# New Mexico EARTH MATTERS

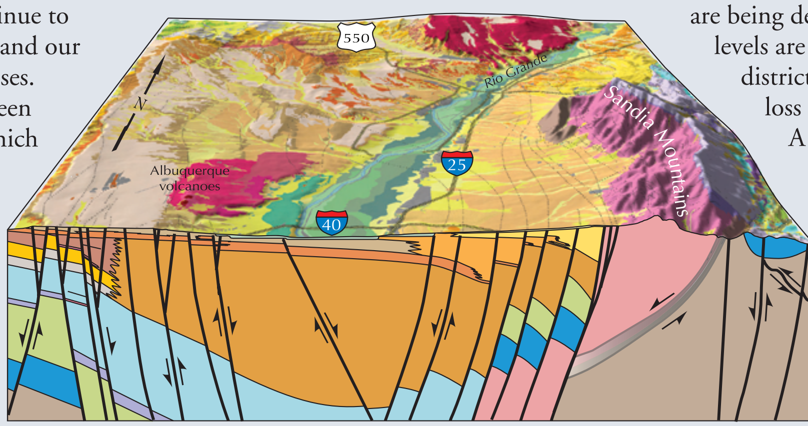
Winter 2008

## GEOLOGIC MAPPING: MEETING NEW MEXICO'S NEEDS IN THE 21ST CENTURY

Some of the most pressing challenges facing New Mexico stem from the rapid growth of our population and the increasing competition for our natural resources. Scientists have long sought to understand these issues and provide the critical data that planners and policy makers need. In the earth sciences, we continue to improve both our techniques and our understanding of earth processes. Geologic mapping has long been one of the primary ways in which we go about our business, and it is one of the critical tools we use to help others understand the geologic framework of our state.

Geologic maps are much admired by those who are fascinated by the art of graphic display. They are essentially the two-dimensional representation of complex three-dimensional relationships, including the distribution of different rock types and structures (like faults and folds). They provide at least a cursory understanding of the subsurface, as well. Drawing largely on field data but with help from the laboratory and remote sensing techniques, such maps have allowed for an understanding not only of the earth as we know it but of the processes and geologic history responsible for its formation. At their most basic, they are streamlined representations of complex information about the physical world we inhabit; at their best, they are endlessly fascinating works of art, whose successful interpretation serves a broad audience of users.

With the development of advanced mapping techniques, more powerful computers and software packages, more sophisticated laboratory analyses, and our growing understanding of geologic processes, geologic maps have reached new heights of sophistication and usefulness. Still relying heavily on skilled field work, we now have the ability to produce maps that convey more information than ever, and in ways that are more exciting and accessible. These new sophisticated approaches to geologic mapping have allowed us not only to produce new and better maps of New Mexico (detailed geologic maps have to date been produced for less than a third of the state), but to return to those areas that have been mapped with an eye toward extracting additional data. All of this effort can now be directed at problems that either didn't exist or were poorly understood when earlier maps were produced.




*Oblique view of the Albuquerque metropolitan area, with the geologic map draped over a 3D digital elevation model. The 1.4-billion-year-old Sandia granite is shown in pink to the east, and the 140,000-year-old Albuquerque volcanoes are shown in red to the west. The Rio Grande corridor and its associated deposits are shown in green. From an interpretation of these data, geologists can create geologic cross sections like the one shown here, which provide a vertical slice through the crust. An understanding of the distribution of rocks both on the surface and in the subsurface is critical to understanding the local and regional geology.*

### Applied Geologic Mapping and the Aquifer Mapping Program

The management and protection of our water resources remain top priorities for New Mexico. In many parts of the state, regional aquifers and surface waters are being depleted, local ground water levels are declining, and agricultural districts are finding themselves at a loss for adequate irrigation water. A detailed understanding of the geologic and hydrologic framework of our aquifers can and should form the basis for sound water policy and regulation, to ensure that future generations of New Mexicans have access to this critical natural resource.

For the past ten years, the bureau has been engaged in hydrogeologic studies of New Mexico's aquifers, in cooperation with the state's Office of the State Engineer and the Environment Department. The Aquifer Mapping Program is the synthesis of our ongoing geologic mapping program with geophysical, hydrologic, chemical, field, and laboratory analyses to characterize the quantity, quality, and sustainability of ground water resources. The objective is to provide critical information on the state's ground water resources. Baseline data gathered during the studies improve our understanding of the geologic framework of aquifers, their hydrologic characteristics, water levels in the aquifers and how they change over time, and the level of natural contaminants such as arsenic and uranium that affect the quality

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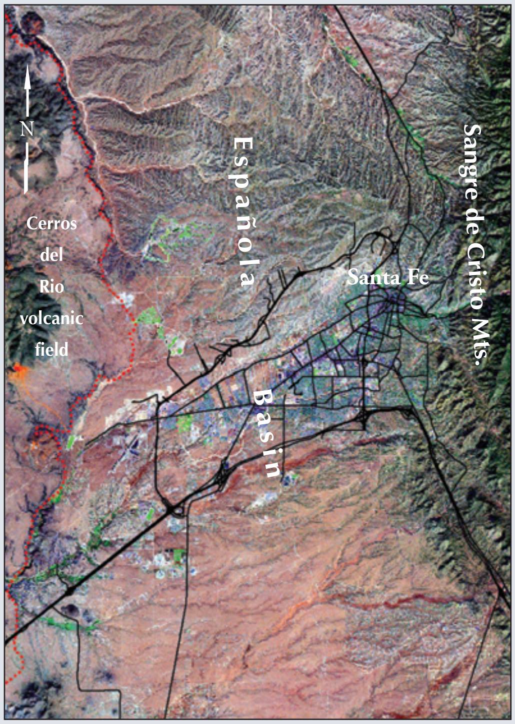



*Figure 1—Satellite image of the Santa Fe area, including a portion of the Española Basin. The Sangre de Cristo Mountains are to the east and the Cerros del Rio volcanic field to the west. The higher resolution satellite and digital orthophoto imagery now available allows researchers to map the distribution of drainage patterns and identify structural lineaments that may be difficult to see in the field.*

of ground water. The synergy between geologic mapping and aquifer mapping provides invaluable information on the distribution, movement, quality, and quantity of our ground water resources.

The series of figures shown here illustrates how geologic maps can be related to other data sets to provide a better understanding of local geology and hydrology. Figure 1 is a satellite and digital air photo image of the Santa Fe area with the Sangre de Cristo Mountains to the east and the Cerros del Rio volcanic field to the west. The city of Santa Fe lies within the Española Basin. The higher resolution satellite imagery now available allows researchers to map the distribution of drainage patterns and identify structural lineaments that may be difficult to see in the field.

Figure 2 shows the geologic map for the same area. Much of the Española Basin here is composed of sand and gravel, detritus shed from the Sangre de Cristo Mountains mixed with deposits of the Rio Grande. Faults (shown in red) are found throughout the basin but tend to be concentrated in networks. These faults are enormously important to the hydrology of the basin, as faults may facilitate the movement of ground water, or they may form barriers to ground water flow. The Cerros del Rio volcanic deposits mostly cover and interfinger with basin fill material, but mapping their distribution is important, as well; such deposits may be the source of naturally occurring contaminants like arsenic.

The aeromagnetic anomaly map in Figure 3 shows the composite magnetic signature of earth materials. These data are gathered by aircraft equipped with sensitive instruments that measure the magnetic properties of earth materials. The colors indicate the polarity of the material in the map area; the shading integrates the relative intensities of the magnetic signals preserved in the rocks. Basement metamorphic rocks on the east and volcanic rocks on the west contain abundant magnetic minerals and thus are shown with high "relief." This type of data is useful for mineral resource evaluation in other parts of the state. Here in this part of the state they are more useful in locating faults. The Española Basin is composed of material largely derived from the metamorphic and igneous highlands of the Sangre de Cristo Mountains, but in reworked sedimentary material, the polarities are randomly arrayed, and the magnetic intensity is weak. Nevertheless, some features are still visible and may prove useful for solving geologic problems. In the southern Española Basin, where the basin fill material is relatively thin, the magnetic signal of the underlying bedrock is still visible, and within the bedrock many faults are visible (bottom center of map). Some of these linear features can be traced south of the map area to exposed faults. They may be significant for the local hydrology, and they help us better understand the underlying structural floor of the basin. In the northern part of the map area, the picture is much more subdued, but some features are readily recognizable, including faint traces of linear features that are interpreted to be faults within the basin. Some have a surface expression; others may be poorly exposed or covered by younger deposits. By locating these structures geologists can better understand the history of faulting in the basin, and hydrogeologists can evaluate the relative influence these faults have on the local and regional aquifer, including aquifer compartmentalization or changes in hydrologic gradient.

However we arrive at it, this understanding of surface geology and subsurface structure helps hydrogeologists more accurately interpret regional and local ground water flow. Figure 4 is a contour map of the regional water table, showing the elevation of the ground water surface. It clearly shows the general westward gradient of the water table in the Española Basin, which ranges from 7,300 to 6,000 feet in elevation, and the direction of ground water flow. The shades of blue indicate the depth to the ground water table; deeper blue colors indicate areas where the ground water is buried deeper than lighter blue areas. The green areas indicate places where the water table intersects the ground surface, places where wetlands are sometimes found. The closed contours within the city of Santa Fe show the effects of drawdown as a result of pumping by city water wells. In the center of the map, the contours are closely spaced, indicating a steeper hydrologic gradient that corresponds to the mapped faults shown in Figure 2.

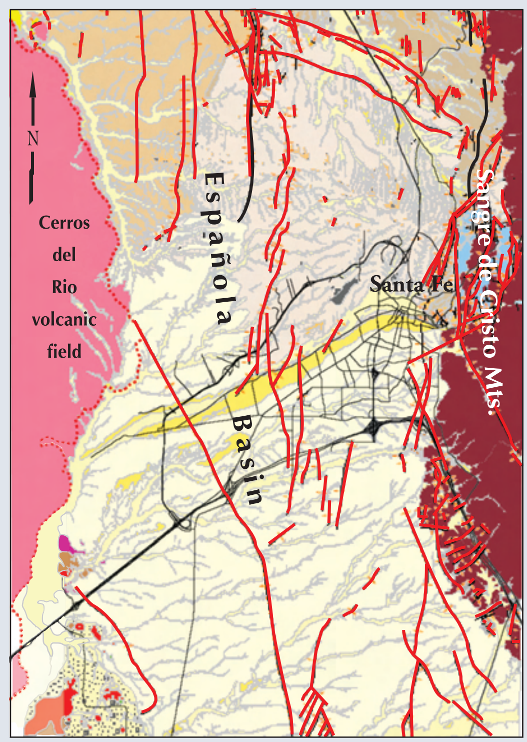



*Figure 2— Geologic map of same portion of the Sante Fe region shown in Figure 1. Much of the Española Basin here is composed of sand and gravel from the Sangre de Cristo Mountains, mixed with deposits of the Rio Grande. Faults (shown in red) are found throughout the basin but tend to be concentrated in networks. These faults are enormously important to the hydrology of the basin, as they may facilitate the movement of ground water, or they may form barriers to ground water flow. The Cerros del Rio volcanic deposits on the west are shown in pink.*

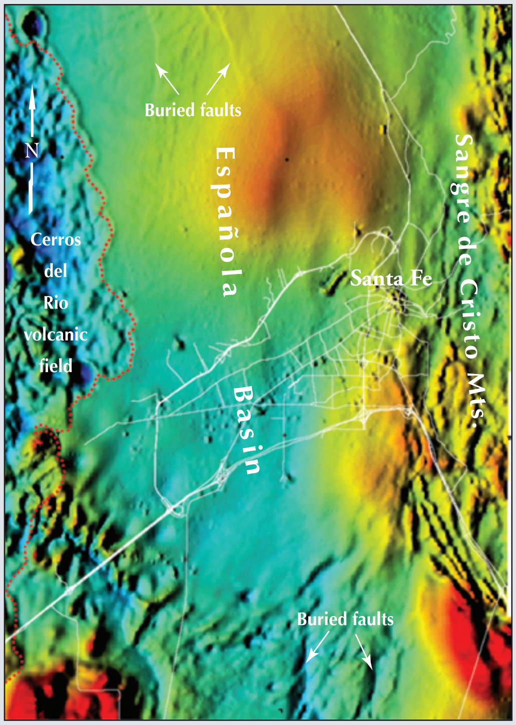



*Figure 3—This aeromagnetic anomaly map shows the composite magnetic signature of earth materials in the region. The colors indicate the polarity of the material in the map area; the shading integrates the relative intensities of the magnetic signals preserved in the rocks. Basement metamorphic rocks on the east (in the Sangre de Cristo Mountains) and volcanic rocks on the west (in the Cerros del Rio volcanic field) contain abundant magnetic minerals and thus are shown with high "relief." Magnetic intensities are weak in the reworked sedimentary material in the basin itself, but some features, including buried faults, are still visible. Data courtesy of U.S. Geological Survey.*

Finally, a better understanding of the surface geology and the subsurface structure offers important insight into the geochemistry of our aquifers. Here again, by examining the geologic mapping and detailed descriptions of rocks within the basin, both at the surface and in well cuttings, a correlation can be made between naturally occurring contaminants in the aquifer and the local geology. Figure 5 shows a contour map of arsenic concentration in ground water. These data show that arsenic concentration is not equally distributed in the basin; some areas have elevated concentrations. Detailed descriptions of rock units in the subsurface (shown in the stratigraphic column to the right) show that basin fill material of the Tesuque Formation overlies a series of volcanic rocks that may be the source of elevated arsenic concentrations. This also suggests that overprinting the general westward movement of ground water shown in Figure 4 is an upwelling of deeper water, perhaps along buried faults, that contains higher concentrations of arsenic derived from buried volcanic rocks.

This series of five maps represents detailed mapping techniques that may not have been available to us in the past. These maps provide important data that allow researchers, policymakers, and planners to better understand the geologic and hydrologic framework of the Española Basin. Concurrent geologic mapping and aquifer assessment is going on in a number of other areas in New Mexico, including Albuquerque, Santa Fe, Taos, and the Sacramento Mountains. Where these studies have been conducted, our understanding of the aquifer resources and controls on their distribution has greatly improved.

## Geologic Hazards

Population centers are increasingly at risk of damage due to geologic hazards. Floods, hydrocompactive soils, sinkhole collapse, earthquakes, erosion, rock falls, debris flows, and landslides are all hazards of which New Mexico residents and planners need to be aware, in order to minimize costly damage and the potential loss of life. Across the entire state, these natural hazards impact local communities to varying degrees depending largely on the geology. Many geologic events—earthquakes, floods, debris flows, and landslides—leave some record of their occurrence. Faults are the record of past earthquakes. Detailed geologic maps can help us decipher this record and gain an understanding of the frequency and ages of these events.

## The Costs and Benefits of Geologic Mapping

Geologic mapping requires a relatively modest investment that delivers multiple benefits to the state and local communities. Mapping is labor intensive; geologists may spend as long as six months mapping a single 7.5-minute quadrangle (approximately 60 square miles). Of the 2,040 7.5-minute quadrangles in New Mexico, only 584 (less than a third) have been mapped in sufficient detail. Much of this time is spent in the field exploring the landscape and describing the distribution of rock types and structures that deform the formations. Field mappers must be experts in identifying and describing geologic formations and structures. Most important of all, geologists must be able to visualize the landscape and geology in three dimensions. Although the surface geology is the essential first step for understanding the composite geologic history of the area, most of the people who apply our maps to solving specific geologic problems are interested in the subsurface. Finally, a geologist must be able to synthesize multiple data sets including the surface geology, geophysical data (gravity and seismic surveys—similar to ultrasound imaging), geochemical data, and geochronology. The scale of our investigations is beyond the scope of most private consultants, who work on limited contracts to address very specific problems. The role of the state and federal geologic surveys is to tackle these larger scale geologic investigations, and to provide the baseline geologic data for subsequent research, often within the private sector.

## New Mexico's Geologic Mapping Program

For much of our 80-year history, the New Mexico Bureau of Geology and Mineral Resources has been producing

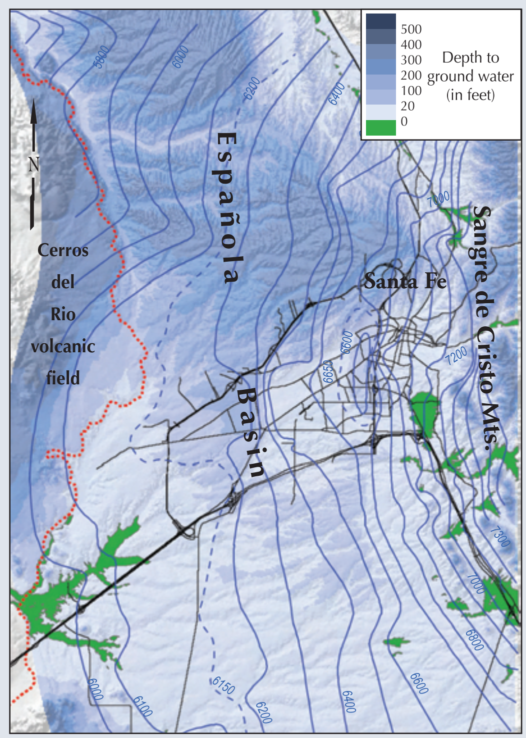



*Figure 4—Contour map of the regional water table in the vicinity of Santa Fe, showing the elevation of the ground water surface. The shades of blue indicate the depth to the ground water table; deeper blue colors indicate areas where the ground water is buried deeper than lighter blue areas. The green areas indicated places where the water table intersects the ground surface. Note that the depth to ground water is greater in the western portion of the Española Basin.*

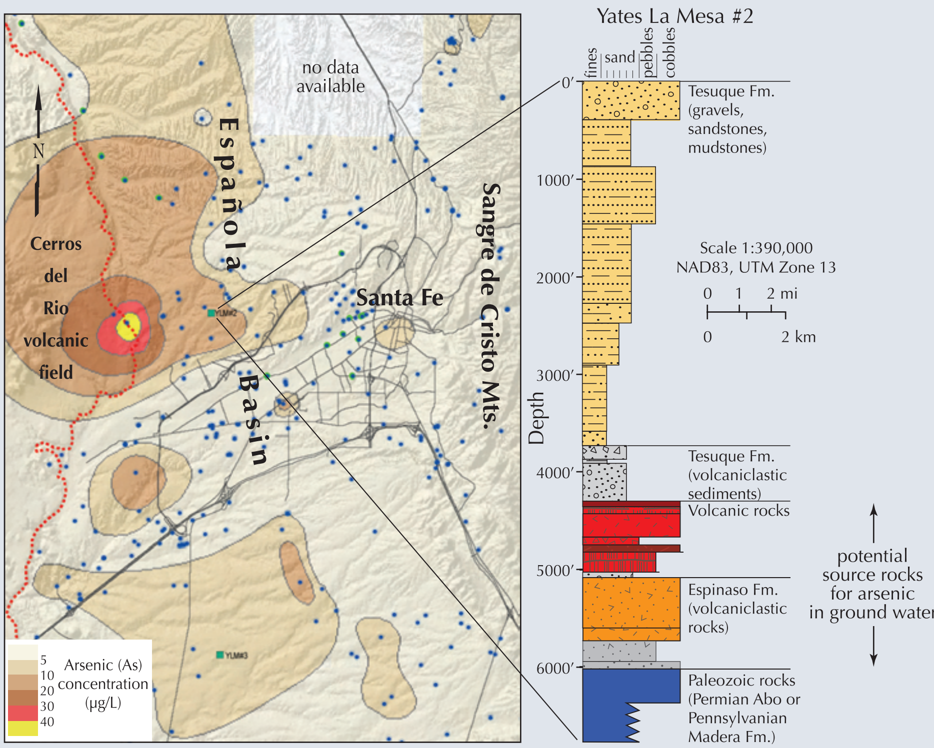



*Figure 5— Contour map of arsenic concentration in ground water. Arsenic concentrations are highest along the margin of the Cerros del Rio volcanic field. Detailed descriptions of rock units in the subsurface (shown in the stratigraphic column to the right) show that basin fill deposits of the Tesuque Formation, one of the major water-bearing units in the basin, overlie the volcanic rocks of the Cerros del Rio volcanic field, which may be the source of elevated arsenic concentrations.*

geologic maps to address many of New Mexico's natural resource needs. Early maps identified many of the mineral and other economic resources within the state, facilitating many years of economic expansion. But the reality is that many of New Mexico's limited mineral resources have already been cataloged. The primary use of modern geologic maps is to provide federal, state, and private entities with critical data related to resources (like water) that have become far more critical to New Mexicans. The mixed legacy of historic mining has forced both lawmakers and industry to recognize the impacts of mining on local communities and the environment. The goal of geologic mapping today in these areas is to understand and minimize these impacts. New Mexico's geologic mapping program provides the critical information we need to address the state's most pressing challenges. Many of our map products are now used by planners and regulators to better manage the resources we have, develop strategies for the wise development of these resources, and minimize the impact of continued resource development.

The geologic mapping program at the bureau works closely with the National Cooperative Geologic Mapping Program, a federal program, managed by the U.S. Geological Survey, with a mandate to fund geologic mapping by state geologic surveys throughout the U.S. Each year state geologic surveys submit competitive proposals, which must be matched dollar for dollar with state funds. Geologic mapping priorities within the state are set by a 42-member Advisory Committee composed of hydrologists, geologists, and planners from state, local, federal, tribal, and private agencies. The program is a cooperative effort involving our own geologists, university faculty and students, consultants, and the U.S. Geological Survey. We work closely with local communities and state agencies to provide geologic maps that are responsive to their needs.

The way in which we distribute our results has changed significantly, as well. With the advent and widespread use of GIS systems in all disciplines, we are now able to provide layers of digital geologic data that can be extracted, manipulated, and integrated with other kinds of data, including geographic, biologic, ecologic, and agricultural. An increasingly diverse group of users, from medical professionals to urban planners, desire the geologic data we offer, but they want it in a form that they can manipulate to suit their own needs. Finally, it is no longer feasible to display the complete array of information geologic mappers now collect in two dimensions, however elegantly we may try. The answer is to provide multidimensional layers of digital information that can be adapted by the users as they see fit.

These new mapping efforts mark a fundamental shift in emphasis. Our focus is on major population corridors; we generate these state-of-the-art maps more quickly and provide them to our end users digitally. In the fifteen years of the cooperative mapping program, we have produced as many maps as in the previous 65 years. This is due in part to the added federal dollars, and to advancements in digitizing and serving maps on the internet. The long-term goal is to continue to expand projects into areas in where modern geologic maps hold promise for solving problems, meeting new challenges related to New Mexico's growth and to the increasing competition for our very finite natural resources.

—J. Michael Timmons

*Dr. Timmons is the director of the geologic mapping program at the New Mexico Bureau of Geology and Mineral Resources. He is the senior author of a new geologic map of the eastern Grand Canyon, published in 2007 by Grand Canyon Association and available for sale through the bureau.*

Special thanks to the staff of the Aquifer Mapping Program, including Peggy Johnson, Brigitte Felix-Kludt, and Stacy Timmons, for many of the illustrations used in this article. Thanks also to Sean Connell, Dan Koning, David J. McCraw, and Adam Read on our staff, and V. J. S. (Tien) Grauch of the U.S. Geological Survey, for providing data and/or cartographic expertise.

# Bureau News

## Earth Science Achievement Awards

On January 25 the 2008 New Mexico Earth Science Achievement Awards were presented to Maxine Goad, for outstanding contributions advancing the role of earth science in areas of public service and public policy in New Mexico, and to Dr. Robert S. Bowman, for outstanding contributions advancing the role of earth science in areas of applied science and education in New Mexico. These awards, co-sponsored by the New Mexico Bureau of Geology and Mineral Resources, a division of New Mexico Tech in Socorro, and the Energy, Minerals and Natural Resources Department in Santa Fe, were initiated in 2003 and are given annually to honor those often unrecognized champions of earth science issues vital to the future of New Mexico.

Maxine Goad was instrumental in the development of the state's ground water protection program in the 1970s and was heavily involved in the oversight of uranium mining in the 1980s. In the early 1990s Maxine was involved in the development and negotiation of a mine reclamation act for New Mexico. Maxine is currently an "at large" member of the state's Water Quality Control Commission.

Rob Bowman is currently chair of the Department of Earth & Environmental Science at New Mexico Tech, where for the past twenty years he has taught hydrology and mentored over forty graduate students, many of whom are now working in industry, consulting, government, and academia. His primary research interests relate to the origin of dissolved materials in surface and ground water. His research has also focused on the development of practical and affordable methods for the removal of pollutants from ground water. Rob was pivotal in a statewide effort to improve estimates of evapotranspiration in the Rio Grande riparian corridor. Rob has served on the board of the Socorro Soil & Water Conservation District, and has overseen the development of the Socorro–Sierra Regional Water Plan.

The Earth Science Achievement Awards are given each January. Nominations for next year's awards are welcome from the general public and may be made directly to Peter Scholle, state geologist and director of the New Mexico Bureau of Geology and Mineral Resources.

## New Mexico Book Awards

*The High Plains of Northeastern New Mexico—A Guide to Geology and Culture*, one of the bureau's most popular publications, was the winner of the 2007 New Mexico Book Award in the travel category. Our 2005 Decision-Makers Field Guide on *Mining in New Mexico* was one of four finalists in the reference category. The 2007 winners were announced at the New Mexico Book Awards banquet, November 9, 2007, in Albuquerque. New Mexico. Authors Rudolfo Anaya and Tony Hillerman also were honored at the banquet with special Lifetime Achievement Awards.

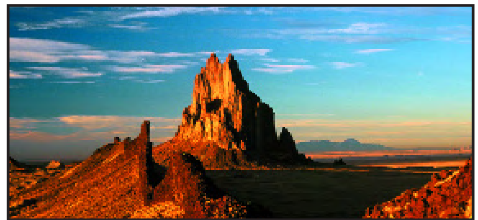
Organized by the New Mexico Book Co-op, the annual New Mexico Book Awards recognize the best in New Mexico books. This year's 359 entries, representing both small regional publishers and large publishing companies, were judged by a distinguished panel of scholars, booksellers, and librarians.

## New Hires

We welcomed several new staff persons to the bureau this past fall. Connie Apache is our new administrative services coordinator, working in the director's office. Frederick K. Partey joined our staff as an analytical geochemist and hydrologist. His primary responsibility will be in the bureau chemistry lab, but he will also be involved in aquifer characterization. In the front office we welcomed both Kitty Pokorny, the new manager of the publication sales office, and Barbara Gargotta, who joined us in January of this year.

## AGI President Elect

In October of this year Peter Scholle, state geologist and director of the New Mexico Bureau of Geology and Mineral Resources, will assume the presidency of the American Geological Institute (AGI). AGI is a nonprofit federation of 44 scientific and professional associations that represents more than 100,000 geologists, geophysicists, and other earth scientists. Founded in 1948, AGI provides information services to geoscientists, serves as a voice of shared interests in our profession, plays a major role in strengthening geoscience education, and strives to increase public awareness of the vital role the geosciences play in society's use of resources and interaction with the environment.



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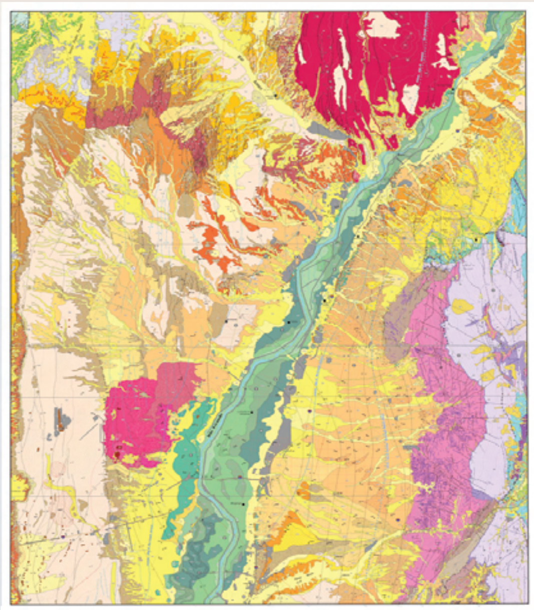
# Maps in Progress



Geologic map of the Albuquerque metropolitan area

For fifteen years the New Mexico Bureau of Geology and Mineral Resources has been engaged in an intensive cooperative mapping program with the federal government. Through that program, known as STATEMAP, we have provided new detailed geologic maps for over 150 quadrangles, at a scale of 1:24,000. Current mapping efforts are directed at critical areas throughout the state, including the lower Pecos River (Carlsbad, Artesia, Roswell, Fort Sumner); the Sacramento Mountains (Alamogordo, Ruidoso, Tularosa, Cloudcroft, and Capitan); the Las Vegas area; and the Grants uranium district and Mount Taylor. Many of the maps are available as open-file reports and may be downloaded free from the bureau's Web site.

Among the derivative products to come out of that program are several geologic map compilations currently in production, which will be made available as oversized, full-color printed sheets. The first of these, *Geologic Map of the Albuquerque–Rio Rancho Metropolitan Area and Vicinity*, will be available this summer. At a scale of 1:50,000, the two oversized sheets will provide a detailed geologic portrait of the Albuquerque metropolitan area, including detailed cross sections.

Also in progress is a geologic map compilation for the Valles caldera and the Jemez Mountains of northern New Mexico, including the Valles Caldera National Preserve. Incorporating new geochronologic data as well as detailed field maps that have been completed in the past eight years, this will be the first detailed map of the area since the U.S. Geological Survey published its map sheet of the region in 1970. We anticipate that this map will be available in 2009.

Other compilations in progress include maps of the southern Española Basin, the Ruidoso area, and the East Mountains region east of the Sandia Mountains. Preliminary versions of these maps and many others are available electronically as free downloads on our Web site as open-file reports or preliminary map sheets. Check out the following links for more detailed information:

geoinfo.nmt.edu/publications/maps/geologic/home.html

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Geologic map of the Valles caldera

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