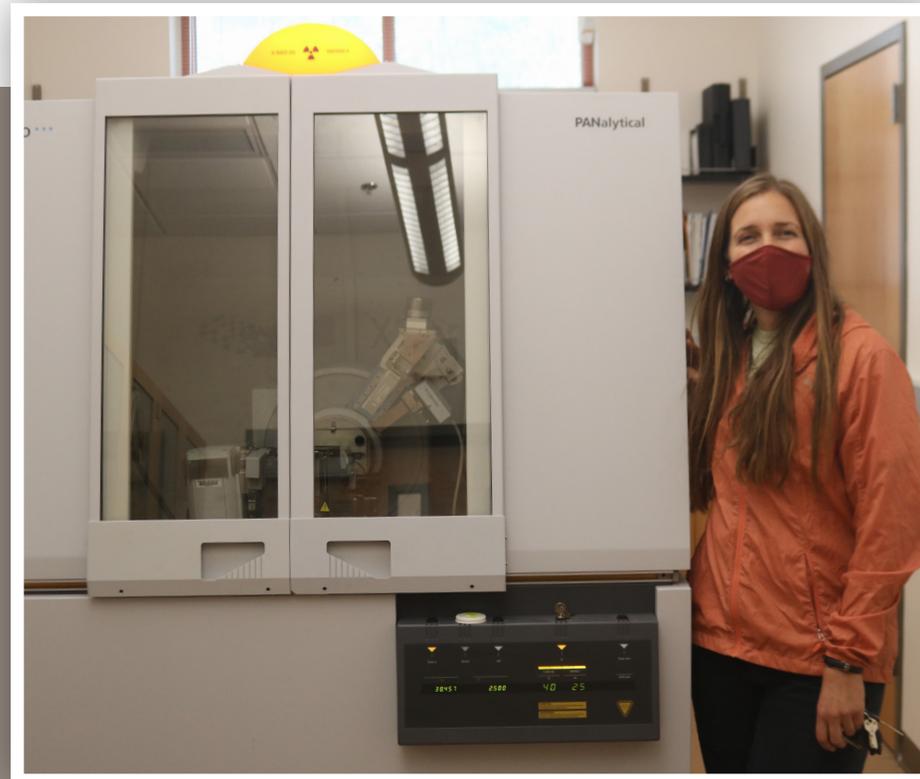


Lite Geology

Tour the New Mexico Bureau of Geology and
Mineral Resources—Your State Geologic Survey

Fall
2021

Volume
49



Welcome to the New Mexico Bureau of Geology and Mineral Resources

Experience a small taste of the New Mexico Bureau of Geology and Mineral Resource's (NMBGMR) scientific research from the comfort of your home. In this edition of Lite Geology, we explore a few of our labs and meet the geoscientists who work in them. These scientists investigate the geology and hydrology of New Mexico. We start our tour with Kelsey McNamara and Virgil Lueth at the X-ray Diffraction Lab, where they will discuss the science behind x-ray diffraction, then we'll go down the hall to visit Lynn Heizler and Nels Iverson at the Electron Microprobe Lab, where we'll learn about the electron microprobe and do an activity that uses an electron microprobe image to help students determine the pore size in a sample. Our tour will then leave the building and drive up the hill to visit the Subsurface Library with scientists Luke Martin, Joseph Grigg, and New Mexico Tech (NMT) geoscience student Hailey Dietz, and they will explain the importance of warehousing drilling cores and rock samples. We'll then circle back to the NMBGMR building and visit the Chemistry Lab, where Dustin Baca will discuss basic chemistry concepts and water sample analysis. We will then visit the Apatite Fission-Track Lab, where Jake Thacker and Shari Kelley will share information about their research. To complete our tour, we'll walk down the hall to the Argon Lab to meet geoscientist Matt Heizler, NMBGMR Associate Director of Labs and Sr. Geochronologist, as part of our ongoing "Through the Hand Lens" interview series. We hope you enjoy this virtual tour of the NMBGMR. Bon appétit.

X-ray Diffraction Lab	2
<i>Kelsey McNamara, Museum Curator/X-ray Diffraction Lab Manager and Virgil W. Lueth, Sr. Mineralogist-Economic Geologist/Museum Director</i>	
Electron Microprobe Lab	6
<i>Lynn Heizler, Geochemist/Microbeam Analyst</i>	
Teacher Activity:	
Micron Scale Examination of Porosity and Permeability Using an Electron Microprobe	8
<i>Nels Iverson and Lynn Heizler, Geochemists/Microbeam Analysts</i>	
Subsurface Library	11
<i>Luke Martin and Joseph Grigg, Petroleum Geologists</i>	
New Mexico Bureau of Geology Water Chemistry Analysis	12
<i>Dustin Baca, Chemistry Lab Tech</i>	
Earth Matters:	
Low-Temperature Thermochronology in the Bureau of Geology Fission-Track Lab	13
<i>Jacob O. Thacker, Field Geologist and Shari A. Kelley, Sr. Geophysicist/Field Geologist</i>	
Through the Hand Lens with Matt Heizler	14
<i>Matt Heizler, Associate Director of Labs/Sr. Geochronologist</i>	
About the New Mexico Bureau of Geology and Mineral Resources	15

Cover Photo

New Mexico Bureau of Geology Mineral Museum Curator/X-ray Diffraction (XRD) Lab Manager Kelsey McNamara stands beside the X'Pert PRO x-ray diffractometer—an instrument used to identify crystalline materials by detecting the angles of x-rays diffracted from atomic planes in a powdered sample. Photo by Cynthia Connolly

X-ray Diffraction Lab

Mineral identification is one of the most fundamental components of the geosciences. The types of minerals found in a rock or in different geologic settings can help geoscientists determine the geologic history of a region, the potential for developing economic resources, or the possibility of geologic hazards. Despite the numerous physical properties of minerals (color, luster, streak, crystal form, and cleavage), some samples are impossible to classify with the standard identification tools, such as the streak plate, scratch test, hand lens, and microscope. Every once in a while, someone will deliver a “head-scratcher” for mineral identification that we can’t figure out. These mystery minerals are typically poorly formed crystals or amorphous (lacking crystal structure), too small to see even with a hand lens or high-powered microscope, or a combination of the two. Luckily, there is yet another method for mineral identification—x-ray diffraction! In this article, we describe the x-ray diffraction (XRD) method and the XRD Laboratory at the New Mexico Bureau of Geology and Mineral Resources. But first, it might be a good idea to refresh on some basics back from high school physical science—x-rays and the electromagnetic spectrum.

Dropping some knowledge: x-rays and the electromagnetic spectrum

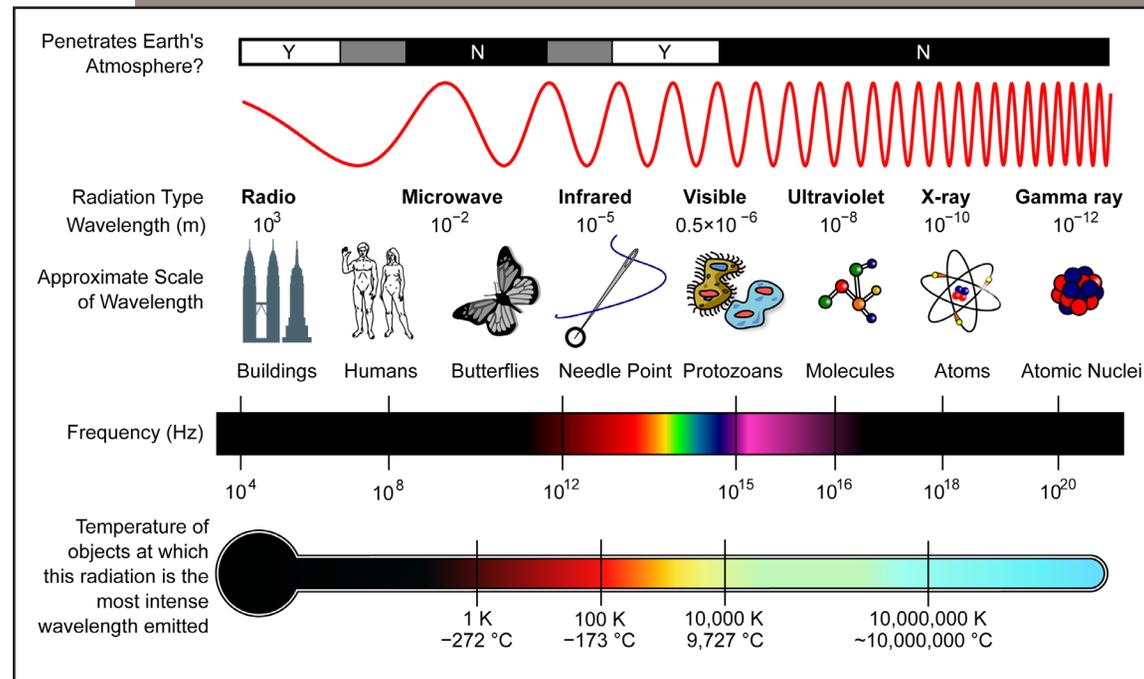
X-rays are a type of electromagnetic radiation (wave energy transmitted by variations in electric and magnetic fields) classified in the electromagnetic spectrum according to the energy level of individual photons, also expressed as wavelength. Also known as Röntgen radiation, they possess a wavelength range of ~0.1 to 10 nanometers (frequency of 3×10^{16} Hz to 3×10^{19} Hz). X-rays were produced and detected by a German scientist named Wilhelm Röntgen on November 8, 1895. He named it x-radiation, using the mathematical term “x” for something unknown.

To better clarify electromagnetic radiation, let’s compare visible light to x-rays. Both are forms of electromagnetic waves. However, our eyes are

sensitive to the wavelength range of visible light, but not to shorter wavelength x-rays or longer wavelength electromagnetic (radio waves, for example). X-rays are most familiar to the public in their use in the medical industry, producing images of structures within the human body. They are absorbed in different amounts dependent on the density of the material they pass through. The soft tissue of your body is composed of smaller atoms, compared to the larger calcium atoms making up bones. X-rays largely pass

through the small atoms of the soft tissue and are absorbed by the larger atoms of bones.

Since discovery, x-rays have been pivotal in the scientific advancement of medicine (radiography), physics, astronomy, and crystallography. X-rays are particularly useful in the study of crystallography—the branch of science focused on the physical structures of crystals—because their wavelengths closely match the distances between atomic planes (the layer of atoms) in crystalline substances.

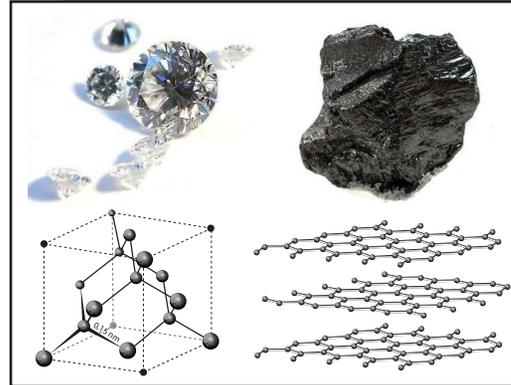


A helpful illustration of the electromagnetic spectrum, showing the type of radiation, whether or not it penetrates Earth's atmosphere, scale of wavelength, frequency (Hz), and temperature with most intense wavelength. Note that the scale of x-ray wavelength is at the atomic level, which has been favorable not only in medical studies, but also crystallography, quantum mechanics, and cosmology (to name a few!). Image from open source: https://en.wikipedia.org/wiki/Electromagnetic_spectrum#/media/File:EM_Spectrum_Properties_edit.svg

Unlike the x-rays used in medicine, which are similar to white light (composed of a wide range of wavelengths), mineralogists use a special type of x-ray called monochromatic (single wavelength). To create monochromatic x-rays, a target metal is used to produce characteristic x-rays of the metal and metal filters are employed to screen out surrounding wavelengths. This target metal is most commonly copper, but iron, molybdenum, and cobalt are also used. The type of metal filter used depends on the type of monochromatic x-ray; for the element copper we use a nickel filter.

Crystallography and x-ray diffraction (XRD)

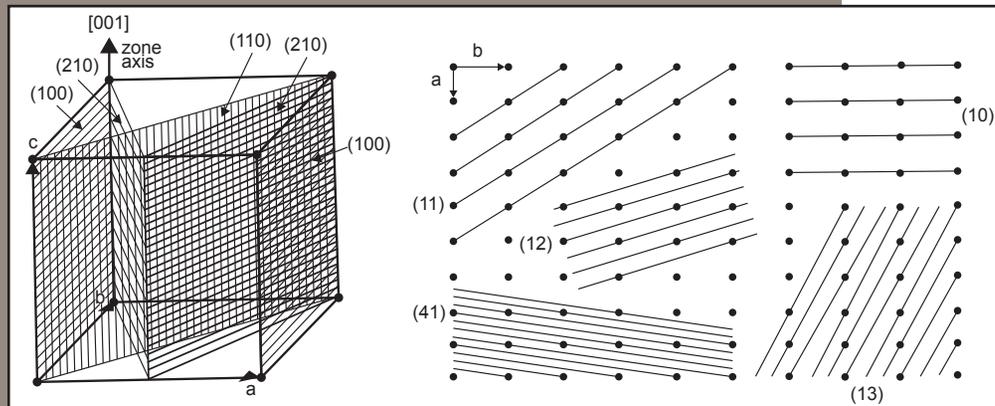
Crystallography is the study of the arrangement of atoms in a crystalline solid in three-dimensional space. This arrangement is called a lattice and can be represented as dots uniformly placed in three-dimensional space (a two-dimensional lattice is a series of dots on a piece of paper). The planes represented by the dots (atoms) have different spacing between them depending on orientation. The number of atoms on any plane also changes with how they are oriented. The “regularity” of the spacing and ordering of the atoms determine how diffraction works in the lattice—producing large or small signals at different orientations.



Diamonds (left) and graphite (right) are both pure carbon. X-ray crystallography was used to study the crystal structure, or arrangement of atoms shown below each mineral to understand their different properties. Carbon atoms in a diamond are arranged in a tetrahedral fashion with covalent bonds, while graphite is composed of carbon in hexagonal stacked sheets with covalent bonding in each sheet (not between). The variations in structure and bonding account for the large difference in strength between diamond and graphite.

Image from open source:

https://en.wikipedia.org/wiki/X-ray_crystallography#/media/File:Diamond_and_graphite2.jpg



Examples of lattice planes. (left) Planes in a cubic structure where atoms are at each of the corners. Imagine more of these cubes stacked in all directions around the example. (right) A two-dimensional lattice showing how the planes can be oriented. Each four dots represent the face of a cube lattice. Crystallographers identify each plane by using a standard coordinate system based on direction and distance called Miller Indices.

Cullity, B.E., 1978, *Elements of X-Ray Diffraction, Second Edition*, Addison-Wesley Publishing Co., Inc., Reading, Massachusetts

A concept called “Braggs Law” explains how x-ray diffraction works. The simplified equation is:

$$n\lambda = 2d \sin\theta$$

where: n = an integer (1 is typically used), λ = the wavelength of the x-ray energy, d =distance between atomic planes, $\sin\theta$ = the sine of the angle where diffraction occurs.

Since λ is fixed by the type of characteristic x-ray radiation produced and we measure the angle of diffraction, we solve for the interplanar spacing. Mineralogists understood the atomic spacing of crystals before they could even measure them by using rules of geometry. X-ray diffraction later proved that the mineralogists were correct in their geometric models and provided a method for determining exact crystal structures.

It should be noted that a crystalline structure is not unique to just minerals; they form in a variety of materials such as alloys, semiconductors, salts, pharmaceuticals, and organic to inorganic molecules. X-ray diffraction has been paramount in many scientific fields to understand atomic structure and atomic-scale differences, as well as to provide data on physical and chemical properties in crystalline materials.



An example of five powdered samples loaded into holders and ready to be scanned. Note the variable colors of the powders, which suggest different mineral assemblages present in each sample.
Photo by Kelsey McNamara

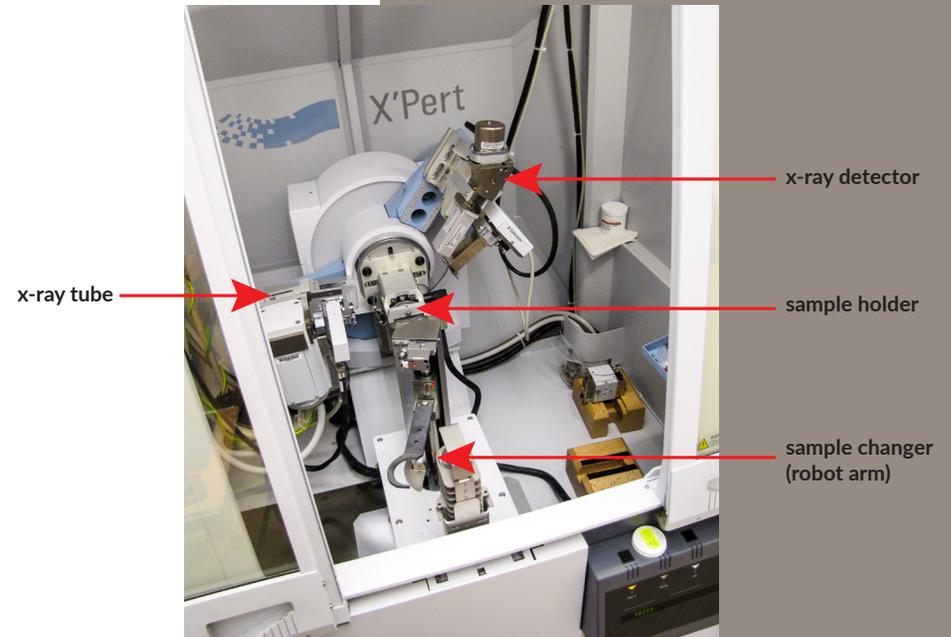
There are two types of XRD techniques, single crystal and powder. The difference between these methods is scale. As the name suggests, a single-crystal analysis is focused on exact atomic positions of a single well-ordered crystal, while powder XRD characterizes a sample of bulk material. We analyze powder samples at the New Mexico Bureau of Geology and Mineral Resources XRD Lab.

How does XRD instrumentation work?

X-ray diffraction is performed by an x-ray diffractometer, which consists of several components including an x-ray tube, an x-ray detector, and a sample holder.

X-rays are produced in a cathode tube by heating a filament, which then emits electrons. These electrons are then accelerated toward a metal target, commonly composed of copper. When the electrons interact with the copper target, they lose energy in the form of monochromatic x-rays (a single wavelength). The produced x-rays are then collimated (made parallel to one another) and directed toward the sample.

The interior of the Panalytical X'Pert Pro Diffractometer.
Photo by Kelsey McNamara



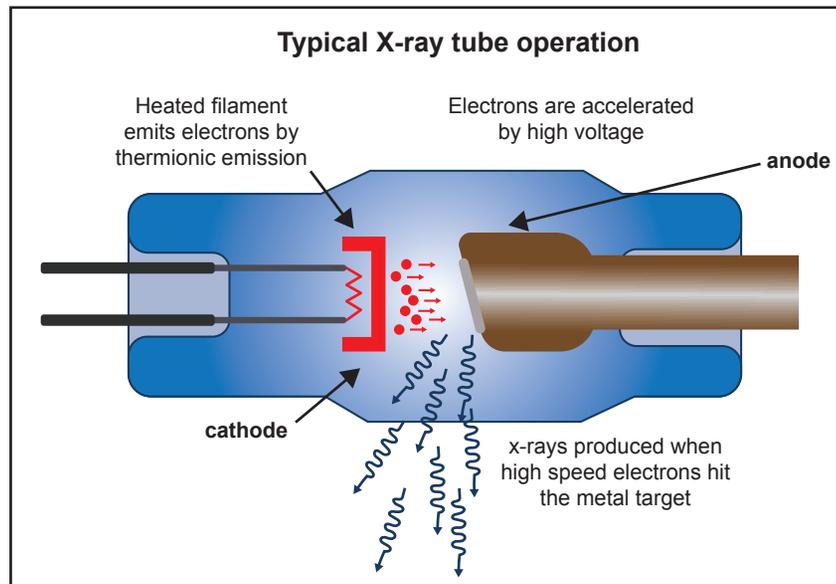
Computer workspace and the Panalytical X'Pert Pro Powder Diffractometer in the NMBGMR X-ray Diffraction Laboratory.
Photo by Kelsey McNamara

The x-ray tube and detector rotate around the sample while the intensity of the diffracted x-rays is recorded. The interaction of the x-rays with the geometry of crystallographic planes produces a characteristic XRD pattern called a diffractogram, which is used to identify minerals, measure crystallite size, determine thicknesses of atomic layers, recognize deformation of crystals, and other phenomena. To identify the mineral(s) present, a database of over 800,000 powder diffraction patterns is referenced. This method can be thought of as analogous to the same technique performed at a crime scene—fingerprints are collected and then compared to a fingerprint database to discern a match.

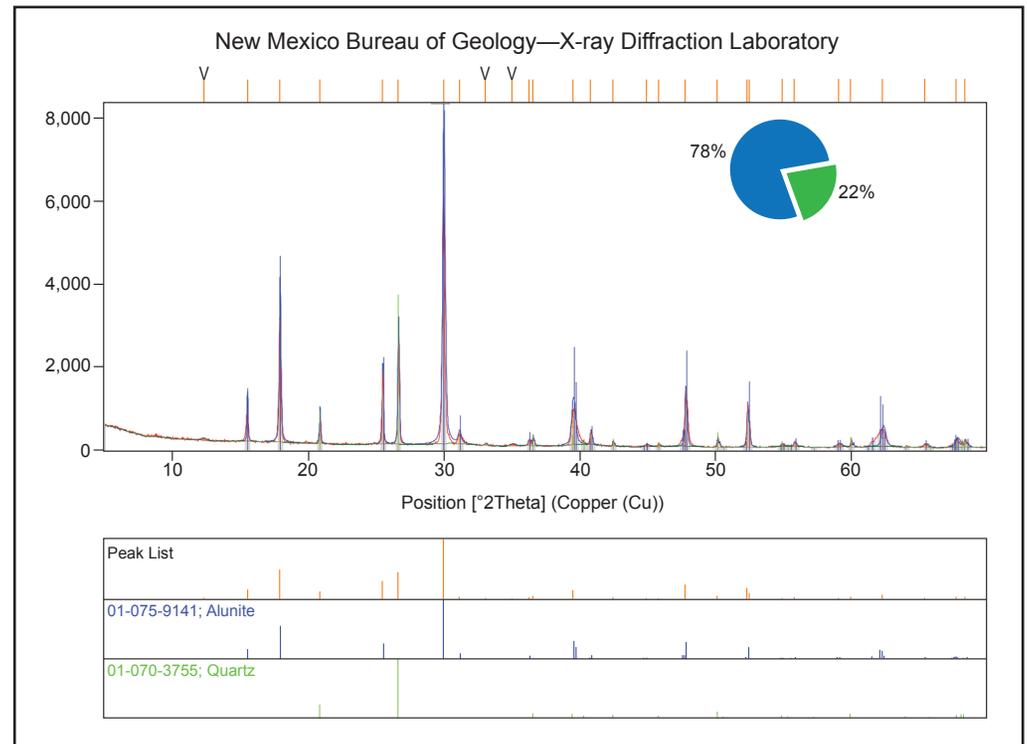
The New Mexico Bureau of Geology and Mineral Resources XRD Laboratory provides services to further research and education at New Mexico Tech, as well as serves agencies and industries of New Mexico by providing analyses that cannot be obtained through commercial sources. Each year a class is offered through the Earth and Environmental Science Department to teach students XRD analysis, including the subjects of x-ray generation and properties, crystallography, diffraction, and data interpretation. Many professors and graduate students across a number of disciplines conduct research in this lab. We estimate that 75% of the hands-on use of the equipment is by graduate and undergraduate students of New Mexico Tech.

—Kelsey McNamara and Virgil W. Lueth

The x-ray powder diffractogram shows peak positions where the x-ray beam is diffracted by the crystal lattice. The positions of the peaks are unique to specific crystalline structures. The intensity (or counts) is the number of times a detected x-ray diffracts at a particular angle. This diffractogram indicates that alunite and quartz are present in the samples. The relative peak intensities are used to determine the relative proportions of the minerals after correcting for crystal structure. In this example, we were looking for contamination by other minerals in alunite that was to be used in Ar age analysis since sample purity is important for dating.



Schematic diagram showing how x-rays are generated in an x-ray tube.
Image from Design World online article: <https://www.designworldonline.com/x-rays-and-ionizing-radiation/>



Diffractogram indicating the presence of alunite and quartz.

Electron Microprobe Lab

The New Mexico Bureau of Geology and Mineral Resources also operates an Electron Microprobe Laboratory. Our Cameca SX-100 Electron Microprobe is a high-powered microscope that uses electrons instead of light to examine samples. The high degree of magnification allows us to conduct detailed examinations of samples that are extremely tiny, in the micron scale range. Electrons that are accelerated and focused on the surface of polished samples produce a number of signals that we can use to gain information about a wide range of materials such as rocks and minerals, alloys and ceramics.

One of the most useful signals utilized when first examining a sample under the electron beam is the backscattered electron (BSE) signal. Backscattered electrons generate images that look just like photographs, but the images are actually the result of differences in the average atomic number of each mineral phase in the sample. Our eyes see these differences as variable shades of grayscale. Although BSE images cannot identify specific elements, they contain useful compositional information that provides clues to a mineral's identification. In general, minerals composed primarily of lower atomic number (Z) elements (such as sodium, Na) will appear dark in comparison to those containing a high concentration of higher Z elements (such as iron, Fe) that appear brighter (Figure 1a). We can also collect secondary electron (SE) signals on non-polished (rough) sample surfaces that yield information on surface topography and generate high-magnification, 3-D images similar to those of insects you may have seen in magazines such as *National Geographic* (Figure 1b).

Once we have a general idea of the number of mineral phases present based on grayscale intensities, we rely on another very useful signal to help identify elements or minerals in the sample.

In addition to BSE and SE signals, electrons interacting with a sample generate x-rays (Figure 2a). Each element in the periodic table has a specific wavelength that will produce "characteristic x-rays" unique to that element.

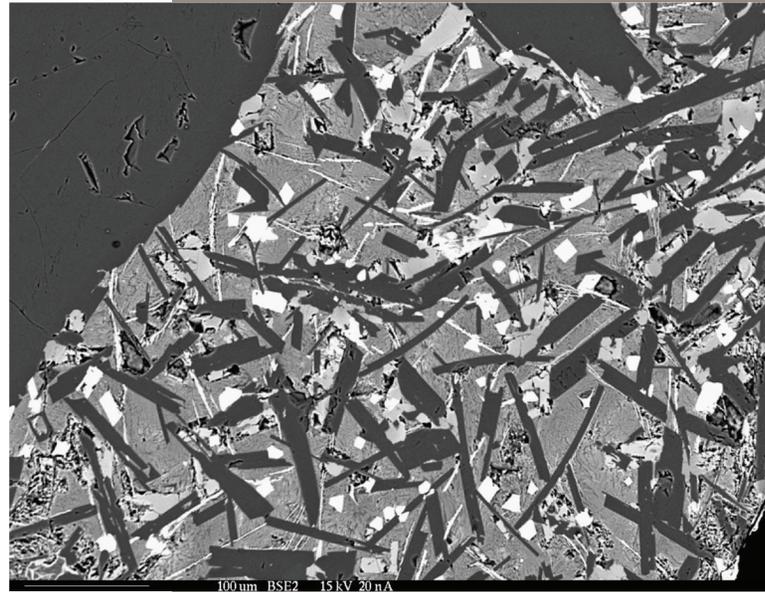


Figure 1a. Backscattered electron (BSE) image of a basalt fragment composed of multiple mineral phases that have gray scale values ranging from dark to light. BSE images reveal differences in composition but do not identify specific elements. In general, minerals composed primarily of lower atomic number (Z) elements (such as Na) will appear dark and those containing higher Z elements (such as Fe) will appear bright.

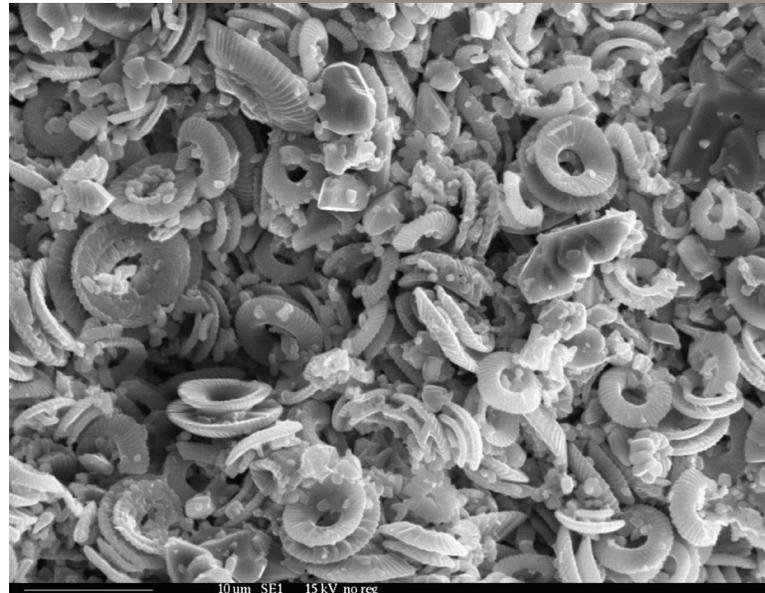


Figure 1b. Secondary electron (SE) image of diatoms (single-celled microalgae with siliceous skeletons). Based on the 10 micron scale bar, the field of view is on the order of 50 microns. This is the average cross section of a human hair. The human eye cannot see anything smaller than 40 microns in size. Note: A micron is an abbreviated term for micrometer, or a millionth of a meter.

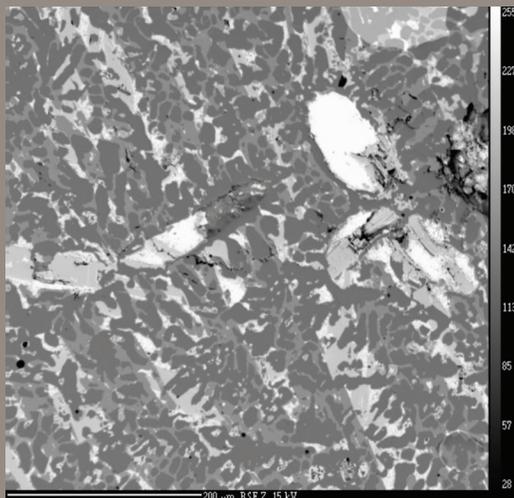


Figure 2a. Backscattered electron (BSE) image of ore melt sample composed of multiple phases of varying gray scale. The corresponding Cu, Sn, Pb and As chemical maps reveal that the dark gray phase contains copper (Cu) and arsenic (As), the medium gray phase tin (Sn) and arsenic (As) and the bright phase lead (Pb).

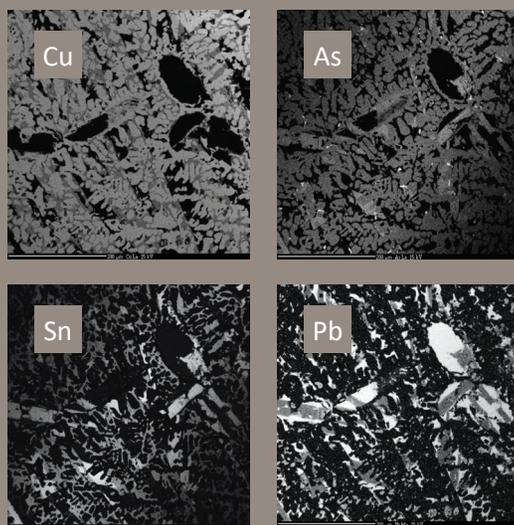


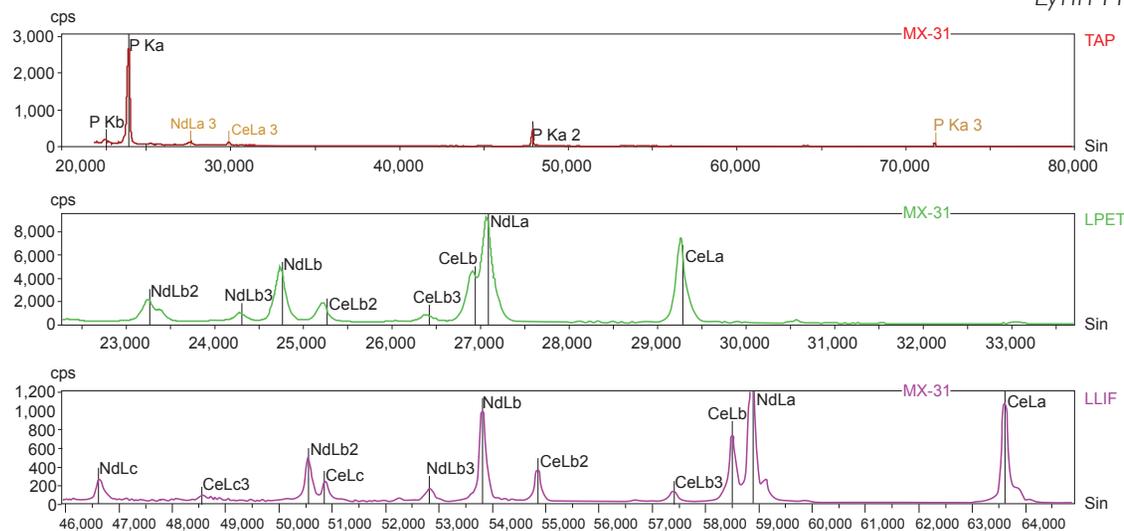
Figure 2b. Cu, Sn, Pb and As chemical maps. Brighter areas within the maps indicate higher concentrations of the selected element.

Our electron microprobe has four spectrometers, each with a different crystal optimized for a specific wavelength range of the electromagnetic spectrum. By setting each spectrometer to a different element of interest and sweeping or “rastering” the beam back and forth across an area of the sample we can determine the presence or absence of an element in the area of interest. The appearance of bright pixels denotes the presence of the element and pixel density gives an estimation of the relative abundance of the element(s) in 2-dimensions. We can run a “quick quali” (or quick qualitative analysis that takes ~12 seconds) to rapidly determine whether or not an element is present or program the instrument to generate high resolution fine-detail chemical maps over longer time

periods (Figure 2b). We may also choose to have each spectrometer run through its entire wavelength range to produce “qualitative scans” that show the peaks and relative abundance of the elements present in a sample (Figure 3). Finally, we can use characteristic x-rays not only to identify minerals but also to determine the chemical composition of very small areas (~1 micron) of a sample surface. This ability to analyze samples “quantitatively” is one of the most powerful capabilities of the electron microprobe.

For more information on the NMBGMR Electron Microprobe Laboratory, please visit this site: <https://geoinfo.nmt.edu/labs/microprobe/home.html>

—Lynn Heizler



Weight% Comment	Si	P	Y	La	Ce	Nd	Dy	Er	O	Total
MX31-01	0.12	13.05	0	0.12	27.40	32.23	0	0.03	27.06	100.02
MX31-02	0.11	13.09	0	0.13	27.46	32.61	0	0.04	27.18	100.61
MX31-03	0.11	13.18	0	0.08	27.39	32.65	0	0.04	27.30	100.75
MX31-04	0.10	13.16	0	0.12	27.34	32.53	0	0.02	27.23	100.52
MX31-05	0.12	13.16	0	0.14	27.65	32.29	0	0.02	27.26	100.65
mean	0.11	13.13		0.12	27.45	32.46		0.03	27.21	100.51
stddev	0.00	0.08		0.01	0.18	0.04		0.01	0.14	0.45

Figure 3. Qualitative scan of the x-ray spectrum of a single point on monazite. The observed peaks indicate the relative abundance (peak height) of elements in the sample using three separate spectrometers, each outfitted with a crystal (TAP, LPET, LLIF) covering a different range of the x-ray spectrum (denoted by color). The corresponding quantitative analyses show the actual abundance of elements in selected points on the monazite grain.

Teacher Activity: Micron Scale Examination of Porosity and Permeability Using an Electron Microprobe

What is an electron microprobe?

An electron microprobe is a high-powered microscope that uses electrons instead of light to examine samples. This allows us to observe samples at much higher magnification and in much finer detail than with a conventional microscope. In addition, the electron microprobe is also capable of providing detailed chemical information on very small selected areas of a sample.

How does the electron microprobe work?

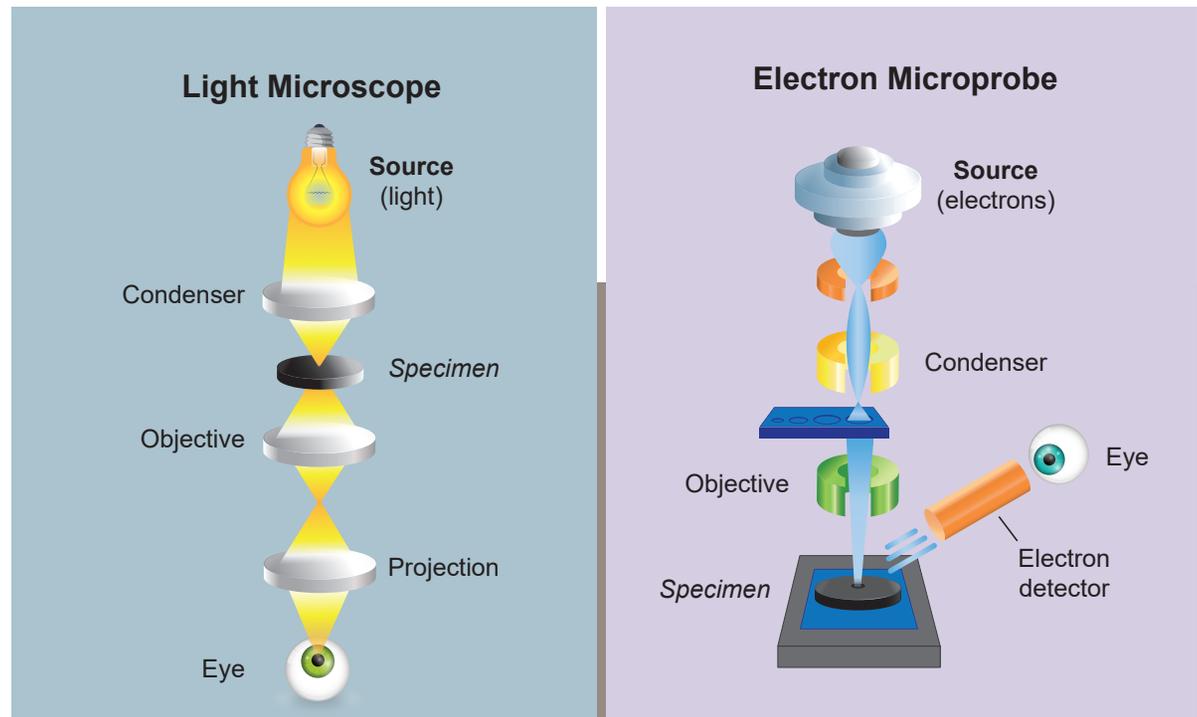
To understand how an electron microprobe works we can use the simple analogy of a light bulb. In a light bulb, a stream of electrons or “current” passes through a thin coil filament made of tungsten. The electrons collide with atoms in the wire causing it to heat up and emit a cloud of photons. The generation of visible light photons causes the light bulb to glow. The light is then focused by glass lenses down to the sample. The light interacts with the samples and then is projected back to a detector, in this case, our eyes.

Similarly, in the microprobe, a tungsten hairpin filament is heated to a very high temperature (2,700 Kelvin or 4,400 Fahrenheit), causing electrons to be emitted from the tip. The electrons are accelerated and focused to a point on the sample. The electron beam is focused by magnetic lenses to shape and move the beam across the surface of the sample. The stream of electrons interact with the sample producing a number of different products (secondary electrons, backscatter electrons, and x-rays) that give us important information about the sample.

Backscattered electron (BSE) imaging

One useful signal resulting from the electron beam impacting the sample surface is a backscattered electron (BSE) signal. The intensity of the BSE signal is proportional to the atomic mass of the sample and allows for different phases to be observed. This is the signal that is generating

the image you see on the screen. These images look just like photographs but actually show you not just the shape of the minerals being imaged but also provide information about their chemistry through the grayscale of the image. Minerals that contain heavier atoms appear brighter than those that contain lighter atoms. For example, magnetite (Fe_3O_4) is heavier than quartz (SiO_2) producing a higher BSE signal that will be brighter in the image.



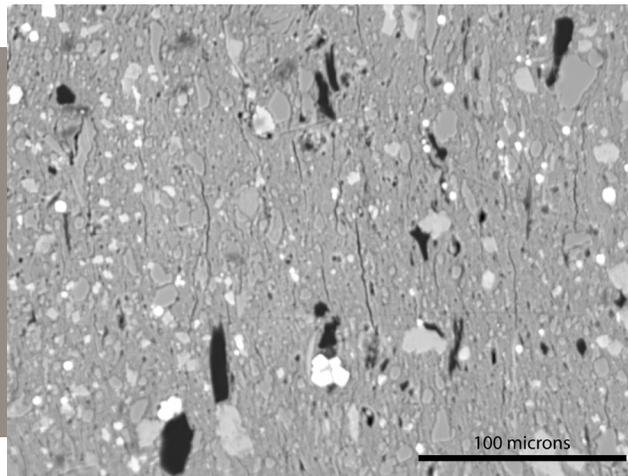
Comparison of a light microscope to that of an electron microprobe.
Image from NMBGMR

Magnification

The images below are greatly magnified. Measure out 2.5 mm on a ruler. This is the true width of the image at the lowest magnification of the microprobe. Because the features we observe when using the microprobe are very tiny, we use the term micrometer or micron, for short (μm), when describing their size. To convert from millimeters to microns we need to multiply by 1,000; so 2.5 mm is equal to 2,500 microns ($1 \mu\text{m} = 0.001\text{mm}$). For reference, the average thickness of a human hair is around 50 microns. The scale bar on the lower right of image FWW-7642.46-1 is a micron scale bar. The scale bar changes as the magnification is increased or decreased. Use the scale bar to measure some of the grains in the image on the screen. Can you find grains that are smaller (or larger) than the width of a human hair?

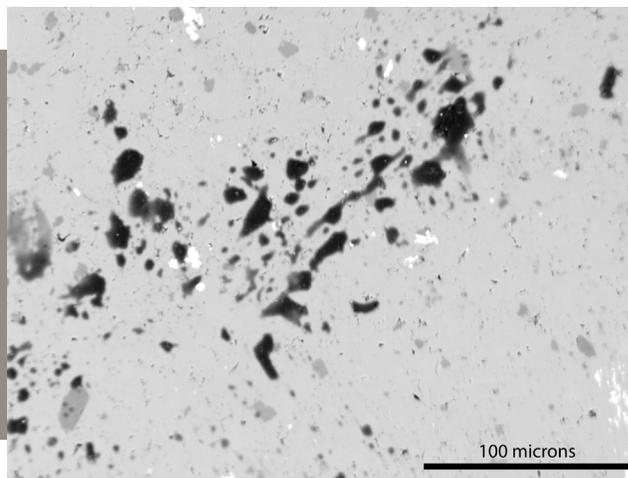
FWW-7642.46-1

Backscatter electron image of Fransworth Unit of the Morrow Formation. Notice the varied grainsize, with fine-grain clays mixed with coarse sand-sized particles. Bright areas are particles made of iron (oxides) and darker particles are quartz, feldspar and clays (silicates). Black lines and elongated areas are voids in the rock. This is the pore space and the long skinny lines help connect the pores, increasing permeability. *BSE image by Nels Iverson*



FWW-7545.51-2

Backscatter electron image of the Fransworth Unit of the Morrow Formation. Notice the lack of different grain sizes. There are some bright spots (oxides) and a few dark gray spots (silicates). Most of the image is a uniform light gray. Black oblong areas are the void spaces and many do not connect, making the porosity and permeability different. *BSE image by Nels Iverson*



Activity: In the following activity we will compare backscattered electron (BSE) images from two different samples.

- I. FWW-7642.46-1 and FWW-7545.51-2 are backscattered electron (BSE) images from a sandstone and a mudstone.
 - Q1. Examine the BSE images. What differences (or similarities) do you see between the two samples (i.e., shapes of grains, textures, etc.)?
 - Q2. Are the grains all the same shade of gray or are they different? What do you think causes the differences in color (grayscale) between grains?
 - Q3. Areas within the images that appear black represent void (open) space or porosity. Which sample do you think has the highest amount of porosity? Which has the lowest?
- II. The student will then cut out all of the pores they can on the BSE image with scissors.
- III. The students will then use a precise scale to weigh their BSE image. They will first measure the total weight of their image (cut and non-cut portions). Then weigh only the grains portion (lighter colors) of the BSE image.
 - Q4. Calculate the porosity for your BSE image from the weighed paper. How did your calculation compare to the others using the same thin section? What is the average porosity of the two samples?
- IV. Microprobe measurements: We can also determine the percentage of porosity using the microprobe. To do this we first assign a gray scale color (in this case black) to represent void space or porosity. The beam is then scanned back and forth across the selected area pixel by pixel and the number of dark pixels that represent porosity are totaled and the result given as a percentage.

Now let's compare your estimates of the percentage of porosity in each sample to those obtained by the microprobe (Answers—FWW-7642.46-1: **6% porosity**, FWW-7545.51-2: **10% porosity**). Are your estimates higher or lower than that obtained with the microprobe? Can you think of a reason(s) your estimates might differ from those obtained using the microprobe?

Glossary

Atom—basic building block for all matter in the universe. Atoms are extremely small and are made up of three even smaller “subatomic” particles; negatively charged electrons, positively charged protons, and neutrons, which are electrically neutral (no charge). The heavier protons and neutrons make up the center (or nucleus) of the atom and the electrons orbit the nucleus in a small cloud. Atoms have different numbers of electrons, protons, and neutrons. If there are the same number of electrons and protons in an atom, then the atom is said to have a neutral charge. A chemical element is uniquely defined based on the number of electrons, protons, and neutrons each atom contains. There are 92 naturally occurring elements.

Electron—negatively charged particle that spins around the outside of the nucleus. Electrons spin so fast that scientists can never be 100% sure where they are located. Electrons are attracted to the nucleus by the positive charge of the protons. Electrons are ~1,800 times smaller than neutrons and protons.

Grayscale—images in which the only colors are shades of gray. The contrast ranges from black at the weakest intensity to white at the strongest.

Kelvin—the standard unit of temperature that is most used by scientists. When writing a temperature in Kelvin you use the letter K. Kelvin uses absolute zero as the 0 point of its scale. It has the same number of increments (100) between the freezing and boiling points of water as the Celsius temperature scale. Absolute zero (when molecular motion stops) is the coldest possible temperature that any substance can reach. It is equal to 0 Kelvin (-273.15°C or -459.67°F).

Micron—derived from the Greek word “Mikros,” which means small. The term “micron” is short for “micrometer,” a unit of measure in the metric system equal to 1 millionth of a meter in length (one micron equals one-thousandth of a millimeter; one millimeter equals one thousand microns). The average cross section of a human hair is 50–80 microns. The human eye cannot see anything smaller than 40 microns in size.

Photon—the smallest discrete amount (quantum) of electromagnetic radiation and the basic unit of light. All electromagnetic energy (i.e., microwaves, visible light, radio waves, x-rays) is made up of photons. Photons are always in motion in a vacuum, and travel at the speed of light (2.998×10^8 m/s). They have no mass and no electrical charge (electrically neutral). They can act both as waves and particles. The original concept of the photon was developed by Albert Einstein.

Porosity—the percentage of a material’s total volume that is open space. Porosity most often consists of the spaces between particles in soil, sediment, and sedimentary rocks, but other types of porosity include cracks, fractures, faults, and vesicles in volcanic rocks.

—Nels A. Iverson and Lynn Heizler

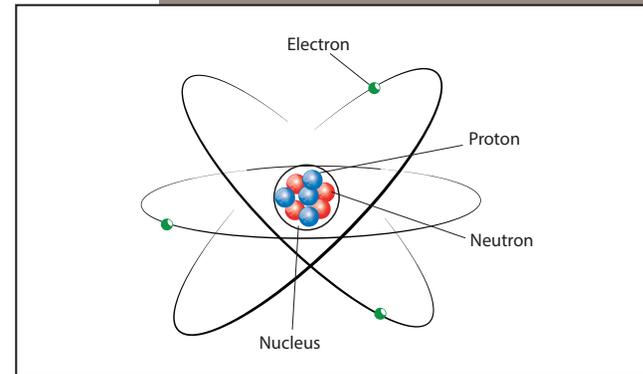
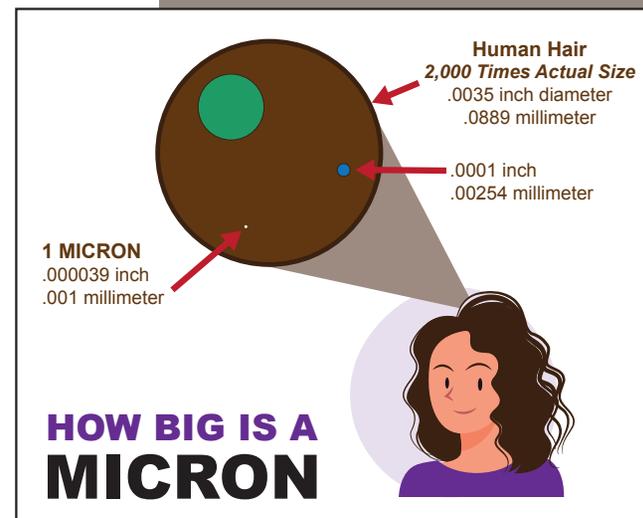
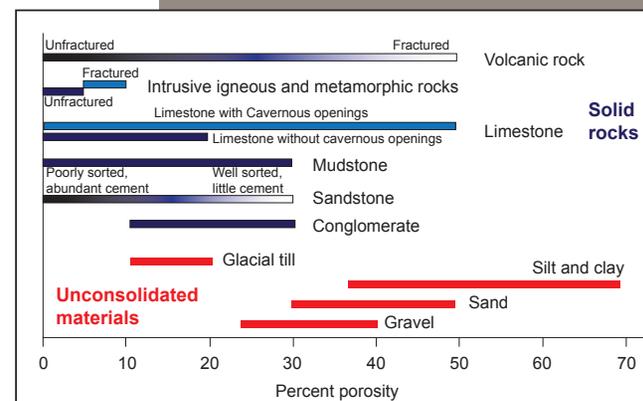


Diagram of an atom.
Image by NMBGMR



The size of a micron compared to a human hair.
Image by NMBGMR



Variations in porosity of unconsolidated materials (in red) and rocks (in blue) [SE].
Open source image by Steven Earle
Creative Commons Attribution 4.0 International License

Subsurface Library

The state of New Mexico has a long history of subsurface oil, gas, and mineral exploration and extraction. The primary method of investigation for these resources is drilling and sampling boreholes beneath the surface of the ground. From the boreholes, rock samples are collected in various sizes, ranging from sand-size drill cuttings to core samples that are several inches in diameter. Other sampling methods rely on measuring the rock properties with geophysical logging tools that are lowered down the borehole.

Rock samples and geophysical logs are expensive to acquire and the insight they provide into the subsurface can provide substantial return on investment. However, the storage of these samples becomes expensive relative to their value over time. As companies change focus, merge, or close, their sample collection becomes surplus. Donation of these data is a viable option.

The NMBGMR maintains a robust Subsurface Library that catalogs and stores subsurface samples for research and educational purposes. The NMBGMR Subsurface Library provides a long-term option for companies to donate their cores, cuttings, logs, and analyses. Company donations may qualify as tax



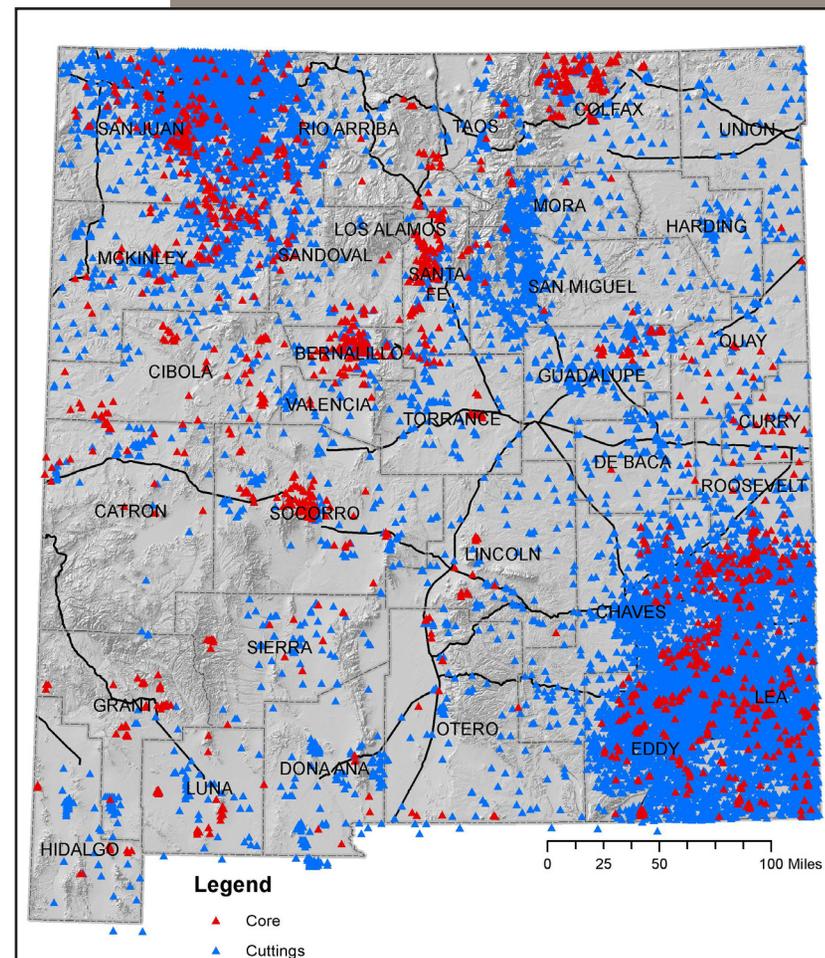
Student Haley Dietz examines core. Photo by Ethan Haft

deductions and allow scientists, students, researchers, and industry geologists to have access to publicly available data for research.

The NMBGMR Subsurface Library maintains more than 540,000 linear feet of core from 1,433 drill holes. The cores are primarily from oil and gas wells, with many others from mineral assessment, coal tests, and other sources. These cores are stored in warehouses on the NMT campus. Also included in the Subsurface Library are 51,000 boxes of drill cuttings from 16,700 drill holes. This represents 150 million linear feet of drill hole. The cuttings are stored in a new modern facility constructed in conjunction with the new main Bureau of Geology building in 2015.

Currently, efforts are underway to make the Subsurface Library data more readily available to the public. An interactive map is being created that contains the locations and other pertinent information regarding core, cuttings, and logs housed at the NMBGMR. Another near-term goal is to digitize select geophysical logs and photograph cores in order to make them available through an interactive map.

All records, including core, cuttings, geophysical logs, and associated publications and data maintained by the Bureau are publicly available to any interested party. All data are stored on the NMT campus in Socorro, NM, and are available for viewing by appointment; viewing is free of charge. If parties are unable to travel, delivery of materials can be arranged at the user's expense.



Location of cores and cuttings available through the NMBGMR subsurface library.

For more details and to schedule appointments please contact Annabelle Lopez at (575) 835-5139, Annabelle.Lopez@nmt.edu or visit us online at geoinfo.nmt.edu/resources/petroleum/home.html.

—Joseph Grigg and Luke Martin

New Mexico Bureau of Geology Water Chemistry Analysis

The New Mexico Bureau of Geology Analytical Laboratory analyzes water and soil samples for our Bureau scientists, New Mexico Tech (NMT) students and professors, government agencies, businesses, and private individuals. Our staff members, which include NMT students, assist Bureau scientists in analyzing natural waters from rivers, lakes, streams, and wells, helping them to characterize, monitor, and map our state's important water resources. We work with NMT graduate and undergraduate students doing sample analysis, and with setup and processing of the various experiments that they perform for their academic research. We analyze samples for NMT professors, who use the data for their experimental research. And we analyze water samples for members of the public who want to know the quality of their well water and drinking water.

Our laboratory staff analyze water samples for general chemistry (that is, dissolved mineral content) and for trace elements, which together can characterize the quality of a water. Water quality is controlled by the minerals it has dissolved, resulting in ions in the water. These ions are either negatively charged (anions, which have retained electrons) or positively charged (cations, which have lost electrons). In most natural water, for every positively charged ion there will be a corresponding negatively charged ion present, resulting in an overall neutral charge since they cancel each other out.

The analyses conducted in our lab measure these ions with the following methods:

pH is the measurement of how acidic or alkaline (basic) a water sample is. A pH of 7 is neutral, neither acidic nor basic. A pH less than 7 is acidic, and more than 7 is alkaline.

Specific conductance is the measure of the electrical conductivity of a water sample, which indicates how pure it is. Pure water does not conduct electricity well, but as more minerals are added, the ions from the

minerals allow electricity (the movement of electrons) to be conducted through the sample.

Alkalinity determines how much carbonate and bicarbonate a sample contains by adding a known concentration of sulfuric acid, and recording how much volume is required to neutralize the carbonate and bicarbonate base, by monitoring the pH. Carbonate and bicarbonate are anions, which are molecules with extra electrons that produce a negative charge.

Major anions such as chloride, sulfate, fluoride, and nitrate are measured by **ion chromatography**, which separates them from each other based on the strength of their charge, and then monitors the conductance of each analyte separately.

Major cations such as sodium, calcium, magnesium, and potassium are measured by **optical emission spectroscopy**, which breaks the sample down to the level of individual elements using an argon plasma, and then monitors the emissions of light at wavelengths particular to each element.

Mass spectrometry can measure less than one part per billion. Elements present at very low levels (trace levels), such as arsenic, uranium, lead, and aluminum are measured by breaking the sample down to the level of individual elements using an argon plasma, and monitoring the electron signal of a particular atomic mass.

After this data is collected, an ion balance is calculated by comparing the total amount of anions to cations, which should have corresponding and equivalent amounts. If there were an imbalance between these, it would indicate that there was an ion that had not been accounted for or measured. For more information about the NMBGMR Chemistry Lab contact Dustin Baca at dustin.baca@nmt.edu.

–Dustin Baca



Dustin Baca works with New Mexico Tech student Kamryn Gordon on the laboratory's Picarro Cavity Ring-Down Spectrometer. The instrument is used to measure the oxygen and hydrogen isotopes of water, which can indicate the processes that have affected groundwater or surface water and help researchers better understand water recharge or flowpaths. Photo by Bonnie Frey

Earth Matters: Low-Temperature Thermochronology in the Bureau of Geology Fission-Track Lab

Low-temperature (<250°C) thermochronology is a popular tool used by geoscientists around the world. Unlike geochronology that dates when a rock formed, thermochronology dates when a rock cooled through a certain temperature range. Low-temperature thermochronology is typically conducted on the minerals apatite and zircon using one of two techniques: fission-track and (U-Th)/He (“uranium-thorium-helium”) analysis. The Fission-Track Lab is equipped to prepare samples for both analyses; fission-track analysis is conducted in-house.

Spontaneous fission (splitting apart) of uranium-238 leaves zones of lattice damage (scarring), called “tracks,” in apatite or zircon crystals. These tracks can

be used to determine the age of cooling. A higher density of tracks signifies an older age. As a simplistic example, one can envision how, with time, more and more cracks accumulate on a tiled floor due to everyday household use. In an apatite or zircon crystal, the length of the tracks can also tell if the sample cooled quickly (long tracks), slowly (short tracks), or if a complex cooling/reheating history took place (both short and long tracks). For apatite, the most common mineral for fission-track analysis, tracks are present in the crystal below 110–60°C; above 110°C the tracks anneal (i.e., the crystal lattice scars “heal” due to chemical diffusion processes). To conduct fission-track analysis, rocks are first processed by crushing and apatite is concentrated via mineral separation techniques using Bureau of Geology lab facilities.

Separated apatite is spread out on a glass slide and solidified in epoxy. Epoxy mounts are ground down, then bathed in nitric acid for 20 seconds to reveal the fission tracks. Samples are then sent to a nuclear reactor to be irradiated, a necessary step for dating the sample in order to determine the original or “parent” uranium concentrations in the sample. Fission-track analysis is then completed on the returned samples using a Nikon petrographic microscope that is used to measure track density, lengths, and angle of tracks relative to the long axis of apatite crystals in the sample.

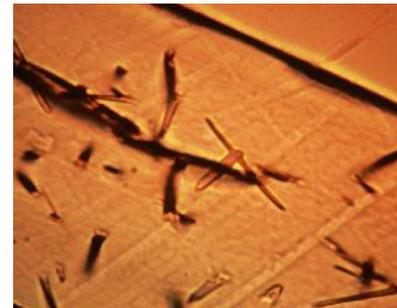
(U-Th)/He analysis is commonly conducted on apatite and zircon. Alpha decay of uranium and thorium at known rates results in atoms of helium-4 daughter product. Accumulated helium-4 can be measured to determine how much time has elapsed

since cooling occurred (more helium would mean an older age). Helium will accumulate in zircons below 210–50°C and in apatites below 90–40°C; helium-4 diffuses out of the crystals above these respective

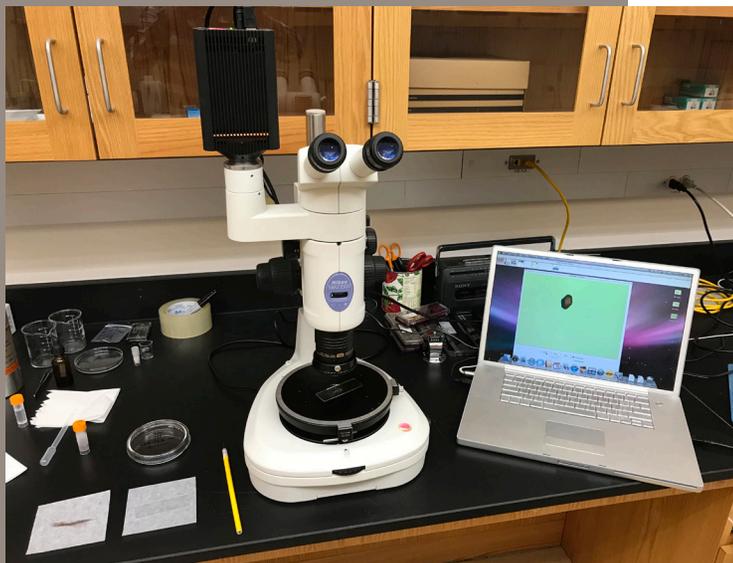
temperatures. In order to obtain successful results using the (U-Th)/He technique, the apatite or zircon crystals must be big enough (>70 µm wide), euhedral (well-formed), and lack inclusions of other minerals. Among hundreds to thousands of grains, it is not uncommon to only find a handful of good grains suitable for analysis. In the Fission-Track Lab, grains are picked using tweezers with the aid of a Nikon binocular zoom microscope with rotating stage, crossed polars, and digital camera with measuring capabilities. The picked grains are then packed into 1 mm-long metal packets that are then sent to an outside lab to be analyzed.

Recent work in the Fission-Track Lab has examined fission-tracks and prepared (U-Th)/He samples from a variety of geologic locations with researchers from New Mexico State University, the University of New Mexico, and across the United States. The data has been used to interpret the tectonic history of the Rio Grande rift, when the westernmost Grand Canyon was carved, and when and how the Zuni Mountains in west-central New Mexico formed. Current work in the lab is examining the thermal history of the Granite Mountains in central Wyoming with both apatite fission-track and (U-Th)/He analysis on apatite and zircon. Low-temperature thermochronology is also commonly used to evaluate the thermal history of petroleum-producing sedimentary basins, such as the San Juan Basin in northwestern New Mexico and the Uinta Basin in Utah.

–Jacob O. Thacker and Shari A. Kelley



Etched fission tracks in apatite.
Image by Shari A. Kelley



Binocular zoom microscope used for picking apatite and zircon for (U-Th)/He analysis. Laptop screen shows a zircon crystal at full magnification. Red-brown line of material on the white paper in the bottom left is a zircon separate that was examined for crystal selection. Photo by Jacob O. Thacker

Through the Hand Lens with Matt Heizler

What is your education and professional background?

University of Minnesota-Duluth, BS in Geology, 1982

University of Maine, MS in Geochemistry, 1985

University of California-Los Angeles, PhD in Geochemistry, 1993

Following my master's degree, I became Geochronology Lab Manager at SUNY-Albany where I also pursued my PhD part-time. After five years in New York, I became Geochronology Lab Manager at UCLA and completed my PhD there. I was at UCLA for three years and then came to the NMBGMR in 1993 as the Bureau's Geochronologist. I am also an adjunct professor in the Department of Earth and Environmental Sciences at New Mexico Tech. Currently, I am Principal Geochronologist and Associate Director of Laboratories at the NMBGMR.

What inspired you to become a geologist?

Like many children I always enjoyed rocks and the outdoors. I also had a knack for both math and chemistry and because the geosciences combine all of the physical sciences in understanding our complex world, a career in geochemistry seemed like a good fit.

What is argon geochronology and how is it used?

Argon geochronology is one of many methods to date geological materials. It is based on the natural radioactive decay of the parent isotope ^{40}K to the radioactive daughter isotope ^{40}Ar . The half-life of ^{40}K is about 1,250 million years and thus argon geochronology can be used for rocks as old as our Earth (about 4.56 billion years) and for very young rocks (about 1,000 years). There are many potassium-bearing rocks and minerals and therefore the argon method has great utility for aspects of geosciences because it can be used for nearly all rock types of all ages. It is commonly

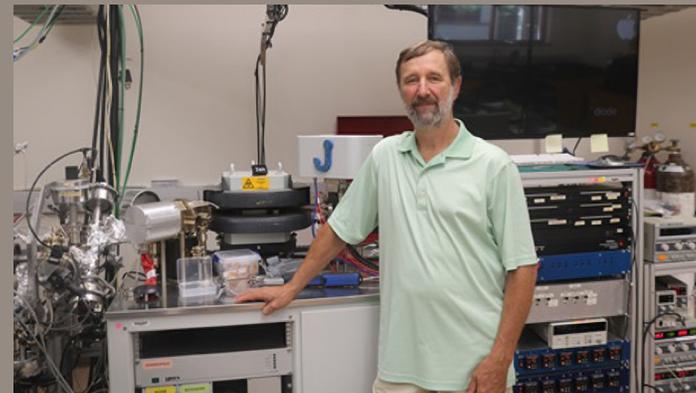
used to understand the age of volcanic rocks, to study tectonic processes, to determine the age of ore deposits, to understand climate change, and many more important geological questions.

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

I have been fortunate that my path to becoming a geochemist has only required hard work with no significant obstacles blocking my path. Even in the very small town that I grew up in I had outstanding teachers during my K-12 years. Science was highly valued in my school system, where math, physics, chemistry, and biology were available to students who desired these courses.

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

Many students have an aptitude for science, but too often they cannot receive the mentorship or courses to develop their desires to understand our physical world. We need to capture the youthful exuberance that most children possess for science and continue to make it engaging, rewarding, and fun as they move into their high school years. Probably at no other time than today do we need more scientists to solve existential threats such as climate change, population growth and, as illustrated by Covid-19, viral threats to human existence. Students need to leave their K-12 years with an excitement to explore a science career and knowing that they will lead the future of making a better world.



Geochronologist Matt Heizler with spectrometers Felix (left) and Jan (right). The New Mexico Geochronology Research Laboratory has some of the most advanced mass spectrometers in the world. Felix is a large radius instrument designed to provide highly accurate results via high resolution where small isotope mass differences can be deciphered, whereas Jan is much smaller and thus much more sensitive providing the ability to yield extremely precise measurements on exceptionally small gas quantities. *Photos by Cynthia Connolly*

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

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

Senior Mineralogist and Museum Director:
Dr. Virgil W. Lueth
(575) 835-5140, virgil.lueth@nmt.edu

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

Education Outreach: *Cynthia Connolly*
(575) 835-5264, cynthia.connolly@nmt.edu



Founded in 1927, the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) 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. *NMBGMR photo by Cynthia Connolly*

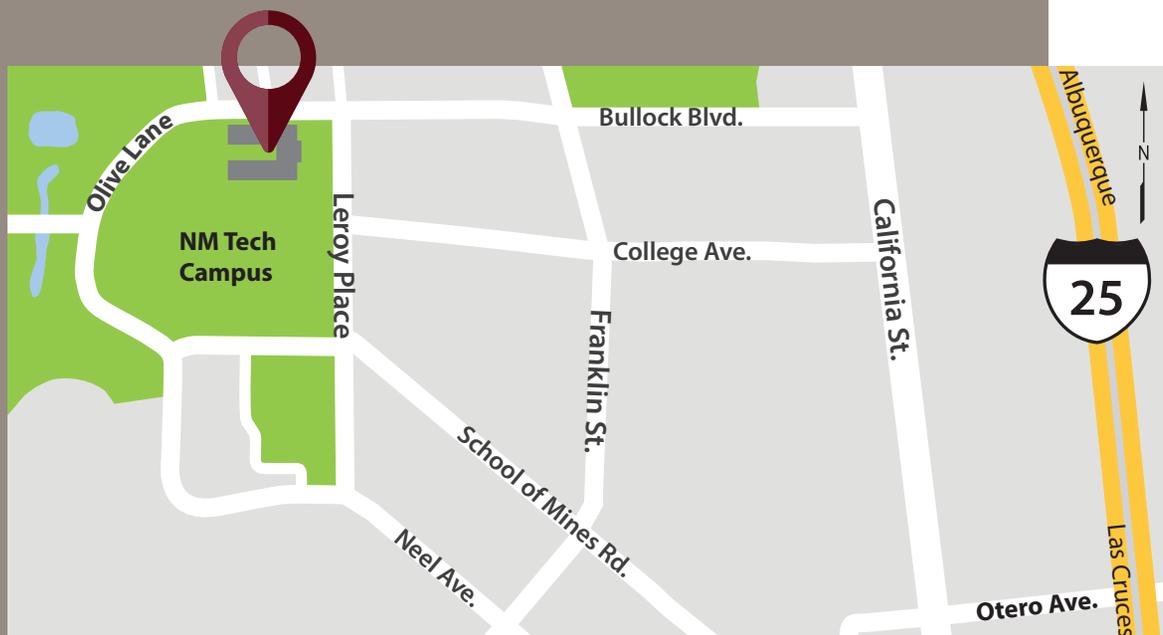
Publication Sales Office

A wide selection of resources for teachers is available, including publications on New Mexico's geology. Many are written for the amateur geologist and general public.

Teachers are given a 20 percent discount

on Bureau of Geology and Mineral Resources and New Mexico Geological Society publications. For phone orders, please call (575) 835-5490. For more information, visit our website at: geoinfo.nmt.edu/publications

New Mexico Bureau of Geology and Mineral Resources Mineral Museum and Publication Sales



The Mineral Museum and Publication Sales Office are housed in the Bureau of Geology and Mineral Resources building on the New Mexico Tech campus in Socorro, at the corner of Leroy Place and Bullock Boulevard.

Visitor parking on the east side of the building provides convenient access.

We Offer

- Popular and educational geologic publications
- Topographic maps for the entire state of New Mexico
- Geologic maps for selected areas of New Mexico
- U.S. Forest Service maps
- Jewelry, children's science kits, gifts, puzzles, clothing and more

Lite Geology Credits

Managing Editor: *Cynthia Connolly*

Editorial Assistance: *Shari Kelley and Belinda Harrison*

Graphics and Layout: *Stephanie Chavez and Lauri Logan*

Web Support: *Adam Read*

Editorial Board: *Virgil Lueth, Marissa Fichera, Bonnie Frey, Lynn Heizler, Kevin Hobbs, Nels Iverson, Shari Kelley, Dan Koning, Ethan Mamer, Luke Martin, Kelsey McNamara, Talon Newton, Kristin Pearthree, and Stacy Timmons*