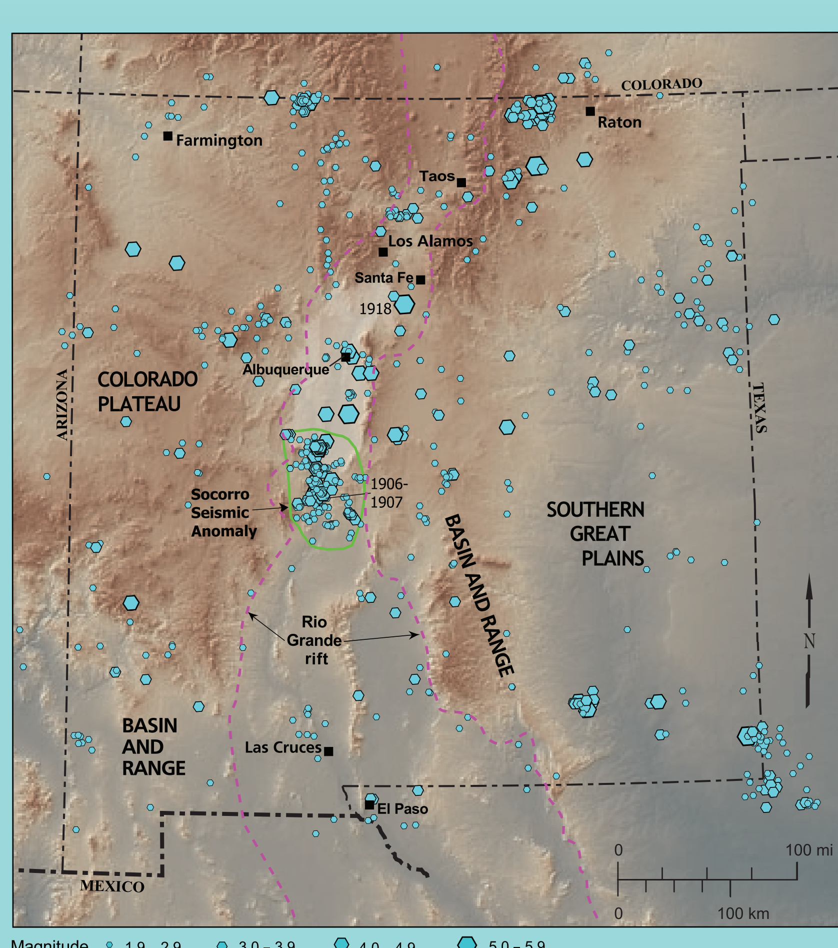
New Mexico EARTH MATTERS

WINTER 2009

Earthquakes in New Mexico

Most of New Mexico's nearly 2 million people live along the Rio Grande valley, which spans the entire state and includes the major cities of Santa Fe, Albuquerque, Las Cruces, and El Paso. The valley is within the Rio Grande rift, a region of tectonic, volcanic, and seismic activity that extends from north-central Colorado southward to Chihuahua, Mexico. Small earthquakes occur somewhere in New Mexico everyday, but no earthquake larger than magnitude (**M**) 6.2 has occurred within the New Mexico part of the rift since 1849, and probably no damaging event occurred in the previous few hundred years, based on oral history. However, New Mexico's short and incomplete earthquake record is a poor indicator of the earthquake potential of the region. Geologic evidence shows that large earthquakes (**M** > 6.5) have occurred in the recent past in the Rio Grande rift. Because of the large number of active faults in the Rio Grande rift, the probability of a future large earthquake in the rift is significant.

Ground shaking from any large earthquake within the rift could be quite severe because of the presence of alluvial sediments that blanket the Rio Grande valley. These sediments can amplify the ground motions to very damaging levels. A large earthquake in the Rio Grande valley could result in significant damage and casualties, particularly because of the extensive use of unreinforced masonry (adobe) construction and the existence of many older structures.



*Map of the Rio Grande rift and historic seismicity (**M** ≥ 2.0) in New Mexico, 1869 to 2008. Earthquake data are from the U.S. Geological Survey and New Mexico Tech. Boundaries of the Rio Grande rift and the Socorro Seismic Anomaly are also shown. Some clusters of seismic events in southeast New Mexico and the Raton Basin were induced by fluid withdrawal or injection in oil and gas fields.*

What Is an Earthquake?

In 1910 H. F. Reid suggested that earthquakes were the result of a phenomenon called "elastic rebound," based on his observations of the great 1906 **M** 7.9 San Francisco earthquake. This theory states that an earthquake is generated by rupture or sudden displacement along a geologic fault when it has been strained beyond its elastic strength. In the process of strain accumulation, the opposing sides of the fault are stressed until failure occurs, sudden displacement takes place, and the sides rebound back to an unstrained position. The result of each cycle of strain accumulation along a fault is an earthquake. The elastic rebound theory has become the accepted model for the generation of most, but not all, earthquakes. Some volcanic earthquakes and deep earthquakes may have different mechanisms. Also, displacement along a fault does not necessarily always result in an earthquake. Creep, slow displacement without accompanying earthquakes, has been observed along some faults.

Faults can be classified into three general types based on their sense of displacement: normal, reverse or thrust, and strike-slip. The San Andreas fault is a major strike-slip fault that separates the Pacific and

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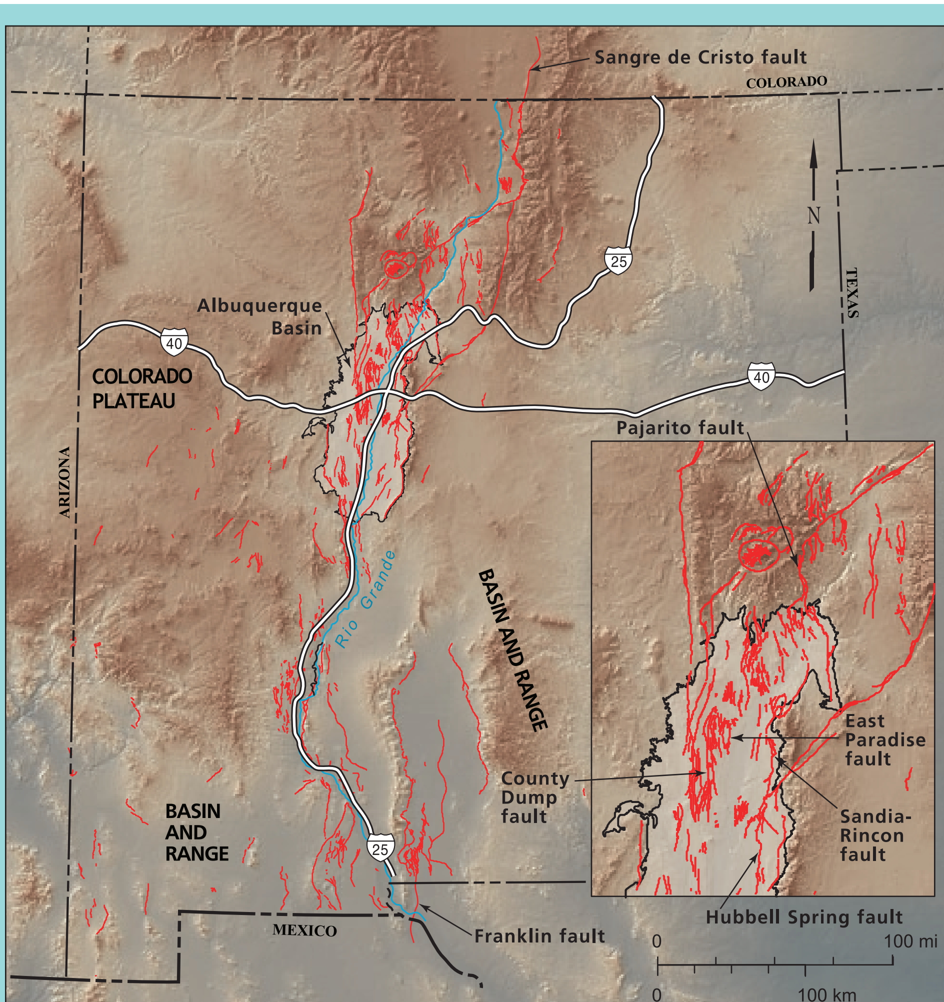


Of the Quaternary faults in New Mexico more than 100 are in the Rio Grande rift, and at least 20 of them show evidence for movement in Holocene time (roughly the past 11,800 years). The paleoseismicity of the labeled faults has been studied in detail. Active faults are present on the southern Colorado Plateau, west of the rift, and in the southeast Basin and Range, west and east of the southern rift. Data from the U.S. Geological Survey's Quaternary Fault and Fold Database of the United States (http://earthquake.usgs.gov/regional/qfaults/).

North American tectonic plates. Earthquakes as large as **M** 7.9 occur along the fault where the two plates slide horizontally past each other. In extensional tectonic terranes where the earth's crust is being stretched, normal-faulting earthquakes have created the uplifted mountains and valleys of the Basin and Range province and the Rio Grande rift.

Most of the seismic energy released in the world is from earthquakes along tectonic plate boundaries, particularly around the Pacific Rim or the so-called "Ring of Fire." Specifically, the earth's greatest earthquakes are the result of plate movement within subduction zones. The largest known earthquake was the 1960 **M** 9.5 earthquake that occurred along the South American subduction zone off the coast of Chile. The next largest earthquakes, both from subduction zones, include the 1964 **M** 9.2 Alaska earthquake and most recently, the 2004 **M** 9.2 Sumatra, Indonesia, earthquake that generated the tsunami that killed more than 200,000 people.

New Mexico Earthquakes—Where and How Big?

The largest regional historic earthquake was the 1887 **M** 7.4 earthquake that ruptured 63 miles (101 km) of the Pitaycachi fault in Sonora, Mexico. The event was felt as far away as Santa Fe to the north, Toluca near Mexico City to the south, Yuma, Arizona, on the west, and 155 miles (96 km) east of El Paso, Texas. The earthquake caused 51 deaths in small communities close to the epicenter due to collapsed adobe structures. Many landslides and ground cracks were reported.

The first documented earthquake in New Mexico occurred in 1849. Since then more than 2,000 earthquakes within the state have been recorded, most of them smaller than **M** 3. The rate of earthquake activity in New Mexico can be characterized as moderate. For example, there have been 15 earthquakes of **M** 4.0 and larger in the state since 1980 when seismographic coverage of the southwest U.S. became uniform. This compares with 25 and 47 earthquakes in the neighboring states of Arizona and Utah, respectively. In contrast, 950 **M** 4.0 and larger earthquakes have occurred in southern California since 1980.

Only six earthquakes of **M** 5.0 or greater have occurred historically within New Mexico, most within the Rio Grande rift. The largest historic earthquake was probably the 15 November 1906 earthquake near Socorro of estimated **M** 6.2. The event was felt throughout central New Mexico. This earthquake was part of a sequence in 1906 to 1907, which began on 2 July 1906 with two jolting earthquakes that were felt within a 50-mile (80 km) radius of Socorro. Earthquakes were felt almost daily from 2 July 1906 to 21 July 1907, the most severe occurring on 12

How We Measure Earthquakes

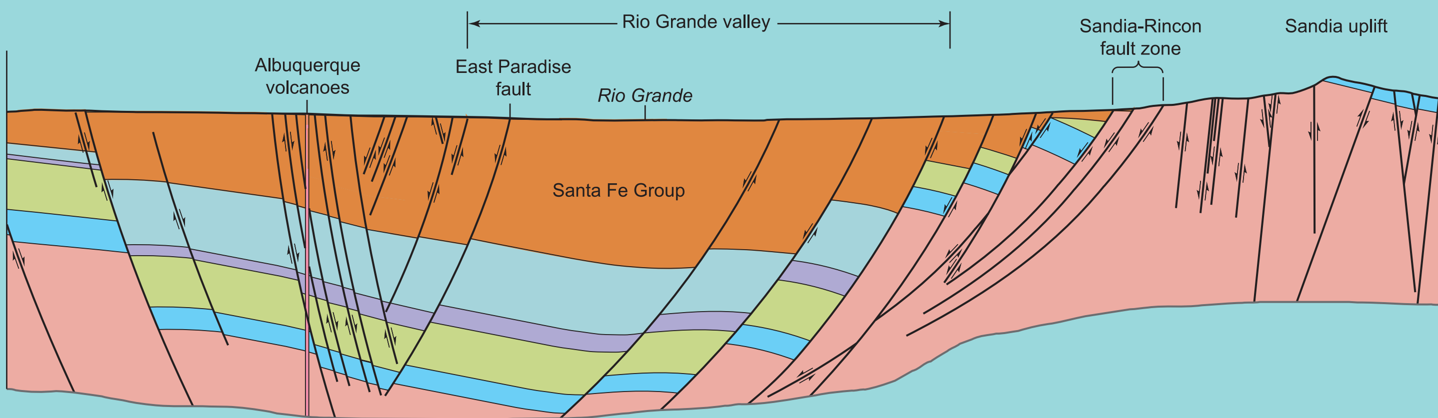
In the early 1930s Charles Richter, using an instrument called the Wood–Anderson seismograph, developed the local magnitude (M_L) scale for southern California earthquakes. This was a monumental step in earthquake seismology because it allowed for the first time a precise quantification of the size of an earthquake based on instrumental recordings. Because M_L values are based on the amplitude of the largest wave recorded on a seismogram and were thus simple to calculate, the scale rapidly became a worldwide standard. Since then, several other magnitude scales have come into use. The moment magnitude scale (**M**) is the scale of choice among seismologists because it is based on the seismic moment, which is a function of the fault rupture area, the average displacement on the fault, and the shear modulus, a parameter that is related to the rigidity of the rocks in the fault zone; hence the larger the rupture area, the larger the earthquake. An **M** 7 earthquake ruptures a fault area of about 391 square miles (1,000 square km) or about 31 miles long (50 km long) and 12.5 miles wide (20 km wide). Earthquakes can range in size from magnitudes less than zero, resulting from slippage of a few inches on a fault with dimensions of feet, to the largest events, **M** 9 and greater, where fault displacements are on the order of many feet on faults with rupture lengths of 600 miles or more.

July, 16 July, and 15 November 1906. The 12 July earthquake lasted 15 to 20 seconds, causing adobe walls to crack, some chimneys to fall, and a rockslide to damage a nearby railroad. Many aftershocks followed, including the 16 July earthquake, which damaged additional chimneys, houses, and

National Laboratory.

Faults that are considered "active" have ruptured during the past 1.6 million years (Quaternary Period) and are likely the sources of future earthquake activity. An examination of the distribution of active faults in New Mexico shows them to be

> 6.5) have occurred throughout the rift. Recent research suggests a recurrence interval during the past 11,800 years (Holocene time) of about 400 years based on 24 known surface-rupturing earthquakes on all faults. This number of earthquakes is a minimum, and thus the recurrence interval



East-west structural cross section through the Rio Grande rift in Albuquerque. Major rift-bounding and intrabasin faults are shown. The Sandia uplift is the result of faulting along the Sandia–Rincon faults. Quaternary faults in the Rio Grande rift are dominantly normal faults, generally oriented north-south, have the potential to generate maximum earthquakes from **M** *6.5 to 7.5, have relatively long recurrence intervals between surface-faulting events (typically tens of thousands to hundreds of thousands of years), and show extreme variations in rates of activity. Although individual faults generally have low to moderate rates of activity, their cumulative effect and the apparent variability in rates of activity make it particularly important to include all Quaternary faults in seismic hazard evaluations of the rift.*

the brick post office. The Socorro area is the most seismically active region in New Mexico due to inflation of a magma body at a depth of 12 miles (19 km).

The 1918 earthquake near Cerrillos is the largest historic earthquake in the northern part of the Rio Grande rift. Although of moderate size, it was strongly felt in Cerrillos where chimneys fell, plaster cracked, windows broke, people were thrown off their feet, and a large ground crack appeared at the edge of town. This earthquake has been assigned M_L 5.25.

An examination of the map of historic earthquakes in New Mexico illustrates that, in general, seismicity consisting mostly of small magnitude earthquakes is diffuse and only locally associated with discrete structural or tectonic features. Detailed studies of the Albuquerque and Socorro areas show that seismicity is limited to the top 7.5 to 8.1 miles (12 to 13 km) of the earth's crust, consistent with observations from other rift systems where seismicity typically is concentrated in the upper crust.

One of the problems with the contemporary earthquake record in New Mexico is the lack of a statewide seismographic network that would provide uniform coverage of the state. Currently there are only small networks around Socorro, the Waste Isolation Pilot Project, and Los Alamos

concentrated within the Rio Grande rift, particularly along its boundaries. Most of what we know about the earthquake records along active faults in the Rio Grande rift has been derived from the science of "paleoseismology." Paleoseismology uses geologic techniques to uncover the records of prehistoric (paleoseismic) earthquakes preserved along active faults. A common approach is to excavate a trench across an active fault where the fault cuts through sediments and look for displaced geologic strata, which are indicative of past earthquakes. If the displacement of strata is from a single prehistoric earthquake, then the magnitude of the paleoseismic event can be calculated. By dating the events, the time intervals between events can be measured and the rate of activity of the fault can be estimated. Detailed paleoseismic studies have been performed on the Sangre de Cristo fault near Taos, the Pajarito fault near Los Alamos, the County Dump fault west of Albuquerque, the Sandia–Rincon fault on the east side of Albuquerque at the base of the Sandia Mountains, the Hubbell Spring fault zone near Los Lunas, and the Franklin fault in El Paso.

In marked contrast to the historic earthquake record, paleoseismic studies in the Rio Grande rift indicate that large prehistoric surface-faulting earthquakes (**M**

is a maximum, as most of the faults in the rift have not been studied in any detail. One of the most active faults in the rift is the Pajarito fault. Recent paleoseismic studies have shown that at least two and possibly three large earthquakes have ruptured the Pajarito fault in Holocene time.

New Mexico's Earthquake Hazards

Many of the world's greatest natural disasters have been due to earthquakes. In part, this is because earthquakes, like hurricanes, can generate severe effects over large areas. However, unlike hurricanes, earthquakes almost always occur without warning. Earthquake hazards can be classified into two categories: Primary hazards include ground shaking, surface fault rupture, and uplift or subsidence. Liquefaction, landslides, and water waves such as tsunamis are secondary effects because they are either caused by strong ground shaking or, in the case of tsunamis, sudden uplift or subsidence. In New Mexico, ground shaking, liquefaction, surface fault rupture, and earthquake-induced landslides are the most important hazards.

Ground shaking is the result of seismic waves reaching the earth's surface. This is the most damaging of all earthquake hazards because of its far-reaching effects. Ground shaking or ground motions at a given location are a function of earthquake size and rupture process, distance from the causative fault, the attenuating properties (damping and dispersion) of the earth along the travel path of the seismic waves, and the near-surface geological conditions beneath the site. Strong ground shaking can occur throughout the state but will be concentrated within the Rio Grande rift because of the proximity to active faults and because of the amplifying effects of the alluvial sediments in the basins that make up the Rio Grande rift (e.g., Albuquerque Basin). Also, it has been observed that locations on the hanging wall of dipping faults, as is the case where rift-bounding faults dip beneath the Rio Grande valley,

Exposure of the East Paradise normal fault near Albuquerque. Arrows show downward slip of the hanging wall. Photo courtesy of Steve Personius (U.S. Geological Survey).

will be subjected to enhanced ground shaking relative to the footwall. Finally, ground shaking at long periods will be amplified due to trapping and amplification of long wavelength seismic waves within the basins of the rift. Tall and long structures (tall buildings, long bridges, and highway overpasses) will be impacted by basin-amplified ground shaking.

Surface faulting occurs when an earthquake ruptures the fault to the earth's surface. As a result, movement generated at depth along the fault is propagated upward, resulting in displacement of the ground surface. In the 1887 Sonora earthquake, for example, the maximum vertical displacement at the ground surface along the Pitaycachi fault was 13 feet (4 m). Any structure situated along an active fault is subject to damage in a future earthquake. In the U.S., some states require that critical and important facilities not be built across active fault zones. This is not the case in New Mexico where such structures have been built across known active faults.

When water-saturated sandy and/or silty soil is subjected to strong earthquake ground shaking, a phenomenon called liquefaction can occur. Shaking can realign soil particles, decreasing soil strength and resulting in deformation. In extreme cases, the soil particles become suspended in ground water, and the deposit reacts as a fluid giving rise to sand or mud volcanoes. The phenomenon called lateral spreading is the result of liquefaction on sloping ground or near an escarpment or cliff, resulting in permanent ground displacement. The areas in New Mexico of most concern with respect to liquefaction are concentrated along the Rio Grande due to the presence of a high water table and liquefiable soils.

Earthquake-induced landslides are triggered by strong ground shaking. The rugged topography with steep mountain slopes and canyon walls in the Rio Grande rift are conducive to landslides and rock falls as evidenced by the non-earthquake-related failures documented throughout the state.

Reducing Earthquake Hazards

There is an increasing amount of new scientific research aimed at understanding the earthquake potential and the associated hazards in New Mexico. A large number of pre-building code structures in New Mexico were not adequately designed to withstand earthquake ground shaking, and engineers need to consider feasible and economic approaches for reinforcing these older buildings. Liquefaction and landsliding are not strongly considered in engineering design in New Mexico. Geologists and engineers need to become more proactive in terms of helping to inform the general public and encouraging them to take action to prepare for potential earthquakes.

Earthquake hazards are just one of several natural hazards and one of many public safety issues that New Mexico decision makers have to address. Because of the widespread damaging effects that a large earthquake could generate in New Mexico, there are no easy quick fixes and the economic cost of such fixes would be very large. However, the reality is that a large earthquake will strike New Mexico in the future, and increased efforts need to be made to prepare for that eventuality. Of particular concern is the large inventory of older buildings that do not meet modern standards for earthquake-resistant design. A risk assessment of critical buildings (such as hospitals, police and fire stations, and schools) is a logical and cost-effective first step for communities in New Mexico to reduce earthquake risk. Despite the potential for surface faulting that could accompany a large earthquake in the Rio Grande valley, no state or local laws exist that prevent new building construction astride active faults. Even public facilities have been constructed across active faults that have demonstrated surface rupture in the recent geologic past. Legislation to provide protection for New Mexico's citizens and that support funding of programs that are aimed at hazard identification and mapping, preparedness, response, and mitigation can prepare New Mexico for an eventual earthquake.

Paleoseismic trench excavated across a fault south of Socorro. Photo courtesy of Dave Love (New Mexico Bureau of Geology and Mineral Resources).

—Ivan G. Wong

Ivan Wong is a principal seismologist/vice president of URS Corporation in Oakland, California. For more than 30 years he has done seismic hazard evaluations worldwide and extensive research on the seismicity and active faulting in the western U.S., including New Mexico.

For More Information on Earthquakes

Visit the following Web sites for more information about earthquakes, earthquake preparedness, and emergency services:

New Mexico Bureau of Geology and Mineral Resources' earthquake education and resources Web site, http://tremor.nmt.edu

Lite Geology, no. 24, http://geoinfo.nmt.edu/publications/periodicals/litegeology/home.html

New Mexico Department of Homeland Security and Emergency Management, http://www.nmdhsem.org

American Red Cross, http://www.redcross.org/services/disaster/0,1082,0_583_,00.html

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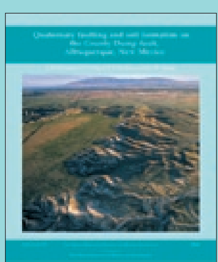
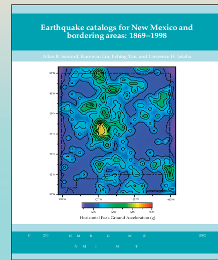
There are many publications that deal with earthquakes and earthquake hazards in New Mexico. The following are a selected few; most are available through our Publication Sales Office.

Machette, M. N., Personius, S. F., Kelson, K. I., Haller, K. M., and Dart, R. L., 1998, Map and data for Quaternary faults and folds in New Mexico: U.S. Geological Survey, Open-file Report 98-521, 443 pp., 1 plate, scale 1:750,000, http://earthquake.usgs.gov/regional/qfaults/.



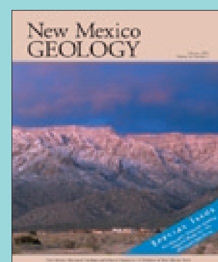
McCalpin, J. P., Olig, S. S., Harrison, J. B. J., and Berger, G. W., 2006, Quaternary faulting and soil formation on the County Dump fault, Albuquerque, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Circular 212, 36 pp. $10.00

Personius, S. F., Machette, M. N., and Kelson, K. I., 1999, Quaternary faults in the Albuquerque area—An update; *in* Pazzaglia, F. J., and Lucas, S. G. (eds.), Albuquerque geology: New Mexico Geological Society, Guidebook 50, pp. 189–200. $50.00



Sanford, A. R., Lin, K. W., Tsai, I. C., and Jaksha, L. H., 2002, Earthquake catalogs for New Mexico and bordering areas: 1869–1998: New Mexico Bureau of Geology and Mineral Resources, Circular 210, 101 pp. $10.00

Sanford, A. R., Mayeau, T. M., Schlue, J. W., Aster, R. C., and Jaksha, L. H., 2006, Earthquake catalogs for New Mexico and bordering area II: 1999–2004: New Mexico Geology, v. 28, no. 4, pp. 99–109. $4.00



Wong, I., Olig, S., Dober, M., Silva, W., Wright, D., Thomas, P., Gregor, N., Sanford, A., Lin, K., and Love, D., 2004, Earthquake scenario and probabilistic ground-shaking hazard maps for the Albuquerque–Belen–Santa Fe, New Mexico, corridor: New Mexico Geology, v. 26, no. 1, pp. 3–33. $4.00

For more information about these and other bureau publications:

- Visit our Web site at http://geoinfo.nmt.edu
- Write or visit our Publications Office on the campus of New Mexico Tech, 801 Leroy Place, Socorro, New Mexico 87801
- Call (575) 835-5490
- E-mail us at pubsofc @gis.nmt.edu
- Publication prices do not include shipping and handling or taxes where applicable.

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BUREAU NEWS

Earth Science Achievement Awards

On January 29 of this year the 2009 New Mexico Earth Science Achievement Awards were presented to Ron Gardiner, for outstanding contributions advancing the role of earth science in areas of public service and public policy in New Mexico, and to James C. Witcher, 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 and the Energy, Minerals and Natural Resources Department (EMNRD) in Santa Fe, were initiated in 2003 to honor those often unrecognized champions of earth science issues vital to the future of New Mexico. Selections were made following a statewide nomination process. The presentation took place at noon in the rotunda of the state capitol building on Thursday, January 29, during the legislative session in conjunction with Earth Science Day.

Ron Gardiner's wide-ranging career in water policy has included watershed planning and management. In New Mexico Ron has worked as a federal field technician in watershed monitoring and management for more than a decade. As a water and natural resources consultant Ron has worked at every level of community water and watershed planning in the Taos region, serving as a public advocate through consulting, writing, and public presentations. As a staff member at the New Mexico State Legislature, Ron's experience on critical water and energy resource committees has been key in helping to support policy-making decisions. For the past decade Ron has persuasively argued for more independent science and technology to support the policy and administration of water and natural resources in New Mexico.

James Witcher is widely recognized as the pre-eminent researcher on geothermal energy in New Mexico. He has thirty years of professional experience in geothermal exploration and development. He is particularly well known for his work on practical applications of geothermal energy, in particular the low-temperature geothermal resources that offer some promise here in New Mexico. He is also known for his understanding of the limitations of geothermal development in a state where water resources are scarce. For most of the last two decades he was on the staff of the Southwest Technology Development Institute at New Mexico State University. Since 2003 he has worked throughout the state as a private consultant, specializing in the exploration and development of geothermal energy and ground water.

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.

Additional Funding for Sacramento Mountains Studies

The Otero Soil and Water Conservation District received another appropriation from the legislature during the 2008 session for $534,000 to support the bureau's Sacramento Mountains Hydrogeology and Watershed Studies. This brings the total project funding to $2,362,000 and extends the study through FY 2012. Additional funding will allow us to:

—Complete geologic mapping in the upper Rio Hondo drainage and the Carrizozo area, and to expand mapping down the Pecos slope along the Rio Peñasco, with the objective of integrating hydrologic interpretations in the Sacramento Mountains with other research down gradient in the Roswell artesian basin and along the lower Pecos River. All geologic quadrangle maps are scheduled for completion by the end of FY 2011.

—Complete bimonthly water level monitoring in the Sacramento Mountains and the Pecos slope in FY 2009, and expand the spring and well inventory and monitoring network in FY 2010 and FY 2011 in the Tularosa and Three Rivers areas.

—Complete geochemical studies down the Pecos slope in FY 2009 and begin to integrate interpretations from existing research in the Roswell artesian basin and the lower Pecos River. Initiate geochemical studies in the Tularosa and Three Rivers areas in FY 2010.

—Conclude collection of hydrologic and evapotranspiration data in the watershed study and determine hydrologic influence of vegetation thinning and climate fluctuation on the local, watershed-scale water budget in the southern Sacramento Mountains.

—Synthesize and interpret the data and publish our findings.

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