New Mexico
EARTH
MATTERS

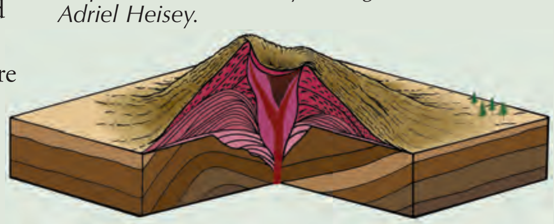
Winter 2006

VOLCANOES OF NEW MEXICO

Perhaps more than any other state in the U.S., New Mexico offers an enormously diverse record of volcanic activity. Many familiar and distinctive New Mexico landscapes are composed of volcanoes and volcanic rocks. The black, barren, lunar landscapes around Grants and Carrizozo are recent lava flows, and the black flat-topped mesas around Albuquerque are remnants of older lavas. Mount Taylor and Capulin Mountain are volcanoes, and Los Alamos is built on the flank of a huge volcano, one so large that it is best viewed from space. Ship Rock is the eroded remnant of a volcano, as is Cabezon Peak. Although not as easy to recognize, many of the rocks in the Gila Mountains and other southern and western New Mexico mountain ranges are also volcanic. The youngest volcanic rocks in New Mexico are a scant 3,800 years old. At the other end of the age spectrum, volcanic rocks in parts of northern New Mexico are more than a billion years old.

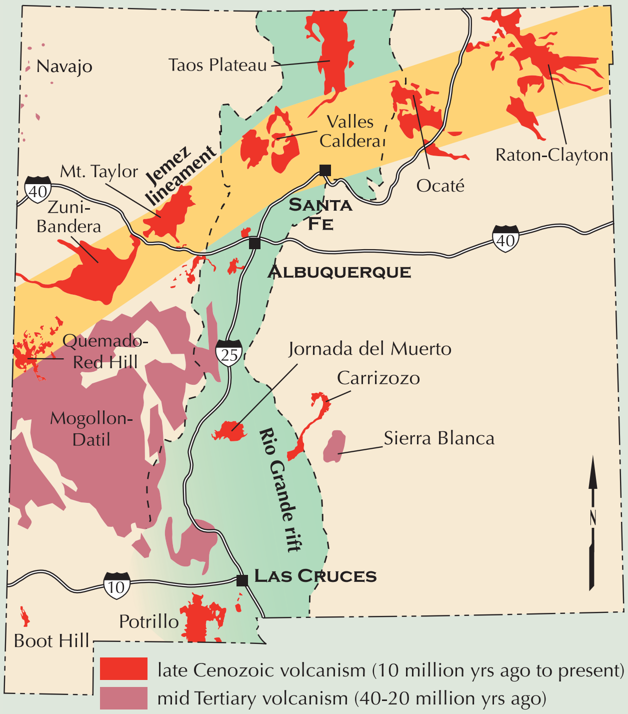
Volcanoes are defined as vents through which magma (melted rock) and gases erupt from below the earth's surface. Volcanoes range widely in size, from small cinder cones, such as Bandera Crater (near Grants), which can be climbed in a matter of minutes, to much larger landforms like the Jemez Mountains, and skyline-dominating volcanoes like Mount Taylor and 12,000-foot-tall Sierra Blanca on the east edge of the Tularosa Basin. Eruptions from some of the largest New Mexico volcanoes, located in the Mogollon–Datil volcanic field in the southwestern part of the state, produced several hundred cubic miles of volcanic rock in single events, hundreds of times larger than the May 18, 1980, eruption of Mount St. Helens. The Mogollon–Datil eruptions were larger than any volcanic events that have occurred in historic time, and the deposits from some of these events produced sheets of rock several hundred miles across. The well-known "Kneeling Nun" landform near Silver City is formed from volcanic rock from one of these enormous eruptions, as are the striking landforms at City of Rocks State Park.

Capulin Mountain in northeastern New Mexico is a classic cinder cone. The cutaway view revealing the structure of a typical cinder cone (below) shows the layers of ash that accumulate around the central vent. The summit crater is often preserved in younger features, such as Capulin Mountain, which erupted about 55,000 years ago. Photo © Adriel Heisey.



The shape of volcanoes, and the time that they take to form, vary widely with the style of eruption. Cinder cone volcanoes, such as Capulin Mountain and Bandera Crater, are perfect cone-shaped hills. Cinder cones typically form quickly and are the result of a more-or-less continuous single episode of eruption. An interesting example is the eruption that formed the famous Mexican volcano, Paricutín. This volcano was born in a cornfield on February 20, 1943, following several weeks of local earthquake activity. The volcano grew to a height of 150 feet on its first day of eruption and was 500 feet high 6 days later, reaching a final height of over 1,000 feet after 3 years of activity.

Most volcanoes, however, are larger and take longer to form. Stratovolcanoes, such as Mount Taylor and Sierra Blanca, form from repeated eruptions over many thousands of years, and the resulting landforms are large, sometimes asymmetrical mountains. The Jemez Mountains in north-central New Mexico are the geographic expression of a series of volcanic eruptions that occurred over the past 15 million years. The two largest eruptions, which occurred 1.2 and 1.6 million years ago, produced the distinctive white-to-salmon-colored cliffs of Bandelier Tuff that form a spectacular backdrop around much of the area. These two very explosive eruptions poured hundreds of cubic miles of hot ash, pumice, and gas over the surrounding land-



The major volcanic fields in New Mexico tend to follow two major zones of weakness in the crust and underlying mantle, the Jemez lineament and the Rio Grande rift.

scape. The rocks were later eroded by water, resulting in the beautiful landscape we see today. It is difficult to recognize the Jemez Mountains as a volcanic landform because they are so large. However, on a digital elevation map (like the one shown on page 3), the volcanic shape and large central crater (caldera) become evident.

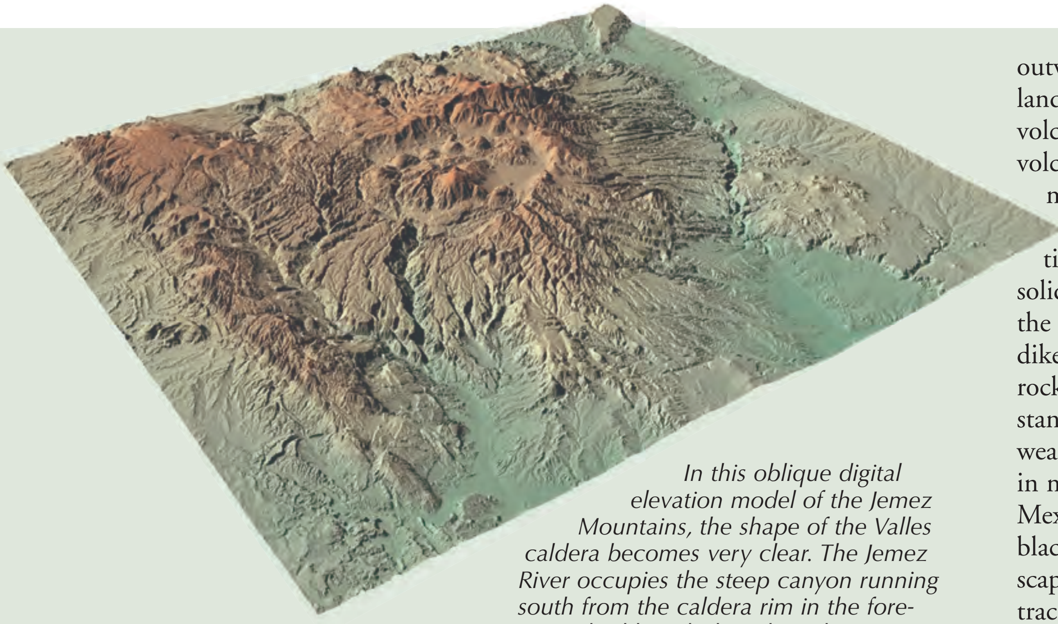
Volcanism in New Mexico

Volcanic activity occurs in New Mexico and elsewhere in the western United States because of the local nature of the earth's crust and mantle. The crust in New Mexico is being stretched by regional plate tectonic forces. This stretching produces areas of weakness in the brittle crust, allowing magma to work its way upward. The very large volcanic field represented by the Jemez Mountains occurs at the intersection of two zones of crustal weakness, the Rio Grande rift and the Jemez lineament. The Rio Grande rift is a major zone of crustal weakness running north to south through New Mexico that formed in order to accommodate stretching of the crust in an east-to-west direction. The surface expression of the Rio Grande rift is a broad, shallow valley caused by down-dropped blocks of the crust along rift-bounding faults. The river flows through a series of broad valleys created by this stretching process. The Jemez lineament is a more subtle crustal feature, expressed as an alignment of volcanic vents, including (but not limited to) the Zuni–Bandera, Mount Taylor, Jemez Mountain, and Raton–Clayton volcanic fields. This zone may be the expression of a weakness formed where two very old blocks of the earth's crust were pressed together. In addition to various styles of crustal weakness, volcanism in New Mexico is also likely related to upwelling of abnormally hot mantle material.

Active, Dormant, or Extinct?

Volcanoes may be classified as active, dormant, or extinct. An active volcano is one that is emitting lava or volcanic gas. A dormant volcano is not actively erupting, but, based on patterns of past activity, is likely to erupt again. With the possible exception of the Jemez Mountains, all volcanoes in New Mexico are probably extinct, meaning that they are unlikely ever to erupt again. However, new volcanoes will certainly form within our state, though probably not within our lifetimes. Dr. Allan Sanford, a geophysicist at New Mexico Tech, has identified the Socorro Magma Body, a large body of molten rock underlying the area from Bernardo to south of Socorro. Many small earthquakes associated with the magma body have been detected using seismometers, and some have been felt by local residents. These earthquakes are caused by swelling of the magma chamber, which fractures the overlying brittle rocks. The magma body is located 12 miles beneath the earth's surface but shows no signs of erupting soon. The swelling of the magma chamber is being studied using high-precision global positioning system (GPS) data and instruments called tiltmeters. The combination of these two instruments allows even tiny changes in the shape of the earth's surface over the magma body to be detected. This research is being carried out by Los Alamos National Laboratory geologist Andy Newman, as well as bureau geologists David Love, Bruce Allen, and Richard Chamberlin. The magma body's activity is being closely monitored by the New Mexico Tech geophysics program (on the Web at www.ees.nmt.edu/Geop/NM_Seismology.html), and any change in activity

A complete section of Bandelier Tuff is exposed along NM–4 north of Bandelier National Monument.



In this oblique digital elevation model of the Jemez Mountains, the shape of the Valles caldera becomes very clear. The Jemez River occupies the steep canyon running south from the caldera rim in the foreground. Although there have been no major eruptions from the Jemez Mountains volcanic field in the last million years, there have been a number of smaller eruptions, the most recent of which occurred about 60,000 years ago.

would be carefully analyzed to assess the possibility of an eruption.

The large explosive events that formed the upper part of the Bandelier Tuff in the Jemez Mountain volcanic field occurred in the relatively recent geologic past. No eruptions this large have occurred anywhere in the world in historic time, and only six have occurred in the U.S. in the past 2 million years, including two from the Jemez Mountains, three from Yellowstone, and one from the Bishop area of California. The initial stages of the Bandelier eruption produced ash that rained out of the sky over much of New Mexico. Following this initial "ash fall," activity shifted to a "pyroclastic flow" eruption. This stage produced a fast-moving, extremely hot cloud of ash, pumice, and gas that would have destroyed anything in its path, traveling as far as 20 miles from the central vent before solidifying into volcanic rock. The buff-colored cliff-forming rock in which the Bandelier National Monument cliff dwellings are found, and on which Los Alamos is built, was formed by this pyroclastic flow. The highly explosive Bandelier eruptions are similar to several million-year-old eruptions from Yellowstone that caused ash to fall as far away as New Mexico.

Another interesting type of explosive volcanism formed the beautiful landform known as Ship Rock, or Tse bit'a'i. This landform (illustrated on the masthead of this publication) is a diatreme, formed when hot magma rising through the earth's crust encountered cold ground water. The resulting violent steam explosions excavated a deep depression in the earth's surface. Magma and a variety of rock fragments and debris fell back into this hole and were cemented together below the earth's surface. Over the 25 million years since the Ship Rock eruption occurred, erosion has removed the surrounding rocks, leaving the hard, cemented throat of the volcano exposed. The "walls" that radiate outward from the main Ship Rock landform are also part of the original volcano. These walls are actually volcanic dikes, formed when hot magma moved laterally through cracks in the earth's surface at the time of the eruption, cooled, and solidifed while still in the cracks. Like the central part of the volcano, the dikes are harder than the sedimentary rocks surrounding them and remained standing while the sedimentary rocks weathered away. Similar dikes are found in many places throughout New Mexico, typically appearing as thick, black walls running across the landscape. Some of these dikes can be traced across the earth's surface for as much as 45 miles.

Our Youngest Volcanoes

In contrast to violent eruptions like Bandelier and Ship Rock, most of the recent volcanic activity in New Mexico has been of a more passive eruption style. This includes the 3,800-year-old McCartys and the 10,000-year-old Bandera Crater lava flows in the Zuni–Bandera volcanic field near Grants, New Mexico; the 5,400-year-old Valley of Fire lava flow near Carrizozo; 55,000-year-old Capulin Mountain; and 930-year-old Sunset Crater in nearby Arizona. These lava flows and/or cones of volcanic cinders

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This basaltic lava flow near Carrizozo displays a classic ropy (pahoehoe) texture. Note the vegetation that has grown in the 5,200 years since the eruption.

Bureau News

Earth Science Achievement Awards

The 2006 New Mexico Earth Science Achievement Awards were presented on January 27 of this year to Consuelo Bokum, for her tireless work on water issues in New Mexico, and to Thomas D. Morrison, chief of the Hydrology Bureau at the New Mexico Office of the State Engineer, who, for over 25 years, has been at the forefront of shaping water management policy throughout New Mexico. These awards, co-sponsored by the New Mexico Bureau of Geology and Mineral Resources and the Energy, Minerals and Natural Resources Department in Santa Fe, are 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 awards may be submitted (no later than November 1, 2006) to Director Peter Scholle at the New Mexico Bureau of Geology and Mineral Resources.

New Staff Members

We've welcomed several new staff members to the bureau in the past year, including Barbara Fazio, executive secretary; Lewis Gillard, GIS technician; Mike Smith, database technician; Stacy Timmons, senior geological research associate; and Patrick Walsh, subsurface fluid geologist.

Award for Outstanding Publication

At the annual meeting of the Association of Earth Science Editors, the New Mexico Bureau of Geology and Mineral Resources received the 2005 Award for Outstanding Electronic Publication for *Tectonics, geochronology, and volcanism in the Southern Rocky Mountains and Rio Grande rift*, edited by Steven M. Cather, William C. McIntosh, and Shari A. Kelley. This award is presented each year to the electronic publication that best demonstrates outstanding editing, design, illustration, writing, effectiveness of production cost, and overall effectiveness in achieving its publication goal.

Astronauts in Taos

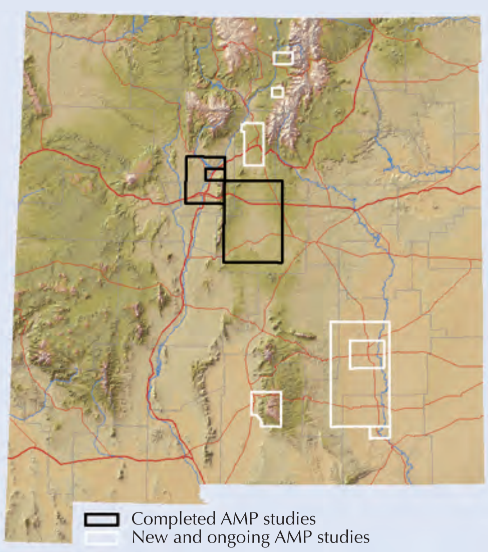
During the summer of 2005, bureau staff provided geologic and geophysical training to eleven NASA astronaut candidates in the Taos area. This was the third class to participate in the bureau's Taos training program since 1999. Astronauts participated in a series of exercises designed to provide them with an introduction to techniques for the geophysical exploration of planets.

The majestic landscapes of the Taos area have long provided textbook examples of various geologic landforms, and have served as a backdrop for astronaut training exercises since NASA's Apollo missions in the late 1960s. The current training program, directed by senior geologist Paul Bauer with assistance from U.S. Geological Survey personnel, provided the astronauts with experience running gravity and magnetic surveys across buried faults on northern Taos Pueblo. The data collected during the exercise will be used in an ongoing bureau program to characterize the geology and hydrogeology of the region.

The current class of astronauts included military pilots, school teachers, a medical doctor, engineers, and three members of the Japanese Aerospace Exploration Agency, JAXA. At the end of the training, NASA officials presented Taos Pueblo leaders with special gold medallions generally given to heads of foreign states, recognizing the Pueblo as a sovereign nation.

Aquifer Mapping Program Tackles New Areas of Study

For the past ten years the bureau staff has been engaged in hydrogeologic studies of New Mexico's aquifers in cooperation with the New Mexico Office of the State Engineer and the New Mexico Environment Department. Beginning in the mid-1990s with geologic mapping and aquifer analysis in the Albuquerque Basin and a hydrogeologic study in Placitas, the bureau has developed an aquifer mapping program (AMP) that applies a combination of geologic, geophysical, hydrologic, and geochemical information to develop descriptive models of ground water flow in important aquifers around the state. The objective is to provide critically needed information on the quality and quantity of the state's ground water. 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 presence of natural contaminants (such as arsenic and uranium) that affect the potability of ground water. Aquifer studies range in scope from short-term local projects to long-term, regional studies engaging a variety of disciplines and collaborators. With support from the 2005 state legislature in the form of a $300,000 one-year appropriation, the program has been able to complete some studies while continuing or starting others. Past efforts include studies in the Albuquerque Basin, Placitas, and the Taos Valley, as well as Bruce Allen's work in the Estancia Basin. Results of a three-year study in the Española Basin are contributing to a collaborative effort by Santa Fe County and the City of Santa Fe to build a regional ground water-flow model to assist with resource administration and management. In 2005 a multi-year water-level monitoring study was continued in the Roswell artesian basin. Studies in Arroyo Hondo north of Taos and the Peñasco Valley were completed, and new investigations were initiated in the Sacramento Mountains east of Alamogordo, and near Seven Rivers in the lower Pecos River valley. Results of these works are contributing to long-term aquifer monitoring networks and regional ground water-flow models, supporting water rights administration and local land-use decisions, and addressing rural water quality concerns.



Index map showing completed and ongoing AMP study areas.

—Peggy Johnson

Peggy is a senior hydrogeologist with the New Mexico Bureau of Geology and Mineral Resources and manages the Aquifer Mapping Program.

A Word About Dates

One important part of understanding volcanic processes involves knowing the chronology, or timing, of volcanic activity. The ways in which volcanic chronology is determined have evolved and improved dramatically over the past 50 years. The main techniques that have contributed to a better understanding of volcanic chronology rely on isotopic measurements. Currently, much of this work is carried out in the argon radioisotope laboratory at the New Mexico Bureau of Geology and Mineral Resources, on the campus of New Mexico Tech. Thousands of volcanic rocks from New Mexico have been analyzed in this laboratory, and these data have greatly improved our understanding of the eruption history of New Mexico volcanoes. The ^{40}Ar/^{39}Ar technique involves measuring the ratio of parent to daughter isotopes and is useful for volcanic rocks of a wide range of ages. Other techniques that have been employed in determining the ages of volcanic sequences in New Mexico include the ^{14}C, ^{36}Cl, and ^{3}He techniques. Many of the ages reported in this article have been determined only in the past 10 years and, in many cases, represent substantial changes from earlier age estimates.

(Continued from page 3)

are formed by the types of eruptions that are witnessed today by so many tourists in Hawaii. Based on past patterns of activity, if a volcanic eruption were to occur in New Mexico in the next 100 or 1,000 years, it would most likely form either a lava flow, a cinder cone, or both. The eruptions that form such features do not include major explosive activity; rather they involve low levels of explosivity that form cinder cones and slow-moving, very hot lava that flows downhill from the vent of the volcano. This type of eruption would be unlikely to cause major loss of life or property, although the initial stages of the eruption could be dangerous to any nearby onlookers.

How likely is an eruption to occur in New Mexico in the near future? A New Mexico Tech graduate student, Ellen Limburgh, attempted to make some estimates. She studied the distribution and age of many of the known volcanoes in New Mexico. She found that there have been more than 700 volcanic eruptions in New Mexico in the last 5 million years, with eruptive styles ranging from dangerously explosive to passive. Volcanoes in New Mexico that have been active in the last 5 million years fall into 11 different geographic areas, or volcanic fields. Limburgh estimated that there is roughly a 1 percent chance that some type of volcanic eruption will occur somewhere in New Mexico in the next 100 years, and a 10 percent chance that an eruption will occur in the next 1,000 years. She estimates that about 100 eruptions will occur in the next million years. Widespread seismic monitoring around the state would help provide forewarning and predict where an eruptive event might take place. Living in New Mexico, we are lucky to be in a place where volcanoes form many dramatic and beautiful landforms. At the same time, we are living in a place with a small but very real chance of volcanic activity in the next century.

—Nelia W. Dunbar

Nelia is a geochemist and the assistant director in charge of laboratories for the New Mexico Bureau of Geology and Mineral Resources. Her research on volcanoes has taken her throughout the state, as well as far from New Mexico, most recently to Mount Erebus in Antarctica.

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Cover photo of Ship Rock, New Mexico
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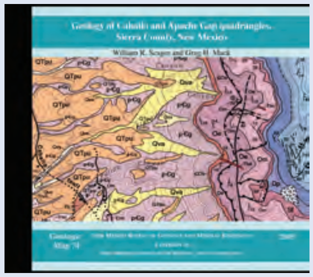
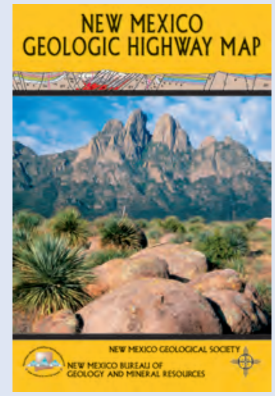
New Publications



Geologic Map 74—Geology of Caballo and Apache Gap quadrangles, Sierra County, New Mexico, by W. R. Seager and G. H. Mack, 2005, 2 sheets, scale 1:24,000, 6 cross sections. ISBN 1-883905-23-0. The map and cross sections are in PDF format. A georeferenced TIFF image is also provided on the CD. No GIS data are available for these quadrangles at this time. Available on CD-ROM only. $15.00 plus $2.50 for shipping and handling and 5% gross receipts tax for New Mexico residents.

The Caballo and Apache Gap quadrangles span an area from the Jornada del Muerto and eastern piedmont slopes of the central Caballo Mountains westward across the Caballo Reservoir and I–25 into basin-fill alluvium and piedmont-slope deposits of the Palomas Formation. Fifty-nine map units range in age from Proterozoic metamorphic and plutonic rocks to Holocene alluvial and fluvial deposits.

This map is part of a larger study of the Caballo Mountains that includes providing complete map coverage at a scale of 1:24,000; six maps have been published to date. As a supplement to the quadrangle maps, Memoir 49, Geology of the Caballo Mountains, New Mexico, *was released by the New Mexico Bureau of Geology and Mineral Resources in 2003.*



New Mexico Geologic Highway Map, compiled by Maureen E. Wilks, 2005. Published jointly by the New Mexico Geological Society and New Mexico Bureau of Geology and Mineral Resources, 1 folded sheet containing text and figures, scale 1:1,000,000, ISBN 1-585460-22-2. $10.00 plus $2.50 shipping and handling and 5% gross receipts tax for New Mexico residents.

In addition to the geologic highway map (1:1,000,000), the single sheet includes full unit descriptions, cross sections, regional stratigraphic columns, photos, and additional text material and maps on the geology of New Mexico. First published in 1982, this new edition has been completely revised and updated to include a map legend, two resource maps, one on energy, and the other on metals and industrial minerals in New Mexico. The new Landsat image was compiled between 1989 and 1993.

For more information about these and other bureau publications: Visit our Web site at geoinfo.nmt.edu; write or visit our Publications Office on the campus of New Mexico Tech, 801 Leroy Place, Socorro, New Mexico 87801; call (505) 835-5490, or e-mail us at pubsofc@gis.nmt.edu. Payment (check or money order payable to NMBGMR) must be enclosed with mailed orders. Telephone orders may be paid with VISA, Discover, American Express, or MasterCard.

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