New Mexico
EARTH
MATTERS

WINTER 2016

SINKHOLES: A HIDDEN, REAL NEW MEXICO GEOHAZARD

The majority of New Mexicans probably regard sinkholes as an exotic geohazard that occurs far away in other parts of the country. In places such as Florida or Kentucky, sinkholes have opened beneath and "swallowed" houses, roads, and classic Corvettes in the National Corvette Museum (which occurred on February 12, 2014). However, New Mexicans living in the east-central and southeastern parts of the state may view sinkhole development as a real and present danger. Indeed, they might be aware that Blue Hole, in the Santa Rosa area, and most of the lakes at Bottomless Lakes State Park east of Roswell are, in fact, sinkholes (see photo on this page). Large cavities have been encountered when drilling water wells in this region, and oil and gas drillers have discovered large voids in the subsurface. Residents in these regions may have also observed sudden muddying of regional well waters after major rainfall events, as well as standing water collecting in low-lying areas in pastures and fields. The phenomena of sinkholes, subsurface cavities, interconnectivity of water-bearing strata directly affected by large weather systems, and the slow, barely noticeable subsidence of depressions in the land surface are all related; they occur in areas characterized by soluble bedrock and are all part of so-called *karst* landscapes. More than 25 percent of the world's population either lives on karst terrain or derives its water from karstic aquifers. In 2008, two very large sinkholes (approximately 111 m [364 ft] and 64 m [210 ft]) in diameter, respectively, abruptly formed in the oil fields east of the Pecos Valley and made national news. See photo on page two. If southeastern New Mexicans were previously unaware of this hidden geohazard, they were alerted by news reports and hazard signs on both state and U.S. highways, warning of the potential for a sinkhole encounter (see second photo on page two).

Mirror Lake, one of several sinkholes at Bottomless Lakes State Park east of Roswell, where upward artesian flow of groundwater through gypsum bedrock has produced solution-collapse sinkholes. Photo by Lewis Land.

Sinkholes associated with oilfield activities differ from the numerous others throughout the region in that they are man-made, or anthropogenic. We now know, largely through geophysical work carried out by the National Cave and Karst Research Institute (NCKRI) with the New Mexico Bureau of Geology and Mineral Resources (NMBGMR), that another potentially catastrophic anthropogenic sinkhole could form on the south side of Carlsbad, beneath the intersection of U.S. Highway 285 with U.S. Highway 62, an interchange known locally as the South Y. This hazard is discussed later in this article.

Karst, hydrology, and solution processes

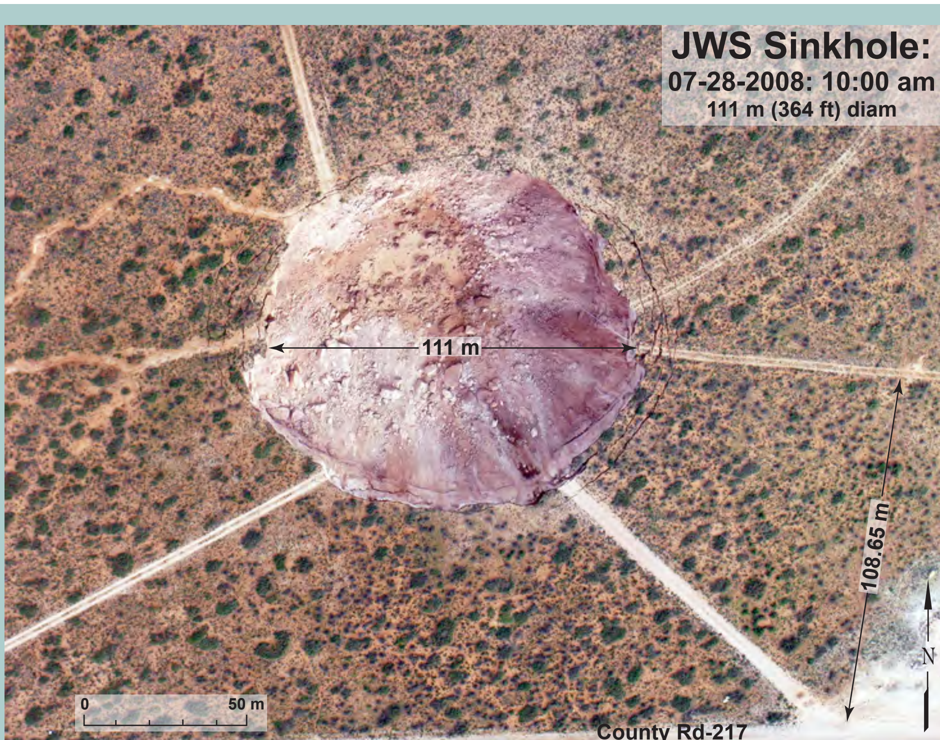
The term karst describes a landscape containing caves, sinkholes, and extensive underground water systems formed by the dissolution of soluble rock by circulating groundwater. What does this mean? For groundwater to circulate, it must be able to move through the subsurface bedrock, primarily through cracks, called "joints." In regions where bedrock is composed of soluble rock types, such as limestone, dolomite, or gypsum, groundwater moving through joints actually dissolves the rock, creating cavities in the subsurface.

The word karst is based on a 19th Century German modification of the Slavic word *kr*s and the Italian *carso*, which essentially both mean "a bleak, waterless place." Although this description could apply to many desert landscapes, it originally referred to a specific region—the barren, high plateau area of what was then northwest Yugoslavia (current-day Slovenia and Croatia). This area is characterized by dry stream valleys, often ending abruptly, and numerous depressions. Water, instead of running freely over the land, seemingly sinks into the ground.

All rocks, given sufficient time, undergo physical weathering, which results from the disintegrative erosional processes caused by flowing water and wind, and chemical weathering, which results when rocks and minerals are dissolved into constituent molecules that can be washed away from the rock mass. In the case of carbonate and evaporitic rocks, water and carbonic acid act as the chemical weathering agents that break these rocks down. Carbonic acid forms when meteoric water (rain) combines with carbon dioxide, which is produced by organic constituents in the soil. Similar dissolution can take place on your teeth, through exposure to carbonic acid in soft drinks, and can cause cavities.

Most karst features in the eastern United States and other karst areas around the

Published by the New Mexico Bureau of Geology and Mineral Resources • A Division of New Mexico Tech



The JWS Sinkhole, one of two anthropogenic sinkholes that opened above brine extraction wells in 2008 in the Loco Hills area of northern Eddy County. Courtesy of National Cave and Karst Research Institute.

world are formed in the carbonate rocks, limestone (calcium carbonate) and/or dolomite (calcium-magnesium carbonate). In arid and semi-arid areas such as southeastern New Mexico, however, karst features more commonly form in evaporitic bedrock. Evaporites are a type of rock produced by salts left behind during the evaporation of saline water. The most common types of evaporite rock are gypsum, composed of calcium sulfate, and halite, the mineral name for sodium chloride, or table salt. Thick deposits of gypsum and halite are present at the surface and in the subsurface throughout the Permian Basin region of southeastern New Mexico and west Texas. From roughly the vicinity of Carlsbad northward, evaporite rocks were formed in mudflats of vast, shallow lagoons, between 270–250 million years ago. As the sea retreated, the water evaporated, resulting in precipitation of the salts. With time, these calcium-, magnesium-, and sodium-enriched deposits were lithified into gypsum and anhydrite (hydrated and anhydrous calcium sulfate, respectively), halite, and other more exotic minerals.

These evaporitic rocks are much more soluble than carbonates in the presence of fresh water, and do not require carbonic acid for dissolution to occur.

Highway sign adjacent to NM State Highway 360, east of Artesia, warning of the possible sinkhole/subsidence hazard. Photo by Lewis Land.

In some geologic settings, karstic cavities may also form by dissolution related to hydrogen sulfide. This gas rises up from deep reservoirs of hydrocarbons. When mixed with groundwater, sulfuric acid is formed. This acid attacks carbonates much more vigorously than meteoric water or carbonic acid. Carlsbad Caverns, Lechuguilla Cave, and other cave systems in the Guadalupe Mountains of southeast New Mexico and west Texas have formed through this dissolution process.

Karst features and landforms

Limestones and dolomites, wherever exposed at the surface, will, over time, show numerous minor solution effects. These small (one to several centimeters in size) etched pits, grooves or runnels, hollows or flutes, are often separated by small, knife-like ridges and pinnacles. Collectively, these features are known by the German term, *karren*. Dissolution may be concentrated along joints in the bedrock, and widening of these joints forms large conduits, enhancing the infiltration and circulation of water through the rocks.

While karren terrain might be painful to bare feet and hard on shoes, it is relatively harmless compared to the hazards wrought by the sudden formation of large-scale karst features. Subsurface karstic cavities enlarge and coalesce, forming underground channels for groundwater flow, ultimately allowing collapse of the overlying land surface. Of the resulting karst landforms, such as closed depressions and sinkholes, are the most common, often occurring by the thousands in major karst areas. Disappearing streams, large springs, and cave systems also typify karst terrain.

Streams "disappear" when surface water flows or infiltrates into underground cavities. This process creates landforms such as *blind valleys* (where a valley terminates against a rock wall and the stream abruptly disappears), *pocket valleys* (essentially the opposite, where groundwater discharges from a spring and flows down a valley), and *dry valleys* (occupied by no surface stream, but often above a subsurface one). During a storm event, surface runoff in dry valleys infiltrates rapidly into subsurface conduits (see photo on page three).

Disappearing reservoirs

Somewhat similar to disappearing streams, two New Mexico reservoirs, the Hondo Reservoir and Lake McMillan, "disappeared" during the 20th Century and ultimately had to be abandoned. Problems began for the Hondo Project even before the reservoir was built to store water for irrigation. In 1904, the director of the newly created U.S. Reclamation Service was shocked to discover that large cavities occupied the floor of the proposed reservoir site, located about 18 km (11 mi) southwest of Roswell. Nevertheless, officials were mollified by proponents' claims that there were more than sufficient quantities of local clay for sealing the floor. The reservoir was completed in 1907 but was never able to hold significant quantities of water. In several of the post-construction years, attempts were made to repair the lakebed, but larger holes kept being discovered, and the repairing of the reservoir floor was finally abandoned. Around 1917, the Reclamation Service gave up on the project entirely.

Lake McMillan Reservoir, which stored Pecos River water for the Carlsbad Irrigation District, also leaked for much of its 98-year history and was eventually replaced by Brantley Reservoir, located 10 km (6 mi) downstream. Lake McMillan Dam, completed in 1893, the first large-scale irrigation project on the Pecos River, was designed with a storage capacity of 138,000 acre-feet. Improvements made on the dam in 1894 and 1904 following damaging floods made it the largest dam in the world at that time. Nevertheless, because of the gypsum bedrock beneath the lakebed, and adjacent gypsum bluffs of the McMillan Escarpment east of the valley, the reservoir almost immediately began leaking, particularly along the eastern margin of the lake. Much of the reservoir water, lost through karstic conduits, resurfaced in a series of springs in the Pecos River appproximately 6 km (3.5 mi) downstream. A seepage-control and containment levee was constructed in 1908–09 to prevent the water from reaching the bluffs, but during high water levels and occasional breaks in the levee, whirlpools could be seen on the lake, and high rates of leakage occurred. In 1991 McMillan Dam was breached and Lake McMillan was allowed to drain into Brantley Lake. Based on recommendations by the U.S. Geological

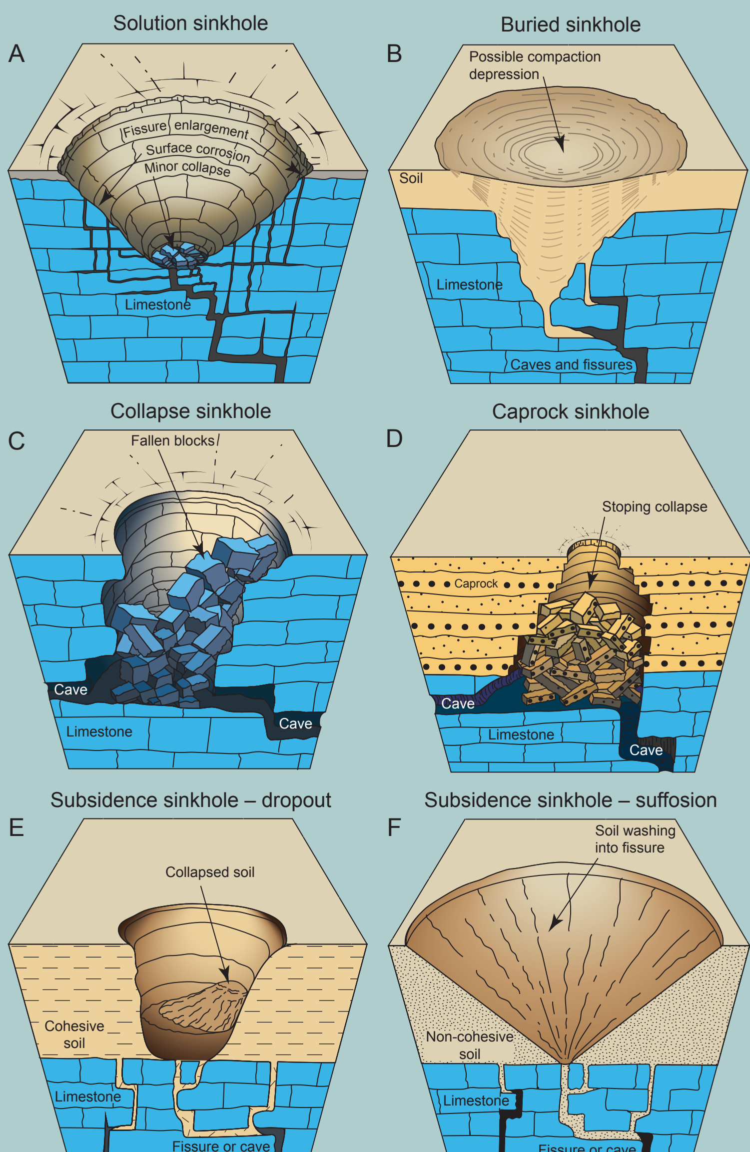
This tributary of Chalk Bluff Draw, southeast of Artesia, is a typical karst dry valley. Surface runoff, quickly infiltrates into the ground via the two small sinkholes that developed in the channel floor. Photo by David J. McCraw.

Survey, the new reservoir is located mostly on carbonate bedrock, which is less prone to sinkhole formation than the gypsum bedrock underlying former Lake McMillan.

Sinkhole formation and the human impact

Sinkholes are a diagnostic karst landform. Sinkholes are typically circular to elliptical in shape, and wider than they are deep. Shapes vary considerably, ranging from a disc or shallow bowl to the much more common funnel form to even a vertical cylinder. Although numerous mechanisms are responsible for the creation of sinkholes, they can be generalized into three categories: 1) Those formed by surface or near-surface bedrock dissolution (panels A and B) on left; 2) Those formed by collapse of bedrock overlying cavities (panels C and D); and 3) Those formed entirely in the soil overlying solutional cavities in the bedrock (panels E and F).

Solution sinkholes and buried sinkholes (A and B) are widespread around the world, but they form relatively slowly, resulting in minimal human impact. Like all solutional landforms, these are dependent on the following factors: topography and slope, the type of bedrock and its degree of jointing, and the amount of vegetation and soil cover. Typically, for solution-sinkhole formation and growth to occur, three conditions are met: 1) Location in swales on otherwise flat terrain where ponding accelerates infiltration; 2) Presence of well-jointed bedrock beneath the swale, which favors zones of cavity-causing, preferential fluid flow, as opposed



Mechanisms of sinkhole formation. Modified from Waltham, 2008, Quarterly Journal of Engineering Geology and Hydrogeology, v.41, p. 292.

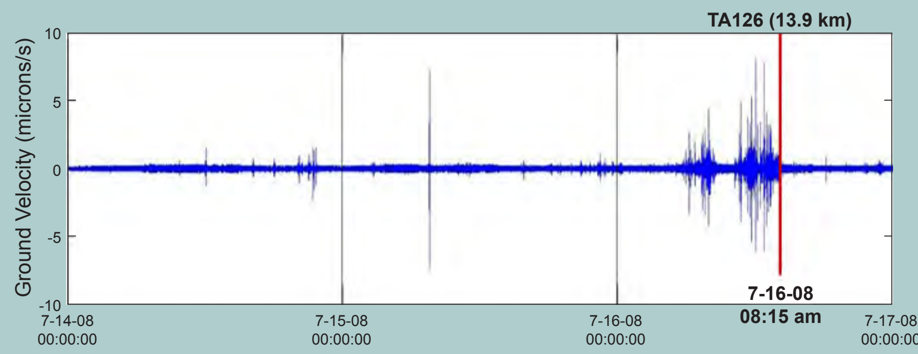
to areas of diffuse infiltration; 3) Presence of good vegetation and soil cover, which provides an ample CO_2 source to form acidic waters for dissolution.

Bedrock-collapse sinkholes (panels C and D) are fairly rare and therefore have little societal impact. Like cave formation, these features take several thousands of years or more to develop before the subsurface cavities grow to sufficient size that weight of the overlying bedrock can no longer be supported.

The most common type of sinkholes, and also those that represent the most serious geohazard, form either by collapse or by subsidence of the soil or surficial sediments (cover or overburden) (panels E and F). Cover-collapse sinkholes, or dropout sinkholes, form by the abrupt collapse of compacted, often clay-rich sediments over a cavity. Cover-subsidence sinkholes, on the other hand, form by *suffosion*, a process wherein loose soil and sediments wash downward into open fissures and cavities within the top of the underlying bedrock. Like the buried sinkhole example shown in panel B, depression of soil can be a slow process. However, most sinkholes of this type experience a sudden initial drop, followed by additional slow subsidence.

Pseudokarst

City streets occasionally collapse due to a burst, buried water main. Although the news media call these collapses "sinkholes," they do not meet the defining criteria, as they do not form by dissolution. During collapses caused by water main failure, suffosion is the initial culprit. After pipe failure, high-pressured water starts immediately washing away the finest grained sediment. As small voids develop the remaining sediment begins to flow into these new voids and is also washed away, allowing void spaces to grow. Eventually



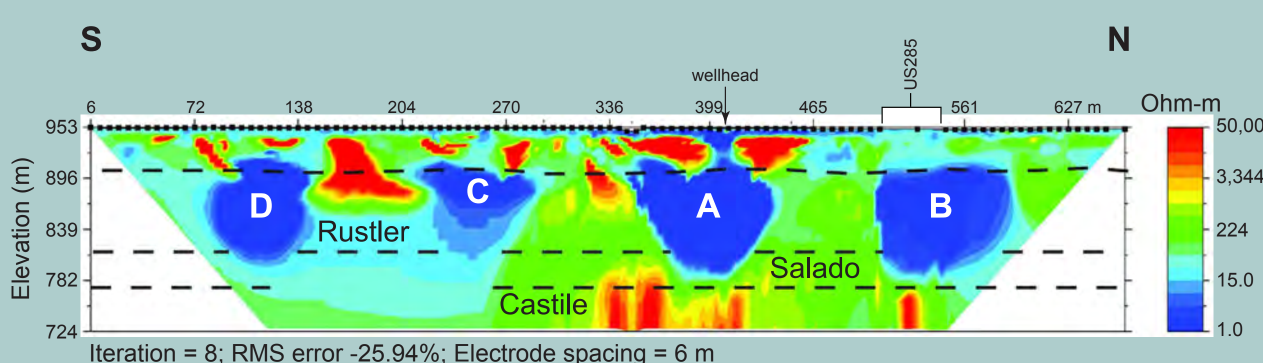
A July 2008 three-day seismograph record of vertical ground velocity measured by seismometer TA126, located approximately 13 km (8 mi) from the JWS brine well, showing more than six hours of ground motion leading up to sinkhole formation. The estimated time of surface breaching (8:15 am) is depicted by a vertical red line. By Lewis Land.

the weight of the surficial sediments, pavement, etc. can no longer be supported, and dropout collapse occurs. This process results in *pseudokarst*, and it can occasionally be catastrophic. In a suburb of Guatemala City in 2007, a major sewer failure following a period of heavy rains triggered a dropout of more than 20 m (66 ft) across in the middle of the night, swallowing five houses and a road and killing three people.

Other anthropogenic sinkholes and the Carlsbad "South Y"

In the evaporitic rocks of southeastern New Mexico and west Texas, improperly cased abandoned oil wells, as well as solution mining practices used to obtain brine from near-surface salt beds, have created subsurface voids directly responsible for catastrophic collapse-sinkhole formation. During solution-mining operations, fresh water is pumped into the salt bedrock, circulated until it reaches saturation, and the resultant brine is pumped out. The brine from extraction wells is used during construction of oil and gas wells to enhance production. Examples of solution-mining induced sinkholes include the Wink sinks in Winkler County, Texas, the Borger sinkholes in Hutchinson County, Texas, the Jal sinkhole in Lea County, New Mexico, and the 2008 Loco Hills and JWS sinkholes in northern Eddy County, New Mexico. Fortuitously, four months prior to formation of the JWS sinkhole, a seismometer had been installed as part of the National Science Foundation's EarthScope USArray program approximately 13 km (8 mi) to the southeast. About six hours prior to the collapse, the instrument (TA126) began recording high frequency seismic signals, presumably produced by the collapse of large blocks off the brine cavern's roof. These signals continued until the collapse occurred at 8:15 am on July 16th (above). Less than four months later, another brine-well collapse occurred in northern Eddy County within the small community of Loco Hills.

Following the collapse of the Loco Hills sinkhole, the New Mexico Oil Conservation Division (NMOCD) imposed a six-month moratorium on all brine well operations and began a review of other brine wells in the state. In the review, it was determined that the I&W brine well on the south (continued on last page)



Profile of ER array line INW4 showing four distinct cavities in blue (A–D); black dots show individual electrode locations. The names Rustler, Salado, and Castile indicate the geologic formations represented in the cross section. By Lewis Land.

BUREAU NEWS

Photo courtesy of Peter Mozley.

AAPG award for Scholle book

Drs. Dana Ulmer-Scholle (Research Professor at NM Tech) and Peter Scholle (Emeritus Director of the Bureau of Geology and Mineral Resources) were the lead authors on a recently completed book—A Color Guide to the Petrography of Sandstones, Siltstones, Shales, and Associated Rocks. Published by the American Association of Petroleum Geologists (AAPG) as Memoir 109, the 540-page, full-color, hardbound book is designed to help students, instructors and industry professionals with the microscopic study of siliciclastic rocks and associated deposits (cherts, evaporites, and others). It contains over 1,100 light microscope and scanning electron microscope images of grains, textures, and structures of clastic terrigenous rocks as well as their diagenetic alteration (compaction, cementation, dissolution, and replacement) and porosity reduction or enhancement. In addition, full-color diagrams, an extensive glossary, index, foldout birefringence chart, and an included DVD with Powerpoint files of all of the petrographic images provide additional information for both novices and experienced practitioners.

The volume also provides classification diagrams for accurate description of sedimentary rocks and their porosities. Perhaps most importantly, the book, through its extensive picture captions, emphasizes paragenesis, the sequencing of events in the post-deposition history of sedimentary rocks. The ability to distinguish the relative timing of compaction, dissolution, cementation, and deformation events is critically important in petroleum and minerals exploration (and in general geologic investigations as well), and petrography is arguably the most important tool to accomplish such studies, especially when used in conjunction with a variety of radiometric dating and thermal history analysis tools.

Although most of the examples within the book are from the United States and Puerto Rico (New Mexico samples, like the cover art, are common throughout the book), there are also photographs of samples from 32 other countries.

Photo courtesy of Martha Cather.

Demolition of old Bureau of Geology building

While machinery knocked down the old bureau building in December, there was much discussion of the 45-year history that building represented. Since its inception in 1927, the bureau has been located in 4 different buildings on campus. First, the basement of Brown Hall until 1949, second, in old Workman Center, and third, the Workman Annex built during the mid 1970s. The bureau is now located in the much-celebrated Headen Center. For more information about the bureau's history go to: **geoinfo.nmt.edu/publications/periodicals/earthmatters/5/n2/em_v5_n2.pdf**

View new video about the Bureau of Geology

This short informational video, produced by the staff of the New Mexico Bureau of Geology and Mineral Resources, explains who we are and what we do for the State of New Mexico. In addition to highlighting our research and service missions, the video also showcases our new building, which was completed in April 2015. View the video at: **geoinfo.nmt.edu/about/video/home.html**

New Mexico
EARTH
MATTERS

Volume 16, Number 1
Published twice annually by the
New Mexico Bureau of Geology and Mineral Resources
Matthew J. Rhoades, CPG, RG
State Geologist and Director
a division of
New Mexico Institute of Mining and Technology
Daniel H. López
President
801 Leroy Place
Socorro, New Mexico 87801-4750
(575) 835-5420

Bureau Albuquerque office
2808 Central SE
Albuquerque, New Mexico 87106
(505) 366-2530

Visit our website at:
geoinfo.nmt.edu

Editors
Nelia Dunbar
Gina D'Ambrosio
Richard Arthur

Layout & Graphics
Gina D'Ambrosio
Leo Gabaldon

Earth Matters is a free publication.
For subscription information please call
(575) 835-5490, or e-mail us at
publications@nmbg.nmt.edu

Cover photo of Chimney Rock, New Mexico
© **Matthew Zimmerer**

New Mexico Bureau of Geology & Mineral Resources
New Mexico Institute of Mining & Technology
801 Leroy Place
Socorro, New Mexico 87801-4750
Return service requested

SINKHOLES: A HIDDEN, REAL NEW MEXICO GEOHAZARD *(continued)*

side of Carlsbad was in a similar geologic setting to the JWS and Loco Hills sinkholes and had a similar drilling history, continuously pumping brine since 1979. Because the I&W operation was located near the intersection of two major U.S. highways known locally as the "South Y," the BNSF rail line, the Carlsbad Irrigation District's South Canal, a feed store, a mobile home park, a truck stop, and a church, NMOCD permanently closed the brine well operation and fined I&W, which then declared bankruptcy. The City of Carlsbad and Eddy County established a Brine Well Working Group, and with NMOCD research funds set up a monitoring array of tilt-meters to warn of potential collapse and established emergency management protocols. Attempts were made to measure the size and shape of the cavity using sonar methods, but these attempts were unsuccessful. NCKRI, in conjunction with NMBGMR personnel, was then funded to conduct an electrical resistivity (ER) survey in 2011 to measure the cavity's approximate size and shape.

During an ER survey, evenly spaced electrodes are driven into the ground in a linear array and a direct electrical current is generated between a pair of electrodes, while an adjacent pair is used to record the ground voltage. Given the current flow and voltage drop between electrodes, differences in subsurface electrical resistivity can be determined, and profiles illustrating vertical and lateral variations in subsurface resistivity are generated. Subsurface voids filled with brine are easy to detect because of the very low resistivity of saline water.

The South Y ER survey consisted of six array lines of 112 electrodes each, spaced six meters apart. As seen on the accompanying plot of line INW4 (on page 4), four distinct blue polygons (labeled A-D) representing subsurface voids, can clearly be seen. These four cavities were created by the two I&W injection/extraction wells. Sinkhole hazard warning signs are now posted on all roads leading into the South Y interchange; the area is now continuously monitored using surface and downhole tilt-meters; and remediation plans are under consideration by NMOCD and the city of Carlsbad.

Depressions form and enlarge, and new sinkholes form almost on an annual basis in southeastern New Mexico. The NMBGMR continues to focus on geologic mapping and research as well as hydrogeologic assessments, aquifer characterization, and groundwater monitoring in this region. We are also involved in public outreach and education, and provide decision makers with state-of-the-art scientific data and interpretation to make informed environmental and emergency management decisions regarding the potential hazards of living in a karst-prone region.

—David J. McCraw and Lewis Land

David J. McCraw has worked for 20 years at the bureau concentrating on geologic mapping, geologic map making, and earth surface processes.

Lewis Land is a karst hydrogeologist with the bureau and is the bureau's liason with the National Cave and Karst Research Institute in Carlsbad, New Mexico.

For more information about the bureau and its publications:

Visit our website at **http://geoinfo.nmt.edu;** Call (575) 835-5490, or e-mail us at **publications@nmbg.nmt.edu**; or visit our Publications Office at our new location on the corner of Bullock and Leroy on the campus of New Mexico Tech, 801 Leroy Place, Socorro, NM, 87801.