Lite Geology

New Mexico Bureau of Geology and Mineral Resources

Fieldwork

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New Mexico Bureau of Geology and Mineral Resources Fieldwork

In addition to conducting research in New Mexico Bureau of Geology and Mineral Resources (NMBGMR) laboratories, NMBGMR scientists work in the field to map geologic features and collect data about mineral, energy, and water resources. Data and samples collected in the field are also used in geologic and hydrogeologic research. In partnership with the University of New Mexico and the United States Geological Survey, the NMBGMR maintains an array of seismic instruments throughout the state. The NMBGMR collaborates with a network of partners to monitor public and private wells to assist with water resource management. As the geologic survey for the state of New Mexico, we are a non-regulatory agency that freely shares information with scientists, decision makers, educators, and the public, via the NMBGMR webpage (https://geoinfo.nmt.edu/geoscience/research/postcards/home.cfml) and Facebook (https://www.facebook.com/NMBGMR/).

Cover Photos

Left to right:

Enthusiastic Hydrogeologist Ethan Mamer collecting a groundwater sample on a sunny summer day in southeast New Mexico. *Photo by Marissa Fichera*

Senior Geophysicist/Field Geologist Shari Kelley examining pumice in the Jemez Mountains using a hand lens. *Photo by Richard Kelley*

NMBGMR Director Nelia Dunbar, Bill McIntosh, and Dawn Sweeney walking near the summit of Mt. Erebus volcano in Antarctica. *Photo courtesy of Peter Kelly*

What's in Your Pack?

Kevin Hobbs

When working in the field, geologists must be prepared not only to conduct research but also to remain self-sufficient in the face of unexpected circumstances in a natural setting. Unlike work in a lab or office, fieldwork usually does not allow a quick trip down to the supply closet for extra paper clips or pencils. Since there is no thermostat in the great outdoors, the field geologist must also be prepared for changing weather conditions. Because of these factors, a geologist's field pack is often filled to the brim with items necessary for successful and safe fieldwork. Here, some New Mexican field geologists describe what is in their packs while they are working in their field areas.

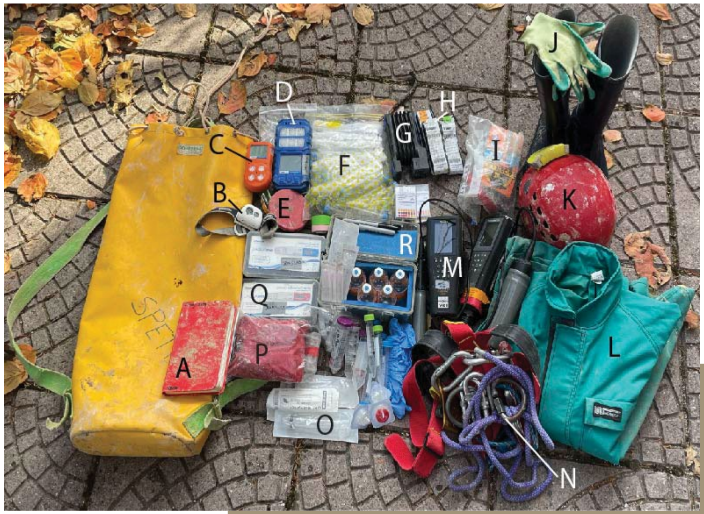
Shari Kelley, Senior Geophysicist and Field Geologist, NMBGMR:

As a field geologist and geophysicist, Kelley focuses on mapping the rocks and geological features visible at Earth's surface, collecting samples, and making accurate descriptions of what she observes during her field trips. Some of the contents of her pack help her to accomplish scientific objectives, whereas others are included for comfort or safety. A field geologist like Kelley would use items like her hand lens, camera, and field notebook on every outing, while hoping never to need the raincoat, mosquito net, or first aid kit.

The contents of Shari Kelley's field pack. A. hand lens; B. rain coat; C. pack cover; D. first aid supplies; E. pack repair supplies, matches, and whistle; F. sunglasses; G. mosquito net; H. headlamp; I. bug repellent; J. sunscreen; K. hand sanitizer; L. toilet paper; M. field case with pens, pencils, colored pencils, magic markers, field book, and scale bar; N. rock hammer; O. topographic map for keeping track of geologic observations in the field; P. GPS; Q. magnet used to detect magnetic minerals; R. bottle of dilute hydrochloric acid used to test for carbonates; S. an extra pair of reading glasses; T. binoculars; U. sample bags; V. Brunton compass; W. extra batteries; X. camera; Y. spot locator device for emergencies; Z. Handyman tool; AA. extra markers, pencils, and pens; BB. tape measure; CC. pencil sharpener. *Photo by Shari Kelley*

Dan Jones, Assistant Professor, **Mackenzie Best**, Geobiology Ph.D. student, and **Zoë Havlena**, Geobiology Ph.D. student, Department of Earth and Environmental Science at New Mexico Institute of Mining and Technology (NMT):

On a recent trip to the Frasassi cave system in central Italy, members of the NMT Geomicrobiology team took the time to document their packs' contents. In order to study the microorganisms responsible for the formation of the Frasassi cave system, the packs they carried differed in both form and contents from a typical geologist's pack. Everything had to be waterproof, and great care was taken to protect each pack's contents from the sulfuric acid present in the cave's waters. Additionally, since the team was collecting biological specimens, sterilized equipment was a necessity. Rounding out their chemistry needs, delicate instruments like multimeters and gas detection tubes were necessary. The Frasassi cave system contains vertical drop-offs, so their packs also contained climbing ropes and harnesses. To prevent contamination of delicate cave ecosystems, all gear had to be thoroughly cleaned between each field visit—quite the departure from a typical geologist's cleaning routine!



Cave pack (yellow) and labeled contents for cave geomicrobiology research in the Frasassi cave system, Ancona, Italy. A. field book; B. spare headlamp; C. portable ENMET meter for CO and O_2 gases; D. portable ENMET meter for other gases (CO_2, SO_2, H_2S, NH_4, O_2); E. tape measure; F. sterile transfer pipets; G. Dräger tube pump; H. Dräger tubes (NH_4, CO_2, SO_2, H_2S); I. miscellaneous bag with extra batteries, Super Glue, granola bars, and tape; J. cave gloves and boots (we use rubber boots because the sulfuric acid eats through regular hiking boots); K. helmet with mounted headlamp; L. cave suit (washed after every cave visit to keep each cave clean of mud from other caves); M. water chemistry multimeters (for pH, specific conductivity, temperature, dissolved oxygen, and oxidation–reduction potential); N. climbing harness and gear (descender, ascender, cow's-tails, D-ring, chest ascender); O. syringes and filters for water sampling; P. first aid kit; Q. pH meter for dripwater; R. labeled N_2 incubation serum bottles with caps and crimps. *Photo courtesy of Mackenzie Best*

The contents of NMBGMR hydrogeologists' field packs. A. steel water level measuring tape (lowered into a well to measure the water level); B. chalk for steel tape (coated on the lower few feet of the steel tape, which allows us to see when the tape hits water); C. electric water level measuring tape (This nifty device is a measuring tape with a sensor on its end and is used to measure water levels. The tape is lowered into the well, and when it hits water, it makes a loud beeping sound, letting the hydrogeologist know the depth to groundwater in the well.) D. field gloves (for clearing tumbleweeds and spider webs out of the work area); E. tools (All wells are a bit different. These are two of the common tools required to remove the cap on a well casing.) F. measuring stick (used to determine the height and diameter of a well casing); G. acoustic sounder (measures a well's depth to water by transmitting an acoustic sound wave down a well and bouncing the sound off of the water surface); H. pressure transducer data loggers (These hang inside a well below the water surface and make continuous records of the water pressure above them, allowing us to measure water depth.) I. field computer (Many of the wells we visit have a device installed that collects data continuously. When we visit a site with one of these devices, we use the laptop to download the data.) J. download puck (This is one of the many connectors that allow us to download data from our instruments.) K. clipboard/sampling form (We record information on these forms when a new well is visited, a sample is taken, or a water level is measured.) L. sampling gloves (prevent contamination of water samples and prevent our skin from being burned by some strong chemicals we use to preserve the water samples); M. water quality meter (measures parameters such as water temperature, pH, dissolved oxygen, and specific conductance [a proxy for amount of salts] in the field); N. sampling bottle (Water is stored in these bottles on their journey to a lab, where they're analyzed for chemical data that we cannot measure in the field.) *Photo by Ethan Mamer*

Marissa Fichera and **Ethan Mamer**, Hydrogeologists, NMBGMR:

Hydrogeologists like Fichera and Mamer go into the field to collect data about groundwater and aquifers all over the state of New Mexico. These data help them better understand how groundwater flows in the subsurface. They measure water levels with steel tapes or electric measuring devices. Sometimes they place electronic instruments in a well to collect data automatically, then return a few times a year to download the data that the instruments have recorded. This gives a better picture of how water levels respond to things such as summer irrigation season or a large storm. Fichera and Mamer also collect water samples from wells by filling sample bottles with groundwater. These are then sent to labs for water quality analysis; general chemistry analysis measures the concentration of constituents such as calcium, magnesium, nitrate, sulfate, sodium, chloride, carbonate, and bicarbonate. Stable isotope data help the hydrogeologists know where the groundwater came from, and age data can tell them how old the groundwater is.

Nelia Dunbar, Petrologist and Director, NMBGMR:

Since the 1980s, scientists at the NMBGMR have been involved with field research on Antarctic volcanoes. When working in remote field locations in Antarctica, geologists like Dunbar carry a lot of equipment in their field packs. Some of the equipment is for their geological investigations. Other items are needed to live and work comfortably in a cold, harsh, and remote setting. Because of the cold, researchers carry heavy insulated bottles full of hot drinks and get to eat plenty of chocolate!

The contents of Dunbar's Antarctic field pack. A. spare insulated pants; B. insulated mittens; C. insulated double boots; D. spare windbreaker; E. spare goose-down parka; F. spare insulated hat in case primary hat is blown away; G. spare wool socks in case primary socks become wet; H. nuts and dried fruit; I. sunblock (the sun is up 24 hours a day during the December field season in Antarctica); J. insulated bottle for tea or coffee; K. chocolate bars; L. cloth and plastic sample collection bags; M. rock hammer; N. crampons for work on steep snow or ice; O. field notebook and pencils; P. spare batteries, chemical hand-warmers, and GPS; Q. camera. *Photo by Kevin Hobbs*

Rare Earth Element Deposits in the Gallinas Mountains, Lincoln County, New Mexico

Virginia T. McLemore, Shari Kelley, and Matthew J. Zimmerer

NMBGMR geologists just completed mapping the geology and mineral deposits in the Gallinas Mountains in east central New Mexico, an area with established rare earth element (REE) potential. A small amount of bastnäsite, a REE fluorocarbonate mineral, was recovered during historic processing for fluorite. In addition to fluorite production, lead, copper, zinc, silver, gold, and iron have been produced from the district. Re-examination of the REE deposits in the Gallinas Mountains is warranted considering the economic importance of REE.

Rare earth elements are one group of critical minerals that include the 15 lanthanide elements, yttrium, and scandium. REE are lithophile elements (elements enriched in the crust) that have similar physical and chemical properties and therefore occur together in nature. REE are essential in most of our electronic devices, such as cell phones, laptops, computer chips, wind turbines, and hybrid/electric cars. Other developing technologies such as solar panels, water purification and desalination systems, and efficient light bulbs also require REE in their manufacture. Most of the current world REE production comes from China, but the United States has significant REE resources that are being explored.

Fluorite-bastnäsite hydrothermal breccia vein exposed at the Eagle Nest adit. *Photo by Virginia McLemore*

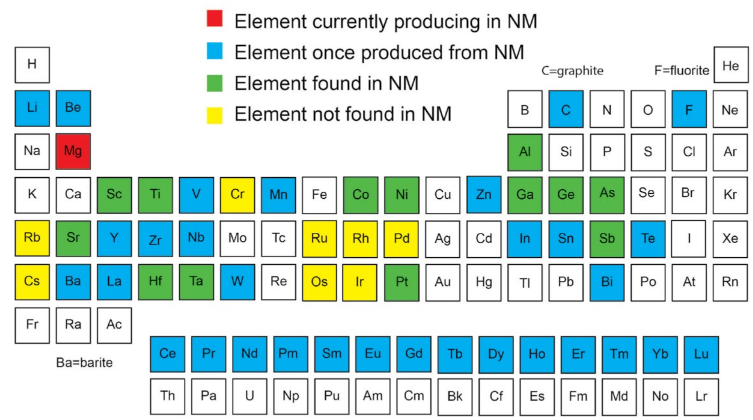
NMBGMR geologists examining a fault breccia. *Photo by Virginia McLemore*

In New Mexico, many REE deposits are found in the North American Cordilleran alkaline-igneous belt, a regional zone of Cenozoic alkaline igneous rocks and associated mineral deposits that extends from Canada through the United States and into eastern Mexico. This zone has been explored and exploited for numerous types of mineral deposits, especially gold, fluorite, and REE. The Gallinas Mountains are part of this regional belt.

Many intrusions in the Gallinas Mountains are poorly exposed. However, specialized mapping techniques not used in previous mapping allowed differentiation of Cenozoic igneous rocks. More than 20 intrusive units have been mapped. New and published $^{40}Ar/^{39}Ar$ ages provide insight into the timing of magmatism, alteration, and mineralization in the Gallinas Mountains. Dating of the intrusions indicates at least two and possibly three periods of magmatic activity. Dikes and sills were emplaced during discontinuous magmatic activity between 38.5 and 29.3 Ma. The majority of the intrusions exposed in the Gallinas Mountains, which include dikes, sills, and laccoliths of syenite, rhyolite, trachyte, and andesite, were emplaced between 29 and 27 Ma, with most activity occurring at approximately 28.8 Ma. Dating of minerals associated with alteration yields ages similar to these intrusions, suggesting that alteration and mineralization are genetically related to the exposed intrusions. Magmatic activity and related alteration may have continued from 25.8 to 24.4 Ma, but this pulse of magmatism is poorly constrained.

Alteration in many areas indicates mineralization because alteration generally forms a halo surrounding the mineral deposits. However, in the Gallinas Mountains it appears the alteration is related to the intrusions. Four types of alteration are described in the Gallinas Mountains, all of which are related to the intrusions. Evidence for early non-mineralized regional silicification (addition of silica to the rocks by silica-rich fluids) and brecciation (breakdown into angular fragments) of host rocks is preserved where the mineral deposits are located. This was followed by regional alteration by iron-rich fluids and alteration of feldspar to mica. These fluids caused the dissolution and brecciation of gypsum and limestone, which locally became enriched in REE. Next, another type of alteration, called fenitization, removed silica (quartz) and increased sodium, potassium, magnesium, and iron (i.e., feldspars, amphiboles, and pyroxenes) from the original host rock. This alteration is associated with the main pulse of mineralization. Close relationships between these altered rocks (or fenites), alkaline igneous rocks, and REE mineralization have been established in many districts of the world. In the Gallinas Mountains, fenitization is interpreted to be coeval with the intrusions (29 to 27 Ma). These fenites are not enriched in REE.

Seven types of mineral deposits are found in the Gallinas Mountains, distinguished by mineralogy, chemistry, form, and host rocks: (1) iron skarn–contact replacement deposits, (2) hydrothermal breccia and fissure veins, (3) fluorite replacements/disseminations, (4) magmatic, intrusive breccia pipes, (5) carbonate breccias, (6) oxidation below the Earth's surface, and (7) oxidation near and at the Earth's surface. Economically, the most important REE deposits are the hydrothermal breccia and fissure vein deposits, which are further subdivided into eight chemical and mineralogical subtypes. The magmatic, intrusive breccia pipes are also a potential economic source of REE. The origin of the mineralizing fluids is uncertain, but data from this study are consistent with previous conclusions that the REE deposits are derived from magmatic-hydrothermal fluids from either an alkaline magma, such as the trachyte and syenite exposed in the Gallinas Mountains, or a deep-seated, buried carbonatite, an unusual igneous rock type composed of calcite, dolomite, and very little silica.



Note that any element or commodity can be considered critical in the future depending upon use and availability. Coal contains several of these critical elements.

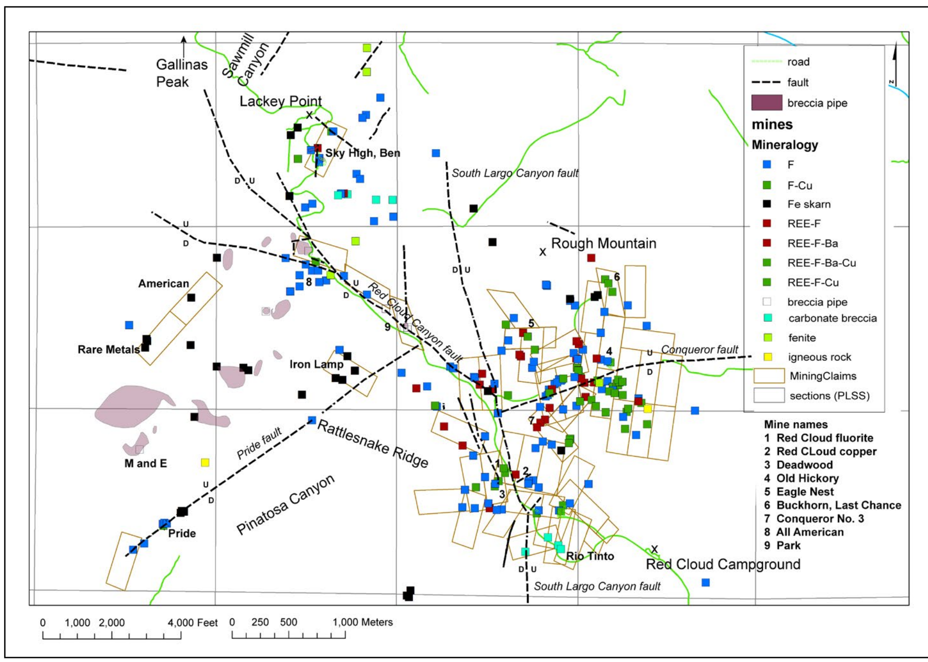
U, Re, He, and K (potash) were removed from the critical minerals list in 2022 and Zn and Ni were added.

Periodic table showing critical minerals (as defined in 2021) in New Mexico. The rare earth elements include Sc, Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu.

In general, many exposed hydrothermal breccias and fissure veins in the Gallinas Mountains are small and low-grade, although samples with concentrations as high as 8% total REE are found in some mineralized zones. Drilling is required to evaluate their potential. The grade of the hydrothermal breccia and vein deposits in the Gallinas Mountains is too low to be economic for gold, uranium, thorium, and niobium in the current market.

For more information on REE see https://geoinfo.nmt.edu/publications/periodicals/earthmatters/11/n2/em_v11_n2.pdf.

For more information on the Gallinas Mountains, including the geologic map, see https://geoinfo.nmt.edu/publications/openfile/details.cfml?Volume=617



Mines, prospects, mining claims, major faults, and geographic localities in the Gallinas Mountains. U and D indicate upthrown and downthrown blocks. The location and summary of information about each mine are available in Appendix 1 of the Mining Districts of New Mexico Open File Report, volume 494 (***https://geoinfo.nmt.edu/publications/openfile/details.cfml?Volume=494***).

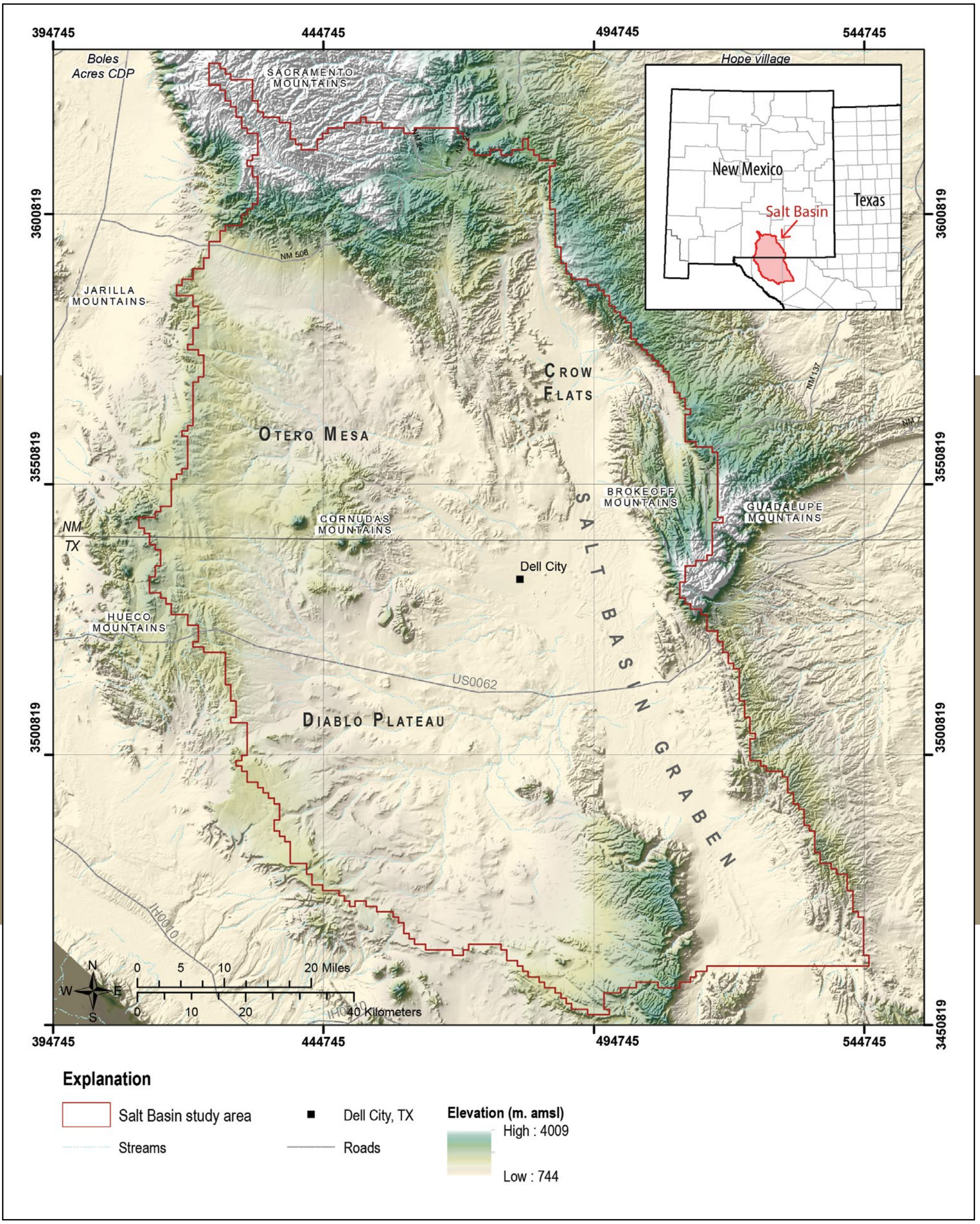
Fieldwork as a Tool for Assessing Groundwater Resources in the Salt Basin of New Mexico and Texas

Shari Kelley and Marissa Fichera

Fieldwork is a research method used by hydrogeologists to further the understanding of groundwater processes. While computers help us understand the subsurface through modeling various hydrologic phenomena such as groundwater flow, recharge amounts, evaporation, and pumping effects, the data needed to run these models must first be collected in the field. The NMBGMR and NMT recently conducted research to assess the water resources of the Salt Basin region of southern New Mexico and westernmost Texas. Fieldwork was a major component of this project and involved multiple trips to the Salt Basin to collect water level, water quality, and geophysical data. These data helped constrain the hydrologic and geologic parameters necessary for accurately assessing groundwater resources.

The Salt Basin of New Mexico and west Texas is a large (5,000 square miles), hydrologically closed, semi-arid groundwater basin. In order to explore the sustainability of water resources in the Salt Basin aquifer of New Mexico, a research team endeavored to compile a complete water budget for the basin; this required the compilation of existing data, fieldwork to collect additional data where needed, and development of a groundwater flow model to address water sustainability questions. The Salt Basin in New Mexico is vast and sparsely populated, requiring travel on mostly dirt roads. Sudden weather changes made fieldwork a fun logistical challenge. In total, we collected 20 new water samples, a handful of water level measurements, and geophysical data at nearly 30 sites over the course of the project.

Hydrogeologists measured water levels to estimate the depth to groundwater and collected water samples to assess water quality. Groundwater levels are typically measured by lowering a steel tape into a well. This is effectively a metal ruler that can be lowered into the well and lifted back out by an attached reel. The steel tape has chalk coating the first few feet so that the measurements can be read when the tape reaches groundwater. (See "What's in your Pack?" in this issue for more descriptions of hydrogeology field equipment).



Location and physiographic features of the Salt Basin study area. Over half of the basin is located in Texas (see inset). The region is vast and covers a variety of geographic and geologic features. In New Mexico these include the Sacramento Mountains, reaching 9,600 feet in elevation; the rolling limestone hills of Otero Mesa; low-elevation playas (the Salt Basin Graben); and the Guadalupe Mountains, reaching 8,000 feet in elevation.

Sunrise over the Cornudas Mountains and a frost-covered Salt Basin on a frigid field morning! *Photo by Marissa Fichera*

Water samples are collected by pumping groundwater from a well into a set of sample bottles. In the field, we can measure water quality parameters such as pH (acidity or alkalinity), specific conductance (amount of dissolved salts), water temperature, and dissolved oxygen. As groundwater discharges from the well, we monitor these field measurements until they stabilize, then collect the water in sample bottles. The bottles of water are then sent to laboratories for additional water quality analysis. Ideally, measurements include general groundwater chemistry, stable isotopes, and age data. The combination of these water quality results can reveal useful information about the aquifer, including where groundwater originated, how old it is, and what rocks it likely travels through.

The type and variety of field data collected in the Salt Basin allowed NMBGMR researchers to answer important questions regarding aquifer properties, groundwater flow, and groundwater availability. (A final report will be released in late 2022). Field techniques are exceptionally important in studying aquifer systems. In a state that relies principally on groundwater, these techniques will continue to be used to provide updated information regarding New Mexico's groundwater.

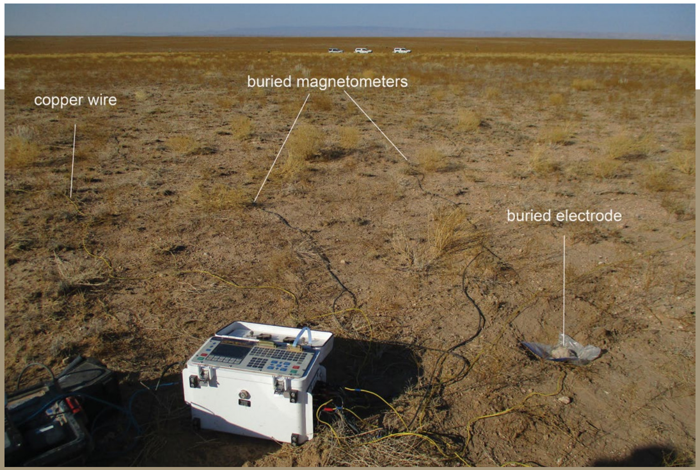
Left: NMBGMR hydrogeologist Scott Christenson measuring the depth to water by lowering a steel tape into a well in the Salt Basin. *Photo by Marissa Fichera*

Right: Former NMBGMR hydrogeologist Trevor Kludt collecting water samples on a sunny day in southern New Mexico. *Photo by Scott Christenson*

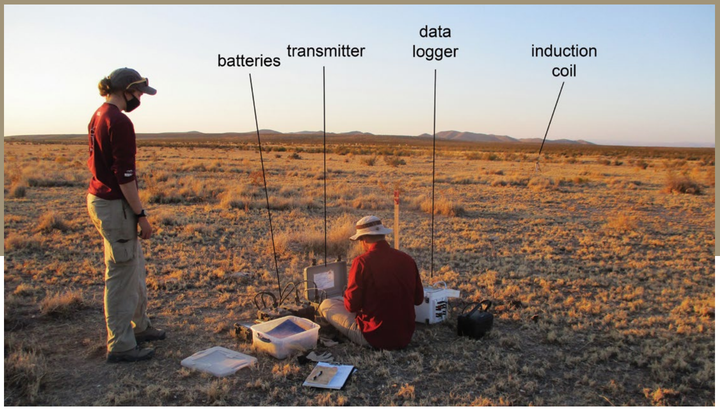
Geophysical Fieldwork in the Salt Basin

Shari Kelley

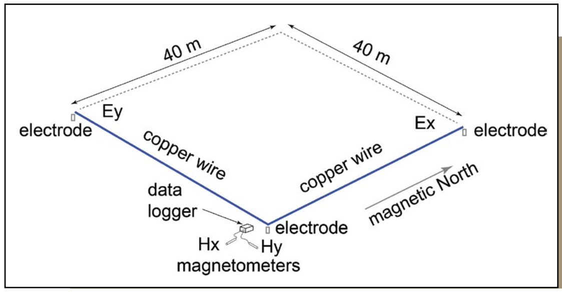
In addition to the tools and techniques outlined in the article about hydrologic fieldwork in the Salt Basin, we incorporated geophysics into the Salt Basin groundwater study to further investigate aquifer properties. The geophysical surveys measure both natural and induced electrical and magnetic signals to explore the subsurface. We used two methods. First, we collected audio-magnetotelluric (AMT) data at 28 sites in the study area. The AMT technique utilizes naturally occurring electromagnetic waves generated by lightning (high frequency) and the interaction of solar winds with the Earth's magnetosphere (low frequency). These natural magnetic field variations induce electrical currents in the Earth's crust that can be measured at the surface to determine subsurface electrical resistivity structure. Low frequency signals penetrate deeper than high frequency waves. The fields are measured using two copper wires attached to buried electrodes and



AMT equipment in the field. This fieldwork was done during the pandemic and following COVID protocol. Only one person could be in each vehicle, so we had to take three trucks (the white objects in the distance). *Photo by Shari Kelley*



The TEM setup in the field. *Photo by Shari Kelley*



Field configuration for AMT data collection. The Ex and Ey electrodes and copper wires measure the electric field in N-S and E-W directions, respectively. Similarly, Hx and Hy magnetometers measure the magnetic field in N-S and E-W directions, respectively.

two buried magnetometers oriented with respect to magnetic north. Second, transient electromagnetic (TEM) data were collected at 12 sites. The TEM method measures the electrical resistivity of the subsurface using an applied current. A transmitter box attached to a power source sends a current into a loop of copper wire that is laid on the ground surface. The current is repeatedly and rapidly turned on and off, inducing downwardly diffusing currents into the subsurface. These currents produce small secondary magnetic fields that induce decaying voltages in a magnetic induction coil placed in the center of the transmitter loop. Decaying voltages recorded at early times quantify the shallow subsurface, while voltages at later times measure resistivity at greater depths. The subsurface resistivity measured by both methods is affected by rock type, porosity, and groundwater salinity. Saline water, clays, and mineralized rocks conduct electric currents well (i.e., are conductive), whereas fresh water, dry anhydrite, and bedrock with little permeability or porosity are poor conductors (i.e., are resistive).

Our study focused on Crow Flats and Otero Mesa in New Mexico. Crow Flats is underlain by gypsum playa deposits. The water table is close to the surface, and the AMT and TEM data indicate that the shallow groundwater is conductive, consistent with the high total dissolved solids (TDS) content of the groundwater measured during previous water quality studies. The geologic and hydrologic interpretation of the AMT data from Otero Mesa is more challenging because, as mentioned above, many factors besides TDS affect the resistivity of the subsurface. We found that limestone in the shallow subsurface (<1,000 feet) is resistive and probably contains fresh water. The interpretation is trickier at depths below 1,000 feet, where at many sites, a conductive zone is recorded in the AMT data. Is the conductive zone due to a clay-rich rock type (Abo Formation) or brackish water? Luckily, several oil wells (actually dry holes) have been drilled in the Salt Basin, and geophysical well logs and rock cuttings from those wells are on file at the NMBGMR. Careful examination of the logs and cuttings revealed that in some instances, the conductive zone correlates nicely with the Abo Formation. However, in other cases the conductive zone is in the overlying Yeso Formation, a unit that contains anhydrite (a dehydrated form of gypsum), which is not conductive unless the calcium sulfate goes into solution. Thus, using evidence derived from the oil wells and AMT data, we hypothesize that brackish aquifers can be identified in the Yeso Formation using this combined approach. This investigation was reconnaissance in nature; the AMT sites were scattered over an area of about 100 square miles. Given our encouraging results, the next step is to conduct more focused experiments near the oil wells to test the interpretation.

Geologic Mapping in the Little San Pascual Mountains

Daniel Koning, W. John Nelson, Scott Elrick, and Snir Attia

An exciting geologic mapping project that we are currently undertaking is focused on the Little San Pascual Mountains. These are the roughly 4-mile-long range that can be seen to the east-southeast of the Bosque del Apache National Wildlife Refuge, 25 miles south of Socorro. The highest peak is only 5,525 feet in elevation, standing 600 to 900 feet above the surrounding landscape. When you look at the Little San Pascuals from the much higher Magdalena Mountains southwest of Socorro, you can see why "Little" is part of their name.

Excellent rock exposure and intriguing geology make up for the diminutive stature of these mountains. Bedrock in the higher northern part of the range (the part visible from the Bosque del Apache) is composed mostly of limestone and lesser shales and sandstones. These sedimentary rocks were initially deposited in shallow seas about 320 to 300 million years ago during the Pennsylvanian Period.

Over geologic time, the initially flat sedimentary rock layers have been faulted, folded, and tilted by tectonic forces. Faults are cracks that have allowed rocks to slide past each other. In many instances, movement along faults has caused folding in adjoining rocks.

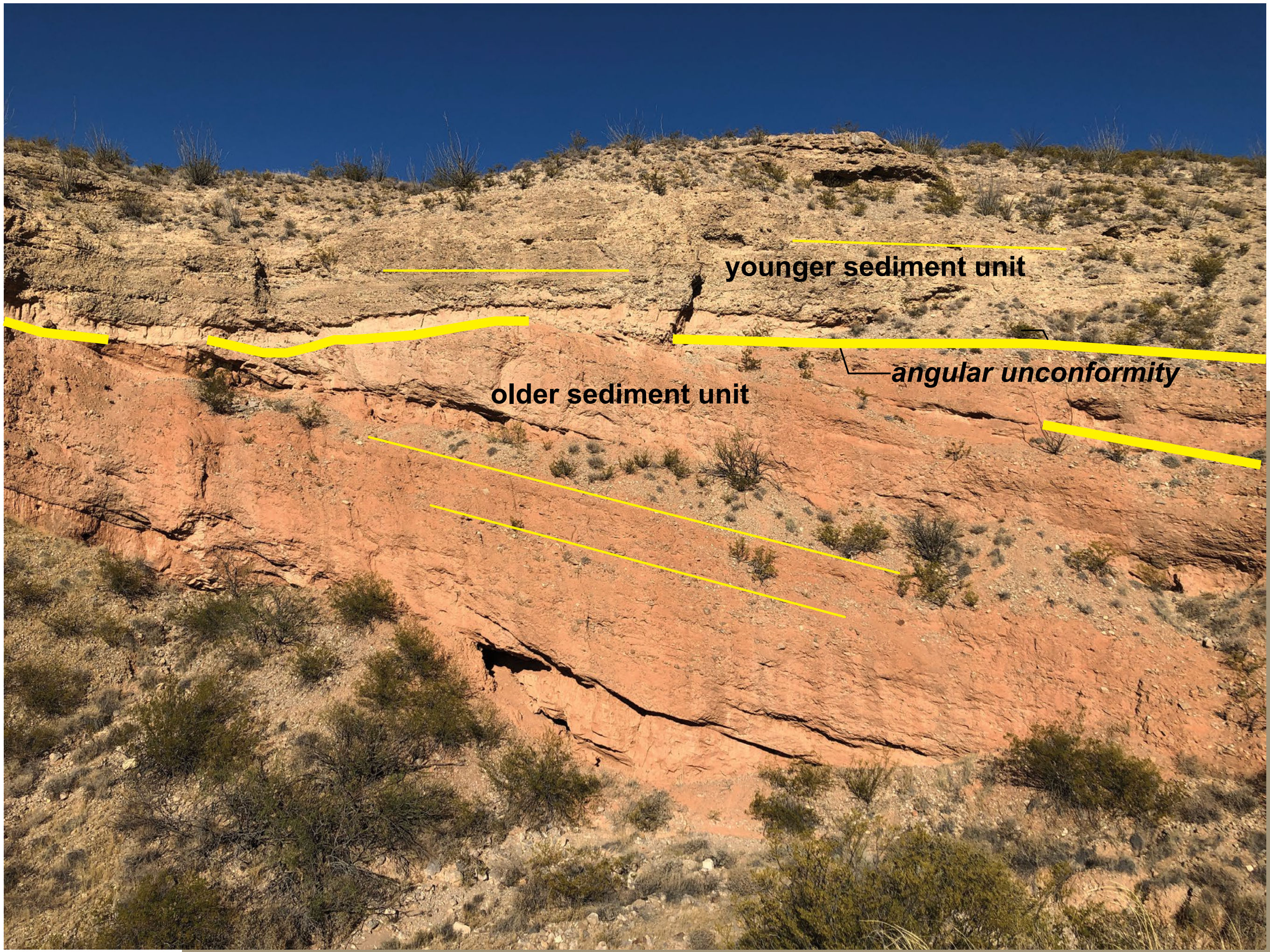
A major fault zone bounds the western foot of the Little San Pascual Mountains; its location is shown by white arrows in this north-northeast view. Yellow lines are drawn between limestone rock layers. Approaching the fault from the right, note how these layers are bent down (dragged) due to the west-side-down motion along the fault that occurred over the past 25 million years. To the left of the fault is sand deposited in the adjoining basin of the Rio Grande rift. *Photo by Dan Koning*

We used remote-controlled, aerial vehicles (drones) to photograph folds and faults. In this photograph looking south, we can see eastward-tilted, layered Pennsylvanian rocks of the eastern Little San Pascual Mountains. The tilt of the rock layers steepens to the east (leftward) and is steeper at the white arrow than the black arrow. *Photo courtesy of Scott Elrick*

The sedimentary rock layers in the Little San Pascuals have been folded into an anticline, as noted by the first geologist who worked here, Richard W. Geddes. The layers are tilted to the east on the east side of the mountains and bow down to the west on the west side. Along much of the foot of the mountains, the rock layers dip down even more steeply due to faults that bound the mountain block on its east and west sides.

Geologic mapping involves carefully drawing on a map the boundaries between rock units and tracing any faults and folds that deform these rocks. A fun part of the research process is figuring out the geometry of these geologic structures and their relative ages. Although still a work in progress, we interpret that most of the folds in these mountains occurred during the Laramide orogeny. This is the mountain-building episode that also formed the Rocky Mountains roughly 80 to 40 million years ago. Across the western United States, compression caused rock layers to be squeezed and blocks of rock to be moved up and over each other along reverse faults. Over the past 25 million years, the basins of the Rio Grande rift formed during extension of the Earth's crust. The Rio Grande follows the rift. Movement along the fault at the western base of the mountains caused the Little San Pascual Mountains to be raised and the adjoining Rio Grande valley to subside.

Thanks to mapping and careful observations, one can learn a big geologic story from the Little San Pascual Mountains!



This photograph shows Rio Grande rift sediment that was laid down by ephemeral streams draining the Little San Pascual Mountains. There are two sediment units separated by a boundary (contact) called an angular unconformity (partially annotated as a thick yellow line) that represents a gap in geologic time. Below the contact lies orangish sediment in layers that were once near-horizontal. Over millions of years, tectonic forces have tilted these layers about 20° to the right. Then erosion occurred and beveled these tilted layers. The youngest sediment (light tannish gray) lies above the unconformity and has not been tilted. *Photo by Dan Koning*

Westside Sacramento Mountains Watershed Restoration Project—Education and Outreach

Talon Newton and Cynthia Connolly

The Westside Sacramento Mountains Watershed Restoration and Fuels Reduction Project (WSMWR) is a collaborative effort to apply prescribed fire and vegetation thinning to improve forest health along the western slope of the southern Sacramento Mountains (USDA, 2016). The NMBGMR agreed to contribute to this project by crafting an education and outreach component in which Americorps-funded EcoRangers were trained to measure and collect soil temperature data as a proxy for measuring soil moisture. The NMBGMR then processed and interpreted these scientific data and reported on the efforts to our partners at the Otero Soil and Water Conservation District (SWCD).

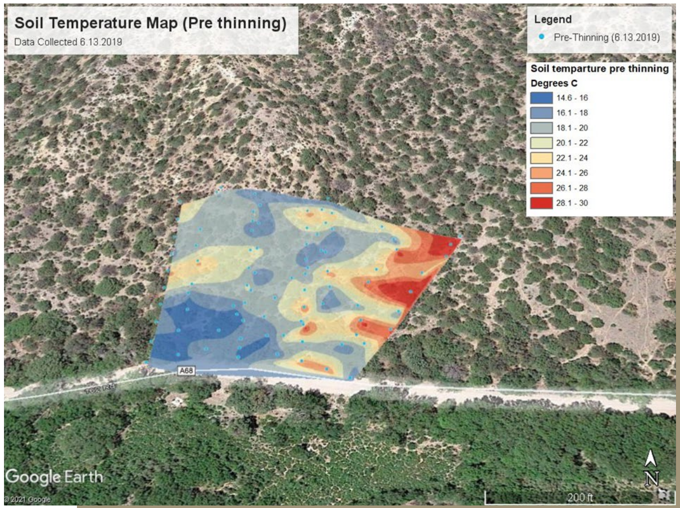
Initially we had planned to use soil moisture probes provided by the Otero SWCD, but the probes did not produce consistent measurements. Instead, we used electric meat thermometers to measure soil temperature as a proxy for soil moisture and compared pre-treatment soil temperatures to post-treatment soil temperatures under similar conditions (including air temperature and precipitation amounts). We assumed that differences in soil temperature would most likely be due to soil moisture differences.

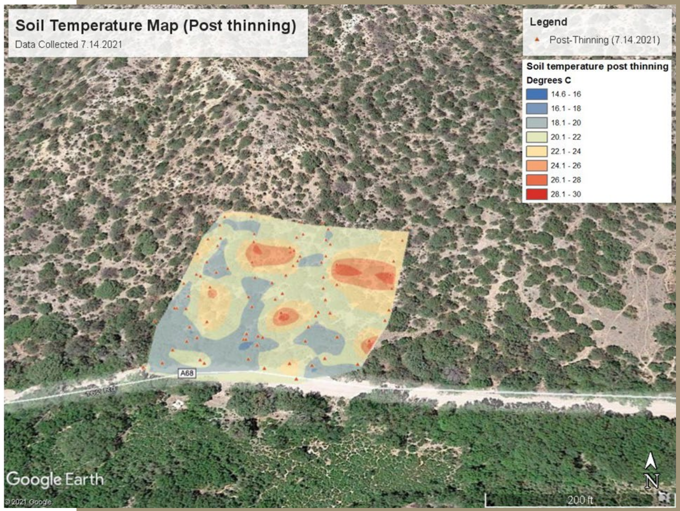
On May 14, 2019, we met Stephen Carter, EcoServant Director and leader of the EcoRangers, and several EcoRangers at the Otero SWCD headquarters, where Newton presented a 30-minute slideshow to describe the project, ecosystem processes, and the study plan. We then drove out to the soil study area, a small transect of the section along La Luz Creek slated for tree thinning. EcoRangers were trained to collect soil temperature measurements along a rough grid and record observations on soil texture and vegetation type. Tree thinning took place between mid-August 2020 and February 2021. On June 13, 2021, we trained a different EcoRanger crew that gathered post-treatment field measurements and data. Data collected by EcoRangers during the summer of 2019 (pre-treatment) and the summer of 2021 (post-treatment) were then processed and interpreted by Newton.

Soil temperature contours for a set of pre-treatment (top) and post-treatment (bottom) measurements are shown at right. These datasets were compared because they represent the most complete spatial overlap. It rained prior to both data collection events, but there was much more rain before vegetation was thinned. Unexpectedly, average post-thinning soil temperatures appeared to be higher than pre-thinning soil temperatures, suggesting that the increased amount of incoming radiation due to thinning was the dominant control on soil temperatures.

Talon Newton training an EcoRanger on how to take pre-treatment soil temperature measurements on May 14, 2019. *Photo by Cynthia Connolly*

GPS coordinates were recorded at each pre-treatment measurement point, and EcoRangers were supposed to use these same points for subsequent measurements. This arrangement did not produce consistent datasets that overlapped spatially. Post-treatment data collection was improved with the addition of placing small flags at each measurement point. Feedback from the EcoServant leader and EcoRanger personnel was positive, and they were interested in the science process and objective of this experiment. Although soil temperature results were inconclusive regarding the effects of tree thinning on soil moisture, the education and outreach portion of this project was successful.





Measurement points and resulting soil temperature contours before vegetation thinning (top) and after vegetation thinning (bottom).

Reference

USDA, 2016, Westside Sacramento Mountains Watershed Restoration and Fuels Reduction Project environmental assessment: Prepared for Sacramento Ranger District, Lincoln National Forest, 96 pp.

Through the Hand Lens with Dan Koning

What is your educational and professional background?

I obtained a B.S. in geology from the University of California Riverside in 1994. As an undergraduate, I worked two summers under Dr. Stephen Wells doing a variety of interesting geology-related jobs. I then worked 2.5 years at an environmental consulting firm in southern California called EMCON. My job duties at EMCON mostly involved installing monitoring wells near landfills and tabulating water sample results from these kinds of wells. I then went to the University of New Mexico to obtain a master's degree in geology and graduated in May 1999. My advisor at UNM, Frank Pazzaglia, procured summer employment for me that involved mapping two quadrangles northwest of Albuquerque. I enjoyed those jobs so much that I worked as a self-employed contractor for the NMBGMR for 3 years after I graduated from UNM. The NMBGMR offered me a full-time job in the summer of 2003, and I have been with them ever since.

What inspired you to become a geoscientist?

I think I ended up choosing geology as a career because of my interest in history combined with my curiosity about how the Earth was formed. Even as a young child, I loved thinking about why landforms were there and their past history. I also remember a fascination in how running water moved and shaped dirt. One thing a neighbor and I did when I was about 7 years old was to leave a garden hose running all night long to see what kind of mini-river and lake would form. That earned both of us a harsh scolding from his older brother about wasting water! I was raised, and still am, a Christian, and thinking about how God made the world always had a personal, spiritual component for me. I also have always liked being outside, feeling dirt in my hands, and doing a job that involved physical labor.

I should also add that my father played a major role in my career development by spending so much time hiking and exploring underground mines with me. Instead of sleeping in on his days off, he would commonly get up at 5 or 6 a.m. to join me in thrashing up steep, brushy slopes in the San Gabriel Mountains of southern California. When I was older (in high school), he also allowed me to do solo hiking in these mountains, which allowed me time to observe and think about nature.

What are you most proud of professionally?

The maps I have made, in addition to the related geologic reports, are probably what I am most proud of. I think the work I have done and am continuing to do on the Española and Albuquerque basins will prove most useful to society. For those basins, a noteworthy thing I have done was to make 3-D models of the geologic layers comprising the groundwater aquifers. I am working on one such model now for Rio Rancho.

What hurdles have you had to overcome to be a successful scientist?

I really like geology, so it wasn't much of an impediment for me to learn the subject and conduct research-oriented projects. My main challenges involved managing unexpected problems on drilling projects while at EMCON, which was a pain at the time but in retrospect was a good experience for me in handling difficult situations and communicating with people.

Why is it important for teachers to focus on geoscience in their classrooms?

Geology, like the rest of science, is important because it is a great tool for us to understand how the natural world operates. People should be cognizant of this reality so they appreciate the natural world and make intelligent decisions about how humans should interact with it.

I would like to add that education, especially that involving natural science, cannot be confined to the classroom. Field trips are really important to foster curiosity and to promote critical thinking. Ideally, a science teacher should develop students' desire, drive, and skills to think about the natural world on their own, at home and in nature.

Dan Koning at an outcrop of the Popotosa Formation adjoining the Little San Pascual Mountains. One can interpret a fascinating geologic history of this area by closely studying the composition, shape, and size of gravel embedded in the orangish sand. This Popotosa Formation is briefly discussed in the article on mapping work in the Little San Pascuals. *Photo by Claire Koning*

About

New Mexico Bureau of Geology and Mineral Resources

Hours, excluding New Mexico Tech holidays, are:

Monday through Friday, 9 am to 5 pm
Saturday through Sunday, 10 am to 3 pm

Founded in 1927, the New Mexico Bureau of Geology and Mineral Resources in Socorro, New Mexico, is the New Mexico State Geologic Survey. We are a research and service division of the New Mexico Institute of Mining and Technology, serving New Mexico through geologic and aquifer mapping, mining and energy resource science, water chemistry analysis, and other geology-related research. *Photo by Cynthia Connolly*

Mineral Museum

The Bureau's mineralogical collection contains more than 16,000 specimens 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. We like to show off our home state's minerals, as well as give students an idea of how minerals end up in products we use every day. For teachers, students, and other groups, we offer free tours of the museum. Museum staff can also identify minerals or rocks 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

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Museum Curator: *Kelsey McNamara*
To schedule a museum tour, contact Kelsey:
(575) 835-5418, kelsey.mcnamara@nmt.edu

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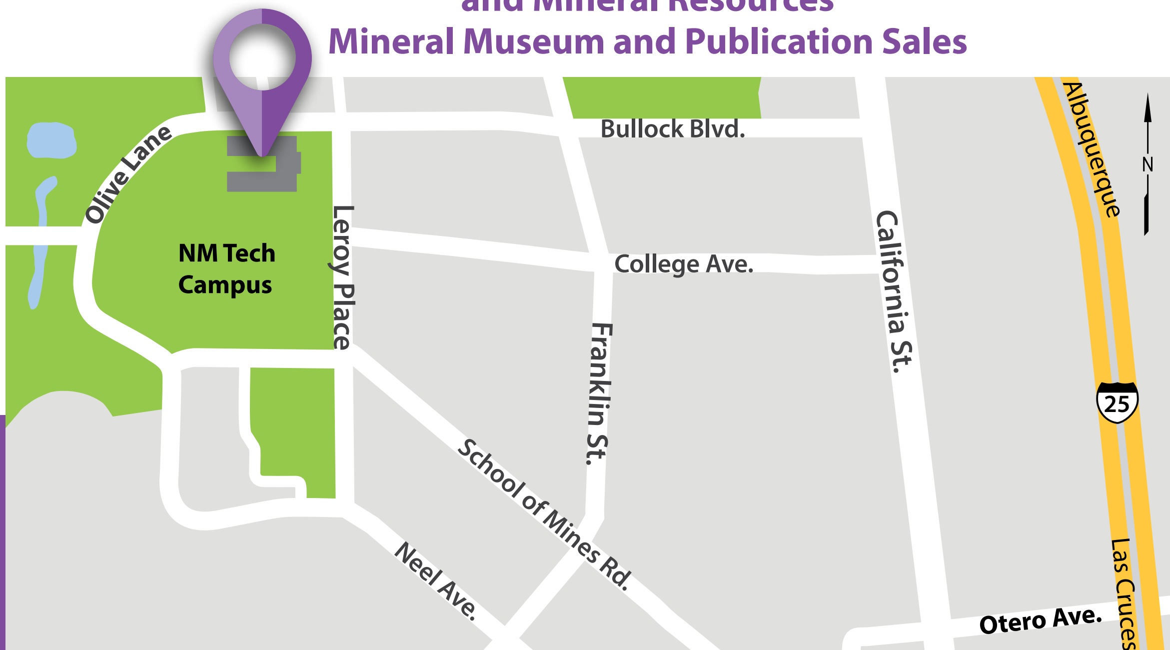

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