



New Mexico EARTH MATTERS

WINTER 2010

THE VALLES CALDERA: NEW MEXICO'S SUPERVOLCANO

New Mexico contains one of the three largest young volcanoes in the United States: the Valles caldera, in the central Jemez Mountains west of Santa Fe. Calderas are large volcanic depressions, more or less circular, the diameter of which is many times greater than that of subsequent, post-caldera vents. The other two large calderas are Yellowstone, Wyoming, and Long Valley, California. Of the three, the Valles caldera is both the oldest and the smallest. But when it formed 1.25 million years ago, the explosions were anything but small. Approximately 95 cubic miles of high-viscosity molten rock (magma) was blasted into the stratosphere and onto the surrounding landscape, forming what is arguably New Mexico's most famous rock, the picturesque Tshirege Member of the Bandelier Tuff. As the tuff (consolidated volcanic ash) was erupted, the caldera floor collapsed, forming a broad circular depression roughly 12 x 14 miles across. In today's jargon, caldera-producing eruptions of this size are called supervolcanoes.

Magma of the Bandelier type, called rhyolite, are exceptionally hot, viscous liquids rich in silicon, aluminum, potassium, and sodium. The explosive power of such magma derives from its high content of dissolved water and other volatile components, as much as 5 to 6 percent water by weight. As this magma rises toward the surface of the earth, a depth is reached at which the pressure of overlying cold rocks is exceeded by the pressure of dissolved volatiles in the magma. The magma is then a mixture of melt, crystals, and bubbles, which can be thought of as an extremely

viscous, high-temperature foam. Much like a shaken champagne bottle when the cork is removed, rapid formation of free gas, mostly steam, eventually causes a violent explosion, but at eruption temperatures of roughly 1,700° F. When the bubble-rich magma fragments are blasted into the cold atmosphere, they "freeze," forming pumice. Pumice is nothing more than solidified magmatic foam.



Redondo Peak (11,254 feet) looking west across Valle Grande. This broad mountain is a resurgent dome formed by structural uplift of over 3,000 feet of intracaldera Bandelier Tuff. Recent research shows that Redondo grew during the 30,000-year period after the caldera formed, an average uplift rate of about one inch per year. Although uplift is caused by upwelling magma at depth, Redondo Peak is not a volcanic dome.

If pumice and ash rain out of the atmosphere during volcanic explosions, distinctive beds called pyroclastic-fall deposits accumulate on the landscape. Such beds are typically composed of light-colored, well-sorted layers of pumice. The layers display uniform bed thickness and mantle existing topography. Fragment sizes are generally dependent on distance from the volcanic vent, with larger pumice

near the vent and smaller ash far from the vent. Pyroclastic-fall deposits can be found throughout the Jemez Mountains but are best exposed in the southern Valles caldera area along NM-4 between the junctions with NM-501 and NM-126.

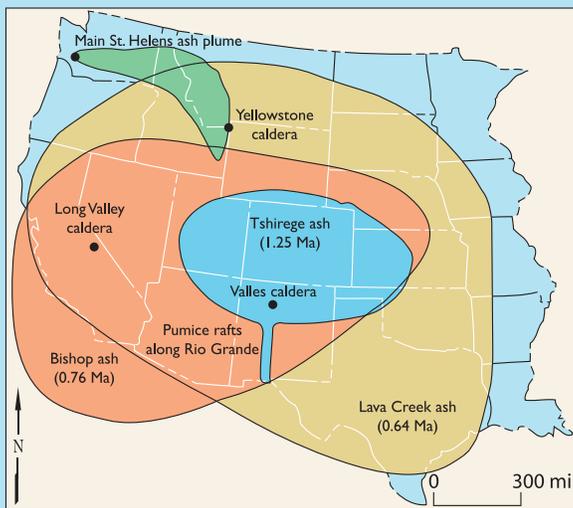
When supervolcanoes explode, they form huge, hot clouds of pumice, ash, crystals, and hot gas, called pyroclastic flows, which radiate outward from the caldera

at speeds of 50 to 200 miles per hour. Depending on volume, distance from the volcanic vent, and other factors, temperatures may easily exceed 1,000° F when the flows come to rest. In recent years pyroclastic flows have become known to the general public through movies such as *Dante's Peak* and a multitude of documentary films. Geologists call large pyroclastic-flow deposits ash-flow tuffs or ignimbrites. These rocks are mixtures of pumice, fine ash, crystal fragments, and pre-eruption rock debris (lithic fragments). The lithics are reamed out of the volcanic vents during eruption or picked up as the pyroclastic flows race over the countryside.

If emplacement temperatures are hot enough, the ash-flow deposits may "weld," a process in which enough heat is retained in the deposit to flatten pumice and glass shards and fuse them together. In most deposits viewed outside the Valles caldera (e.g., at Bandelier National Monument), the Tshirege (or upper) Member of the Bandelier Tuff is a nonwelded to moderately welded ash-flow tuff. However, some deposits of Tshirege inside the caldera are so densely welded they have formed glassy layers of rock resembling obsidian. Glassy,

welded ash-flow tuffs are sometimes called vitrophyres.

Volcanic ash from supervolcano explosions is often carried long distances by wind, but it can be distinguished by geochemical composition and by age. Because of our ability to obtain radiometric dates on volcanic materials, ash layers can provide important indicators of age in deposits that are otherwise difficult to date. Thus, we know that ash from the Valles caldera explosion was carried by winds as far away as central Utah and eastern Kansas and was rafted by the ancestral Rio Grande as far south as El Paso. If ash of known age is found in river, lake, and ocean sediments, it can provide accurate time constraints on sedimentation rates and other earth processes.



Minimum distribution of Valles caldera ash deposits; the prevailing wind direction at the time of the explosion was generally to the north. Rafts of pumice that floated down the Rio Grande formed deposits still observable as far south as El Paso.

Caldera Formation

From research published in the 1960s by Robert L. Smith and Roy A. Bailey of the U.S. Geological Survey, the Valles caldera became famous as the location where the first model of large caldera formation was devised: As large volumes of magma accumulate a few miles beneath the earth's surface, there may be swelling of the ground surface, rupture of faults and fractures, seismic activity, and heating of overlying ground water. Eventually gas pressure exceeds confining pressure of overlying rocks, and the magma explodes, producing immense pyroclastic falls and flows. Emptying of the magma chamber destabilizes pre-existing rock masses, which

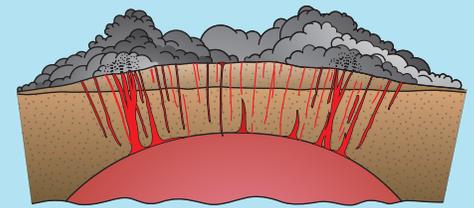
collapse into the chamber, forming a circular caldera depression. Much of the exploded pyroclastic material falls back into the collapse depression, but much is dispersed around the caldera and into the atmosphere.

After the caldera forms, several events take place almost simultaneously: Caldera walls slough inward forming an apron of sediments and landslides adjacent to steep slopes; a lake (or lakes) develop in the caldera depression from rain and snow melt; small volcanic flows and domes erupt into the lake, becoming interlayered with the sediments; and the caldera floor begins to lift from continued rise of magma from below. Rapid uplift of the caldera floor soon after caldera formation is called resurgence. After resurgence, more magma erupts along the ring of buried collapse faults, forming lava domes and flows between the resurgent dome and the caldera walls. These later eruptions, called ring-fracture or moat eruptions, become interlayered with yet more sediments and lake deposits. The interior of a well-developed, mature caldera eventually becomes a complicated maze of uplifted pyroclastic flows, lava flows, and sediments flanked by a ring of younger moat lava domes and sediments.

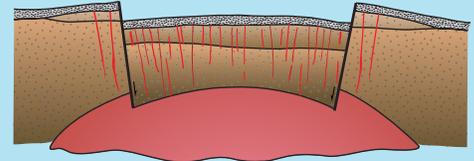
The Valles caldera forms an almost perfect circular depression containing a resurgent dome with more than 3,000 feet of central uplift above the caldera floor and a nearly complete ring of moat eruptions.

It is no wonder that the Valles caldera is the type example of a resurgent caldera and the place where volcanologists come to study caldera timing, deposits, and morphology. Most other calderas are not as perfect in form. For example, Yellowstone displays an elongate, elliptical shape with two resurgent domes. Ring-fracture eruptions were so voluminous that one resurgent dome and the west caldera wall are buried in younger lava flows. As a result, Yellowstone was not recognized as a resurgent caldera until many years after the Valles model was studied, published, and applied to other suspected calderas.

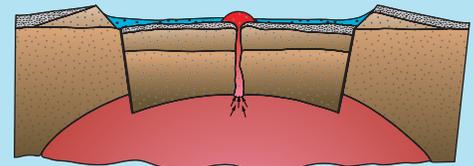
Because they commonly occur along hot spots, tectonic boundaries, and other locations where anomalously large amounts of heat rise from the mantle through the



Stage 1—Final stage of eruption



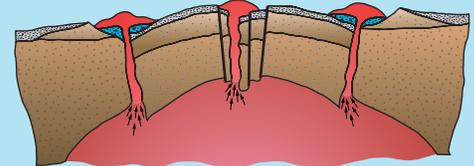
Stage 2—Post-eruption (caldera collapse)



Stage 3—Eruptive domes & lakes



Stage 4—Structural resurgence (resurgent dome)



Stage 5—Post-resurgent eruptive domes

General model of caldera formation.

earth's crust, calderas tend to form in clusters. Thus, the Valles caldera (1.25 million years old) was preceded in this region by the comparably sized Toledo caldera (1.62 million years old). Much of Toledo caldera was obliterated during formation of the Valles caldera. In Wyoming the Yellowstone caldera (0.64 million years old) was preceded by the smaller Henry's Fork caldera (1.3 million years old) and the larger Big Bend Ridge caldera (2.1 million years old). The San Juan Mountains of southwest Colorado contain more than fifteen calderas that formed between 24 and 30 million years ago, and the Gila Wilderness-Black Range region of south-

west New Mexico contains another ten calderas that formed between 25 and 35 million years ago.

Predicting the Next Eruption

People often ask if the Valles caldera is dormant or extinct. The youngest eruption within the caldera is the Banco Bonito lava flow dated at roughly 40,000 years ago, which is partially traversed by NM-4 in the southern caldera. Roughly twenty-five eruptions have occurred since the Valles caldera formed 1.25 million years ago, about one eruption every 50,000 years. Thus, on this crude statistical basis, we might expect the next eruption in another 10,000 years or so. But the length of time between these twenty-five eruptions is highly irregular, so predicting the next eruption on eruption frequency is not realistic. However, an eruption sometime in the



Digital elevation model of Valles caldera. Blue outline shows maximum extent of lakes in Valle San Antonio and Valle Grande approximately 500,000 years ago. The lakes formed when San Antonio Mountain and South Mountain lava domes erupted, blocking San Antonio Creek and East Fork Jemez River.

(albedo) causing climatic cooling. Such eruptions would presumably affect oscillatory climate patterns such as El Niño. Climate disruptions could continue for decades while the ash blanket is slowly eroded. Many researchers also have concluded that such eruptions have detrimental effects on animal populations; thus, formation of the Toba caldera, Indonesia (74,000 years ago), produced a huge outpouring of ash that bottlenecked human and animal migration and evolution. On the other hand, some of the world's most fertile regions are areas where deposits of volcanic ash accumulated, and marine life can benefit from the infusion of iron and silica from volcanic ash. Fortunately, gigantic caldera eruptions occur at an estimated frequency of only two to four events per million years. Nonetheless, it is impossible to predict when the next supervolcano will blow (making great fodder for "act of God" disaster movies).



Flow test of well VC-2a, May 1987, Sulphur Springs, Valles caldera, from a single fracture in Bandelier Tuff at 1,607 feet, 410° F. The geothermal "reservoir" underlies a thin cap of acid hot springs, fumaroles, and gas vents surrounded by rocks containing sulfur, kaolin, and other acid-stable minerals. Author photo.

future is likely; the Jemez volcanic field has produced hundreds of eruptions during its 14-million-year history, and the Valles caldera still retains immense quantities of heat within its interior. Most volcanologists would probably classify Valles as dormant.

Resources

The immense heat associated with caldera magma chambers and their eruption products creates hot springs, fumaroles, and underground reservoirs of hot water. In younger calderas these features are collectively called active hydrothermal systems or geothermal systems. The geothermal system of Yellowstone caldera, which includes Old Faithful, is world-renowned, but the Valles caldera also contains an active geothermal system with distinctive thermal features and a small, but hot (650° F), underground reservoir. Baca Land and Cattle Co. and Union Oil of California unsuccessfully explored the Valles reservoir for electricity generation potential between 1962 and 1984. Hydrothermal fluids dissolve metals from adjacent rocks and may form ore deposits in favorable underground horizons. In older, eroded calderas, such as Creede, Colorado, or Questa, New Mexico (26.9 and 25.7 million years old, respectively), these ore deposits are economically significant. Gold, silver, copper, lead, zinc, and molybdenum are commonly mined from hydrothermal deposits in eroded calderas.

The Impact on Climate

Recently much attention has been paid to the impact that supervolcanoes have on climate. A continent-sized ash blanket would produce significant sunlight reflectivity

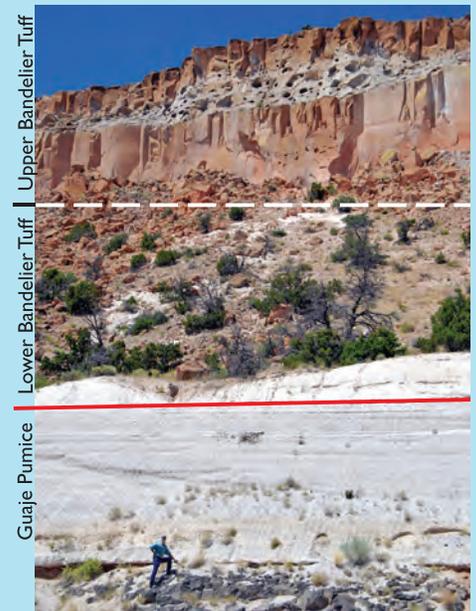


Photo of Tshirege Member (upper member) of the Bandelier Tuff, produced during the Valles caldera eruption (1.25 million years ago). It overlies the Otowi Member (lower member) of Bandelier Tuff from the comparably sized but earlier Toledo caldera event (1.62 million years ago). The Guaje pyroclastic-fall deposit underlies the lower Bandelier Tuff. Author photo.

Because calderas form collapse depressions, the resulting basins collect water that form lakes. Erosion of caldera walls and eruption of ring-fracture lavas can

cause repeated cycles of lake drainage and renewed lake formation. Lake deposits from the Valles caldera are dated by determining the age of interlayered volcanic deposits; thus, we know that a large lake occupied Valles soon after the caldera formed (1.25 million years ago) but that subsequent lakes occupied parts of the caldera roughly 800,000, 500,000, and 55,000 years ago. The South Mountain lake formed when eruption of the South Mountain rhyolite dome and flow complex blocked the ancestral drainage of the East Fork Jemez River roughly 520,000 years ago. Drilling of South Mountain lake deposits in Valle Grande produced cores that revealed a 200,000-year history of sediment accumulation, the longest mid-Pleistocene lake record in the southwestern U.S. Presently these cores are being studied to document climate cycles during this geologically “not-too-ancient” climate period. Similarities between our present climate and portions of the South Mountain climate cycles have been noted by several groups of researchers. These records may be useful in developing future climate models and predictions of future climate variations.

The Valles Caldera National Preserve

In 2000 the U.S. government purchased the Baca Land and Cattle Co. and created the 88,900-acre Valles Caldera National Preserve. The preserve is managed by the Valles Caldera Trust, whose mandate is to “protect and preserve the scientific, scenic, geologic, watershed, fish, wildlife, historic, cultural, and recreational values of the Preserve, and to provide for multiple use and sustained yield of renewable resources within the Preserve.” Detailed geologic maps of every 7.5-minute topographic quadrangle covered by the preserve are among the many multi-institutional scientific activities funded since 2000. These maps may be obtained from the New Mexico Bureau of Geology and Mineral Resources at: <http://geoinfo.nmt.edu/publications/maps/geologic/ofgm/home.cfm>. In 2010 the bureau will release a 1:50,000-scale color compilation as a single Valles caldera geologic map. Its appearance will no doubt spawn a new wave of geoscience research on the caldera.

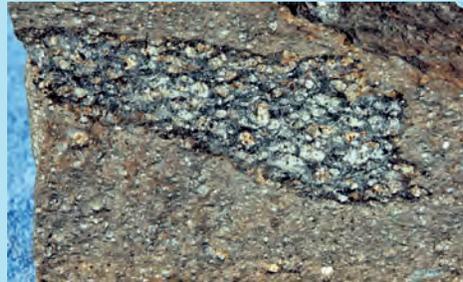
The Valles caldera will forever be a location of focused geoscientific research because it has so much to offer: well-characterized “supervolcano” features and



A 0 1 in



B 0 1 in



C 0 1 in



D 0 1 in

A—Bandelier pumice, an example of “frozen” magmatic foam; B—Nonwelded Bandelier Tuff (note the lithic and pumice fragments); C—Moderately welded Bandelier Tuff with large partially collapsed pumice; D—Densely welded Bandelier Tuff, so welded that it resembles obsidian. Author photos.

pyroclastic deposits, the “global model of caldera resurgence,” a classic, high-temperature geothermal system with analogs to fossil ore deposits, and a sequence of lake deposits recording late Pleistocene climate cycles. The Valles caldera is truly New Mexico’s “State Volcano,” a geologic treasure and one of the most famous calderas in the world.

—Fraser Goff

I give particular thanks to my colleague Jamie N. Gardner and my wife Cathy J. Goff (Janik) for their geologic and geothermal insight and unwavering support during my many years of Valles research. I also offer many, many thanks to the host of geoscientists who have worked on the Valles caldera since the turn of the last century. Long-term financial support from Los Alamos National Laboratory, the Valles Caldera National Preserve, the U.S. Forest Service, the U.S. Geological Survey, and the New Mexico Bureau of Geology and Mineral Resources is gratefully acknowledged. Thanks also to Nelia Dunbar for reviewing the manuscript.

Fraser Goff has spent 32 years working in the Jemez Mountains and Valles caldera. He was employed by Los Alamos National Laboratory from 1978 to 2004 to conduct geothermal energy and volcanology research and now works with the New Mexico Bureau of Geology on the STATEMAP Program. He received his B.S. in chemistry from San Jose State College (1971) and his Ph.D. in earth science from the University of California, Santa Cruz (1977).

Additional Reading

Valles Caldera – A Geologic History by Fraser Goff. University of New Mexico Press, 2009.

Valles Caldera: Map and Geologic History of the Southwest’s Youngest Caldera by Kirt Kemper and Dick Huelster. High Desert Field Guides, 2007.

Encyclopedia of Volcanoes, Haraldur Sigurdsson, editor-in-chief. Academic Press, 2000.

When Yellowstone Explodes by J. Achenbach. In *National Geographic*, v. 216, pp. 56–69, 2009.

BUREAU NEWS

Earth Science Achievement Awards

On February 4 the 2010 New Mexico Earth Science Achievement Awards were presented to Dr. Gary King, for outstanding contributions advancing the role of earth science in areas of public service and public policy in New Mexico, and to Dr. Bruce Thomson, for outstanding contributions advancing the role of earth science in areas of applied science and education in New Mexico. These awards are 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 (EMNRD) in Santa Fe. They 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.

Gary King has long been a champion of natural resource protection and environmental issues. A native New Mexican from Stanley, Gary King holds a Ph.D. in organic chemistry from the University of Colorado and a law degree from the University of New Mexico. He was assistant secretary for environmental management at the U.S. Department of Energy and served for twelve years in the New Mexico State Legislature. During this time, he sponsored a bill that would establish a mining reclamation law in New Mexico for the first time. Dr. King served as a commissioner and chairman of the Mining Commission. In 2006 he was elected Attorney General of New Mexico, where he continues his efforts.

Bruce Thomson is director of the University of New Mexico Water Resources program and a professor in the Department of Civil Engineering, where he now serves as Regents Professor. His research is focused on the chemistry and treatment of inorganic contaminants in ground water, especially arsenic and uranium. Recent research projects have been directed toward issues associated with reuse of treated waste water. He has served on several local, state, and national committees dealing with water issues, including ten years of service on the Water Quality Protection Advisory Board, which reports to the City of Albuquerque, Bernalillo County, and the Albuquerque Bernalillo County Water Utility Authority.

Upcoming Retirements

It is with regret that we announce the retirement this summer of four bureau researchers with over a century of combined service. Three of them will remain on staff one-quarter time. **Richard Chamberlin** began his 30-year career at the bureau as a uranium economic geologist. Since 1990 he has concentrated on geologic mapping in volcanic terranes of central New Mexico. Research includes his work on domino-style crustal extension in the Rio Grande rift, a detailed eruptive history of the Socorro caldera, and an ongoing study of mafic dikes that radiate outward from the caldera cluster southwest of Socorro. Former director Frank Kottlowski once referred to Richard as “my idea man.” Richard is well known for his work on the tectonics and thermal history of central and southwestern New Mexico. **Robert Eveleth**, the bureau’s mining engineer, has spent 33 years keeping track of New Mexico’s mineral production activities. Bob has probably answered every conceivable question on New Mexico mining history, mining law, and mining claims and has explained every aspect of the mineral extraction industry. Bob has been associate curator of the bureau’s mineral museum for years and participated in the Abandoned Mines Program on underground metal mines. He is the creator and manager of the bureau’s mining archives and database, which include more than 5,000 historic and irreplaceable photographs. **Ibrahim Gundiler** has served New Mexico Tech as a professor in the Department of Metallurgy and as a researcher. Since becoming the bureau’s extractive metallurgist in 1989 Abe has been involved in countless projects—researching noncyanide extraction of gold and silver, solving corrosion problems in oil and gas wells, improving the processing of potash ores, and reprocessing mine tailings, to name a few. However, when asked what a metallurgist does, Abe defers to the definition of his professor Terkel Rosenqvist: “A metallurgist should be a jack of many trades and a master of some.” **Marshall Reiter** joined New Mexico Tech in 1970, first teaching in the geology department for five years, then moving to the bureau where he pursued geothermal studies in New Mexico and neighboring areas. He and his students have identified the high heat flow of the Rio Grande rift and the San Juan Mountains and have used measurements of subsurface temperature gradients to study ground water flow.



New Mexico EARTH MATTERS

Volume 10, Number 1
Published twice annually by the
NEW MEXICO BUREAU OF GEOLOGY
AND MINERAL RESOURCES

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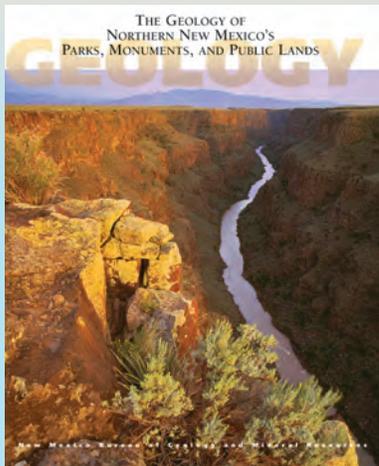
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Coming Soon



The Geology of Northern New Mexico's Parks, Monuments, and Public Lands, L. Greer Price, editor, 380 pp. Available May 1. ISBN: 978-1-883905-25-5. \$24.95

Few places in the U.S. boast as rich a diversity of landscape and public lands as northern New Mexico. Here in one volume is an authoritative overview of the geology of these parks, monuments, and public lands, with information on the regional setting, the rock record, and the most prominent geologic features. The book includes chapters on nine national parks and monuments, seventeen state parks, and many of the most popular Bureau of Land Management and U.S. Forest Service units in this part of the state. Also included are chapters on two of our newer units, the Valles Caldera National Preserve and Kashe-Katuwe Tent Rocks National Monument. With nearly 300 full-color geologic maps, graphics, and photographs, the book is a perfect introduction to some of New Mexico's most significant geologic landscapes.

*We are currently working on a new **Geologic Map of the Valles Caldera, Jemez Mountains, New Mexico**, by Fraser Goff, Jamie N. Gardner, Steven L. Reneau, Shari A. Kelley, Kirt A. Kempter, and John R. Lawrence. This detailed map, which will be printed at a scale of 1:50,000, has been compiled from detailed larger-scale maps of nine 7.5-minute topographic quadrangles completed as part of the federally funded STATEMAP program. The new map compilation encompasses the Valles Caldera National Preserve and includes the westernmost parts of Bandelier National Monument and Santa Clara Pueblo. This is the first geologic map of the Valles caldera to be published since 1970 when the U.S. Geological Survey released its 1:125,000-scale geologic map of the Jemez Mountains, New Mexico, by Robert L. Smith, Roy A. Bailey, and Clarence S. Ross. Since 1970 four decades of new geologic studies and mapping and new geochronologic data have added to our understanding of the relations of stratigraphic units in and around the Valles caldera. The new map and its accompanying cross sections, unit descriptions, and correlation chart represent the collective work of dozens of researchers, mappers, and lab technicians. We hope to have it out by the end of 2010.*

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