New Mexico EARTH MATTERS

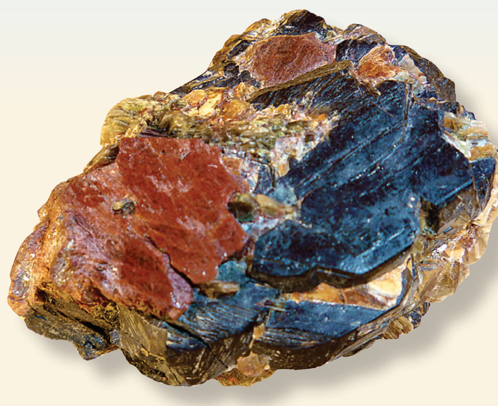
SUMMER 2011

Rare Earth Elements for Emerging Technologies

Before 2010 most Americans had never heard of rare earth elements, except maybe in high school chemistry class when studying the periodic table of elements. However, in April 2010 China announced that it would impose export quotas on rare earth elements immediately, in order to address internal environmental issues at their mines, regulate illegal mining operations, and provide for a sustainable rare earth element production and supply for China. This announcement triggered an increase in price and some panic buying. In late September 2010 China halted exports of rare earth elements to Japan, following an international dispute over territorial fishing rights. Japan uses rare earth elements in their highly profitable electric/hybrid automobiles and many electronic consumer products. Although China reinstated exports to Japan in early November 2010, this incident placed rare earth elements in headlines and on the lips of resource planners, politicians, investors, and journalists throughout the world.

What Are Rare Earth Elements and How Are They Used?

Rare earth elements are some of the more important commodities required to manufacture products associated with emerging green technologies, including wind turbines and hybrid/electric cars. They are essential in most of our electronic devices, including cell phones, laptops, iPods, computer chips, etc. Other technologies are being developed that require rare earth elements in their manufacture, technologies used in water purification, desalination, magnetic refrigeration, and more energy-efficient light bulbs. The so-called rare earth elements include the 15 lanthanide elements (atomic numbers 57–71), yttrium, and scandium. They are commonly divided into two chemical groups: the more abundant light rare earth elements (lanthanum through europium) and the lesser abundant heavy rare earth elements (gadolinium through lutetium, and yttrium and scandium). They are important because of their uniquely efficient electronic properties, including the ability to readily give up or accept electrons, a property useful for magnets, optics, electronics, and other applications.



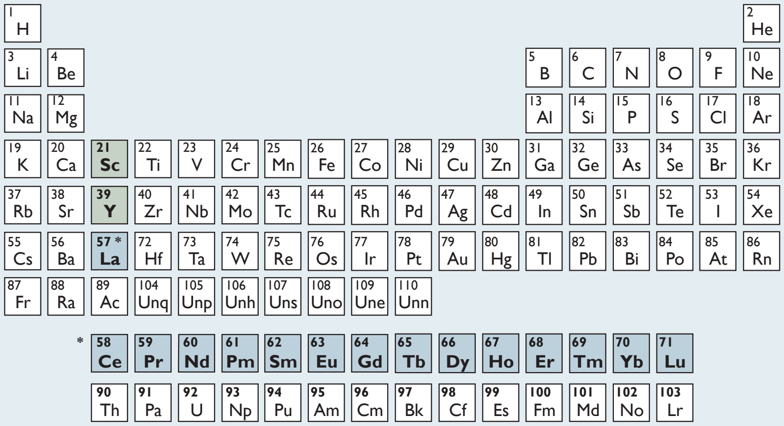
Monazite (in red), a rare earth mineral. From a pegmatite in the Petaca mining district in northern New Mexico. Photo by Leo Gabaldon.

Rare earth elements are *lithophile* elements (or elements enriched in the crust) that have similar physical and chemical properties, and, therefore, occur together in nature. The name is misleading; their content in the earth's crust ranges from 60 ppm (parts per million) for cerium to approximately 0.5 ppm for terbium and lutetium, which is greater than the crustal abundance of silver. Four of them (yttrium, lanthanum, cerium, and neodymium) have larger crustal abundances than lead. However, they are not always concentrated in easily mined economic deposits, and only a few deposits in the world account for current production.

Where Are Rare Earth Elements Found?

Commercial deposits of valuable rare earth elements are not evenly distributed around the world. They tend to be concentrated in specific localities based on favorable geologic conditions. Currently more than 95 percent of the rare earth elements required for emerging technologies is obtained from mines in China. Rare earth elements are not found naturally as pure metallic elements. Instead, they are incorporated in hundreds of minerals, but only a few minerals are economically important. Bastnasite, a carbonate mineral, and monazite, a phosphate mineral, are the most economically important rare earth minerals in the world at this time. Most of the world's largest concentrations of bastnasite are in carbonatites, igneous rocks that contain more than 50 percent carbonate minerals. Carbonatites are found as dikes, sills, plugs, lava flows, and large stocks. Rare earth elements also may be concentrated in pegmatites and granitic intrusions or as placer deposits. Each ore deposit is different, and a detailed understanding of the mineralogy and chemistry, as well as an understanding of the lithology, structure, and alteration of the deposit are required to determine economic potential.

Between 1950 and 1964 monazite placer deposits in South Africa and elsewhere supplied the small amounts of rare earth elements needed. From 1965 to 1998, most of the rare earth elements were produced from the large Mountain Pass mine in California, from carbonatites similar to those now being mined in China. Rare earth elements also are produced from igneous rocks on the Kola Peninsula in Russia, clay deposits in China, heavy mineral sands (placer deposits) in India and Brazil, and as a byproduct of tin production from mines



The periodic table of the elements, with the 15 lanthanide elements shown in gray. Two related elements, scandium and yttrium are shown in green. Together these comprise the so-called rare earth elements. Atomic numbers and atomic weights for each of these 17 elements are shown in the table on the right.

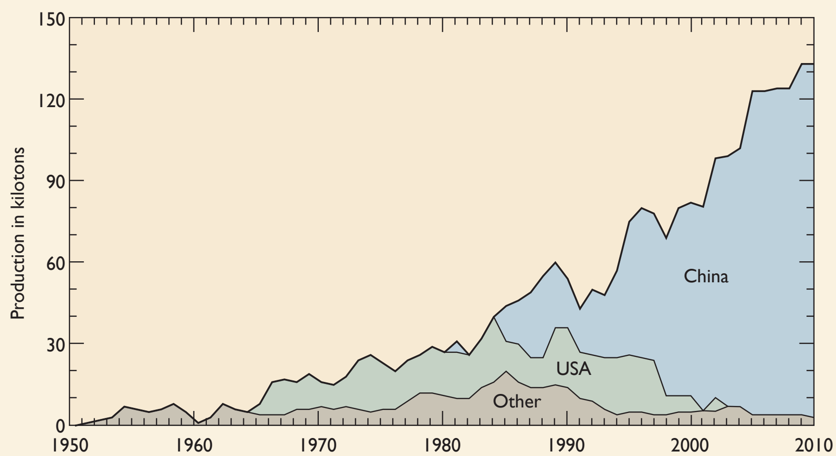
ELEMENT	SYMBOL	ATOMIC NUMBER	ATOMIC WEIGHT
Lanthanum	La	57	138.9
Cerium	Ce	58	140.1
Praseodymium	Pr	59	140.9
Neodymium	Nd	60	144.2
Promethium	Pm	61	145
Samarium	Sm	62	150.4
Europium	Eu	63	152.0
Gadolinium	Gd	64	157.3
Terbium	Tb	65	158.9
Dysprosium	Dy	66	162.5
Holmium	Ho	67	164.9
Erbium	Er	68	167.3
Thulium	Tm	69	168.9
Ytterbium	Yb	70	173.0
Lutetium	Lu	71	175.0
RELATED ELEMENTS			
Scandium	Sc	21	45.0
Yttrium	Y	39	88.9

in Malaysia. Smaller deposits in Indonesia, the Commonwealth of Independent States (12 countries, including Russia, formerly part of the Soviet Union), Nigeria, North Korea, and Vietnam sometimes produce small quantities. In the future other deposits throughout the world may provide sources, including uranium deposits in Australia, Canada, and Kazakhstan.

Where in the U.S. Are Rare Earth Elements Found?

Rare earth elements were produced from pegmatites in the U.S., including New Mexico, before 1950. California's Mountain Pass mine began production of rare earth elements in 1952 but closed in 2002 because of environmental problems and the availability of cheaper supplies of rare earth elements from China. Molycorp, Inc., plans to reopen the Mountain Pass mine in 2012 to provide a domestic source to meet the growing demand for rare earth elements.

Other areas in the U.S. have undeveloped deposits of rare earth elements, mostly in igneous rocks, including deposits at Bokan Mountain in Alaska, Lemhi Pass in Idaho, and the Bear Lodge Mountains in Wyoming. Rare earth elements are found in the Peas Ridge iron mine in Missouri, and production from the tailings there could provide a source in the near future. Rare earth elements are also found in phosphorite deposits in the southeastern U.S. along the Atlantic Coastal Plain from North Carolina to the center of the Florida Peninsula.



Global production of rare earth elements, in kilotons, from 1950 through 2010.
Data from the U.S. Geological Survey.

Where in New Mexico Are Rare Earth Elements Found?

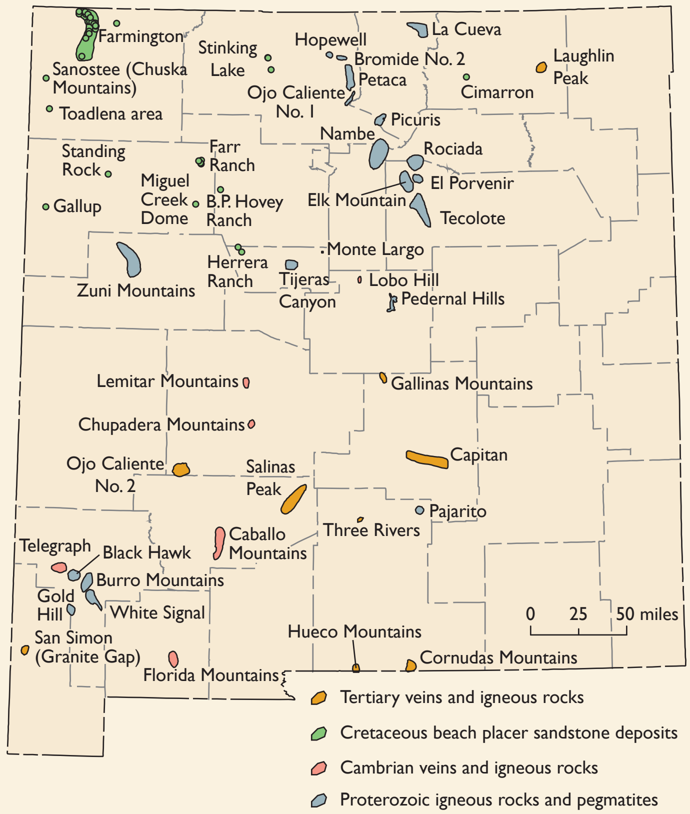
Rare earth elements are found throughout New Mexico, and several areas are undergoing current exploration. Strategic Resources, Inc., plans to drill in the Gallinas Mountains in Lincoln County this summer, where rare earth elements are found in vein deposits. Bastnasite was produced from the Gallinas Mountains in the 1950s as a byproduct of fluorite production. Strategic Resources, Inc., has completed drilling the carbonatites in the Lemitar Mountains in Socorro County and is awaiting final test results before proceeding further. Geovic Mining Corporation has staked claims in the Cornudas Mountains in the Otero Mesa area in southern New Mexico and applied for drilling permits. BE Resources, Inc., has drilled at Apache Warm Springs on the Sullivan Ranch in Socorro County, where they found anomalous concentrations of rare earth elements associated with beryllium vein deposits. Claims have been staked in the Caballo and Burro Mountains where rare earth elements are found in vein deposits and in igneous rocks. Deposits of yttrium and zirconium are found in igneous rocks at Pajarito Mountain in the northeastern Mescalero Apache Indian Reservation, south of Ruidoso. Although Molycorp, Inc., reported recoverable resources of 2.7 million short tons grading 0.18 percent yttrium and 1.2 percent zirconium in 1990, the Mescalero Apache Indian Nation is not interested in developing these deposits at this time.

New Mexico mines were producing rare earth elements as early as the 1940s, from pegmatite deposits found in San Miguel, Santa Fe, Rio Arriba, and Taos Counties in northern New Mexico, and in Grant County in southwestern New Mexico. Pegmatites are coarse-grained igneous rocks with granitic composition. They contain quartz and feldspar and represent the last crystallizing phase of igneous rocks. However, New Mexico pegmatites typically are too small to be mined for rare earth elements today. Rare earth elements are also found in sandstones (fossil placers) in the San Juan Basin in northwestern New Mexico, but these deposits are also too small to be mined at current prices.

Challenges Associated with Production

Not all rare earth element deposits can be mined, even if they are high grade deposits. A number of variables determine if a deposit can be mined. The mineralogy of the deposit must be known; rare earth elements can be recovered economically only from selected minerals like bastnasite, monazite, and xenotime. Some deposits have complex mineralogy that may not be amenable for recovery of rare earth elements. The deposit must have a high enough grade to be mined at a profit. The deposit must be low in impurities, especially uranium and thorium. Finally, the deposit must be mined and processed with minimal impacts to the environment.

The first step to determine if a deposit is economic is the exploration stage: Geologists sample surface exposures and drill to determine the mineralogy and chemical composition of the deposit. Feasibility studies are conducted using these data to determine if the deposit has enough material to mine at a profit. Metallurgical tests are conducted to determine if the rare earth minerals can be economically separated. Potential environmental issues are identified. Exploration can take two years or more. Many deposits will never be mined, even after millions of dollars have been spent on exploration, if the feasibility studies indicate that the deposit cannot be mined at a profit at that time. Companies may examine the same deposit many times as economic conditions change.



Known deposits containing high concentrations of rare earth elements in New Mexico, by mining district.

Once it is determined that the deposit is economic to mine, plans are developed and permits obtained. Rare earth element deposits are mined by both conventional underground and open-pit methods. Additional environmental issues are identified and plans developed to minimize them. Archaeological, biological, hydrologic, and other studies are conducted to determine pre-mining conditions. In the U.S. and most countries, new mines must have extensive mine and reclamation plans, and companies must identify post-mining land use before permits are issued. This permitting process can take as long as two to five years to complete and in many cases may take much longer.

DISTRICT NAME	PRODUCTION
Gallinas Mountains	146,000 lbs of bastnasite concentrate
Petaca	112 lbs of samarskite, few hundred lbs of monazite, 12,000 lbs of Ta-Nb-REE ore
Elk Mountain	500 lbs of Ta-U-REE concentrate
Rociada	Several thousand tons of REE-Ta ore
Tecolote	$10,000 worth of beryl, tantalite-columbite and monazite
Gold Hill	REE production in the 1950s

Production of rare earth elements (REE) in New Mexico, to date.

Meeting the Demand

Substitution of other materials in many of the components requiring rare earth elements generally is not an option. Most of the production will have to come from new mines, although recycling and conservation can reduce the demand. Geologists know where many potential rare earth element deposits are, but funding is needed to define and develop these deposits.

In the past, mining companies responded to an increase in demand by increasing production or opening new mines. Today, mining companies cannot always meet the rapid shifts in supply and demand, partly because of the complexities involved in the permitting processes, but in large part because of the rapidly changing economics of the market.

Processing

Rare earth elements are not traded on the open market like most commodities. Instead they are processed to specific manufacturer specifications. The deposits can have a complex mineralogy and can be difficult to process. Once mined, rare earth minerals are first separated from non-ore materials by various physical means, including gravity, flotation, and magnetic separation. This initial process is called concentration. The mineral concentrate is further processed using acid and other chemicals to separate the individual elements. The process of extraction and recovery is enormously complex, because rare earth elements have similar physical and chemical properties. Each element requires a different degree of processing. Furthermore, this separation process currently is performed only in China. Similar separation processing facilities may be built in the U.S., Australia, and other countries in a few years.

Environmental Issues

Deposits of rare earth elements nearly always occur with quantities of uranium and thorium. These radioactive elements are generally not found in high enough concentrations to make them economic, but they occur in high enough concentrations to require special handling in the disposal of the waste rock that remains after mining and processing. In addition, the processing of rare earth elements requires large amounts of acid and other hazardous chemicals, and the resulting toxic waste must be handled carefully.

Mining and processing also requires large amounts of water, and in many areas in the U.S. and the world, conflicts arise over water use and potential impacts. For example, the Apache Warm Springs deposit in Socorro County is near Ojo Caliente and other warm springs, and residents are concerned about potential impacts to the springs from exploration and mining. Environmentalists are also concerned about potential exploration and mining impacts to the fragile desert ecosystem in the Otero Mesa area, where Geovic Mining Corporation plans to drill for rare earth elements in the Cornudas Mountains. Each deposit will have its own unique environmental issues that must be addressed.

RARE EARTH ELEMENT	2009 (2nd QUARTER) US $/kg	SELECTED USES
Lanthanum	6.05	re-chargeable batteries, catalyst
Cerium	4.60	catalyst, glass, polishing, re-charge. batt.
Neodymium	14.58	magnets, lasers, glass
Promethium	14.50	magnets, glass colorant
Samarium	4.75	magnets, lighting, lasers
Europium	465.38	TV color phosphors
Gadolinium		magnets, superconductors
Terbium		magnets
Dysprosium	108.62	magnets, lasers
Erbium		fiber-optics telecommunication cables
Yttrium	45	phosphors, ceramics, lasers

Selected uses of rare earth elements, and prices (in U.S. dollars per kilogram, in 2009).

Other Challenges to Production

Financing for exploration and development of new mines is now competitive on a global scale, not only with other mineral deposits but with other types of investments. Mining companies must engage the local community and obtain a social license to operate; without community support, production delays are inevitable. Mining companies must meet expensive regulations and pay taxes. Mining companies, regulating agencies, universities, and others are now recognizing the shortage in trained personnel as the aging, experienced workforce is retiring. The permitting process in the U.S. (and elsewhere) now requires contingency plans for natural disasters (volcanic activity, earthquakes, droughts, floods, tornadoes), and those can be difficult and expensive. In some areas of the U.S. and throughout the world, infrastructure (including roads, railroads, electricity, water, etc.) is not adequate for mines to operate, and in other areas, the existing infrastructure requires maintenance and repair. The mining companies must include these costs in their feasibility studies, thereby decreasing profitability. Lowering permitting and environmental standards is not an option to overcome these challenges.

The Future

Consumers are demanding more cell phones, televisions, computers, iPods, video games, wind turbines, hybrid/electric cars, and solar panels—all of which require more rare earth elements. Although it is difficult to predict the amount of rare earth elements that we will need in the future, it is likely that future production could be met with six to ten new mines in the world. The new mines that can meet current regulations and obtain mining permits first will likely be the next producers of rare earth elements, even if better deposits are discovered later. New Mexico has some deposits that are in the early exploration stage, but it will take years for these deposits to be developed, even if they prove to be economic.

For most applications, there are no known substitutes for rare earth elements. New research is ongoing to develop technologies that will require less of them, and manufacturers are finding ways to be more careful about how they use rare earth elements. Just as aluminum cans became thinner as the price of that metal soared, companies will learn to make better use of the resources that are available. Scientists are researching ways to develop synthetic rare earth elements, but that technology, if developed, will take many years. In the meantime, we would be wise to take stock of our own domestic resources, as we continue to evaluate the potential for the prudent development of those resources, in light of our own growing needs.

—*Virginia T. McLemore*

For More Information

The New Mexico Bureau of Geology and Mineral Resources has a number of reports on rare earth occurrences in New Mexico. Information on national and international occurrences, along with other pertinent statistics, is available through the U.S. Geological Survey and the U.S. Department of Energy. Many of these resources are available online. Some of the more pertinent ones include:

The Principal Rare Earth Elements Deposits of the United States—A Summary of Domestic Deposits and a Global Perspective by K.R. Long, B. S. Van Gosen, N. K. Foley, and D. Cordier, 2010. U.S. Geological Survey, Scientific Investigations Report 2010-5220. Available at **http://pubs.usgs.gov/sir/2010/5220/**

Geology and Mineral Deposits of the Gallinas Mountains, Lincoln and Torrance Counties, New Mexico; *Preliminary Report* by Virginia T. McLemore, 2010. New Mexico Bureau of Geology and Mineral Resources, Open-file Report OF-532. Available at **http://geoinfo.nmt.edu/publications/openfile/downloads/OFR500-599/526-550/532/ofr_532.pdf**

REE, Niobium and Thorium Districts and Occurrences in New Mexico by V. T. McLemore, R. M. North, and S. Leppert, 1988. New Mexico Bureau of Mines and Mineral Resources, Open-file Report OF-324. Available at **http://geoinfo.nmt.edu/publications/openfile/downloads/OFR300-399/300-325/324/ofr_324.pdf**

Minerals, Critical Minerals, and the U.S. Economy, National Research Council, 2008. National Academies Press. Available at **http://www.nap.edu/catalog.php?record_id=12034**

Critical Materials Strategy, U.S. Department of Energy, 2010. Available at **http://www.energy.gov/news/documents/criticalmaterialsstrategy.pdf**

Rare earths statistics and information, U.S. Geological Survey. Available at **http://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/index.html#myb**

Virginia McLemore is a senior economic geologist and mineral outreach liaison with the New Mexico Bureau of Geology and Mineral Resources.

Bureau News

Director Search Continues

The search for a new director for the New Mexico Bureau of Geology and Mineral Resources continues. Peter Scholle retired on June 30, after 12 years of service. A number of qualified candidates have been identified, and interviews will continue into August. L. Greer Price is serving as the bureau's interim director until a new director comes on board. Greer came to the bureau in 2001, has served as an associate director since 2004, and has been deputy director since 2007.

Mine Map Project

The New Mexico Bureau of Geology and Mineral Resources received an additional $25,000 for the current fiscal year from the U.S. Department of the Interior, Office of Surface Mining. These funds are in support of our ongoing work on acquiring and georeferencing coal mine maps in the San Juan Basin, under the direction of Maureen Wilks and Gretchen Hoffman. This is the seventh year of this project.

Southwest Book Design and Production Awards

The New Mexico Bureau of Geology's recent publication *Geology of Northern New Mexico's Parks, Monuments, and Public Lands* won two awards at the 2nd Annual Southwest Book Design & Production competition in June. The popular book placed first in the guide and travel category, and was also a finalist in the scholarly and technical category. Sixty-nine contestants, many from major publishers across the West, vied for recognition in 11 categories in the competition, which is sponsored by the New Mexico Book Association. The focus was on accessibility to the reader. The winners were honored at the annual meeting in Santa Fe in June.

STATEMAP Award

This year the New Mexico Bureau of Geology and Mineral Resources once again received funding from the National Cooperative Geologic Mapping Program (STATEMAP). This year's program at the bureau was funded in the amount of $230,427. The bureau first received funding for this program in 1993 and continues to rank No. 1 in funding among the states involved in the program. The National Cooperative Geologic Mapping Program was recently reauthorized for an additional ten years. This year, 45 states requested a total of $9.8 million.

Rockin' Around New Mexico

The New Mexico Bureau of Geology and Mineral Resources conducted its annual teachers' workshop, "Rockin' Around New Mexico," on July 5–8, 2011, at the Valles Caldera National Preserve Science Education Center in Jemez Springs. Teachers representing grades K–12 came from across the state to learn more about the geologic history of the Jemez Mountains. The Las Conchas fire restricted field activities to Jemez Pueblo, the San Diego Canyon area around Jemez Springs, and White Mesa. The group was allowed to drive to Valle Grande and witness the southwestern extent of the burned area. The teachers attended lectures on earthquakes and earthquake-caused liquifaction in Christchurch, New Zealand, and on fire ecology. The lectures were followed by discussions on volcanic, seismic, and fire hazards, and on safety awareness. Many of the attendees were from New Mexico Tech's Masters of Science in Teaching (MST) program. For information on the 2012 workshop, contact Susie Welch at **susie@nmt.edu**.

Healy Foundation

The New Mexico Bureau of Geology this year received a second gift of $50,000 from the Healy Foundation of Taos, New Mexico. This gift is in support of our Aquifer Mapping Program.

A Familiar Face

Many of you will have noted that there is a new (but familiar) face in the Publication Sales Office. Susie Ulbricht, who worked for us from 2001 to 2005, has joined our Publication Sales Office staff once again, this time as Publications Resource Specialist. Susie is currently working half time and is one of the people you are likely to talk with if you call to order publications directly from the bureau (575-835-5490). The office is staffed Monday through Friday, 9 a.m. to noon and 1 p.m. to 4 p.m.

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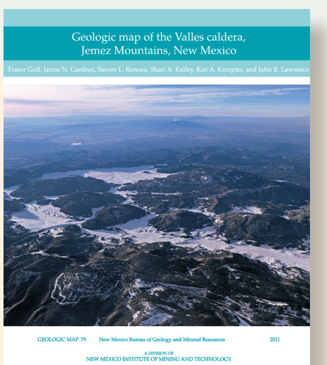
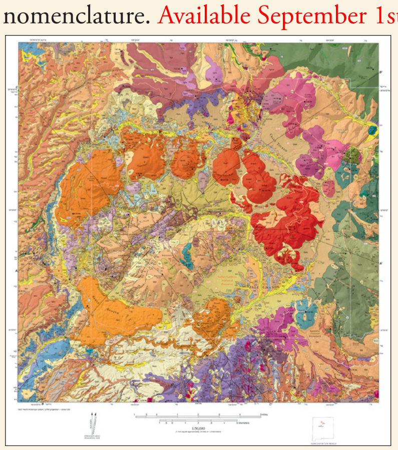
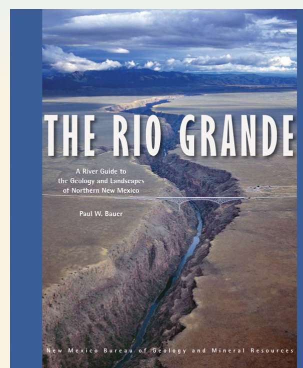
Coming Soon



Geologic Map of the Valles Caldera, Jemez Mountains, New Mexico by Fraser Goff, Jamie N. Gardner, Steven L. Reneau, Shari A. Kelley, Kirt A. Kempter, and John R. Lawrence. Geologic Map 79—30-page text, 1 sheet. Scale 1:50,000, 3 cross sections, ISBN 978-1-883905-29-3. $18.95 plus $6.50 for shipping and handling and 5% gross receipts tax for NM residents. Also available rolled; call for details.

This new Valles caldera map and cross sections represent the cumulative research efforts of countless geologists over the past 40 years, and several state and federal agencies. GM–79 compiles detailed geologic mapping completed in the past eight years from parts of the nine 7.5-min USGS topographic quadrangles that encompass the caldera. More than 150 map units are described in detail. Also incorporated are new geochronologic data and recent refinements to nomenclature. Available September 1st.





The Rio Grande: A River Guide to the Geology and Landscapes of Northern New Mexico by Paul W. Bauer. 120 pp., full color. Spiral bound, on waterproof paper. $18.95 plus $6.50 shipping and handling plus 5% gross receipts tax.

This comprehensive river guide provides detailed, full-color maps of 153 miles of the Rio Grande, from Lasauses, Colorado to Cochiti Dam in New Mexico. Divided into eleven river stretches, including the popular whitewater runs in the Taos Box, Racecourse, and White Rock Canyon. The river maps are developed on an aerial photographic base (digital orthophoto quads), allowing the user to more easily identify locations. Available August 1st.

For more information about these and other bureau publications:

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