf of Mexico, making it the fourth-longest river in North America. Features as large as the entire Rio Grande are only visible from space. However, if we are in a plane, we can see smaller features, like the Carrizozo lava flow, which meanders for 46 miles through the Tularosa Basin, making it one of the longest single lava flows in North America. Jumping in a car and stepping down in scale, we can see the Sandia Mountains rising 5,700 ft (over a mile) above the Rio Grande, or Shiprock towering 1,583 ft over the San Juan Basin. And finally, walking around on our feet, we can see the dunes of White Sands National Park, which can reach up to 60 ft in height. All these geologic features we can see and explore are made up of many small components. Some are visible to the naked eye, while others require a magnifying glass or analytical instruments with higher magnification. In this issue of *Earth Matters*, we'll zoom in on the very small-scale features of "Micro New Mexico," uncovering the tiny building blocks that make up some of our state's greatest natural features and gaining insight into the geologic processes that form our remarkable landscapes.

The Sandia Mountains just before sunset.
Photo by Brandon Stephenson, flickr.com/people/falkon311

Magnifying the Micro

First, let's talk about the word *micro*. The term *mikros*, Greek for "very small," is the source of the English word micro. To be more specific, in a scientific context, micro means "one millionth" of whatever unit it modifies. So, a *micrometer* (also called a *micron*) is one millionth of a meter and is represented by the symbol µm. The term micro can also be represented as the number 10^{-6}, or 0.000001, which is a very small number. To use examples of everyday things in our lives, 100 micrometers is the same thickness as your average sheet of printer paper, or about the width of a human hair. The building blocks of many natural geologic features can be found in the micro world.

How can we observe these very small features? Our eyes can only see down to about 100 micrometers, so we need other tools to delve deeper. With a hand lens (a small magnifying glass used by geologists), we can collect light from a small object and project that image back to our eyes, making it appear 5× to 20× (times larger). This helps geologists closely examine rocks in the field. To achieve higher levels of magnification, we need to move to the laboratory. With an optical microscope, we can achieve 500× magnification and see particles or features as small as 1 micrometer in diameter. However, this is as far as light can take us because the wavelength of visible light is between 400 and 700 *nanometers* (nm), or 0.4–0.7 micrometers. Objects much smaller than the wavelength of visible light will appear blurry. So, to zoom in further, we'll need to change tactics and use a higher-resolution instrument.

How Do We Characterize Geologic Materials?

Minerals are the fundamental building blocks of most geologic materials. A mineral has two fundamental characteristics: a defined composition of chemical elements (its *chemistry*) and a specific arrangement of the atoms of those elements (its *structure*). Minerals (also referred to as crystals) are the building blocks of rocks, and multiple minerals can grow and interlock or stack upon each other to form the rocks that make up the enchanting landscapes of New Mexico.

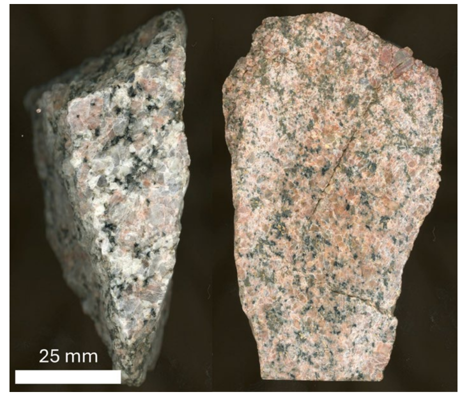
Many advanced analytical instruments have been developed for geological studies, but no single instrument can give you both the chemistry of a mineral and the structural arrangement of atoms at the same time. Multiple instruments are needed to fully determine both the chemical composition and atomic structure of minerals and rocks. The two instruments we will discuss here rely on a steady stream of electromagnetic radiation, called an electron beam, that has a shorter wavelength than visible light, thus providing greater magnification. These instruments are the *scanning electron microscope* (SEM) and *electron probe microanalyzer* (EPMA). Each uses electron beams to illuminate samples, allowing magnification up to 100,000×. In addition to showing the size, shape, and texture of objects, SEM and EPMA also provide information about the chemical composition of spots as small as 1 micrometer. Each of these sophisticated techniques provides specific information about the sample's shape, size, and chemical composition.

The Building Blocks of a Mountain

Now that we understand how to look at small things, let's take a trip around New Mexico and talk about our landscapes as we see them with our own eyes, then move down to the microscale. We'll start with one of the most familiar and likely overlooked features in New Mexico: the Sandia Mountains. Because the Sandias are the backdrop of New Mexico's largest city, more than 750,000 people lay eyes on these mountains every single day. But what do you notice most about the Sandias? Is it the name, which means "watermelon" in Spanish? One popular origin story for the name is that the mountains look like a slice of watermelon. The pink fruit, in this case the red Sandia granite, is topped by layers of gray limestone and a conifer-laden skyline, which makes up the rind.

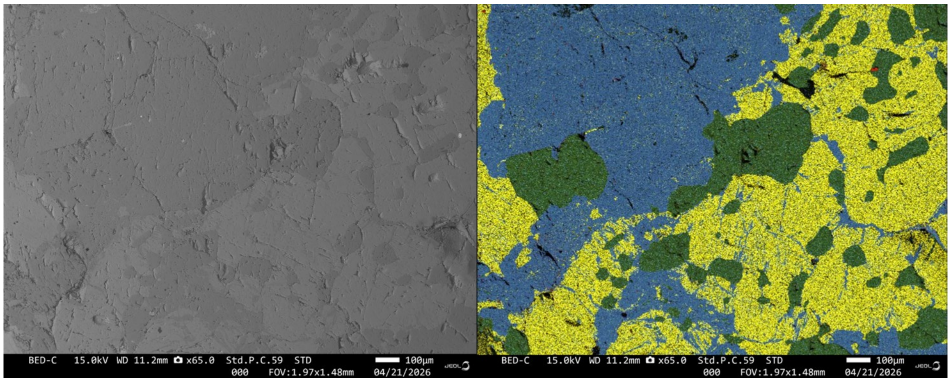
Here we will focus on the Sandia granite—the core of the watermelon—and what geologists refer to as a large pluton. *Plutons* are bodies of igneous rocks that were once molten magma, which then cooled and crystallized deep in the Earth's crust, never erupting at the surface to form volcanoes. The Sandia granite is a single pluton approximately 20 miles long from north to south and 12 miles wide, with at least 4,000 ft of vertical exposure, making it a stunning backdrop for Albuquerque. But what is this 1.4-billion-year-old pluton made of? It consists largely of four minerals. Dominant are large microcline crystals (red-colored potassium feldspar) within a matrix of smaller quartz (clear), plagioclase feldspar (white), and biotite (black) crystals. Each of these minerals has its own distinctive chemical composition and atomic structure, but they all grew directly from the original magma in a way that's similar to how salt crystals form from evaporating saltwater. The abundance and color of the mineral microcline give the Sandia granite its namesake red color. There are some small color variations (more red or less red) throughout the pluton—unsurprising, given that it covers an area of more than 130 square miles.

Let's take a closer look at the minerals that make up the Sandia granite. Quartz, commonly found in beach or dune sand, is one of the hardest common minerals on Earth. It has a simple chemical composition—one silicon atom for every two oxygen atoms (SiO_2)—and a strong, durable atomic structure. Quartz is one of the most abundant minerals in the Earth's crust. Microcline, a type of feldspar, has a



Color variation in scanned and polished samples of Sandia granite. In these hand samples, you can see the four main minerals that make up the Sandia granite. The pink mineral is microcline, the white mineral is plagioclase, the clear or gray mineral is quartz, and the black minerals are mostly biotite. The color and texture vary greatly across the pluton. *Images by Nels Iverson*

(Left to right) Dr. Nels Iverson, Bureau of Geology geochemist/microbeam analyst, and New Mexico Tech graduate students Willa Obringer and Samantha Beauchaine at work using the bureau's JEOL field emission electron microprobe, recently funded by the National Science Foundation. *Photo by Frank Sholedice*



Backscatter EPMA image (left) and X-ray map (right) of a sample of Sandia granite, magnified 65×. Colors in the right-hand image represent different mineral phases of the granite that are hard to distinguish in the grayscale backscatter EPMA image. Green = quartz, yellow = plagioclase, and blue = microcline. *Image and map by Nels Iverson*

slightly more complex atomic arrangement and chemical composition, incorporating potassium (K) and aluminum (Al) into its structure. It has a mineral formula, which is how scientists communicate the chemical makeup of a mineral, of $KAlSi_3O_8$. Plagioclase, also a feldspar, takes it one step further by replacing potassium with varying amounts of sodium (Na) or calcium (Ca)—$(Na, Ca)_{1\text{-}2}\,Al_{1\text{-}2}\,Si_3O_8$. Finally, biotite, a mineral in the mica family, adds even more elements to the mix, including magnesium (Mg), fluorine (F), and structural water (OH^-)—$K(Mg, Fe)_3(AlSi_3O_{10})(F, OH)_2$. The chemical makeup of minerals and their relative abundance, as determined by examining hand samples or microscope slides, is the information that geologists use to name rocks. However, if we take this rock to the lab, we can tease out much more information to help us learn how and where it formed, or whether it was emplaced deep in the Earth's crust or at the surface.

We can use the electron probe microanalyzer to delve deeper into the types of minerals and chemical composition of geologic samples, extracting information from the smallest crystals. EPMA *backscatter electron images* are grayscale images produced by bombarding the sample with a stream of electrons, then measuring the number of electrons "sent back" from the sample surface. The number of electrons backscattered is proportional to the mineral's mean *atomic mass*. An element's atomic mass is the weight of its protons plus neutrons, which ranges from a mass of 1 for hydrogen (H) to 294 for oganesson (Og), a human-made element.

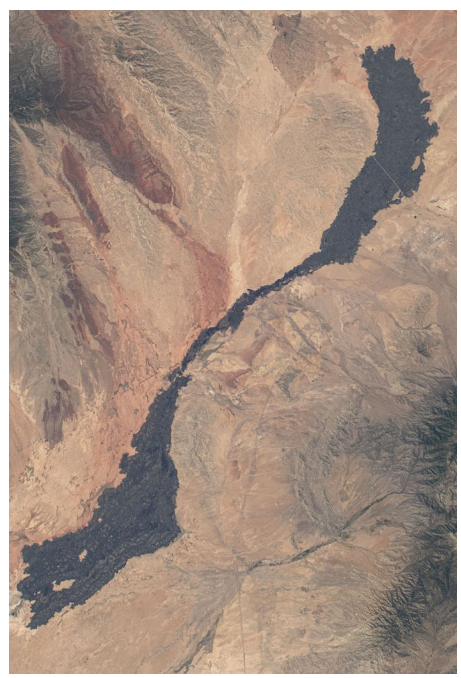
We can calculate the mean atomic mass of a mineral by adding the atomic mass of each element in its structure and dividing by the number of atoms of each element. For example, quartz (SiO_2) has a mean atomic mass of 20; the silicon atom (Si) has a mass of 28, and the two oxygen atoms (O_2) each have a mass of 16, which adds up to 60, and 60 divided by the total number of atoms (3) is 20. Magnetite (Fe_3O_4) has a mean atomic mass of 33 ($Fe_3 = 168 + O_4 = 64 \div 7$ atoms $= 33$), which is 65% higher than quartz. So, any magnetite present in the sample would backscatter 65% more electrons relative to quartz, resulting in a brighter signal because of a higher proportion of returned electrons. Microcline and quartz can be difficult to distinguish in backscatter images because of their similar mean atomic masses (darkest gray in the figure above). Although plagioclase has just a slightly higher mean atomic mass (21) than microcline and quartz, the difference is enough that we can distinguish plagioclase from the other two minerals. For microcline and quartz, however, we need to use another technique to distinguish the mineral phases: X-rays emitted when the sample is bombarded by the electron beam.

X-rays have two defining, interrelated characteristics: wavelength and energy. SEM and EPMA have specific detectors to measure the X-rays emitted by the samples. Every element in a mineral produces X-rays of a specific energy and wavelength proportional to its atomic mass. By measuring the X-rays emitted by the sample, we can map the chemistry and distribution of elements within minerals, and even the abundance of each mineral within the sample. In the image above, the green-colored quartz crystals on the right, within the yellow-colored plagioclase, are smaller than the quartz crystals (also colored green) interspersed between the microcline and the plagioclase in the middle of the image. Geologists can use backscattered electron and X-ray imagery to examine the spatial and chemical relationships among rock-forming minerals, allowing us to understand how a rock originally formed and what conditions it has experienced over time.

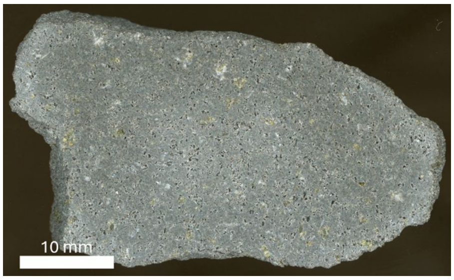
The Valley of Fire

The Carrizozo lava flows, located in the Tularosa Basin of south-central New Mexico, are also igneous rocks. However, these lavas are about as different from the igneous Sandia granite as could be imagined. The Carrizozo lavas are among the youngest volcanic features in New Mexico, erupting around 5,000 years ago, in contrast to the 1.4-billion-year-old Sandia granite. Rather than crystallizing deep in the Earth's crust like the Sandia granite, the Carrizozo lavas flowed across the Earth's surface for almost 50 miles while they cooled and crystallized. A hand sample of Carrizozo lava appears mostly uniform in color, with only a few crystals of a green mineral called olivine detectable by the eye alone. In contrast, many large individual crystals are visible in a hand sample of Sandia granite. Finally, the black-to-gray color of the Carrizozo lavas, contrasted with the light red-to-pink color of the Sandia granite, indicates a different chemical composition, one higher in iron, magnesium, and calcium. This chemical composition, forming a rock called *basalt*, is typical of lavas found in the Hawai‘ian Islands.

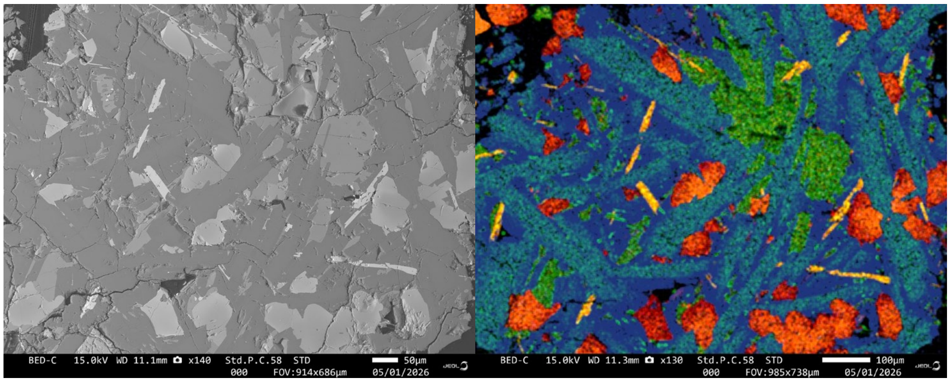
A microscopic examination of Carrizozo basalt using the EPMA technique described above allows us to compare its history and composition to that of the Sandia granite. First, the crystal size in the basalt is much smaller than in the granite. The backscatter image of the basalt shown on page 4 is magnified twice as much as the granite, yet the crystals appear much smaller. Many of the quartz and feldspar crystals in the



International Space Station image of the black-colored basaltic Carrizozo lava flows located near Carrizozo, New Mexico. This 46-mile-long lava river erupted from a vent near the north end of the flows, then the fluid lava flowed south and downhill through the Tularosa Basin under the influence of gravity. *Image by NASA*



A polished slab of Carrizozo lava, showing a gray color and fine-grained texture. Most of the gray is composed of very fine-grained plagioclase feldspar and pyroxene. The green minerals are olivine. Dark spots are void spaces called vesicles. *Image by Nels Iverson*



Backscatter EPMA image (left) and X-ray map (right) of a sample from the Carrizozo lava flows, magnified 130×. Four minerals can be seen in the images. The darkest gray (blue on the X-ray map) is plagioclase feldspar, and the next-lightest phase (green on the X-ray map) is pyroxene. The mineral with gradational gray shades (red to orange on the X-ray map) is olivine, and the bright white (yellow on the X-ray map) is magnetite. *Image and map by Nels Iverson*

granite are more than 1 millimeter in size, with some exceeding 1 centimeter (10 mm). In contrast, many of the crystals in the basalt are on the order of 100 micrometers—the same diameter as an average human hair! This small size is because the lava cooled very quickly as it flowed across the Earth's surface, leaving the crystals little time to grow. In contrast, the granite, which cooled slowly deep in the Earth's crust, had lots of time for larger crystals to grow.

The basaltic lava contains three different minerals that are all made of some combination of iron (Fe), magnesium (Mg), calcium (Ca), and titanium (Ti) in addition to Si, Al, and O. These minerals are called olivine (Fe, Mg), pyroxene (Fe, Ca), and magnetite (Fe, Ti), shown in orange-red, green, and yellow, respectively, on the X-ray map above. These minerals make up a large part of the basalt sample, in contrast to the granite, where they are either rare or absent because the granitic magma didn't contain enough Fe, Mg, and Ca to form these minerals. Geologists can take this investigation further by using detailed chemical analysis of individual minerals to calculate the magma's temperature, the rate of crystal formation, and how quickly the lava cooled as it flowed across the landscape. These micro-observations reinforce not only that the two rocks formed from magmas with very different compositions, but also that the physical history of the two magmas was radically different—one cooling deep in the Earth's crust and the other flowing across the Earth's surface. Analyzing the mineral texture and chemical composition together is a powerful combination for understanding the geologic history of these two iconic New Mexico landscapes.

Where the White Sand Blows

Another geologic landscape familiar to many New Mexicans is the vast sea of white sand located near Alamogordo. White Sands National Park covers nearly 150,000 acres of the western Tularosa Basin and is the largest gypsum sand dune field on Earth. Most sand dunes in the world are made of quartz, which is a very stable mineral. Gypsum ($CaSO_4 \cdot 2H_2O$), however, readily dissolves in water and tends to wash away before forming a dune field. The Tularosa Basin is a closed basin, with no outlet for water to escape except through evaporation. As water evaporates, gypsum accumulates in Lake Lucero in the lowest part of the basin, southwest of the dune field. During times of high rainfall, Lake Lucero can be the largest natural lake in New Mexico. During dry times, it forms a dry lakebed or *playa*. This dry lakebed is the source of our gypsum sand, blown by high winds in the basin to form sand dunes. The sand dunes are held intact in part because the water table is close to the surface, where the water helps the gypsum grains stick together, stabilizing the dunes and keeping them in place.

As we move from Lake Lucero toward the northeast, the dunes take on various shapes. Closest to the lake are small dome-shaped dunes that travel across the Earth's surface at up to 40 ft per year. In other places, the dunes are *parabolic* (U-shaped with arms pointing upwind), with long tails that can be held in place by the local soap tree yucca. As we get to the heart of the dune field where our image is from, we start to see a mix of *transverse* (ridge-shaped) and *barchan* (U-shaped with arms pointing downwind) dunes. The *lidar* image on page 5 was generated using a remote sensing technique in which beams of light are scanned over the Earth's surface and reflected back to a detector, using the speed of light to determine the distance from the detector to the surface. If we scan over larger areas, we can examine surface features at a small scale. There are several things we can

continued on page 5

The white gypsum dunes of White Sands National Park. *Photo by Nels Iverson*

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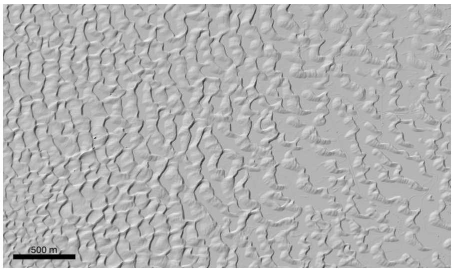
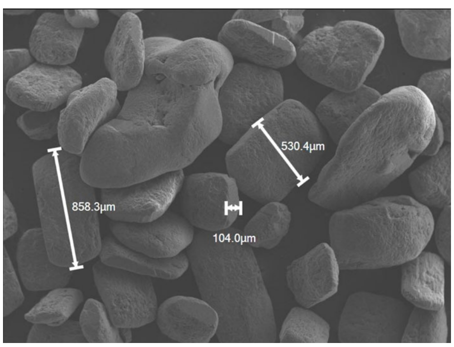


Lidar image of dunes in White Sands National Park. This image is from the center of the dune field. Lidar data acquisition and processing completed by the National Center for Airborne Laser Mapping, distributed by OpenTopography. https://doi.org/10.5069/G97D2S2D

extract from the lidar image. For example, the average dune wavelength (distance from the top of one dune to the top of the next dune) in this image ranges from 260 to 500 ft in the west to over 800 ft on the east side of the dune field. The west side of the image is dominated by transverse dunes, which gradually give way to barchan dunes. Why does the wavelength of the dunes change as we move from west to east? Likely, as we move away from the San Andres Mountains, located west of White Sands, the wind becomes steadier. Because of the steadier winds, the dunes rise 60 ft higher in elevation at the farthest distance from their source in Lake Lucero.

We can see the dunes with our naked eye, but what are the little building blocks that can be moved by the wind and stacked so high? Scanning electron microscopy can provide information on the shapes of very small samples by producing high-magnification (up to 100,000×) 3D images of a wide variety of geological and biological materials. Sand grains can have all sorts of shapes, from blocky like a brick to round like a baseball. The shape depends on a few things: mineral type, mode of transport (water or wind), and the distance that the grain has been transported from its source.



Secondary electron microscopy image of White Sands gypsum sand grains. Grains are magnified 40×. *Image by Nels Iverson*

The farther the grains are from the source, the more likely they will be rounded. Also, the softer the mineral, the more easily it will be rounded. Gypsum is about three times softer than quartz, and you can easily scratch it with your fingernail. For comparison, quartz can easily scratch stainless steel. The gypsum grains in the SEM image below are subrounded to rounded. The grain size is variable, but for the most part, the blocks are about 800 micrometers (µm) long, 500 µm wide, and only 100 µm tall (about the thickness of a human hair). You can see some chipping or pitting (10–20 µm in size) on the grains, likely a combination of abrasion while being blown around and chemical dissolution when it rains. The blockiness and roughness of the sand grains allow them to lock together and stack up, creating the largest white dune landscape on the planet.

Continuing the Micro Adventure Throughout New Mexico

When you travel around New Mexico, you can experience some of the most spectacular landscapes in North America. From the red glow of a Sandia Mountains sunset to moonlit walks through white dunes to exploring our vast, harsh volcanic landscapes across the state, New Mexico is truly the Land of Enchantment. The features we discussed here, along with the new skills you've now acquired for observing landscapes, can be translated across the state. Granites and other intrusive igneous rocks can be found at the cores of numerous mountain ranges, from the Bootheel Ranges to the Sangre de Cristo Mountains. Volcanic features, such as the Carrizozo lava flow, are also very common, covering close to 12% of the state's surface, with much of the state being composed of basaltic lava flows and other volcanic features, like igneous rocks that make up the Mogollon-Datil volcanic field in the Gila Wilderness. On the other hand, White Sands National Park is extremely unique—within the state and globally—but other types of quartz or mineral-sand deposits can be found throughout the state and everywhere along the Rio Grande. So, slow down and take a closer look at the micro features. Think about what shapes, colors, and minerals are present and how they are linked to the grand vistas we get to take in and enjoy every day.

Dr. Nels Iverson

Dr. Nels Iverson is a geochemist/microbeam analyst at the New Mexico Bureau of Geology and Mineral Resources. He also manages the bureau's electron microprobe lab.

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Cover photo of an SEM image of ash particles from the Bandelier Tuff, located in the Jemez Mountains. *Image by Nels Iverson*

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Bureau News

David W. Love Receives the 2026 Earth Science Achievement Award

A respected field geologist, collaborator, and educator, Dr. David W. Love is the recipient of the Bureau of Geology's 2026 Earth Science Achievement Award for Research and Education. The award recognizes Love's career of research and public service—spanning more than four decades—that has significantly advanced understanding of New Mexico's geology while inspiring fellow scientists, students, and teachers across the state. Throughout his career, Love has been widely admired for his detailed field observations, broad curiosity in all things geology, and collaborative spirit. His work spans geology, geomorphology, sedimentology, and environmental hazards, with a particular focus on the landscape evolution of the American Southwest. Even late in his career and into (quasi) retirement, Love continues to explore new questions about New Mexico's geology, participate in field investigations, and collaborate with colleagues. That lifelong curiosity, combined with a remarkable generosity, kindness, and humility, undoubtedly made him a respected figure in the geological community.

New Mexico Water Data Initiative Recognized in "50 States, 50 Breakthroughs" Showcase

The New Mexico Water Data Initiative (WDI) has been selected as New Mexico's featured innovation in 50 States, 50 Breakthroughs—a national showcase highlighting one breakthrough public service project from every U.S. state. The showcase, a collaboration between the peer-to-peer learning platform Apolitical, the National Academy of Public Administration, and Humans of Public Service, celebrates the most pioneering public sector projects driving better government in the United States. The WDI, led by the New Mexico Bureau of Geology and Mineral Resources, was launched as part of the 2019 New Mexico Water Data Act, a landmark piece of legislation that set the state on a path to become a national leader in collecting, standardizing, and sharing water data.

Bureau of Geology and New Mexico Tech Awarded $2.5M Department of Energy Grant to Establish Research Hub for Critical Minerals

A team of researchers, including (left to right) Dr. Laura Waters, Dr. Alex Gysi, and Dr. Nicole Hurtig, has received $2.5 million in funding through a U.S. Department of Energy grant to establish a hub for critical minerals research. In addition to enhancing research capabilities, the project will support two Bureau of Geology staff, two postdoctoral fellows, five PhD students, and four undergraduate students. Critical minerals are essential to the economic and national security of the United States and are also vulnerable to supply chain disruptions. They are crucial ingredients in the manufacturing of a wide range of products—from smartphones to solar panels to satellites—and are used in many industrial processes. With the funding, new equipment will be acquired to expand the experimental capabilities of laboratories at the Bureau of Geology and NMT. "Very few labs are equipped to conduct high-pressure and high-temperature hydrothermal experiments that mimic ore-forming conditions in Earth's crust," said Gysi. "Our goal is to better understand how critical minerals deposits form in geologic systems, and ultimately to develop predictive models and new technologies to locate, extract, and refine these resources."