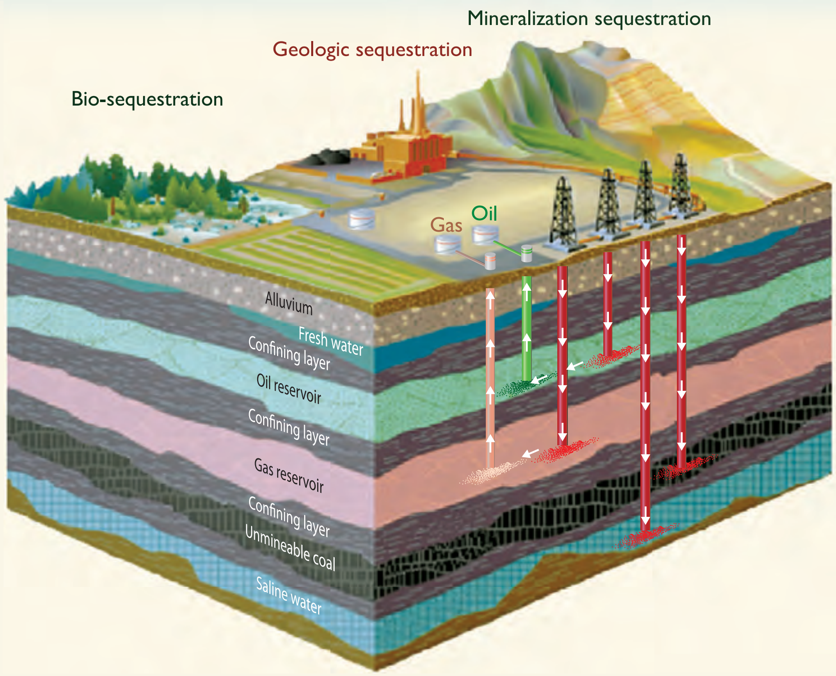
New Mexico EARTH MATTERS

SUMMER 2010

Carbon Sequestration in the Context of Climate Change



Major types of terrestrial carbon sequestration that currently hold some promise for the future.

Carbon dioxide (CO_2), a gas that comprises only about 0.04 percent (392 ppm) of our atmosphere, is constantly in the news for one simple reason: It is a major greenhouse gas (along with methane, CFC's, and water vapor). That means it is transparent to energy coming from the Sun as visible light, but absorbs part of the energy being emitted back into space from Earth as infrared (IR) radiation. That IR absorption increases temperatures on Earth, a good thing overall because this planet would be a frozen wasteland without such atmospheric gases, but not such a good thing if carried to extremes.

The problem lies mainly in the fact that atmospheric CO_2 levels are rising dramatically and at ever-increasing rates. Since 1957 (when continuous measurements were started, at Mauna Loa, Hawaii) atmospheric CO_2 has increased from 318 ppm to the current 392 ppm. The current level of CO_2 is 38 percent higher than at any previous time in the past 600,000 years, as determined from atmospheric gases trapped in Antarctic ice. Although humans are not the only source of atmospheric CO_2, the burning of fossil fuels, deforestation, and various industrial processes are major contributors. In 2006, 28.4 billion metric tons of CO_2 were emitted worldwide from human sources according to both United Nations and U.S. Energy Information Administration statistics. China is now the leading emitter with 21.5 percent of global anthropogenic CO_2, whereas the U.S. has fallen to second place, releasing 20.2 percent of the global total (but we are still #1 in per capita emissions, and our emissions are projected to rise by 14 percent between now and 2030). Here in New Mexico, the current per capita contribution is 32 tons of CO_2 each year.

The information given above is, by and large, undisputed. The interpretation of the significance of the data is not. A large majority of climate scientists believe that the measured human-caused changes in atmospheric CO_2 have contributed substantially to temperature increases on our planet (about 0.75° C in the twentieth century). That conclusion is controversial because there have always been natural variations in Earth's climate, including the well-known ice-age cycles of our recent past. It is also controversial because it is not easy to measure an average temperature for the earth and because the methods of measurement have changed so much over time (from local thermometer readings to global satellite observations).

Although controversy over these issues will not disappear any time soon, the magnitude of predicted changes in the twenty-first century from a variety of climate models—1.1 to 6.4°C temperature increases, major shifts in precipitation belts, melting of sea ice and glaciers that could lead to sea level rise of 1.5–6.5 feet, and increased storm intensities, among others—are so great as to make policy changes imperative, even in the absence of absolute certainty.

Potential Solutions

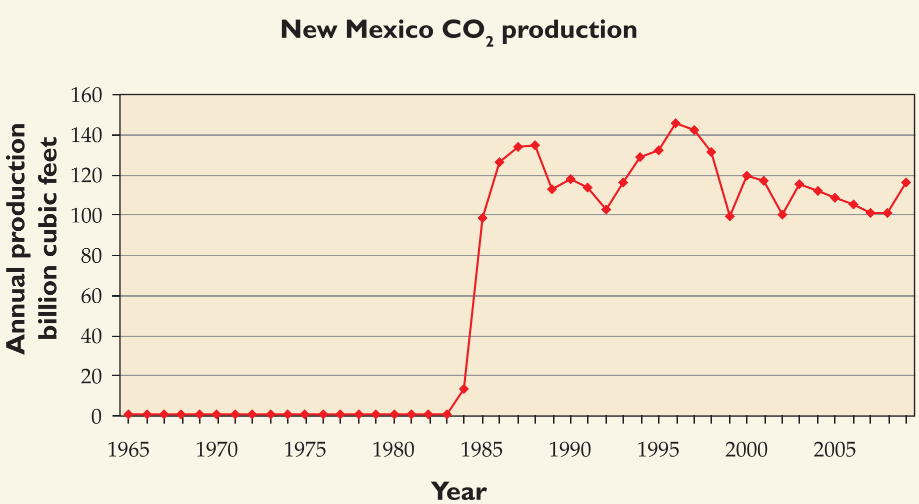
So how do we change, or even reverse, the trajectory of atmospheric CO_2 increase? There is no single solution, but clearly the first steps must include reduced production of CO_2 through increased efficiency and reduced use of CO_2-generating processes. These include increased thermal efficiency in homes and office buildings, increased motor vehicle fuel-economy standards, improvements in mass transportation, reduced deforestation, and a shift to energy generation from sources that do not produce CO_2 (wind, solar, geothermal, hydro, or nuclear). These actions can actually save us money in the long run, and will take us part way to the goal of emissions reductions. Alone, however, they will not even get us close to a goal of zero increase in future atmospheric CO_2 levels (and certainly not to the even more difficult, but possibly necessary, target of lowering CO_2 levels to 350 ppm), especially in the face of growing world populations and rising worldwide standards of living.

Several other methods of CO_2 reduction are also feasible, and all involve some form of carbon sequestration—tying up carbon in a form other than atmospheric CO_2. Reversing deforestation by planting more trees (bio-sequestration) is commonly proposed, but is difficult to achieve at needed scale in light of a growing world population with ever expanding needs for land. Sequestration of CO_2 in the oceans has been proposed as another alternative, especially because about a quarter of anthropogenic CO_2 is already taken up by ocean water. It would be possible to pump additional CO_2 into seawater and allow it to circulate through the deep oceans for a thousand years or more. Unfortunately the oceans are already becoming more acidic via natural uptake of atmospheric CO_2, and acidification would be accelerated by artificial CO_2 storage in seawater. Increasingly acidic ocean waters adversely impact the shells of marine organisms and may be contributing to the decline of coral reefs. Mineral sequestration, a process where CO_2 is reacted with other chemicals to produce solid and stable mineral precipitates such as calcium carbonate or calcium silicates, may be feasible.

The real problem is where to put all the precipitated materials. Although few large-scale tests have been conducted, two methods hold promise. Precipitation of minerals in situ underground in basalts or other highly porous or fractured rocks may be possible in some areas. In addition, surface precipitation of materials that have potential widespread use, such as cement or limestone for building material, may also be a viable option.

Carbon Capture and Storage

Another concept—concentrating CO_2 from major point sources of generation such as electric power plants (carbon capture) coupled with injection of the CO_2 deep underground (carbon storage or sequestration)—is the focus of much current research and testing. Carbon capture currently is the more difficult and less tested part of the combined process. Existing coal-fired power plants have about 10–15 percent CO_2 by volume in their smoke-stack emissions. Concentration of the CO_2 to nearly pure form and compressing it for pipeline transport and underground injection is both difficult and expensive, consuming roughly a third of the power generated by the plant and raising the cost of produced electricity by about that same factor. U.S. Department of Energy (DOE) research programs have demonstrated that newly constructed coal-fired power stations can reduce capture costs substantially by using pre-combustion and oxy-combustion capture systems. Such systems probably will be incorporated into most or all new coal-fired power plants, and oxy-combustion along with new post-combustion CO_2 capture methodologies may also be applied to existing plants to enable more efficient carbon capture.



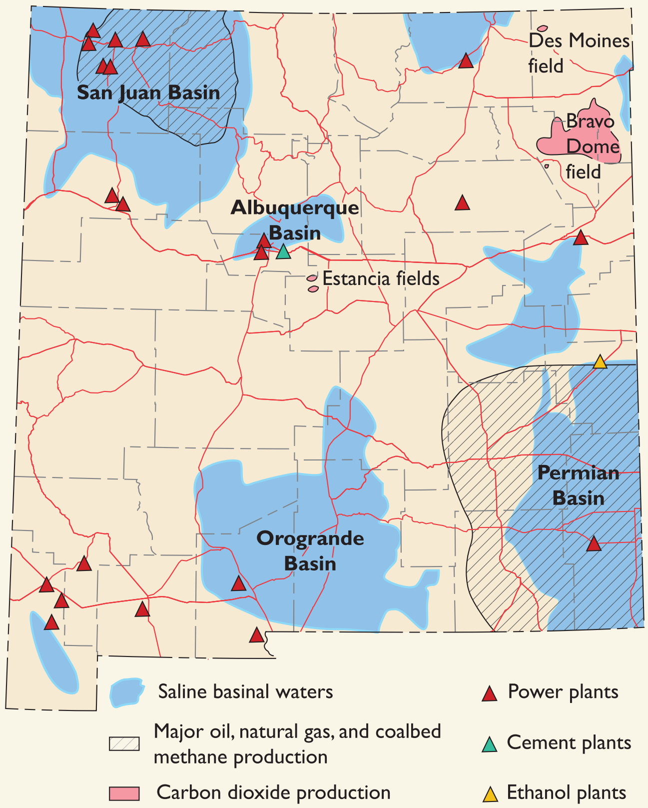
Annual production of CO_2 in New Mexico from 1965 to 2010. The dramatic increase in production in the mid-1980s was due to the increased demand for CO_2 for enhanced oil recovery, mainly in west Texas.

The second half of the process, geologic carbon sequestration, is already a more proven technology. The process involves pressurizing the CO_2 and injecting it into porous subsurface rocks, typically at depths of at least 2,500 feet below the land surface. The same pore spaces in those rocks that normally hold water, oil, or gas, then become filled with CO_2 in the form of a high-pressure super-critical liquid. Such injection can take one of two forms: economically profitable use of injection to enhance recovery of oil and natural gas or injection purely to sequester CO_2 with no ancillary economic benefit.

The petroleum industry has used CO_2 injection for 35 years to drive enhanced oil recovery (EOR) in many parts of the world. Currently more than 13,000 wells in the U.S. alone receive CO_2 for EOR according to the American Petroleum Institute, and more recently CO_2 injection also has been applied to enhancing coalbed methane production. The first commercial EOR project using CO_2 injection began in the SACROC unit of the Kelly–Snyder oil field of west Texas in 1972, a project that continues to this day. The original source of CO_2 for that EOR project came as a byproduct of ammonia production in Val Verde; subsequently, New Mexico has supplied much of the CO_2 by directly producing and pipelining it from the Bravo Dome field. In west Texas, CO_2 injection has added about 10 percent to the total oil production of the SACROC unit, and according to the DOE, CO_2 injection has the potential to boost U.S. conventional oil production by 89 billion barrels and unconventional oil recovery by an additional 341 billion barrels.

Beneficial geologic sequestration is limited to known oil fields that have potential for increased or revived production. Far more storage volume is needed, however, if geologic sequestration is to have a real impact on reducing atmospheric CO_2 levels. Unmineable coal beds offer attractive sites for additional sequestration because CO_2 is bound onto the coal surface, assuring long-term retention of the gas. But these are relatively rare. The most volumetrically important sites for proposed sequestration are deep, saline aquifers. These are large, occupy many deep basins, have little prospect of being used in the near future for water supplies, and in some cases have already been used for chemical waste disposal.

Several projects have shown the feasibility of CO_2 sequestration in deep saline basins. Statoil and its partners are currently sequestering about a million tons of CO_2 per year that is recovered as a byproduct of oil production at Sleipner field in the North Sea. By reinjecting that CO_2 into saline formations well below the oil field, the partners are minimizing the CO_2 taxes that would otherwise be paid to the Norwegian government. So this project, which has been operating since 1996, is an example not only of the feasibility of relatively long-term CO_2 injection into saline reservoirs, but also highlights the influence of government policies on such projects.



Major point sources of CO_2 (power plants, cement plants, and ethanol plants), and potential reservoirs for CO_2 sequestration in New Mexico. The Bravo Dome field is the only major natural subsurface accumulation of CO_2 in New Mexico and is the only one currently productive.

New Mexico Area Activity

Closer to home, the Southwest Regional Partnership, one of seven DOE-funded regional carbon sequestration consortia, will evaluate the CO_2 sequestration potential within the southwestern United States (Arizona, Colorado, Kansas, Nevada, New Mexico, Oklahoma, Texas, Utah, and Wyoming). The Southwest Regional Partnership is using three pilot tests to assess the feasibility of geologic CO_2 sequestration within depleted oil reservoirs and unmineable coal seams and will soon be testing commercial-scale CO_2 injection into a saline aquifer. Each pilot study is designed to validate the most promising carbon sequestration technology and infrastructure concepts, with the idea that knowledge obtained from these pilot operations can be used as a framework for larger-scale operations. The pilot injection sites are the SACROC unit in the Permian Basin of Texas, the Aneth oil field in the Paradox Basin of Utah, and Pump Canyon in the San Juan Basin of New Mexico. Both SACROC and Aneth are using CO_2 primarily for EOR operations, whereas the San Juan Basin is using CO_2 for enhanced coalbed methane (ECBM) recovery.

The pilot test in the San Juan Basin recently concluded with the injection of approximately 18,400 tons of CO_2 into the coal-bearing Fruitland Formation. Although that amount of injected CO_2 is considered minimal, the San Juan Basin test proved the efficacy of a suite of monitoring approaches tailored for its unique geology (e.g., increased geodetic surveys to assess swelling of coal beds) and value-added benefit (methane production). The San Juan Basin is exceptionally well positioned for potential CO_2 sequestration opportunities due to the region's: 1) favorable geology and high methane-content coal beds (ECBM operations), 2) many coal-burning power plants with abundant CO_2 output, 3) relatively low capital and operating costs, 4) existing natural gas and CO_2 pipeline systems, and 5) industrial expertise in coalbed methane recovery.

The lack of railroad infrastructure in the San Juan Basin means that the hundreds of millions of dollars worth of coal mined there annually must be burned locally, and sequestration must be local to be cost competitive. Fortunately, the geology of the San Juan Basin includes several potential sequestration targets, including the Fruitland Formation (coal) and many "stacked" saline aquifers (primarily high-permeability sandstones). It also provides thick seal units (massive, low-permeability shales). Potential saline aquifers amenable to CO_2 sequestration include the Dakota, Morrison, and Entrada sandstones. Conservative estimates of the capacity of the Fruitland Formation exceed 70 million tons of CO_2, whereas the cumulative capacity of the Dakota, Morrison, and Entrada aquifers exceeds 6.3 billion tons of CO_2. Elsewhere in New Mexico, geologic formations within the Permian

Natural Reservoirs of CO_2 in New Mexico

CO_2 is a common constituent of subsurface natural gases but usually occurs only in minor amounts. Natural gases that are almost pure CO_2 (greater than 99 percent) are relatively rare in nature but have been produced from four fields in New Mexico. The Bravo Dome field is the only major accumulation and is the only one currently productive. Before the 1980s, the CO_2 produced from these fields was mostly converted to dry ice for use as a refrigerant or was converted to bottled, liquid CO_2 that was used for such things as carbonation of drinks or in fire extinguishers. During the early 1980s, a new use for CO_2 emerged: enhanced recovery of oil that would otherwise remain stranded underground within the rock reservoirs of mature oil fields. As a result, the Bravo Dome field, which was discovered in 1916, was rapidly explored, drilled, and developed, resulting in major production increases. The CO_2 now is produced from more than 400 wells that penetrate the Permian-age Tubb sandstone at an average depth of 2,200 feet. The CO_2 is then transported via underground pipeline to the oil fields of southeastern New Mexico and west Texas. During 2009, 116 billion cubic feet of CO_2 gas worth $117 million was produced from the Bravo Dome field. This brought in taxes of $5.9 million and royalties of $3.4 million, with value added through employment generated by exploration, production, and processing as well as revenues and employment associated with enhanced oil production in southeastern New Mexico. So while the world is wrestling with the problem of CO_2 emissions reduction, its production remains of significant economic benefit for this state.

—Ron Broadhead

Basin, Estancia Basin, Sierra Grande uplift, and Orogrande Basin, among others, yield a total potential CO_2 sequestration capacity of an estimated 33–132 billion tons.

Caveats and Conclusions

Although geologic sequestration may become a future necessity, there are major concerns related to expense, safety, and adequate regulation. The added costs of carbon capture, pipeline transport to sequestration sites, and pressurization and injection all will add to the price of electricity. So large-scale carbon capture and storage will only happen if taxes on carbon emissions exceed costs for sequestering the carbon or if sequestration costs are passed on directly to the end user. Cap and trade programs are specifically designed to allow industries that can inexpensively sequester carbon to do so and then sell carbon rights to others for whom sequestration would be prohibitively expensive. Thus the long-term viability of the important coal and coal-power generating industries in New Mexico is very much related to the state's potential for carbon sequestration, and to how carbon emissions are taxed in the future.

Safety is a major concern when handling substances under high pressure. More than 3,500 miles of high-pressure CO_2 pipelines are currently operating in the U.S., including the line from Bravo Dome to the Permian Basin of southeastern New Mexico and west Texas, so we have demonstrated technological expertise to conduct such operations safely. But injection of huge volumes of CO_2 into basins with many old and poorly plugged wells or basins with incomplete geologic knowledge will provide new challenges.

Many unanswered or partially answered questions surround the future of geologic sequestration of CO_2. Who will regulate such storage operations, and will they do a better job than oil regulators in the offshore Gulf Coast? Who actually owns subsurface pore space, and how will carbon sequestration rights interface with water rights, mineral rights, and surface rights? How will the safety of injection operations be monitored? If sequestration operations are publically subsidized (either directly or through higher energy costs) in order to offset carbon input to the atmosphere, who will actually certify that the injected CO_2 is adequately sequestered and is not leaking directly back into the atmosphere? How will state and national governments deal with climate change in general and

CO_2 injection header at the Aneth Enhanced Oil Recovery project in Utah. Each one of the valves controls the injection to an individual well. Photo courtesy of Resolute Energy.

carbon emissions specifically (no action, carbon taxes, cap and trade programs, sequestration incentives, or other policies)? At this point, the high potential for carbon sequestration to serve as one of the many avenues that we may need to pursue to deal with climate change issues at the very least warrants further attention.

—Peter A. Scholle and Richard Esser

Peter Scholle is state geologist and director of the New Mexico Bureau of Geology and Mineral Resources. His varied career has included 9 years with the U.S. Geological Survey, 17 years of university teaching, 10 years at the New Mexico Bureau of Geology and Mineral Resources, and many years of working with or consulting in the oil and gas industry.

Richard Esser graduated from New Mexico Tech in 1996 with a Masters Degree in Geochemistry and began working in the Argon Geochronology Lab at the New Mexico Bureau of Geology. In 2007 Richard moved to Utah to work on CO_2 sequestration-related issues at the University of Utah in conjunction with the Southwest Carbon Partnership.

Ron Broadhead is a principal senior petroleum geologist with the New Mexico Bureau of Geology and Mineral Resources in Socorro, where he has worked for nearly 30 years. Most recently he has been involved in oil and gas resource assessments of the Tucumcari Basin, the Permian Basin, and Colfax and Mora Counties.

For More Information

Two Web sites in particular provide good places to start for more information on carbon sequestration. The National Energy Technology Laboratory of the U.S. Department of Energy has a site that includes a Carbon Sequestration Atlas for the United States and Canada. Visit them at: http://www.netl.doe.gov/technologies/carbon_seq/natcarb/index.html

The Southwest Carbon Partnership also offers a wealth of information on their Web site, including sections on the different kinds of carbon sequestration, climate change, monitoring and mitigation, and the regulatory framework (as well as a page devoted to kids, parents, and teachers). Visit them at: www.southwestcarbonpartnership.org

CO_2 Sequestration Courses at New Mexico Tech

The Earth and Environmental Science Department at New Mexico Tech (ees.nmt.edu) is offering courses in the science of geological CO2 sequestration at many academic levels. The courses are offered in conjunction with the DOE-funded Education and Training Center of the Southwest Partnership for CO2 Sequestration. This integrated training program includes instruction for high school students, K–12 teachers, undergraduates, and graduate students. Relevant New Mexico Tech course offerings planned for the 2010–2011 academic year include:

Fall 2010
GEOL 571-1—Climate and Carbon Sequestration (3 credits)

Spring 2011
ERTH 491—Geological CO2 Sequestration Science (3 credits)

Summer 2011
ST 189—Master of Science Teaching: Climate and Carbon Sequestration (2 credits)

High school mini-course: Geology of CO2 Sequestration.

For more information visit ees.nmt.edu/Geol/classes/Carbon or contact Drs. Andrew Campbell (campbell@nmt.edu), Peter Mozley (mozley@nmt.edu), or Bruce Harrison (bruce@nmt.edu).

Bureau News

National Geothermal Data System

The U.S. Department of Energy has funded a National Geothermal Data System project through the Association of American State Geologists. The 3-year project, which will begin in October of this year, will involve 47 states, including New Mexico. The goal is to create a national data base on geothermal data for the entire U.S., gathering existing data from a wide variety of sources and making it available in a uniform format in a single database. Data gathered will include a variety of well data, including bottom hole temperature and information on porosity and permeability, which should be of use in identifying and developing new geothermal energy resources. Interim products will include maps of active Quaternary faults, and young (less than 5 million years old) volcanic centers. Staff from the New Mexico Bureau of Geology and Mineral Resources will be involved in the project, which is being managed by the Arizona Geological Survey. The entire project was funded in the amount of $18 million through the American Recovery and Reinvestment Act.

Healy Foundation

This year the New Mexico Bureau of Geology and Mineral Resources received a gift of $50,000 from the Healy Foundation of Taos, New Mexico, in support of our Aquifer Mapping program.

Award from the Johnson Space Center

A team of scientists at the New Mexico Bureau of Geology & Mineral Resources recently won the annual Johnson Space Center Director's Innovation Team Award from NASA, thanks to a training program for international astronaut candidates. The award was based on an ongoing hydrogeology study conducted by geoscientists from the bureau. This annual award recognizes those who have developed or implemented positive changes in the operations or programs of NASA or the Johnson Space Center. The award was presented at the annual Honor Awards Ceremony in May 2010 at Johnson Space Center in Houston, Texas. Dr. Paul Bauer, principal geologist and associate director at Bureau of Geology, attended the ceremony. Since 1999 Dr. Bauer has worked with NASA on training astronaut candidates in applied techniques of planetary exploration. The team has provided geophysical training exercises to all of the 76 astronauts who have joined NASA since 1998. The 14 members of the astronaut candidate class of 2009 are participating in the training exercise later this summer near Taos. This is the second award the Bureau of Geology team has received for contributing to NASA's human exploration program. In 2000 the bureau received NASA's Johnson Space Center Group Achievement Award.

Carbon Capture and Storage Studies

The New Mexico Bureau of Geology and Mineral Resources has just received notice of DOE and USGS funding for carbon capture and storage studies involving refined estimates of overall storage capacity and site selection for potential carbon sequestration projects.

Rockin' Around New Mexico

The New Mexico Bureau of Geology and Mineral Resources conducted their annual teacher's workshop, "Rockin' Around New Mexico," on July 7–9, 2010. Thirty-one teachers, representing grades K–12 from across the state, participated in the workshop, which was based this year in Socorro. Many of the attendees were from New Mexico Tech's Masters of Science in Teaching (MST) program. Topics included the geology of local seismic features related to the Rio Grande rift; sedimentology, stratigraphy and paleontology of the Socorro area; and seismic hazards in New Mexico, along with discussions on safety and survival for schools. Teachers were treated to field trips to the Quebradas Back Country Byway and Carthage (southeast of Socorro), where participants learned mapping techniques on a faulted sedimentary outcrop and hunted for fossils. Classroom time included presentations on CO_2 sequestration, abandoned mine safety, and New Mexico energy resources. The workshop involved guest speakers from New Mexico Tech, IRIS/PASSCAL, Etscorn Observatory, PRRC, and the New Mexico Department of Homeland Security and Emergency Management. For information on the 2011 workshop, contact Susie Welch at susie@nmt.edu.

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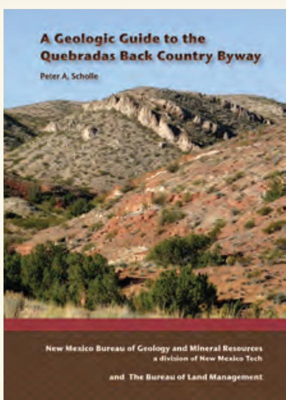
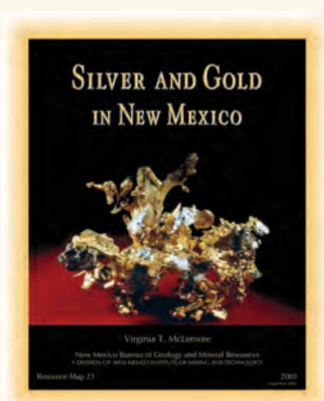


A Geologic Guide to the Quebradas Back Country Byway

by Peter A. Scholle, 24 pp. Free. Available mid-September.

This fall the New Mexico Bureau of Geology and Mineral Resources will release a new, revised, print version of this popular online field guide, which has to date been available only in electronic format on our Web site at http://geoinfo.nmt.edu/publications/fieldguides/quebradas/home.html. Produced in cooperation with the Bureau of Land Management (BLM), the new edition has been edited for a more general audience and is keyed to ten numbered stops along the 24-mile-long byway, which runs from just north of Socorro to just east of San Antonio, on the east side of the Rio Grande in Socorro County. The Quebradas Back Country Byway, which is managed by the BLM (Socorro Field Office) is dirt; a high clearance or 4-wheel-drive vehicle is recommended. Multiple copies for distribution will be handled through the BLM Socorro Field Office (575-835-0412); single copies are available through that office or through the Publication Sales Office at the New Mexico Bureau of Geology and Mineral Resources. For more information on the byway itself, call the BLM Socorro Field Office directly at 575-835-0412.



Silver and Gold in New Mexico

by Virginia T. McLemore, 60 pages, 1 oversize map (1:1,000,000), Resource Map 21, ISBN 1-883905-10-9. $14.95 plus $5.50 shipping and handling and taxes where applicable.

This popular resource map, first issued in 2001, is back in print. The accompanying 60-page text is an exhaustive compilation of information on 163 mining districts and other locations in New Mexico with reported production of silver and gold or with reported silver and gold "occurrences," concentrations 200 times crustal abundance. Since the first mining claim (recognized by historians) was filed in New Mexico in 1685, the lure of mineral wealth has continued to draw would-be prospectors to our state's mountains and rivers in search of Earth's precious resources. From 1848, the year the Treaty of Guadalupe Hidalgo ended the Mexican–American War and ceded New Mexico to the United States, through 2000, almost 3.2 million ounces of gold and 117 million ounces of silver have been produced in New Mexico. This second printing of Resource Map 21 includes those production figures available through 2000. No new data have been added.

For more information about these and other bureau publications:

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