New Mexico EARTH MATTERS

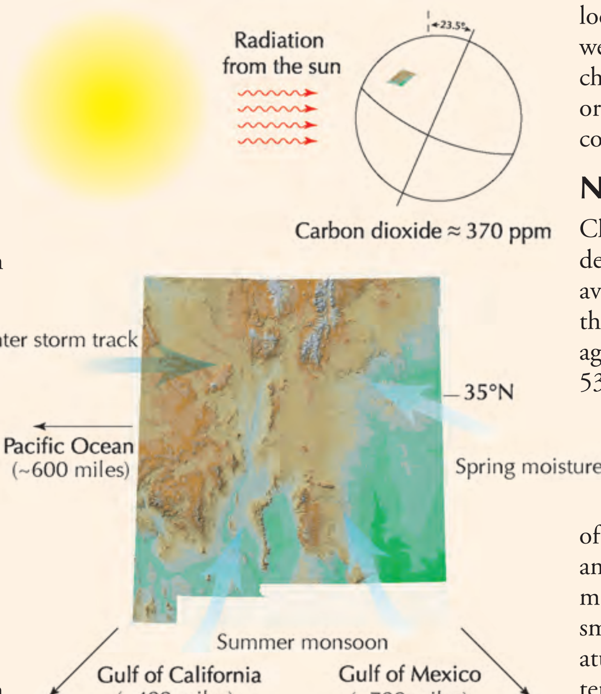
Summer 2004

NEW MEXICO'S CHANGING CLIMATE

The word climate refers to the long-term average and range of weather conditions (the hourly or daily fluctuation of temperature, precipitation, humidity, wind, etc.) that prevail at any given place. Although weather varies a great deal from place to place, the processes responsible for weather are the same. The atmospheric processes that cause an individual thunderstorm, for example, are fundamentally the same whether the storm occurs in New Mexico, Alabama, or Argentina, but the average frequency and seasonal variability of thunderstorms are quite different in each of those places. Climate is most often described in terms of temperature and precipitation.

Climate is determined by fixed or slowly varying factors called boundary conditions, which modulate weather. The primary factor is the intensity of sunlight, determined by the brightness of the sun, Earth's orbital geometry, and latitude. Locations in tropical latitudes receive a steady stream of high intensity sunlight yearround; polar latitudes actually receive slightly more sunlight than the tropics in summer, but no sunlight at all in winter. In addition to the sun's radiation, Earth's surface receives infrared radiation from the atmosphere above. The intensity of infrared radiation received at the surface is determined by cloud cover, humidity, and the atmospheric concentrations of infrared-absorbing trace gases (greenhouse gases such as carbon dioxide).

If our planet were a featureless sphere, then its climate would depend only on the distribution of sunlight, and would therefore be the same at each point along a latitude circle. This is obviously not the case. For example, Albuquerque and Los Angeles are at nearly the same latitude, but their climates are markedly different: Unlike Albuquerque, Los Angeles rarely experiences subfreezing temperatures and receives most of its precipitation in winter rather than summer. The important climatic boundary conditions that vary with longitude include the distribution of oceans and continents, continental topography, and land surface cover. The climate of Los Angeles is considerably moderated by its proximity to the Pacific Ocean, whereas Albuquerque's climate owes a great deal to its elevation above sea level and its distance from any ocean with major mountain barriers in all directions. If we can understand the link between the boundary conditions and local temperature and precipitation, then we have some hope of predicting the changes in climate associated with known or predicted changes in those boundary conditions.

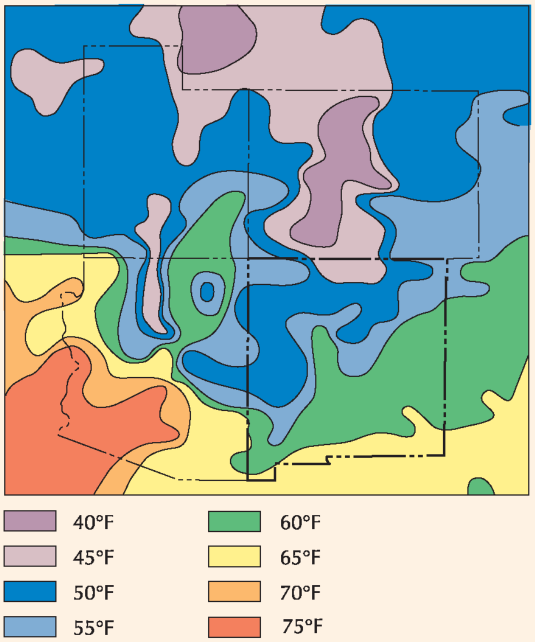


Schematic map of the principal boundary conditions that influence New Mexico's climate. The sun currently sends about 1368 Watts per square meter of radiation into Earth's atmosphere. This "solar constant" is the amount of radiant energy flowing each second from the sun into the top of the atmosphere.

New Mexico's Climate Today

Climatological "normal" conditions are defined rather arbitrarily as a 30-year average measured over the most recent three decades. The statewide annual average temperature for 1961–1990 was 53.1°F (but that average is rising: the 1971–2000 average was almost 53.5°F). New Mexico's temperature is considerably cooler than states to the east at the same latitude because of the high average elevation of the state, and the long distance from the moderating effects of oceans in winter. A smoothed map of annual average temperatures shows the expected decrease of temperature from south to north, due to the gradient in the intensity of sunlight. Superimposed on that pattern, the low-lying Rio Grande valley appears as a tongue of warm temperature extending northward into the center of the state amidst cooler temperatures in high elevation regions (Colorado Plateau, and the Sacramento and Sangre de Cristo ranges). Coldest temperatures are in the north-central mountains along the Colorado border.

Many of the world's deserts are located within the latitude zone between 25° and 35° in either hemisphere, owing to a global circulation system called the



Climatological distribution of annual average surface air temperature across the Southwest.

Hadley Cell that generates a belt of subsiding air (which tends to suppress clouds and precipitation) at these latitudes. (Albuquerque is at a latitude of about 35° N.) In addition to this global circulation, New Mexico's remoteness from oceanic moisture sources acts to keep our climate dry. The lack of humidity has a particularly pronounced cooling effect on nighttime temperatures, because heat stored in surface soil readily radiates away to space during the night. Precipitation increases across the eastern half of the state, where humid air from the Gulf of Mexico penetrates more often, especially in springtime.

New Mexico receives moisture and precipitation from a variety of directions. In winter most of the precipitation is carried in by eastward-moving frontal systems originating over the Pacific Ocean. In an average winter most of these storms track to our north, dumping more snow in Colorado than in New Mexico. Winter snow pack at high elevations is particularly important for water resources statewide, because snowmelt provides a very effective means for recharging ground water and filling reservoirs. However, the wettest season for most of New Mexico is summer, when thunderstorms can produce spotty but locally heavy precipitation across the state. In summer, rainy periods are marked by humid low-level winds from the south, part of the so-called North American monsoon system.

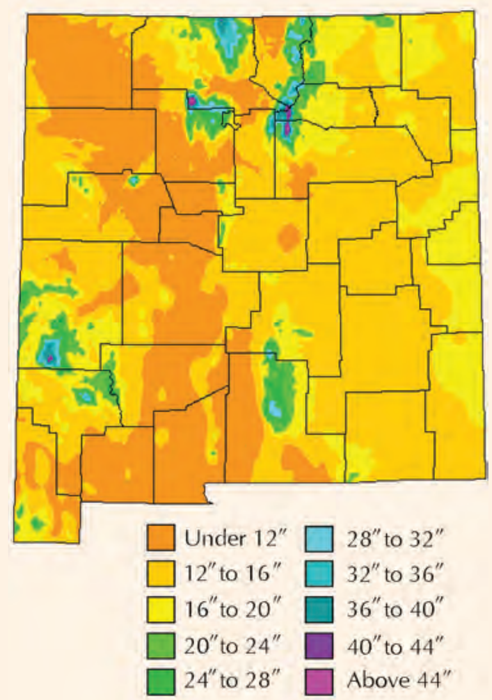
Current Climate Variability

"Average weather" can vary systematically from year to year within a 30-year climate period. Such interannual variability is associated principally with changes in ocean temperatures that modulate storm tracks and moisture transport for entire easons or years. Slow variations in ocean temperature and currents, especially in the Pacific Ocean, are a major cause of wintertime interannual variability across North America. The El Niño cycle is the best known and best understood example of oceanic short-term climate forcing. El Niño is an enormous tongue of anomalously warm Pacific Ocean surface water extending along the equator westward from the South American coast. The mirror-image cold phase is typically called La Niña. The cycle is not periodic, but extreme warm and cold phases each tend to occur several years per decade, reaching maximum amplitude in the Northern Hemisphere winter season. El Niño pulls the North Pacific atmospheric jet stream, and the storm track associated with it, southward and eastward, so that more of the winter storms that usually pass to our north generate precipitation over New Mexico instead (as happened in early 1983, 1987, and 1992). La Niña has the opposite effect, pushing the jet stream northward and leaving New Mexico drier than normal (as in 1971, 1974, and 1989).

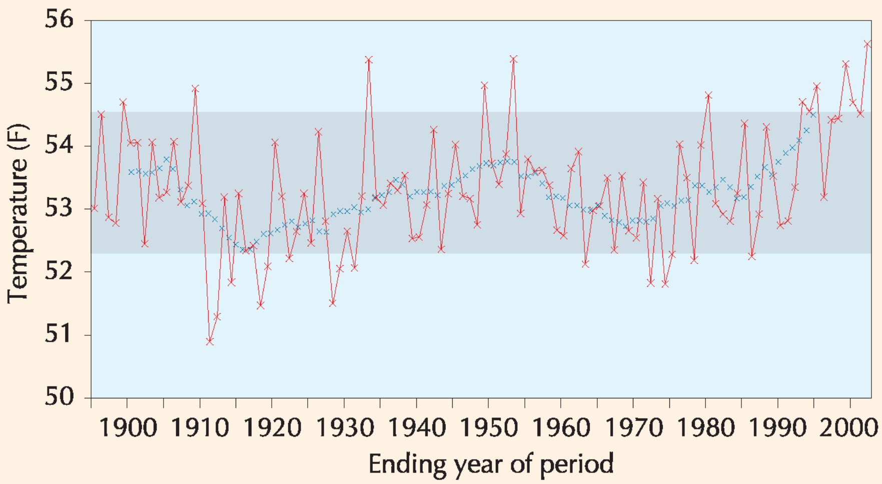
Recent research suggests that longer multi-decadal fluctuations in the North Pacific Ocean also affect precipitation across southwest North America, perhaps helping to explain long-term drought and wet spells across the Southwest. North Pacific Ocean temperatures seem to vary more slowly than tropical El Niño-related anomalies. This Pacific Decadal Oscillation (or PDO) seems to modulate the effects of El Niño, such that in its negative phase the effects of La Niña are amplified and the effects of El Niño are suppressed, whereas in the PDO's positive phase the opposite modulation occurs. The PDO was in a negative phase during the 1950s (when persistent drought plagued New Mexico), then abruptly flipped in 1977 so that the wet decades of the 1980s and 1990s took place during a PDO-positive period. Teasing out the association between decadal climate variability across the Southwest and these slow, multi-decadal oceanic cycles in the Pacific (and perhaps the Atlantic Ocean as well) is a very active area of research.

Climate Change

New Mexico's climate is constantly changing over longer time scales, too. Over the past several decades the statewide average temperature has risen rather steadily and quite rapidly. An 11-year running average of temperature started upward around 1970, and every year since 1992 has been warmer than the "climatological average" value of 53.1°F, with no cooling trend in sight. On the other hand, the early years of the twentieth century, and the 1960s and early 1970s, were generally somewhat cooler than this average value. The figure on page 3 illustrates both the very significant character of the current warming trend (which is observed across much of the world, hence the strong suspicion



Average annual precipitation across New Mexico. The pronounced effects of topography on local precipitation are clearly evident. The dry Colorado Plateau country in the northwestern corner of the state has high mountains blocking it from oceanic moisture sources in all directions. More than 36 inches of precipitation per year falls on the high peaks in the Mogollon, Sangre de Cristo, and Jemez Mountains; not far away, the middle Rio Grande valley receives less than 10 inches per year.



Time series of annual temperature averaged across New Mexico from 1896–2003. Each data point is an average from October through the following September (to avoid splitting winters in half). Red line shows annual data points; blue x's show 10-year running average. Data and plotting routine are available online from the Western Regional Climate Center at www.wrcc.dri.edu. An 11-year running average of temperature started upward around 1970, with no cooling trend in sight.

that the warming can be attributed to worldwide increases in greenhouse gases), and the difficulty in making confident predictions of future temperature changes based just on extrapolating current trends. Our understanding of "natural" climatic cycles and trends has been considerably complicated by the fact that we now have the ability to influence climate (however unwittingly), though there is considerable debate regarding the degree to which we are influencing it. Because natural and man-made climate changes are now occurring simultaneously in unprecedented ways, we cannot confidently extrapolate past variability into the future. So the only way to understand (and predict) future changes in climate is to improve our understanding of the fundamental processes that govern the climate system.

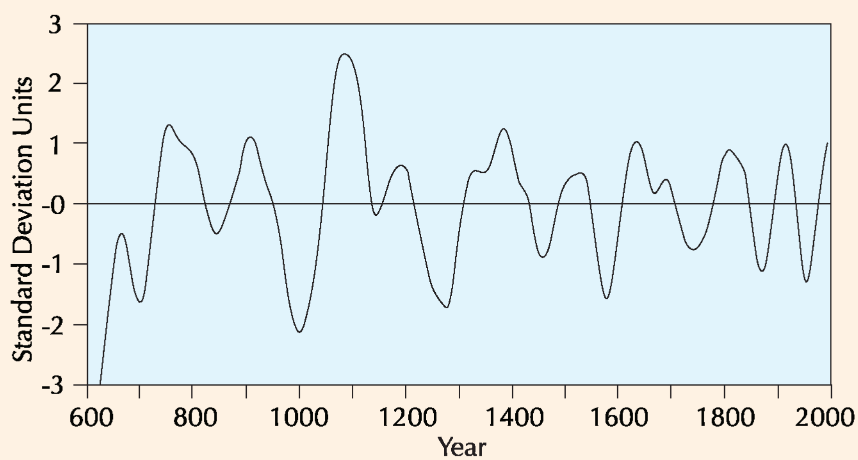
Although the current warming trend in climate is very significant, projected twenty-first century climate changes are still modest compared to changes that have occurred in the past. During the last ice age, which maximized some 15,000–20,000 years ago, abundant geological evidence indicates that huge ice sheets covered much of North America to the north of New Mexico. This event was merely the latest of a long series of ice age cycles that characterize climate during the last 2 million years. These ice age cycles are thought to be caused by wobbles in Earth's orbit that make Northern Hemisphere summers cold, such as would happen when the 23.5° tilt of Earth's rotational axis becomes smaller, making seasons less pronounced. As ice sheets grow, less sunlight is absorbed by Earth's surface (because ice is very reflective), amplifying cold conditions. Bubbles of air trapped in ice cores show that atmospheric CO_2 concentration declined dramatically to around 200 parts per million during the last ice age, decreasing the greenhouse effect and thereby depressing temperature still further.

Although New Mexico itself was not covered with ice 20,000 years ago, the climate here was still much cooler than at present. Large lake beds, now just dry basins, stand as distinct evidence for a very different climate regime. Bruce Allen of the New Mexico Bureau of Geology and Mineral Resources has examined one of these areas in considerable detail: Lake Estancia, in what is now the Estancia Basin east of the Manzano Mountains. Layers in lake bed sediment cores, called varves, contain pollen grains, magnetized minerals, and tiny fossils that can be analyzed to determine the temperature of the lake and how long ago the sediment layer was laid down. Painstaking field work and laboratory analysis yield dated maps of the sequence of former lake levels.

The wetter climate that once supported large lakes in this now-arid land also generated huge ground water reservoirs that now provide us with much of our water supply. Geochemical evidence suggests that much of the well water we now tap must have seeped into the ground during the last ice age. The implication is that we are rapidly "mining" ground water from aquifers that filled up thousands of years ago, and our extraction of this water vastly exceeds the recharge taking place under current, more arid climatic conditions. Thus much of the ground water in New Mexico, like oil, is effectively a nonrenewable resource on human timescales.

New Mexico has undergone some very significant shifts in climate during the past 10,000 years or so since the last major ice sheet retreated. At the University of New Mexico Professor Peter Fawcett and his students, drilling into lake bed sediments in the Sangre de Cristo range and in a dried-up former lake in northern Mexico, have shown that the Southwest was much wetter several thousand years ago than it is today. They have also found evidence for small glaciers in parts of northern New Mexico that currently are unglaciated.

New evidence for decade-scale climate variability during the past 1,000 years has recently come to light from



Reconstructed precipitation in south-central New Mexico, A.D. 622–1994, derived from tree ring records obtained in the Magdalena, San Mateo, and Organ Mountains.

examination of annual growth rings in ancient trees, a proxy indicator of climate that was developed at the University of Arizona early in the twentieth century. The sequence of good and bad growth years in the trees is so distinct that it provides an excellent "fingerprint," allowing archaeologists and geologists to determine when trees were cut or died, an invaluable source of precise dating for many scientific studies. One of the major results of recent tree ring analysis is the discovery of southwestern "drought cycles" on sub-century time scales. A time series derived from a set of old trees across southern New Mexico is illustrated at the bottom of page 3. The severe 1950s drought shows up very clearly as the last major negative departure on this graph, followed by very positive (wet) conditions in the latter half of the twentieth century. There are abundant historical records of the late nineteenth century drought, which spanned the turn of the twentieth century, corroborating the tree ring record of that event.

The tree ring record shows that intermittent severe droughts have been a recurring feature of New Mexico's climate. There is an apparent 50–100 year return period for such droughts that is not currently explained by any known changes in boundary conditions. Furthermore, the terrible 1950s drought does not appear to be extraordinary in terms of either duration or severity—just another "normal" feature of southwestern climate variability! The lessons for us are clear: The most recent few decades represent unusually wet conditions, and we need to anticipate future droughts at least as severe as the 1950s episode. Fifty years later, it is quite possible that we are experiencing the next such drought right now, and climate histories like the tree ring record suggest that our current drought could easily persist for several more years.

Climate variability and change exert profound influences on agriculture, natural ecosystems, wildfires, tourism, and water resources in our state. Our vulnerability to climatic anomalies has been highlighted during the past few years of drought. The prospect of skillful climate forecasting, which was inconceivable just a few decades ago, could provide a useful management tool for policymakers and the public to reduce our vulnerability. However, current skill in climate forecasting is very limited. To achieve a better forecasting capability will require more thorough understanding of how and why climate has changed in the past, and an improved database for monitoring today's climate. Geologists, atmospheric scientists, and computer science experts are working together to make this happen.

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David Gutzler is a professor of meteorology and climatology at the University of New Mexico in Albuquerque. His research is focused on interannual and decadal variability and predictability of climate in the Southwest.

Each issue of Earth Matters features an invited article on a subject of interest to New Mexicans. These articles represent the author's informed opinion on important geoscience issues in New Mexico. The New Mexico Bureau of Geology and Mineral Resources is a non-regulatory agency.

—Ed.

Bureau Staff Involved in Climate-related Research

Several members of our staff are currently involved in research directly related to changing climates. Bruce Allen in our Albuquerque office has worked in the Estancia Basin for some years, focusing on the Pleistocene lakes that occupied this area when wetter conditions prevailed. The geologic record from these basins—today occupied by much smaller, ephemeral lakes—stretches back 45,000 years. A detailed examination of this geologic record, obtained through coring, provides a detailed look at climatic fluctuations at the end of the last ice age. One long-term goal of this work is to provide us with a detailed regional climatic record for the past 50,000 years or so.

Geophysicist Marshall Reiter has for some years been working on highly sensitive well logs that measure ground water temperature as a function of depth. His work in the Albuquerque Basin has been concerned primarily with discerning ground water flow patterns; these logs can offer some insight into climate change, as well. Logging temperatures in the subsurface above the water table in the Albuquerque Basin, Marshall is hoping to be able to identify changes in surface temperature over the past 100–200 years.

Geochemist Nelia Dunbar and geochronologist Bill McIntosh spent six weeks in Antarctica this past winter as part of a team of research scientists. Their primary goal was the collection of climate-related ice samples at Mt. Moulton, in West Antarctica. The summit crater of Mt. Moulton contains a 600-meter-thick section of ice interbedded with at least 40 layers of volcanic ash from nearby Mount Berlin. Radioisotopic dating of the ash indicates that the age of the Moulton ice ranges between at least 10,000 and 492,000 years. The site offers an unparalleled repository of ancient West Antarctic snow and trapped air, which can be used to investigate West Antarctic climate over the last 500,000 years. Several aspects of this unique climatic record will be investigated by collaborative researchers at Pennsylvania State University and the University of Colorado, including analyzing the isotopic composition of oxygen and hydrogen in the ice as well as the measuring the composition of gas bubbles trapped in the ice. These data can provide information about local climatic variations over time and, ultimately, will give us a window on global climate change. Dunbar and McIntosh will focus on dating and chemically fingerprinting the suite of volcanic ashes, in order to provide time lines for the climate information.

Many of our staff are working on detailed geologic mapping in the Albuquerque Basin, unraveling the complex history of the Rio Grande, as well as the sedimentary and tectonic history of the Rio Grande rift, for the past 20 million years. When completed, much of this work will have implications for our understanding of the climatic history of the region, as well.

Details of this research and the ongoing research of our other staff persons are available on individual staff Web pages on our Web site at geoinfo.nmt.edu.

–L. Greer Price

BUREAU NEWS

This year's annual teacher's workshop, ***Rockin' Around New Mexico***, was held in Albuquerque in July. Forty-three teachers from all over the state attended. The three-day workshop included field trips to Madrid, the Cunningham mine in the Ortiz Mountains, the Rio Grande cement plant, the Sandia Crest, and the Albuquerque volcanoes. This year's workshop was led by Bill Chavez of New Mexico Tech and David Love from the bureau, with help from other bureau staff. Special thanks to Larry Crumpler and Jayne Aubele from the New Mexico Museum of Natural History and Science. This year's sponsors included the New Mexico Department of Public Safety /Office of Emergency Management, and the New Mexico Mining Association/New Mexico Minerals Foundation. Next year's *Rockin'* will be held in Ruidoso. For more information, contact Susie Welch at susie@nmt.edu.

This July the bureau participated in the training of sixteen **NASA astronauts** in the Taos region. These days, with a renewed interest in Mars, astronauts are training in a variety of planetary exploration techniques, including photo-interpretation of landforms, rock and soil sampling, and geophysical techniques. The Taos region has long served as an extraterrestrial analog because of the similarity between the deeply canyoned Taos volcanic plateau and the lunar surface. The project was organized by Paul Bauer on our staff, in conjunction with Drs. Patricia Dickerson and Bill Muehlberger, NASA contractors affiliated with the University of Texas in Austin. A number of bureau staff assisted with the training exercise.

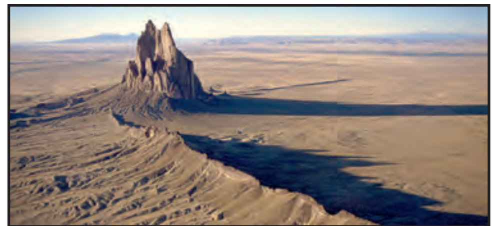
We are soliciting nominations for the next **New Mexico Earth Science Achievement Awards**, to be presented in January 2005. This annual award is co-sponsored by the bureau and New Mexico's Energy, Minerals and Natural Resources Department in Santa Fe. It is presented annually to honor individuals who have made outstanding contributions to advancing or facilitating the role of geoscience in areas of education, research, public service, and public policy in New Mexico. Nominations for next year's award are solicited from at large and may be made at any time between now and January 1, 2005. Names should be submitted directly to Peter Scholle at the bureau (scholle1@nmt.edu). Last year's awards went to Representative Joe Stell of Carlsbad, for outstanding contributions advancing the role of earth science in areas of public service and public policy in New Mexico, and to Dr. John W. Shomaker of Albuquerque, for outstanding contributions advancing the role of earth science in areas of applied science and education in New Mexico.

Michael Timmons joined our staff in May 2004 as manager of the bureau's geologic mapping program. He will be working closely with our STATEMAP mappers and with other staff on a variety of geologic mapping projects. Mike recently completed his Ph.D. at the University of New Mexico in Albuquerque.

OUR MISSION

The New Mexico Bureau of Geology and Mineral Resources, established by legislation in 1927, is a service and research division of the New Mexico Institute of Mining and Technology. It acts as the geological survey of New Mexico with these main goals:

- CONDUCT research and interact with state and federal agencies and industry to facilitate prudent exploitation of the state's geological resources.
- DISTRIBUTE accurate information to scientists, decision makers, and the New Mexico public regarding the state's geologic infrastructure, mineral and energy resources, and geohydrology (including water quantity and quality).
- CREATE accurate, up-to-date (digital and GIS-based) maps of the state's geology and resource potential.
- PROVIDE timely information on potential geologic hazards, including earthquakes, volcanic events, soils- and subsidence-related problems, and flooding.
- ACT as a repository for cores, well cuttings, and a wide variety of geological data. Provide convenient physical and internet access for New Mexicans to such resources.
- PROVIDE public education and outreach through college teaching and advising, the Mineral Museum, and teacher- and student-training programs.



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Cover photo of Ship Rock, New Mexico by
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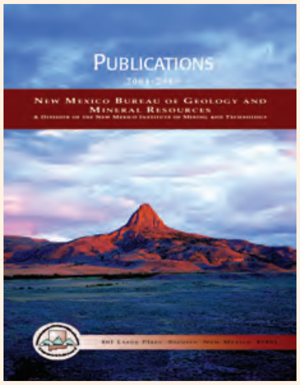
New Publications



Publications catalog 2004–2005
40 pp. Free

This 40-page booklet offers a comprehensive look at the variety of technical and popular publications available, including books, maps, databases, and free publications.

This is the first printed publications catalog issued in nearly 5 years. Special attention is given to the bureau's most recently released and forthcoming publications; however, all of the bureau's more than 400 in-print titles are listed (exclusive of open-file reports). A complete listing of bureau publications, including open-file reports, is available on our Web site at geoinfo.nmt.edu

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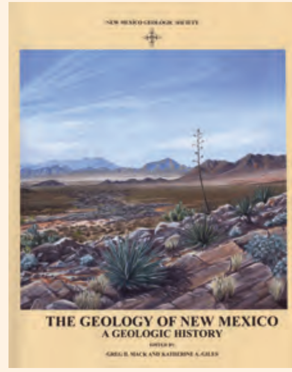

The Geology of New Mexico—A Geologic History, edited by Greg H. Mack and Katherine A. Giles, 2004, 474 pp., over 300 photos and illustrations, color throughout. New Mexico Geological Society Special Publication 11. ISBN 1-58546-010-9 Hardcover $45.00 plus shipping and handling. Price for student members $29.25

This volume is the first of two books on the geologic history and the economic geology of New Mexico. The books celebrate the society's 50th anniversary in 1999 and honor the many field geologists of the early and middle twentieth century whose geologic maps and complementary stratigraphic studies laid the foundation for our present understanding of the geologic history of New Mexico.

Nineteen chapters on major depositional and tectonic events are organized chronologically. Two final chapters on paleomagnetism and the geophysical constraints on crustal structure recognize the important role of geophysics in interpreting Earth history. The authors are either currently working on the rocks in their chapter or are able to provide current information on rock types, age and correlation, and paleogeographic/paleotectonic interpretations.

New Mexico Bureau of Geology and Mineral Resources
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