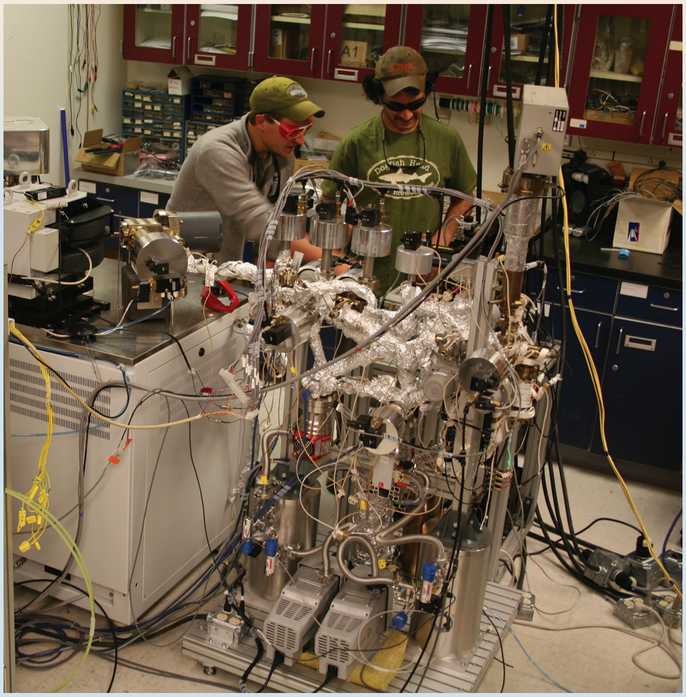
New Mexico
EARTH
MATTERS

WINTER 2014

ANALYTICAL LABORATORIES AT THE NEW MEXICO BUREAU OF GEOLOGY



Post doc Matt Zimmerer and Ph.D. candidate Jake Ross helping to construct the new argon geochronology lab. They are building an ultra-high vacuum system where argon is extracted from samples by heating with a laser. The extracted argon is passed to the mass spectrometer for isotope analysis and age determination.
Image by Nelia Dunbar.

Geology once relied on basic traditional fieldwork done with a rock hammer, hand lens, magnet, and acid bottle. A hundred years ago, this was about the extent of the analytical tools available to geologists. Today, however, a wealth of tools is available to allow geologists to examine many aspects of a rock's genesis and history. New analytical instruments can reveal, in intricate detail, the secrets of a rock's mineralogy, chemical composition, and age, lending greater insight into geological research problems. The more closely you examine a rock to learn about its chemistry and chronology, the more complicated the geological picture of that rock's history is likely to be, but the more completely geologists can interpret and understand the geological history of our planet.

In the late nineteenth and early twentieth centuries, a number of scientific discoveries were made that had direct bearing on rock analysis. The discovery of X-rays in 1895 by Wilhelm Roentgen led to the development of three major geochemical analytical tools: X-ray fluorescence, X-ray diffraction, and the electron microprobe. In the early twentieth century, radioactive decay was discovered, the process whereby a parent isotope of radioactive elements naturally decay to daughter isotopes, at a predictable rate. The need to separate and measure different isotopes led to the development of the first mass spectrometers. These analytical instruments form the basis of a broad suite of geochemical and geochronological techniques that add greatly to the geologist's toolbox.

With the continued development and innovation since then, the New Mexico Bureau of Geology and Mineral Resources today has a number of geochemical and geochronological tools that have tremendous capabilities. Our laboratories house instruments that can measure the chemical components of rocks and water to the part-per-trillion level, provide information on mountain-building by analyzing a single crystal, and determine the chemical composition of a spot on a mineral that is one tenth the diameter of a human hair. The bureau supports a broad range of professional and student research, as well as outreach activities, and our laboratory facilities play an important role in that research.

INSTRUMENTATION

Geochronology

Time is a vital component of almost any geological investigation and can be measured either relatively or absolutely. Relative time (younger versus older) is determined by the spatial relationships of rocks. This may be as simple as observing that one rock unit is above another, and therefore is younger. This principle is known as the law of superposition. Absolute age, in contrast to relative age, means knowing the age of a rock. Measuring daughter isotopes of certain elements, formed by the natural and predictable radioactive decay of parent isotopes, is the most common method used to determine absolute age. This is the science of geochronology. One familiar method of absolute dating is Carbon-14, which allows us to determine the age of carbon-bearing material that is less than about 50,000 years old. There are many other geochronological methods that are useful for understanding Earth's history. The bureau houses a state-of-the-art and internationally recognized potassium/argon (K/Ar) lab.

The New Mexico Geochronology Lab uses a variant of the K/Ar method referred to as ^{40}Ar/^{39}Ar geochronology. This lab

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was established in1993 as the brainchild of former director and state geologist, Dr. Charles Chapin. The bureau, the National Science Foundation (NSF), and Los Alamos National Laboratory provided initial funding for the laboratory. The ^{40}Ar/^{39}Ar method relies on the radioactive decay of the parent isotope ^{40}K to a stable daughter isotope ^{40}Ar. Because potassium is a very abundant element in many common rocks and minerals, and because ^{40}K has a half-life of about 1250 million years, the ^{40}Ar/^{39}Ar geochronology method can be used to date rocks as young as a thousand years or as old as our universe (13.8 billon years). This versatility and the occurrence of potassium-bearing minerals in igneous, metamorphic, and sedimentary rocks makes the ^{40}Ar/^{39}Ar geochronology method the most commonly used dating tool in earth sciences.

After twenty years of working with the original instrumentation, the bureau's geochronology lab recently received more than a million dollars of funding to expand the facility, primarily from the NSF, as well as private and corporate donations. These funds have allowed the purchase of state-of-the-art instrumentation to complement the original equipment. Much of this new technology is unique to this lab, and these advances have vastly improved the ability to determine rock ages with remarkably high precision. With the new instrumentation, we can now date rocks and minerals that are millions of years old with errors of only a few thousand years, allowing unparalleled resolution of geological processes that were occurring millions and even billions of years ago. These measurements are made on an instrument known as a mass spectrometer, which measures argon gas pressure in a rock or mineral. Because the concentration of argon in most rocks is very low, the concentrations that must be measured are extremely small. For example: the argon partial pressure measured in a mineral in our lab is about 0.000000000001 pounds per square inch (PSI). By comparison, the pressure in a typical car tire is 32.0 PSI.

Understanding the absolute ages of rocks allows the rates of geological processes to be studied, which is particularly important when studying globally important biological phenomenon. How, why, and when our planet undergoes mass extinctions and how evolutionary processes respond, has been an intellectual challenge since the development of the science of geology 150 years ago. Rates of climate change, both modern and past, have great societal relevance for scientists and decision makers. Predictions of volcanic, earthquake, and climate-related hazards are possible only through an understanding of the timing of these processes.

Fault zone (diagonal band in center of image) cutting the Sandia Granite near Albuquerque. Frictional motion along the fault results in a damage zone of crushed rock (cataclasite) and melted rock (pseudotachylyte). Clay mineral identification in the cataclasite are determined by XRD analysis, and newly grown minerals in the melted rock can be dated by the geochronology lab to determine age of movement and recurrence intervals for paleo-earthquake assessment. Note person for scale. Image by Adam Read.

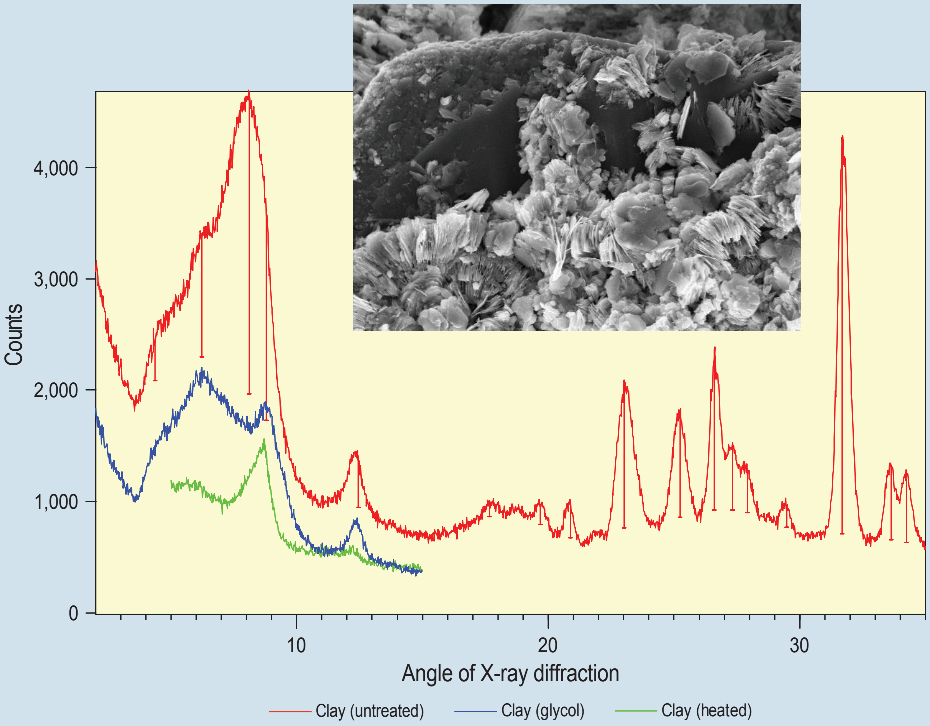
Geochemistry and Mineralogy

Rates and timing of geological processes are very important, but to unravel many geological puzzles, we also need to understand the geochemical and/or mineralogical properties of rocks and minerals. The bureau houses a number of other instruments that use different analytical approaches to analyze the composition of a wide range of rock and mineral samples, from ancient granites to ash from young volcanic eruptions, to precious metals in ore deposits, to meteorites.

Two major analytical techniques are available: X-ray diffraction (XRD) and electron microprobe analysis, both of which use X-rays to determine geochemical information. These high-tech instruments, both geared toward rock and mineral analysis, were purchased with Department of Education and NSF funding. The two techniques are strongly complementary and allow a detailed analysis of mineralogy and geochemistry, with the XRD specializing in mineralogy and the microprobe producing geochemical data. XRD analyses use X-ray energy to determine the arrangement of atomic layers in crystalline substances. Like a fingerprint, every crystalline substance has a unique X-ray diffraction pattern, and these patterns allow accurate identification of individual minerals as small as grains of sand. When coupled with chemical data from the electron microprobe, more information about the material can be gleaned. Electron microprobe analysis is a nondestructive technique that focuses a beam of electrons one tenth the diameter of a human hair onto a sample, thereby generating X-rays characteristic of the individual chemical elements in the sample. By identifying and measuring the quantity of different X-rays, the chemical composition of the sample can be determined. Because of the very tiny beam diameter, the microprobe is capable of analyzing the geochemical composition of very small spots on a sample surface, allowing the composition and chemical variability to be examined in great detail. This instrument can also produce beautiful chemical maps of polished rock surfaces, and three-dimensional images of tiny mineral shapes.

Water Chemistry

In an arid state like New Mexico, water is an extremely important commodity. The value of water is directly related to its quality, which in turn is related to its chemistry. In order to analyze water chemistry, the bureau supports another set of analytical instruments that are housed in the Chemistry Laboratory. Most of the research in this facility involves collecting data about the major salts in our water—



Composite X-ray diffraction scans used for analysis of mixed layer clay from fault gouge, with the y-axis plotting peak intensity (counts) and the x-axis plotting the angle of X-ray diffraction. The red, blue, and green spectra represent different analytical methods where variations in intensities can reveal the relative proportions of kaolinite, illite, and mixed-layer components. Analysis of the peak intensity widths can be used to determine relative size of the clay crystallites. Inset: Electron microscope image of very fine-grained platy clay minerals. Some of the plates, which are roughly hexagonal, are seen end-on, and others are seen in stacks, like the pages of a book. Field of view is around 1/10th of a millimeter, or approximately the width of 10 human hairs. *Image by Nelia Dunbar.*

sodium, calcium, sulfate, and chloride, for example—and trace metals and metalloids, including uranium, lead, and arsenic. However, the laboratory is not limited to water samples. Rock and soil sample analyses can be made if the samples can be digested into liquid form. The Chemistry Lab also has a laser that can vaporize a mineral or rock to a form that can be used for additional analysis.

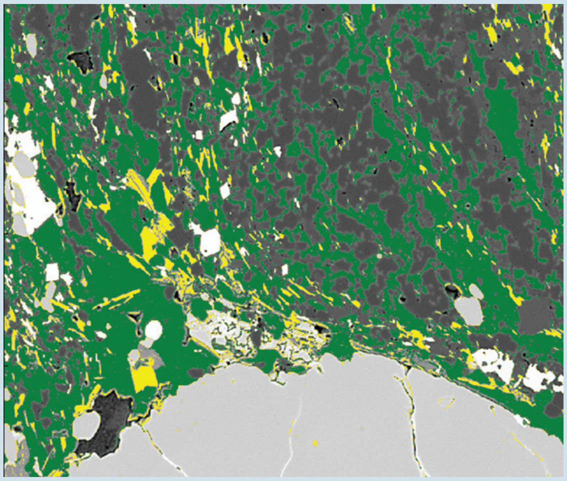
The instruments in the Chemistry Laboratory are high-tech and have appropriately complicated names, such as Ion Chromatograph, Inductively Coupled Plasma-Optical Emission Spectrometer, and Inductively Coupled Plasma-Mass Spectrometer. But the important aspect of all of these instruments is their ability to analyze a wide range of elements in samples. Most of the instruments have detection limits (the smallest amount of a chemical element that can be measured) lower than parts per million (ppm), while some can even detect elements to the parts per trillion (ppt) level. For reference, this would be equivalent to finding one drop of contaminant diluted in twenty Olympic-sized swimming pools of water. These extremely low detection limits are important when measuring the concentrations of elements that can be dangerous to human health, including uranium, arsenic, cadmium, and antimony.

From Microscopes to Mountains: The Anatomy of Faulting

Addressing complex research problems requires more than one analytical method. Understanding the behavior of fault systems, which is critical to a wide range of geological processes, including earthquakes, is one example where the combined efforts of more than one laboratory can provide insight at the microscopic scale into large-scale geological processes that shape our landscape.

The mountains of New Mexico generally owe their origin to volcanism (the Jemez Mountains, for example), or tectonic rock uplift related to faulting (the Sandia Mountains). Tectonically formed mountains develop by faulting and grow, bit by bit, over millions of years. The changes that eventually result in mountain formation occur at the microscopic scale and can be studied by examining rock and water chemistry, mineral properties, and age. Laboratory-based studies of rock chemistry and chronology add a quantitative dimension to fundamental field observations and rock collection. When large-scale tectonic processes stress blocks of rocks by compression or extension, the blocks slip or creep along fault systems. Friction along these faults can grind rock to fine powder, forming a material called *cataclasite*, or fault gouge. Fluids moving through this fine-grained crushed rock can result in the new growth of exceptionally tiny minerals, including a variety of different clay minerals. In some instances, frictional heating caused by fault motion can instantaneously melt the surrounding rock, forming what is known as a *pseudotachylyte*. New minerals grow from the melted rock and can be chemically analyzed and then dated to provide information on the timing of the faulting.

Bureau labs characterize these fault-related rock properties by examining mineralogy, geochemistry, age, and slip rate. Fault gouge is generally made up of submicron-sized mixed clays that are best examined with the XRD because the crystals are so small that the electron microprobe has difficulty measuring their chemical composition and identifying their type. In addition to clay identification, sophisticated data analysis by XRD can evaluate the micro-strain caused by the stress of fault movement and measure grain size down to the nanoparticle (one billionth of a meter) scale. At a slightly larger scale (1 micron to 1 mm), the electron microprobe reveals textural relationships between minerals, the chemistry of the minerals, and the relative timing of growth of minerals and textures. Determining the timing of fault slip and fluid movement is very challenging. However, using electron microprobe imaging and mineral chemistry as a map to extract micro samples for dating has great promise. Minute rock fragments and/or individual minerals formed by the faulting processes can be dated with the new bureau geochronology tools. But it can be tricky or impossible to get exactly the right fragment without the guiding "eye" of the microprobe. A dating method known as in situ geochronology uses a laser to excavate and examine tiny pits within minerals. The rock sample is first chemically mapped with the microprobe, and this map is used to guide the laser to just the right spot on individual crystals for argon extraction and dating. Dating individual slip events yields the fault recurrence interval, which is a crucial piece of information when evaluating and predicting earthquake hazards.



Back-scattered electron microprobe image of a fault-generated pseudotachylyte. Variations in signal intensity correlate to a mineral's mean atomic mass, and chemical analysis of 10-micron diameter spots identify the individual minerals that grew from the melted rocks. Two potassium-bearing minerals are displayed in color (biotite in yellow, potassium feldspar in green); quartz and plagioclase are shown in gray shading. The minerals show a flowing texture that indicates growth in a flowing melt caused by fault motion. This mineralogy map provides the guide for positioning the geochronology lab's laser, in order to heat individual mineral areas and directly date the potassium-bearing minerals to yield fault age. Field of view is 1/3rd of a millimeter.

Another important aspect of faults is that they can influence how water moves in the subsurface. Fault systems can provide pathways for water to move down along deep fractures and to circulate up to the surface. With deep circulation, originally cold surface water temperature will increase and the chemistry will change due to interaction with different rock types. In other cases, faults may act as flow barriers, creating "compartments" that segment aquifers of variable water quality. The bureau Chemistry Laboratory studies how water chemistry is influenced during transport along fault systems. An example of how fault systems control water properties comes from chemistry and temperature measurements near the town of Truth or Consequences. Runoff from the mountains circulates down along fault pathways to depth of about 4 kilometers (2.5 miles), where it heats up and is chemically modified by interaction with subsurface Precambrian granites. Circulation up along the fault back to the surface brings us warm spa waters and provides a great resource for the local economy. However, these deeply circulated waters are not potable because of high total dissolved solids (TDS). In contrast, cooler waters that are used for drinking come from shallower depths within the local limestone bedrock basin and have lower TDS that meet Environmental Protection Agency water quality standards. Detailed study of water chemistry and temperature allows hydrologists to reconstruct what type of rock the water has flowed through, and therefore its flow pathway.

Education and Outreach

A central function of the bureau laboratories is the support of student research. Dozens of students from New Mexico Tech academic departments use our facilities each year, and many graduate students have thesis and dissertation projects in which geochemical and/or geochronological analyses from our labs form the core of their research. Bureau staff teach upper-level, lab-focused courses that examine the theory and practice of their particular analytical technique, contributing to the educational mission of the university. Students from other state universities, and from around the country and the world, come to the bureau for hands-on data collection, partly because of our analytical capabilities and partly because we choose to operate with an open-door policy to promote our sciences and to recruit future students. The bureau labs are showcased during public visits on campus like those associated with Research Day at Tech, Science Fair, and Science Olympiad. These lab tours provide young potential geologists and their parents with an appreciation for the high-tech part of geology.

Bureau laboratories and personnel also provide the analytical capabilities and expertise needed to generate proposals that bring in grant funding. These funds support both research and lab operations. Much of the equipment in our laboratories was purchased without the use of state funds. Today the laboratories are largely self-sustaining and employ vitally important technical staff to operate equipment. For example, the geochronology lab generates approximately $200,000 of income annually. This income supports a full-time senior lab technician and covers most of the lab's operational costs. Bureau labs also employ undergraduate and graduate students, whose knowledge and skills acquired during their tenure is useful for future employment.

Geology continues to be a science that is founded in observation, and the fundamentals are still accomplished through the work of skilled field geologists with trained eyes. But the geology of our time cannot be accomplished without the high-tech analytical capabilities that our laboratories provide. These laboratories serve our core mission, the university community, and a broader professional audience as well. Ultimately they provide the data we need

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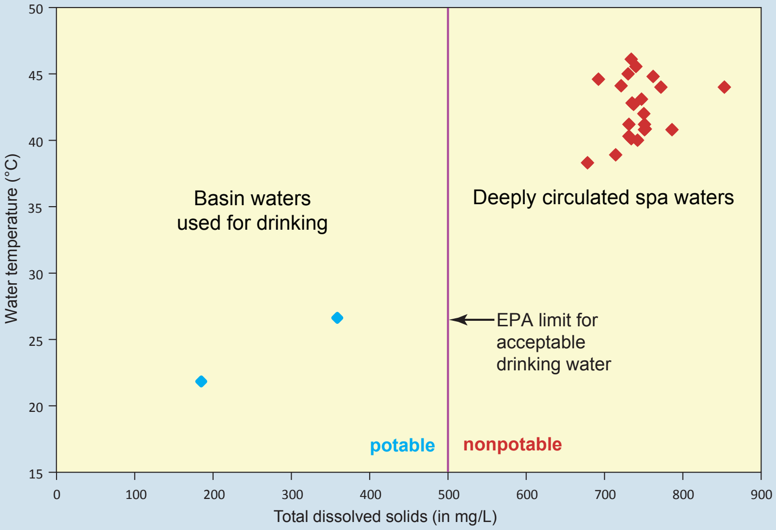

Graph of water quality based on temperature and total dissolved solids (TDS) for the city of Truth or Consequences. The warm spa waters circulate deeply along faults, where they heat up and partially exchange with surrounding rocks, obtaining unacceptably high levels of TDS in the process. Cooler and shallower basin waters have low TDS and provide the potable drinking water for the city.

ANALYTICAL LABORATORIES (CONTINUED)

for the advancement of our knowledge of the geologic framework of New Mexico. That knowledge is vital to the state's economy and welfare, and it is an essential part of what we provide to those who are entrusted with policy-making decisions statewide.

—Matt Heizler and Nelia W. Dunbar

Thanks to Bonnie Frey, Lynn Heizler, Virgil Lueth, and Stacy Timmons for their contributions to this article.

Matt Heizler is a geochronologist and deputy director at the New Mexico Bureau of Geology and Mineral Resources. He has worked at the bureau since 1993, co-directing the New Mexico Geochronology Research Laboratory. He primarily studies rock thermal histories as a means to understand crustal evolution (i.e., mountain building, tectonics, metamorphism). He also applies geochronology to time-scale research and volcanology.

Nelia Dunbar is a geochemist and deputy director at the New Mexico Bureau of Geology and Mineral Resources. She has worked at the bureau since 1992, directing the electron microprobe laboratory and studying the geochemistry of volcanic rocks, particularly volcanic ashes and explosive volcanism, mainly in New Mexico and surrounding regions, and Antarctica.

New Mexico Bureau of Geology's New Building

In November 2013 we broke ground on the new building for the New Mexico Bureau of Geology and Mineral Resources. The new facility will include all of the bureau functions that are currently scattered across campus, including the Mineral Museum, the Geologic Information Center/Publication Sales Office, and our analytical laboratories. There will also be additional classroom space, upgrades to our existing archival space, and flexible work areas for students and staff working on grant-funded projects. The building is going up near the corner of Bullock and Leroy Place on the campus of New Mexico Tech in Socorro, adjacent to the university library (to the South) and the Earth and Environmental Sciences building (to the west). Completion is scheduled for March 2015.

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	Laboratory Type and Name	Instrumentation	Use of Technique
Geochronology	New Mexico Geochronology Laboratory Matt Heizler, Bill McIntosh, and Lisa Peters http://geoinfo.nmt.edu/labs/argon/ 575-835-5271	–Mass spectrometers: A MAP 215-50 and two Thermo Argus VI multi-collectors with low-volume extraction lines. –Lasers: 193 nm Excimer, 810 nm diode, and two 10.6 μm CO$_2$	^{40}Ar/^{39}Ar determined age and thermal history of potassium-bearing rocks and minerals. Applications to volcanology, tectonics, economic geology and planetary science.
	Fission Track Laboratory Shari Kelley 575-835-5306	–Microscopes to count fission tracks. –Digital pad to measure track length	Fission-track determined age and thermal history of apatite and zircon. Applications to rate and timing of mountain building and thermal histories of sedimentary basins.
Mineralogy & Mineral Chemistry	Electron Microprobe Laboratory Nelia Dunbar and Lynn Heizler http://geoinfo.nmt.edu/labs/microprobe/ 575-835-5155	Cameca SX100 electron microprobe	Microscale quantitative and qualitative geochemistry of minerals, glasses, and metals. Chemical mapping of a polished sample surface, morphological and geochemical imaging of samples.
	X-Ray Diffraction Laboratory Virgil Lueth http://geoinfo.nmt.edu/labs/microprobe/ 575-835-5524	Panalytical X'Pert Pro diffractometer	Mineral identification and characterization in simple-to-complex geological and material science samples.
Water & Rock Chemistry	Chemistry Laboratory Bonnie Frey and Dustin Baca http://geoinfo.nmt.edu/labs/chemistry/ 575-835-5160	–Dionex ICS-5000 ion chromatograph –PerkinElmer Optima 5300 Dual View –Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) –Agilent 7500 Inductively Coupled Plasma –Mass Spectrometer (ICP-MS)	Determination of the inorganic chemical composition of a wide range of water, dissolved rock/soil and environmental sample types. Analysis to very low concentrations (parts per billion or lower) is possible.
Physical Characterization	Perlite Laboratory Gretchen Hoffman http://geoinfo.nmt.edu/labs/perlite/ 575-835-6105	4" x 40" vertical expansion furnace sieves	Testing physical properties and expansion characteristics of perlite, including furnace yield, expanded density, brightness, percent non-expansibles, and grain size.
	Clay Materials Testing Laboratory Virginia McLemore http://geoinfo.nmt.edu/labs/clay/ 575-835-5521	–Bruker portable XRF –Sieves –pH meter –Conductivity meter –Furnace	Characterization of the the mineralogical and chemical properties of clay materials.
	Geothermal Testing Shari Kelley http://geoinfo.nmt.edu/labs/geothermal/home.html 575-835-5306	Temperature-logging equipment consisting of a thermistor attached to a wireline cable	Measuring temperature as a function of depth in a water-filled well.