Lite Geology

New Mexico Bureau of Geology and Mineral Resources

Critical Minerals and Mining in the San Juan Basin

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Volume 54

Critical Minerals and Mining in the San Juan Basin

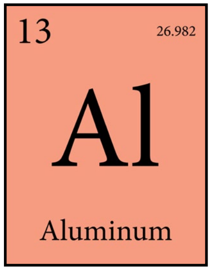
The San Juan Basin is a large, asymmetrical structure in northwestern New Mexico and southern Colorado known for its abundant coal, oil, uranium, and natural gas reserves. The basin ranks second in the contiguous United States in natural gas reserves and second after Wyoming in uranium reserves. The focus of *Lite Geology* volume 54 is critical minerals and mining in the San Juan Basin. Aluminum, a critical metal found in ores called bauxites, is valued for its ductility, durability, and low density. Our first article describes ongoing research at New Mexico Tech (NMT) to investigate new ways to extract aluminum from New Mexico bauxites. San Juan Basin Cretaceous heavy-mineral sandstones contain significant coal, uranium, petroleum, and natural gas resources, and some of these deposits are radioactive due to elevated amounts of uranium and thorium. Our second article discusses research to analyze the content of these heavy-mineral sandstones and map these deposits in the San Juan Basin. Our third article describes the relationship between San Juan Basin clinkers, critical minerals, and coal seams. Our activity pages include an overview of the San Juan Basin with a word search. We've also added a San Juan Basin crossword puzzle for your enjoyment. In our "Through the Hand Lens" segment, New Mexico Bureau of Geology and Mineral Resources (NMBGMR) Senior Economic Geologist Dr. Virginia McLemore shares stories from her career and relates her perspective on the importance of science education.

Cover Photo

San Jose Formation hoodoo overlooking the Lybrook badlands from Sisnathyel Mesa, Sandoval County, New Mexico. *Photo by Kevin Hobbs*

Extraction of Aluminum

Janin Essary, Paul Fuierer, and Virginia T. McLemore



Aluminum is the third-most abundant element in the earth's crust, so it's no wonder that it's used for basically everything. You're probably aware of its use in cars and soda cans, but it's also used in microchips and circuit boards, and its counterpart, aluminum oxide (Al_2O_3), is used for electrical insulation, sparkplugs, and abrasives. It has a low atomic weight (26.98 daltons) and is lighter than most other metals, making it much less dense than metals like iron. It is also very ductile (able to be deformed without losing strength) and less reactive than any metals lighter than it due to how readily it reacts with oxygen. In fact, every piece of aluminum metal is covered by a microscopically thin layer of Al_2O_3 that forms upon exposure to air and prevents any further reaction with the environment.

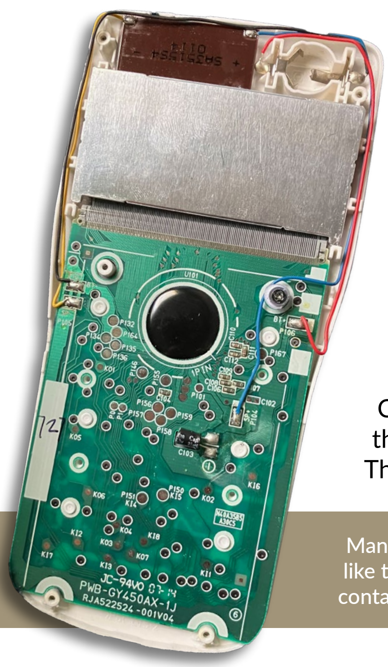
Extraction of aluminum is necessary but not easily accomplished. Aluminum likes being bonded to the nonmetals from the periodic table. It bonds so well that extraction requires two different processes to accomplish the task: the Bayer process to convert ore to Al_2O_3 and the Hall-Héroult process to convert Al_2O_3 to pure aluminum.

- The Bayer process converts the aluminum ore known as bauxite into Al_2O_3. It has a low energy cost compared to other processes that can be used, which is why it is still used today. However, it does have a few drawbacks, the primary of which is that it only works on bauxites that have a low silicon dioxide content (known as low-silica bauxites).
- The Hall-Héroult process is used to convert Al_2O_3 to pure aluminum metal. This requires a tub, graphite electrodes, heat, electricity, and some very corrosive fluoride salts. The aluminum metal is pulled toward the graphite cathode that lines the tub bottom, while the oxygen is pulled toward the anode, where it reacts with the graphite electrodes and creates CO_2.

Many items are either made from or contain aluminum.

A bauxite specimen in the "Critical Minerals" exhibit at the New Mexico Bureau of Geology's Mineral Museum. *Photo by Kelsey McNamara*

Despite aluminum's abundance, the U.S. Geological Survey now lists aluminum as a critical mineral. This is because the world is running low on low-silica bauxites. Luckily, there is hope. There are other processes that can be used for Al_2O_3 extraction, and—even better—these processes don't require bauxite to work.

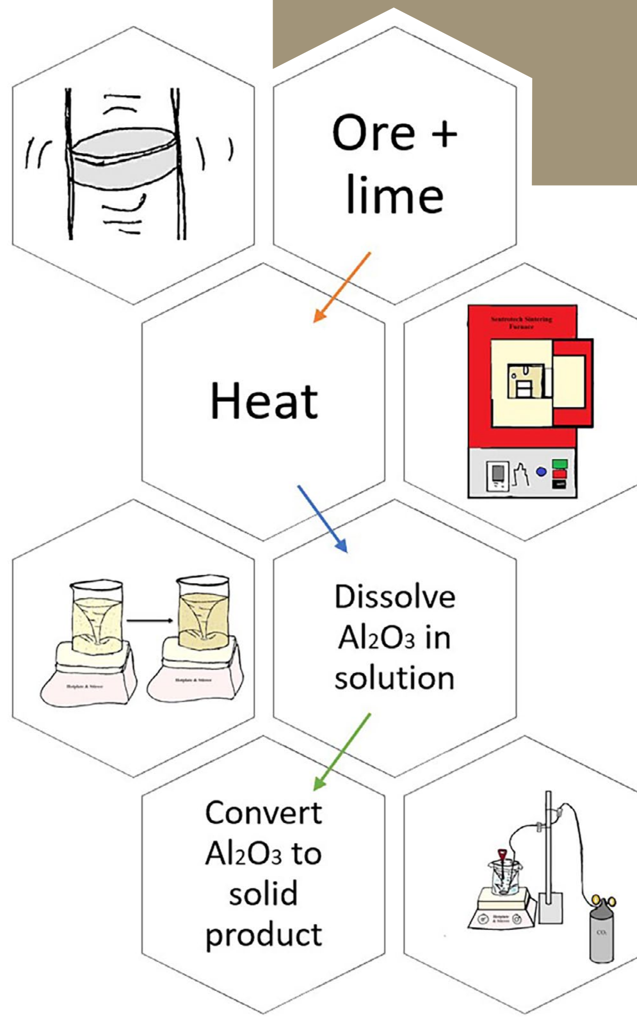


Many electronic devices, like this calculator, contain aluminum.

The most promising is the lime-sinter process, which can extract Al_2O_3 from any ores available, including clay and feldspar. It works by combining lime (CaO, which is created by the heating and breakdown of limestone) with a finely ground rock or clay containing aluminum, then heating to above 1,300°C. This causes a reaction between the lime and the ore that creates calcium-containing compounds, which are spun in a sodium carbonate solution, causing the Al_2O_3 in the sample to dissolve. The Al_2O_3 solution can then be separated from the other insoluble compounds via filtration, and the Al_2O_3 can be removed from the solution by adding carbon dioxide (CO_2).

Currently, research is being done at New Mexico Tech to test the lime-sinter process on ores from around New Mexico. The results are so far very promising.

A simplified overview of the lime-sinter process.

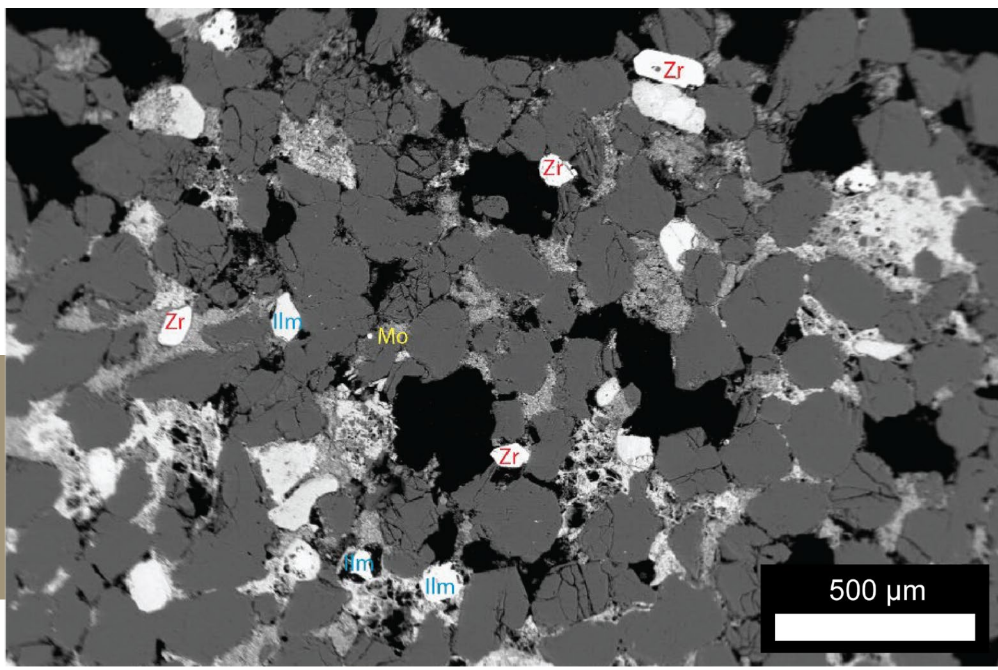


Earth Briefs:
Heavy-Mineral Sandstones as a Source of Critical Minerals in New Mexico

Evan J. Owen and Virginia T. McLemore

Heavy-mineral sandstones (also known as beach-placer sandstones) are accumulations of dense, resistant minerals that form from mechanical concentration by waves, currents, and winds in marginal marine environments. An analogy for the formation of these deposits is how a gold pan can be used to concentrate gold and other dense minerals from stream sediments. These sandstones contain dense, resistant minerals such as zircon ($ZrSiO_4$), rutile (TiO_2), ilmenite ($FeTiO_3$), and monazite ($[Ce,La]PO_4$), which are sources of critical minerals such as zirconium, titanium, and rare earth elements (REE). Critical minerals are mineral commodities that are essential to the economic and national security of the United States but are also vulnerable to supply chain disruptions. The United States is totally reliant on imports for many critical minerals and is currently sourcing them from countries that can easily disrupt supply chains. These commodities are also required for modern electronics, as well as in technologies for the green energy transition, such as wind turbines, solar panels, and electric cars. Heavy-mineral sands, the unlithified (not yet converted to rock) version of a heavy-mineral sandstone, are generally found along or near modern coastlines and are the primary source of titanium and zirconium worldwide.

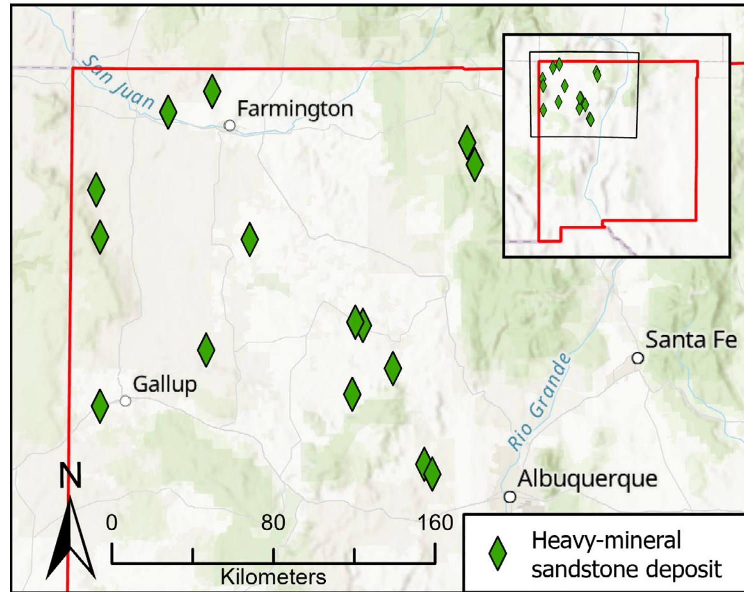
An outcrop in profile of a heavy-mineral sandstone in northwestern New Mexico showing darker layers with more abundant heavy minerals. A scintillation detector, used to detect radiation, rests atop the sandstone.



Backscattered-electron image of a heavy-mineral sandstone from New Mexico. This sample shows zircon (Zr) grains (some of which are euhedral, or well-formed), ilmenite (Ilm), and monazite (Mo) with subrounded quartz (dark grey) cemented by iron oxides. Source: McLemore and Robison, 2016, Exploration of beach-placer heavy mineral deposits in the San Juan Basin in New Mexico: Society for Mining, Metallurgy, and Exploration, 2016 Annual Meeting.

Cretaceous heavy-mineral sandstones are found in the Colorado Plateau within the San Juan Basin in northwestern New Mexico. The San Juan Basin, a Cretaceous- to early Tertiary-age structural basin, extends into southern Colorado and contains significant coal, uranium, petroleum, and natural gas resources. Many of the heavy-mineral sandstone deposits were discovered in the 1950s by airborne radiometric surveys for uranium because the deposits are radioactive due to elevated uranium and thorium, found primarily within monazite and zircon. Previous New Mexico Bureau of Geology and Mineral Resources (NMBGMR) studies have examined numerous heavy-mineral sandstones in the San Juan Basin of New Mexico, compiled historical data, and collected new data, including petrography and geochemical analyses. The NMBGMR is currently reinvestigating heavy-mineral sandstones in the state as part of the U.S. Department of Energy CORE-CM (Carbon Ore, Rare Earth, and Critical Minerals) initiative. Several heavy-mineral sandstone deposits have been recently sampled, mapped with ground radiometric surveys, and analyzed with whole-rock and trace element geochemical methods.

Initial results include ground radiometric maps of four deposits, helping to define the lateral extent of heavy-mineral sandstones. Forty-nine new rock samples were collected from the four deposits and contained up to 29.4% TiO_2, 1.4% total REE, and around 5% ZrO_2. Further work will involve analyzing the critical mineral (particularly the REE) content of each mineral in these deposits.



Map of heavy-mineral sandstone deposits in the San Juan Basin of northwestern New Mexico.


A closeup of a sample from the Apache Mesa heavy-mineral beach-placer sandstone deposit on the Jicarilla Apache Nation. This sample contains 127 ppm total REE and 245 ppm Zr.


The dark-brown to black band is a high-grade heavy-mineral beach-placer sandstone deposit at Sanostee, McKinley County. This deposit is 1 to 4 m thick and is the largest known beach-placer sandstone deposit in New Mexico.

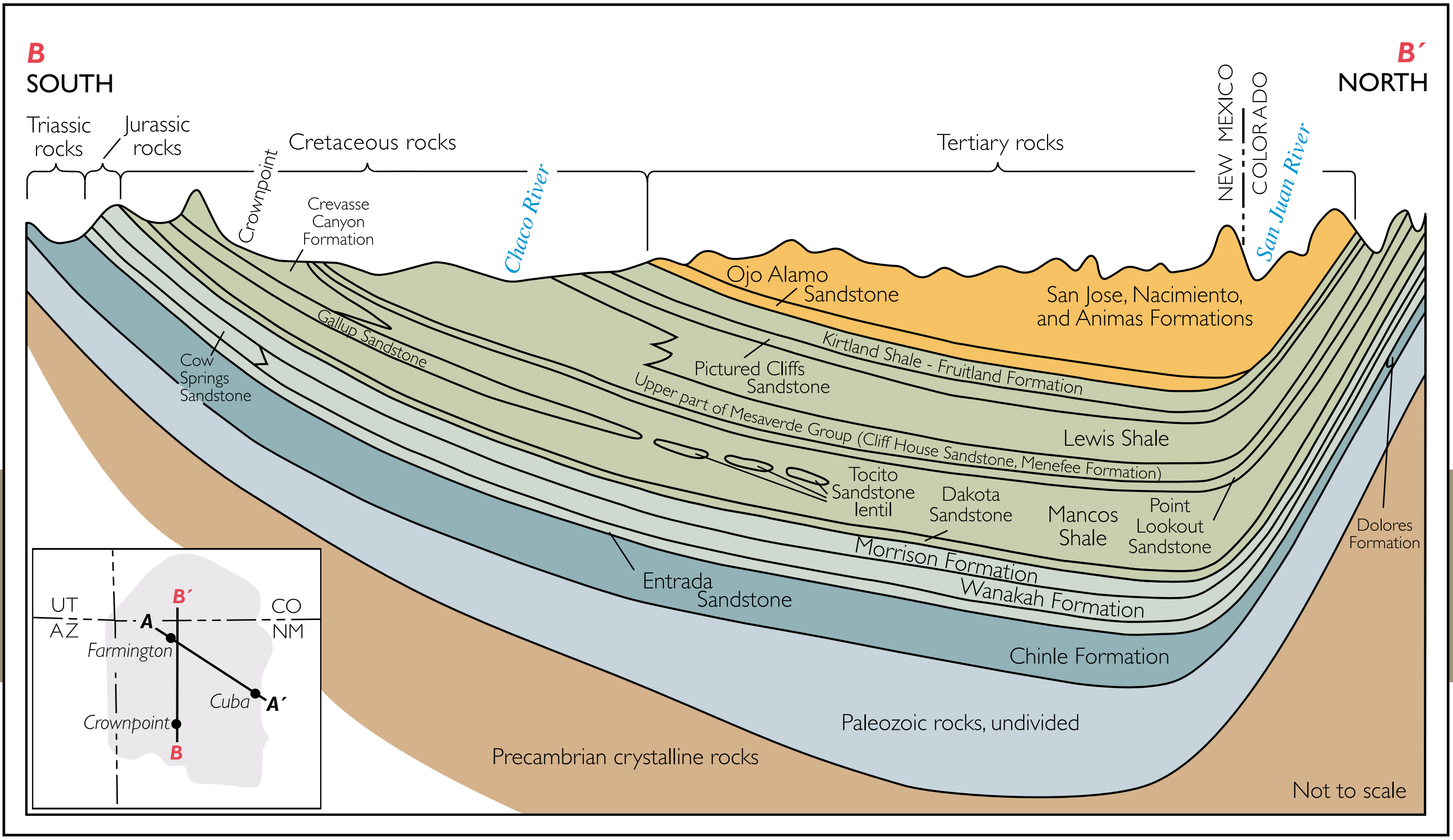
Clinkers of the San Juan Basin, New Mexico

Devlon Shaver

Clinkers are sedimentary rocks that have been altered by exposure to high-temperature underground coal fires. These fires can occur through lightning strikes, lava flows, forest fires, and other heat sources and can affect the surrounding rock layers, depending on the temperature of the fire and the composition of the original rocks. This pyro-metamorphism may have altered these rocks significantly.

The San Juan Basin is a coal-rich region in the northwest corner of New Mexico. The basin is composed mostly of sedimentary deposits that originated from the shores of the Western Interior Seaway, which submerged much of western North America during the Late Cretaceous Period of the Mesozoic Era from 95–73 million years ago (Ma). Coal seams stretch throughout the San Juan Basin. The seams are the result of organic materials being deposited and buried, then exposed to heat and pressure over time, causing the formation of coal. Sediments that overlaid this organic carbon layer would solidify over time to form sedimentary layers that ranged from large-grain, immature sandstones to very fine-grain, smooth siltstones and shales. The Fruitland Formation contains the majority of known clinker samples and also hosts the region's largest coal seams. Clinker rocks are also present in formations of the Mesaverde Group, specifically the Crevasse Canyon and Menefee Formations.

Clinkers are found correlating with coal seams that have burned in coal seam fires. These fires can have various causes, like wildfires that burn exposed seam facies, lightning strikes, or the spontaneous combustion of coal caused by the breakdown of pyrite into sulfuric acid over time.



South–north geologic cross section of the San Juan Basin. Source: Brister and Price, eds., 2002, New Mexico's Energy, Present and Future: New Mexico Bureau of Geology and Mineral Resources Decision-Makers Guidebook.

The fires can reach temperatures up to 800°C in some cases and cause surrounding rock layers to melt into a slag-like state. The extreme temperatures cause any organic material that is still present in the sedimentary rocks surrounding the coal seams to burn away and cause silica minerals in these rocks to melt and form glass. The level of metamorphism that occurs in the sedimentary rocks largely depends on the temperatures the rocks are exposed to, but it can also be affected by the original mineral composition of the rocks, with some minerals being more resistant to high-temperature alteration than others. This baking effect causes the sedimentary rocks to become harder and take on a reddish-orange to dull-yellow coloration as the native iron minerals present in the rocks oxidize as a result of the high temperatures. These clinker rocks can be a common sight in coal-bearing regions because they form hard, weathering-resistant outcrops and beds that can protect underlying layers of coal and sedimentary rocks.

Currently, clinkers are primarily used as aggregates in areas where they appear because they are cheap to mine and last a long time. Used in roads and construction as aggregates and gravels, clinkers have little potential to be used as a source for critical minerals and rare earth elements (REE) due to the low percentages of these minerals in clinkers. The clinkers' pyro-metamorphic nature has not altered their chemical composition.

Red Dog Formation clinker rock, El Segundo mine.

Red clinker in the Bisti coal field. *Photo by Virginia McLemore*

Energy and Mineral Resources in the San Juan Basin Area of New Mexico

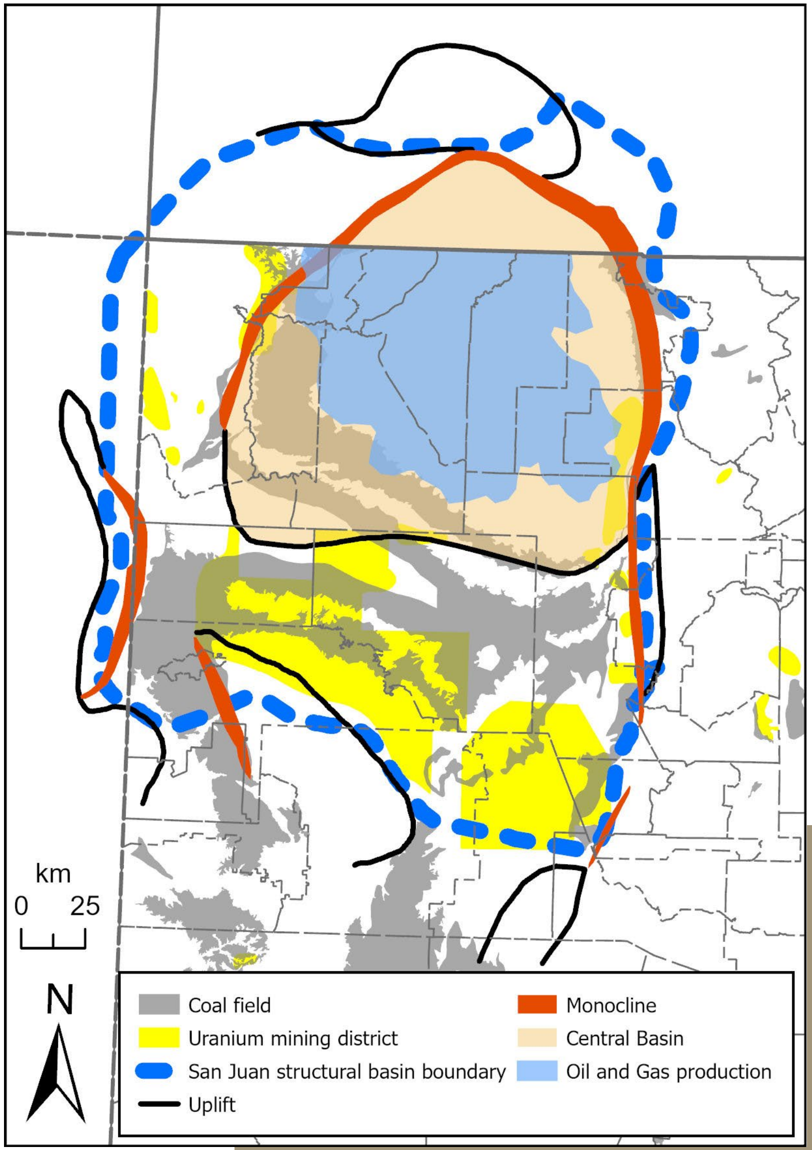
Virginia T. McLemore and Evan J. Owen

The San Juan Basin is the predominant geologic feature in the northwest corner of New Mexico. It covers more than 26,000 square miles and is surrounded by numerous mountain ranges (La Plata, Ute, Nacimiento, Zuni, Carrizo, and Chuska Mountains). The center of the basin contains sedimentary rocks over 4,400 m (14,400 ft) thick, ranging in age from Late Devonian (approximately 383 Ma) to Eocene (approximately 50 Ma), in addition to thin layers of younger surficial sediments that are still active today.

The San Juan Basin is known for its significant production of various energy resources. Oil and gas are produced from the northern portion of the basin, the second-largest producing oil and gas field in New Mexico (after the Permian Basin in southeastern New Mexico). Helium and carbon dioxide are also produced. Coal is produced from three mines in the central basin (El Segundo, Lee Ranch, and Navajo mines) and burned to generate electricity at the Four Corners Generating Station and at electrical power stations in eastern Arizona. Uranium was produced from the Grants and Carrizo districts from 1948 to 2002; the Grants district is among the largest uranium districts in the world, with more than 145 million pounds of U_3O_8 remaining in reserves. Some of these deposits are being investigated for future production.

Several important industrial mineral deposits are also found in the San Juan Basin. Industrial minerals and rocks are any rock, mineral, or other naturally occurring substance of economic value, excluding most metals and gemstones. Industrial minerals and rocks are used to manufacture many products, including ceramics, plastics, refractories, and paper. Gypsum and high-calcium limestone are produced from the Todilto Formation for wallboard and cement, respectively. Humates (weathered coal) are produced from coal and humate mines for agricultural products. Clinkers (burned coal deposits), sand, and gravel are used in road construction. Pumice and perlite are found near Grants.

Current San Juan Basin investigations are examining the potential for critical minerals. Critical minerals are defined as nonfuel mineral commodities that are essential to the economic and national security of the United States and are sourced from supply chains that are vulnerable to global and national supply disruptions. Some of the critical minerals deposits found in the San Juan Basin that were mined or may have future potential include rare earth elements (REE), titanium, and zirconium in Late Cretaceous heavy-mineral beach-placer sandstones, coal ash stored at power plants (cement, REE?), fluorite (Zuni Mountains), vanadium (sandstone U, Grants district), clays, and sediment-hosted stratabound copper deposits. Sediment-hosted stratabound copper deposits are bodies of copper minerals found as disseminations, cement, and veinlets in bleached sedimentary rocks that are restricted to a narrow range of layers within sedimentary host rocks and are found in the Nacimiento and Zuni Mountains. Selected samples from the Nacimiento and Zuni Mountains (i.e., Nacimiento, Coyote, and Zuni mining districts) have elevated heavy REE, vanadium, cobalt, and arsenic.



Map of the San Juan Basin showing geologic features and areas of resource extraction.

Word Search:
Energy and Mineral Resources in the San Juan Basin Area of New Mexico

Virginia T. McLemore

Find the words related to the article above.

C	C	L	I	N	K	E	R	I	N	M	L	R	T	M	M
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I	U	M	M	I	C	R	O	C	H	I	P	S	U	O	S
T	T	C	U	E	T	B	S	N	U	M	U	M	I	A	U
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S	R	L	S	M	U	S	P	Y	G	M	S	M	A	O	S

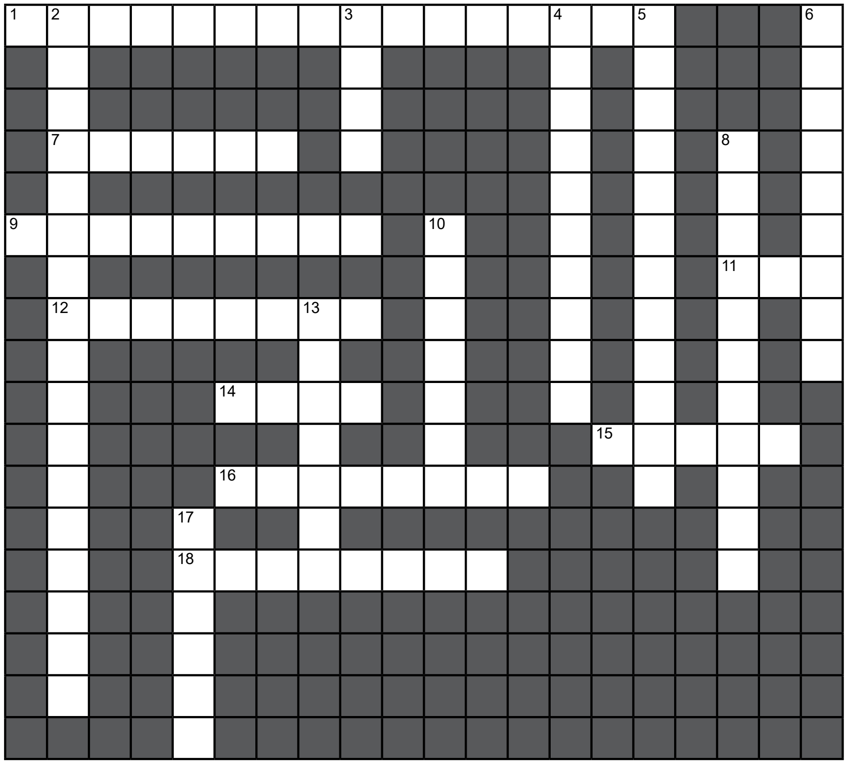
Aluminum
Clinker
Coal
Cobalt
Copper
Critical minerals
Energy
Gas
Gypsum
Humates
Limestone
Microchips
Oil
REE
Rutile
Sandstone
San Juan Basin
Uranium

Access the puzzle online:

Puzzle solution:

Rock Riddler Puzzle:
Critical Minerals and Mining Crossword

Please note that crossword answers with two or more words do not contain spaces.



Access the puzzle online:

Puzzle solution:

Sources

https://www.americangeosciences.org/critical-issues/faq/what-are-rare-earth-elements-and-why-are-they-important

https://geoinfo.nmt.edu/

https://www.merriam-webster.com/dictionary/

https://www.usgs.gov/faqs/what-a-critical-mineral

Across

1. Minerals that are essential to the economic or national security of the United States, have a supply chain that is vulnerable to disruption, and serve an essential function in the manufacturing of a product, the absence of which would have significant consequences for the economic or national security of the country (two words, plural).
7. Usable power (such as heat or electricity) and the resources for producing such power.
9. A sedimentary rock usually consisting of quartz sand united by some cement (such as silica or calcium carbonate).
11. The San Juan Basin is composed mostly of sediment deposits that originated from the shores of the Western Interior Seaway that submerged much of western North America during the Late Cretaceous Period of the Mesozoic ________.
12. A silvery-gray, light, strong, metallic element with atomic number 22 used in alloys, refractory materials, pigments, and medical and dental devices.
14. A black or brownish-black, solid, combustible substance formed by the partial decomposition of plant matter without free access to air and under the influence of moisture and often increased pressure and temperature that is widely used as a natural fuel.
15. Clinkers are found correlating with burned coal seams as a result of coal seam ___________ (plural).
16. Sedimentary rocks that have been altered due to high-temperature exposure to underground coal fires (plural).
18. A silver-white, metallic element with atomic number 13 that has good electrical and thermal conductivity, high reflectivity, and resistance to oxidation.

Down

2. A set of seventeen metallic elements, including the fifteen lanthanides on the periodic table plus scandium and yttrium (three words, plural).
3. To dig into the Earth for ore or metal.
4. Any of several hard, inert materials (such as sand, gravel, or slag) used for mixing with a cementing material to form concrete, mortar, or plaster (plural).
5. A large structural basin in northwestern New Mexico formed during the Late Cretaceous–Paleogene Laramide orogeny about 75 million years ago. The basin contains all or parts of San Juan, McKinley, Rio Arriba, and Sandoval Counties, with a northern portion that extends into southwestern Colorado (three words).
6. The __________ Formation contains clinker samples and is host to the region's largest coal seams. It represents swamps and rivers that formed close to the Cretaceous shoreline of the Western Interior Seaway about 74 million years ago.
8. An energy resource that does not produce pollution (two words).
10. An impure mixture of earthy, hydrous aluminum oxides and hydroxides that is the principal source of aluminum.
13. A silvery, heavy, radioactive, polyvalent, metallic element with atomic number 92 that is found especially in uraninite and exists naturally as a mixture of mostly nonfissionable isotopes.
17. The San Juan Basin is well defined by bounding __________ (plural) (fractures in the crust where there has been movement) and other structural features.

Through the Hand Lens with Dr. Virginia T. McLemore

Dr. Virginia T. McLemore speaks to her students about mine safety at the Chupadera mine adit. *Photo by Cynthia Connolly*

What is your educational and professional background?

I graduated from Woodlawn Senior High School in Baltimore, Maryland, in 1973. I earned my BS in geology, BS in geophysics, and MS in geology from New Mexico Tech (NMT) and my PhD in geoscience from the University of Texas at El Paso. I am a Certified Professional Geologist through the American Institute of Professional Geologists. Currently, I am the Principal Senior Economic Geologist and Minerals Outreach Liaison for the New Mexico Bureau of Geology and Mineral Resources. I am also an adjunct professor in the Department of Earth and Environmental Science and the Department of Mineral Engineering at NMT.

What inspired you to become a geoscientist?

I wanted to be a geologist ever since I took an earth science class in 5th grade. I started a rock collection then, and I still have it (although it has expanded somewhat). My grandmother would bring me rocks from her travels, and she told me I could be anything I wanted to become as long as I got an education. She actually brought me to New Mexico Tech to attend college—we drove from Baltimore to Socorro in a new Toyota! My family did not have any money to pay for college, but New Mexico Tech offered me a combination of scholarships, work-study, and financial aid. My husband and daughters have always supported my work.

What are you most proud of professionally?

I have enjoyed my long career and have learned a lot through the years. I was the first in my family to get a college degree, much less a PhD. I am married and have two daughters and four grandchildren. Now, I am in a position where I can teach others the importance of geology and mining and continue my research on the mineral deposits in New Mexico.

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

When I started classes at New Mexico Tech, there were not many females; I was the only woman in most of my classes. I was often the first woman touring the mines on field trips, and many mines had superstitions about women being underground, but I went, thanks to my professors. I really did not face much discrimination until I became pregnant with my two daughters—mining companies did not want to hire women, especially when pregnant. The only job I could find after graduating with my master's degree was with the New Mexico Bureau of Mines and Mineral Resources (now the New Mexico Bureau of Geology and Mineral Resources). The director at that time, Frank Kottlowski, hired me (and many other women), and I loved what I was doing, so I just stayed. Today it is different—women are hired in all aspects of geology and mining. I have never been bored because my job is so different every day, and I am constantly learning new skills and overcoming new challenges.

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

Geology is a fundamental science, and everything in our world is connected to geology. When we get up every morning, most of us brush our teeth and wash our faces. Our water is directly related to aquifers, rivers, and geology. The toothpaste we use is made of many components that have to be mined (fluorite, limestone, mica)—once again, geology. Most everything you use the rest of the day depends upon mining and geology.

The other thing about being a teacher is that you impact so many students, and you have no idea what they will become. I had good teachers and guidance counselors in my Baltimore schools who helped any student who showed an interest. I was not an exceptional student—I was average or above average—and I wanted to do something no one in my schools ever heard of. Yet my teachers helped me with my studies, science fairs, and after-school activities, even though they were not geologists. I was able to thank some of them, but most of them never knew what I had achieved. I do thank them every day. How else could someone born and raised on the streets of a city get to do what I have done? Thank you, teachers!

About

New Mexico Bureau of Geology and Mineral Resources

Museum and bookstore hours, excluding New Mexico Tech holidays:

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

Photo by Frank Sholedice

Bookstore

Our bookstore offers a wide variety of popular and educational geology publications, topographic maps for the entire state of New Mexico, and a variety of field guides. We also carry a selection of great gifts like jewelry, children's science kits, puzzles, clothing, field notebooks, and more. Kids can check out the play space stocked with plushies of New Mexico animals. Visit us in the Bureau of Geology building on the corner of Bullock Boulevard and Leroy Place in Socorro, or shop online at geoinfo.nmt.edu/publications/featured/home.cfml

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Mineral Museum

Our world-class mineral collection contains over 20,000 specimens from New Mexico, the United States, and around the world. About 4,000 specimens are on display at a time. Exhibits include not only minerals but also mining artifacts, gemstones and lapidary art, fossils, and meteorites. We also offer educational programs like tours, demonstrations, and scavenger hunts for school groups and other visitors. Visit us in the Bureau of Geology building on the corner of Bullock Boulevard and Leroy Place in Socorro, or online at geoinfo.nmt.edu/museum/home.cfml

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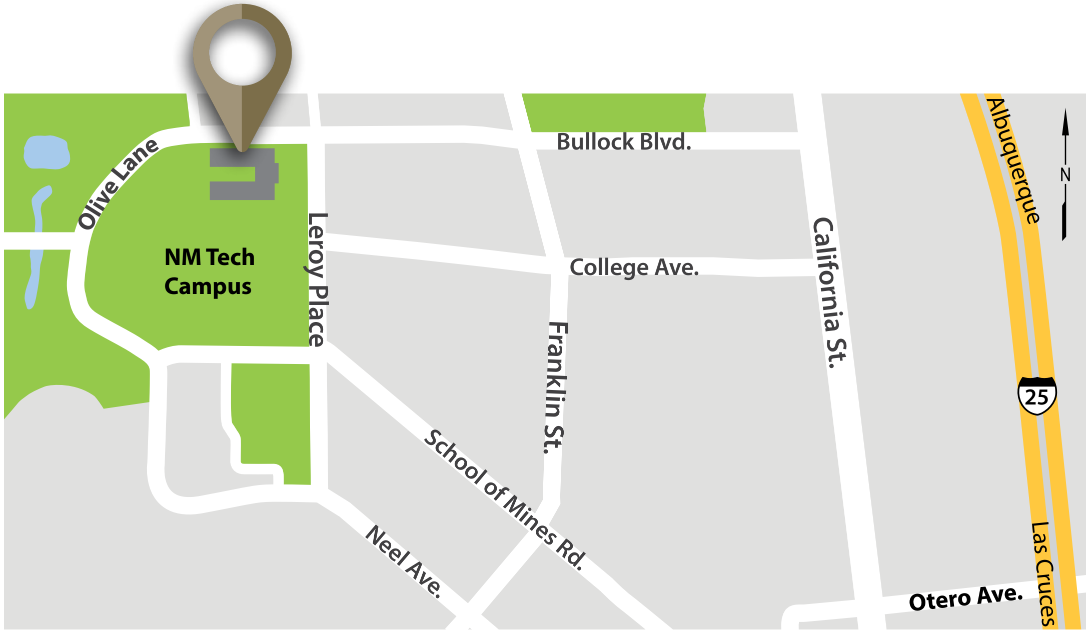
Teachers receive a 20% discount on Bureau of Geology and Mineral Resources and New Mexico Geological Society publications. For phone orders, please call (575) 835-5490. For more information, visit our website: geoinfo.nmt.edu/publications



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, on the corner of Leroy Place and Bullock Boulevard.

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

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