Evaporite karst features and processes at Nash Draw, Eddy County, New Mexico

Dennis W. Powers, Richard L. Beauheim, Robert M. Holt, and David L. Hughes

2006, pp. 253-265. https://doi.org/10.56577/FFC-57.253

in:

Caves and Karst of Southeastern New Mexico, Land, Lewis; Lueth, Virgil W.; Raatz, William; Boston, Penny; Love, David L. [eds.], New Mexico Geological Society 57th Annual Fall Field Conference Guidebook, 344 p. https://doi.org/10.56577/FFC-57

This page is intentionally left blank to maintain order of facing pages.

EVAPORITE KARST FEATURES AND PROCESSES AT NASH DRAW, EDDY COUNTY, NEW MEXICO

DENNIS W. POWERS[1], RICHARD L. BEAUHEIM[2], ROBERT M. HOLT[3], AND DAVID L. HUGHES[4]

[1]140 Hemley Road, Anthony, TX 79821, dwpowers@evaporites.com

[2]Sandia National Laboratories, 4100 National Parks Highway, Carlsbad, NM 88220,rlbeauh@sandia.gov

[3]Department of Geology and Geological Engineering, The University of Mississippi, University, MS 38677-1849, rmholt@olemiss.edu

[4]Washington Regulatory and Environmental Services, P.O. Box 2078, Carlsbad, NM 88221, Dave.Hughes@wipp.ws

Abstract.—Nash Draw, about 30 km east of Carlsbad, NM, is a karst valley developed on Upper Permian evaporite rocks of the Rustler and Salado Formations. Early studies found sodium chloride brine along the draw axis above halite of the Salado Formation, with the brine flowing toward and into the Pecos River. The draw was interpreted as the consequence of erosion, solution, and fill. Later studies report solution of sulfate units of the Rustler, yielding more complicated surficial structures.

More drillhole logs are now available, showing that the eastern margin of Nash Draw (Livingston Ridge) overlies the position where the elevation of upper Salado halite changes, as deos the thickness across the upper Salado and the elevation of overlying units. These elevation changes reflect dissolution of Salado halite. Depressions along Livingston Ridge result from subsidence that has caused recent regrading of arroyos. At Laguna Grande de la Sal, elevations of the top of Salado halite indicate a depression under the lake, and lower halite south of the lake is associated with elongate valley-like depressions as well as rounded basins. The movement of brine at depth may be directed along this surface.

Surface karst features in the southeastern arm of Nash Draw develop on and within sulfate beds of the Rustler Formation and surficial gypsite. Collapse sinks and coalescing collapse in small karst valleys appear to show some evolutionary trends based on period since erosion exposed sulfate beds. Vertical-walled collapse sinks without fill are young, while karst valleys are older. These features are developed along stratigraphic trends. Some of the recharge in this sulfate-dominated environment discharges year-round in local springs, indicating fluid storage within the system. Alluvium in sinks and karst valleys are proposed as part of the storage system.

INTRODUCTION

Nash Draw is an internally drained depression located about 30 km east of Carlsbad, NM (Fig. 1). Nash Draw presents a complicated set of evaporite karst features and processes that have been studied mainly because of their proximity to potash mining, nuclear testing, and radioactive waste disposal. Erosion during the late Cenozoic exposed some of the soluble rocks, and sediments have filled some of the collapse features. Halite of the upper Salado Formation (Permian) and sulfate beds of the overlying Rustler Formation (Permian) (Fig. 2) have been dissolved to varying degrees and are accounted as the cause of the collapse and subsidence features.

The objective of this article is to focus in some detail on specific features, processes, and timing that help illustrate the origins and development of Nash Draw. We are able to focus on the local relationship between dissolution of upper Salado Formation halite and surficial features and subsidence history based on recent drilling and field work. Local surveys of surface features in the southeastern arm of Nash Draw, especially collapse sinks and caves that can function as swallow holes, provide the background for assessing potential vertical recharge to the hydraulic system in and around Nash Draw. This is a work-in-progress and not a complete picture of the features, processes, and history of the area. Field work, including new drilling and hydraulic testing, continues within and near Nash Draw, and the additional information will add to our understanding of Nash Draw. In addition, we do not review various features and processes proposed to show karst at the Waste Isolation Pilot Plant (WIPP). Lorenz (2006) has reviewed many of these other approaches.

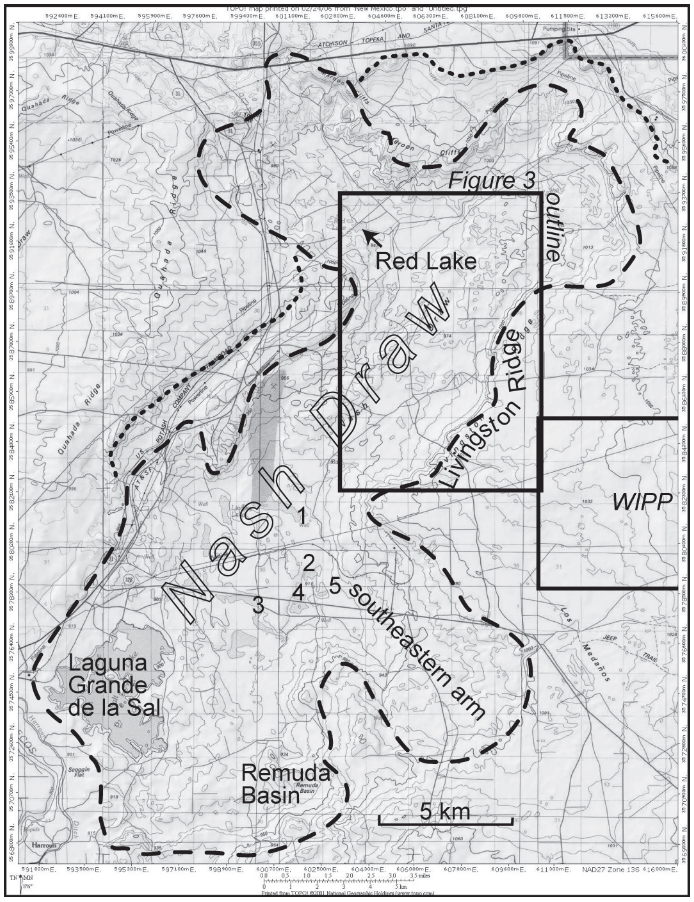

FIGURE 1. General location map of Nash Draw with identified features. Numbers refer to brine lakes informally named Laguna Uno (1) through Cinco (5). The Waste Isolation Pilot Plant (WIPP) site outline does not include the entire WIPP area. The area shown in Figure 3 is outlined here.

General Features

The long axis of Nash Draw runs northeast-southwest and is about 30 km long. The width ranges from about 8 km to 15 km, and the area of Nash Draw is about 400 km^2. It has been described as a "dog bone-shaped depression" because of its wider ends. The maximum relief across the draw is approximately 100 m.

The dominant feature in Nash Draw is Laguna Grande de la Sal (Fig. 1), a natural lake now fed partly by brines from potash mine effluent. Smaller depressions with brine lakes occur north and northeast of Laguna Grande. Integrated drainage is limited, and the largest area with such drainage is located in the northern end of Nash Draw. Red Lake forms ephemerally at the locus of this drainage; there is modest topographic closure at the south end of the Red Lake depression that has apparently not been breached by overflow in recent times. At the southern end of Nash Draw, Remuda Basin has some short, well-developed drainage. Different areas of Nash Draw display small karst features, including caves, sinkholes, dolines, and larger, integrated forms such as valleys or elongate depressions. Some of these features will be described in more detail later.

The northern and eastern margins of Nash Draw are well-defined and include named features such as Livingston Ridge and Maroon Cliffs. Beyond the eastern margin, the topography is generally flat, with much of the limited relief created by vegetated sand dunes. The western margin is more complicated, including Quahada Ridge and Magenta Point. Along the central western margin, there may be an inner and outer margin, but the geological relationships of these areas have not yet been resolved.

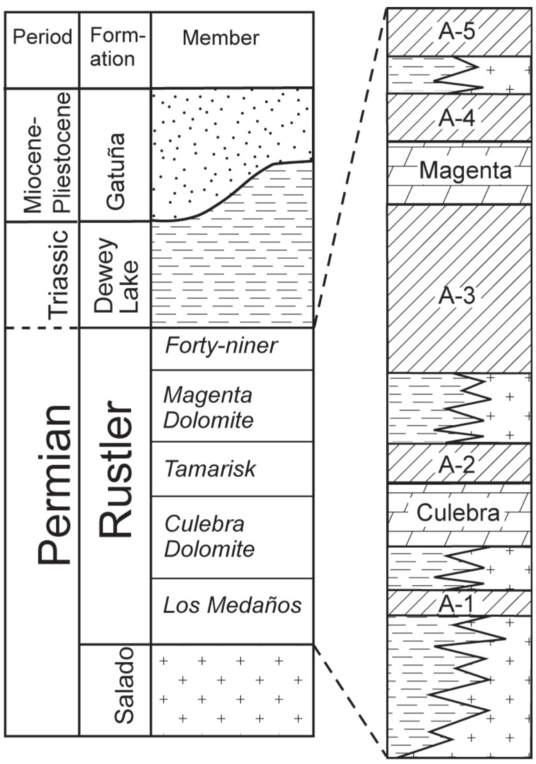

FIGURE 2. Basic stratigraphic units involved in the Nash Draw processes. Informal units of the Rustler Formation are also used in Powers et al. (2006).

North of Nash Draw, Clayton Basin has likely developed from similar processes with a generally similar history. The topographic divide between them is significant, and there are no indications of continuous drainage between them since they began to develop as internally drained basins.

Solution collapse chimneys or "breccia pipes" located in the northwestern arm of Nash Draw and on the divide between Nash Draw and Clayton Basin are not generally related to the development of Nash Draw. These chimneys developed above the Permian Capitan Limestone in response to hydraulic changes within the Capitan (Bachman, 1980; Snyder and Gard, 1982; see review by Powers, 1996).

BRIEF HISTORY OF NASH DRAW STUDIES

Willis T. Lee (1925) called attention to evaporite karst in the lower Pecos River valley, including some of Nash Draw, in an article that proposed a basic process of "erosion by solution and fill" to account for the features he observed. Although Nash Draw was not named by Lee, sinkholes that were described at "Livingston Ranch" (aka Crawford Ranch or more recently Smith Ranch) are located in the middle of Nash Draw. Lee also suggested that Red Lake is a large basin that developed from progressive solution, collapse, and sediment fill that choked the sinkholes. This feature is presumably the Red Lake that exists in Nash Draw's northwestern basin, as Lee described it as being on the road between Carlsbad and Lovington, NM. The road formerly passed through Nash Draw, and there is no other Red Lake toward Lovington. Although we do not concur completely with the process envisioned by Lee with regards to halite solution, his overall concept was applied later by Bachman (e.g., 1980) and remains helpful.

Following the discovery of potash deposits in a borehole just north of Nash Draw, the geology and hydrology became of much greater interest in the immediate area, especially in the search for sources of water used to refine potash ore. Robinson and Lang (1938) reported on the geology and hydrology of the Nash Draw area, and they identified and broadly outlined the extent of a saturated zone of sodium chloride brine that overlies halite of the Permian Salado Formation along the long axis of Nash Draw down to the Pecos River. By associating Salado halite, the sodium chloride brine, and the location of the brine along the axis of the draw, Robinson and Lang (1938) inferred broadly that solution of the salt was the source of brine and the reason the draw exists. The gradient of the brine, corrected for salinity differences, indicated flow down the draw toward the Pecos, with upwelling saline water in springs along the Pecos considered the outflow. Later investigations (e.g., Hale et al., 1954) further investigated this "brine aquifer" and its relationship to salinity in the Pecos River. The association of topography and upper Salado dissolution is one focus of this paper.

Vine (1963) developed the most comprehensive study of the geology of Nash Draw, producing the first known detailed geological map. Vine interpreted elevation contours on the uppermost Salado halite as general support for the relationship between topography and dissolution, but did not feel that the contours clearly defined Nash Draw. He also noted areas of the Permian Rustler Formation with differing structure and elevation from this general model. "Evidence for solution within the Rustler can be found almost everywhere that it is exposed" (Vine, 1963, p. B38). He reported numerous sinkholes and other karstic features developed in the Rustler, with some located on his geological map. Vine concluded that parts of the Rustler were dissolved, creating variable topography broadly controlled by dissolution of upper Salado halite.

Bachman (1981) revised the map of Nash Draw, including more locations of karst features. In numerous publications, Bachman (e.g., 1980, 1985) continued to evaluate the broader geological history of the area and the role of dissolution of various evaporite beds in the development of the topography. Bachman (1987, p. 38-41) specifically discussed the geologic history and processes of Nash Draw.

> "Nash Draw began to form during Pleistocene time. During Gatuña time a tributary drainage system flowed southwesterly across the area now known as Livingston Ridge and Nash Draw toward the main stem of the ancestral Pecos drainage. The Gatuña stream had sufficient carrying power and turbulence to create beds of cross-laminated pebble conglomerate (figure 8).
>
> "As this drainage system eroded into bedrock, it encountered the updip edge of the Rustler formation (figure 17). Dissolution began along the strike of the Rustler beds and initiated the formation of collapse sinks in the evaporites. These sinks were roughly aligned along the strike of the Rustler beds, which resulted in the present alignment of the central portion of Nash Draw.
>
> "As the collapse sinks coalesced during the further development of Nash Draw, the Gatuña drainage system was disrupted. Today the eroded edges of stream gravels in the Gatuña are exposed on both sides of Nash Draw as much as 200 ft (61.5 m) above the floor of Nash Draw. This disruption occurred late in Gatuña time–after the fall of the Lava Creek B ash and before the Mescalero caliche was deposited. Thus Nash Draw was initiated as a karst valley ~500,000 years ago and is a relatively young geologic feature.
>
> "Nash Draw assumed its present orientation as a result of the further coalescence of collapse sinks along the regional strike of evaporites in the Rustler Formation. Dozens of collapse sinks and caves are present in various parts of Nash Draw, and it continues to expand as a karst valley."

This summary remains relevant today. More information on the geology and depositional environments of the Miocene-Pleistocene Gatuña Formation has been reported by Powers and Holt (1993).

TOPOGRAPHY AND UPPER SALADO FORMATION HALITE DISSOLUTION

Vine (1963) was not overly impressed that the surface feature known as Nash Draw mirrored the elevation on top of halite in the Salado. He noted that Laguna Grande de la Sal was located in an area where this surface was low. The Red Lake location in the northwestern part of Nash Draw also had lower elevations for upper Salado halite. He noted that there seemed to be a somewhat higher elevation to top of halite under the area known as Tamarisk Flat in central Nash Draw. We have not yet compiled data across all of Nash Draw on top of halite to revise his conclusions regarding the relationship between surface topography and "topography" on Salado halite. Nevertheless, we now have more data density in selected areas from potash exploration, oil and gas development, and WIPP drilling that enable us to comment on the relationship between halite dissolution and Nash Draw topography.

Livingston Ridge

Top of Salado Formation halite

An important example of upper Salado halite dissolution is located off the northwest corner of the WIPP site, on Livingston Ridge. Oil wells of the Cabin Lake Field supplement other well data to provide stratigraphic information, including the top of Salado halite (Fig. 3).

Livingston Ridge is sharply defined (Fig. 3A), with relief of 15–20 m from the edge of the escarpment to the top of the alluvial slopes. The relief is ~50 m from immediately east of the escarpment to the lower depressions at the base of the alluvial slope. Powers et al. (2003) defined a margin of upper Salado halite dissolution based on marked and abrupt changes in thickness of an interval between stratigraphic units in the lower Rustler and upper Salado. This margin (Fig. 3A, heavy dashed line) coincides remarkably well with the edge of Livingston Ridge (Fig. 1), indicating a clear relationship between the surface and subsurface features.

The top Salado halite elevation (Fig. 3A) displays abrupt differences across this margin of generally 30–40 m. The lowest elevations are below 810 m and occur along the escarpment, with the exception of a single well slightly farther west of the margin.

The top of Salado halite east of Livingston Ridge dips to the east-southeast, conforming to the trend of overlying and underlying units. Halite occurs at the Rustler-Salado contact through this area and is easily mapped. Within Nash Draw, halite in the Salado reaches elevations of 840 m within 2–3 km of Livingston Ridge. Although the elevation of halite mid-draw is slightly higher than the halite elevation on Livingston Ridge, it is lower than the projected halite surface would be, based on extrapolation of the trend from east of Livingston Ridge. The upper beds of the Salado are not identifiable in these wells because they have been dissolved.

Because "top of salt" can depend on drilling operations and the experience of the geologist, a separate, stratigraphically higher unit is mapped for comparison. The elevation on the top of the Culebra Dolomite Member of the Rustler Formation (Fig. 3B) reveals comparable structures. This does not prove the validity of the top of halite elevation since top of halite is not a stratigraphic unit. The structure of the Culebra is, however, consistent with subsidence after dissolution of halite from the upper Salado that produced the current top of halite surface.

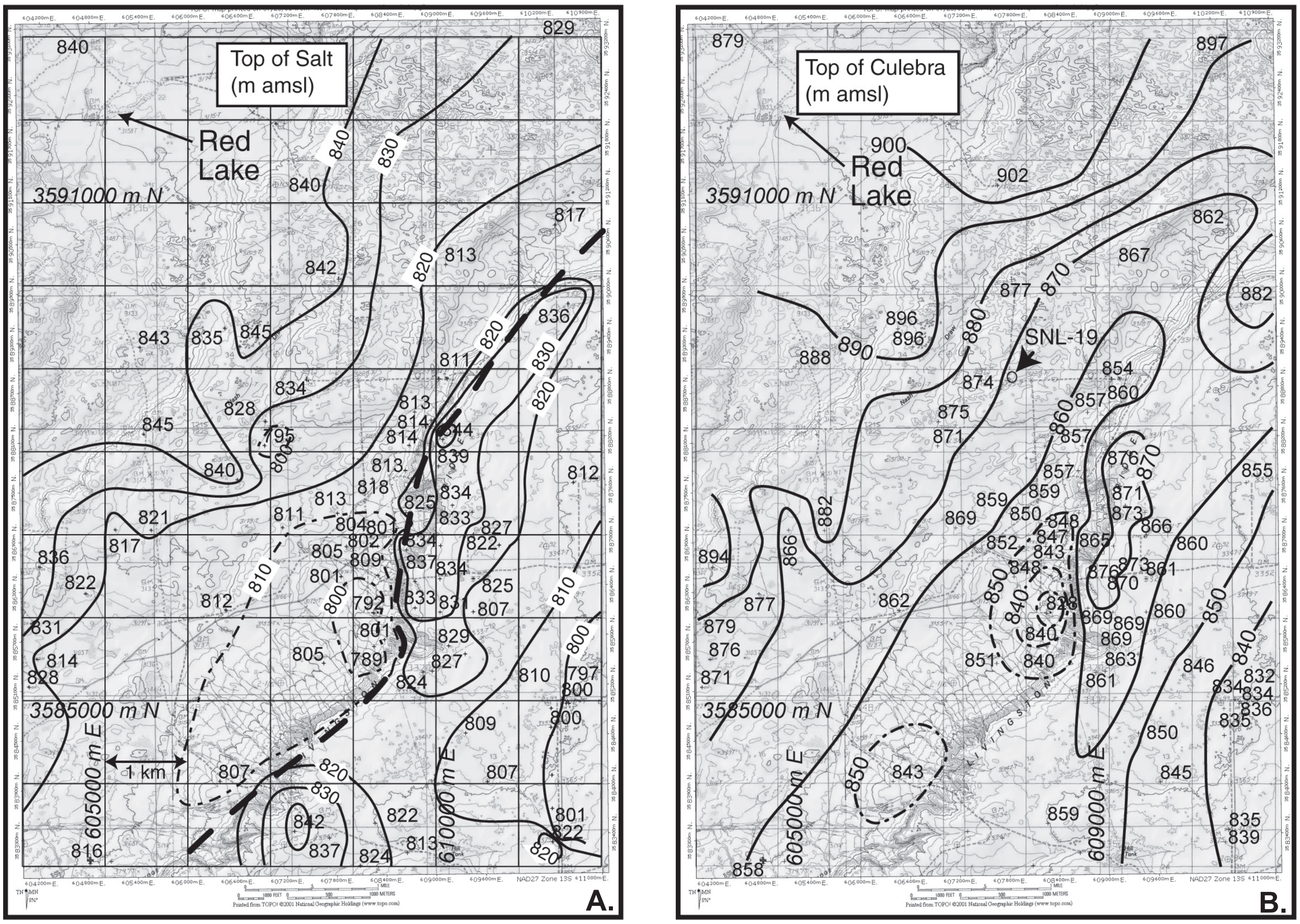

FIGURE 3. A. Elevation of the top of halite in the Permian Salado Formation (m amsl). The heavy dashed line along Livingston Ridge marks the margin of halite dissolution for the Salado inferred by Powers et al. (2003) by examining changes in thickness of the upper Salado and lower Rustler. Depressions are shown with dash-dot contour patterns. B. The elevation of the Culebra Dolomite Member of the Permian Rustler Formation, which overlies the Salado, exhibits structure similar to that shown by Salado halite and other units above halite. Similar "relief" across both surfaces indicates that the Culebra has subsided consistent with the proposed dissolution of halite.

Structural relief on the top of Culebra across Livingston Ridge reaches approximately 50 m, about 10 m greater than for the surface on Salado halite. The difference may reflect some variation in the identification of the first encounter of Salado halite, or may indicate that sulfate in the upper Salado and lower Rustler has been partially removed. Halite is known to cement fine sandstones in the lower Rustler east of Livingston Ridge (Powers et al., 2006), but removal of this cement would be unlikely to create much subsidence.

Surface features adjacent to Livingston Ridge

Immediately west of Livingston Ridge in the northeastern part of Figure 3A, a depression parallels the escarpment and overlies the area of lower elevation of Salado halite (810–820 m amsl) (Fig. 3A). This depression is closed, alluvium-filled, and without discernible swallow holes. The narrow alluvial slope along this part of Livingston Ridge ends in a poorly-defined shallow scarp around the deepest center of the surface depression. Modern arroyos have cut down through side-valley deposits and the narrow alluvial slope, grading to the deeper central depression (Fig. 3A). These relationships indicate that the central depression subsided more recently. The side valley deposits accumulated, and the basic alluvial slope developed in response to an earlier depression base level that was higher (Fig. 4). No swallow holes have been found in the alluvium, indicating recharge is likely slowed here. Available sediment is greater than can be handled by the system. Upland sand dunes also cover the terrain and choke off the development of integrated drainage that would channel additional water into this depression and change the dynamics. Current karst processes may be less active here than in other areas, and halite solution rates may be limited.

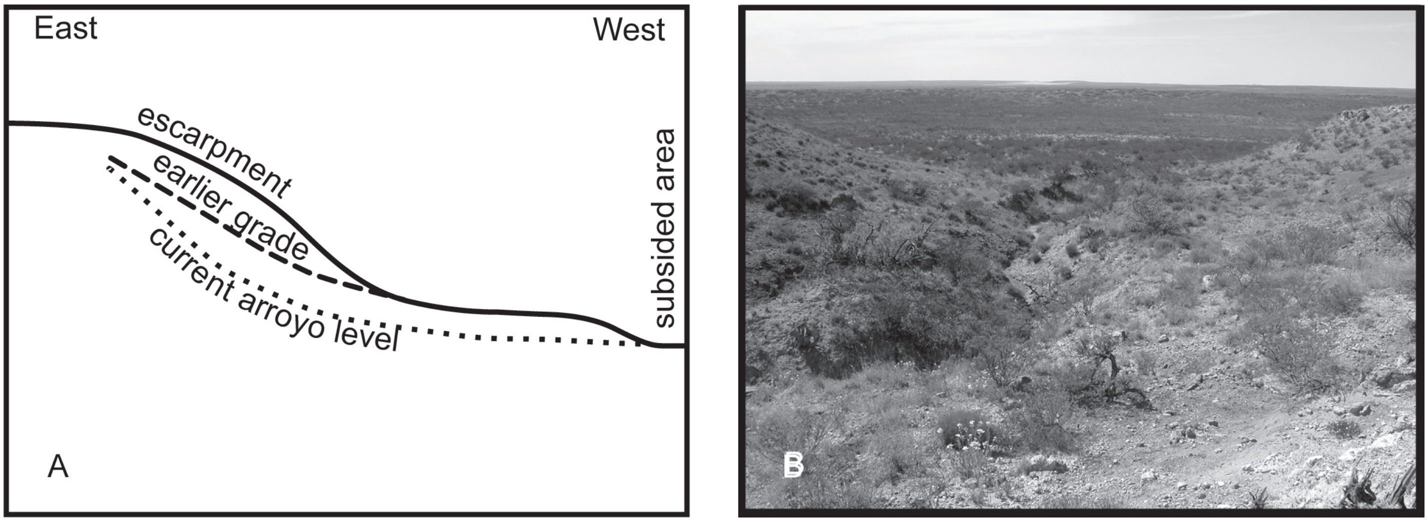

FIGURE 4. A. Diagrammatic cross-section of Livingston Ridge and the depression west of it illustrating the regrading arroyo responding to a subsidence event. B. Photograph of modern cut of arroyo regrading to the depression

Surficial Mescalero caliche along Livingston Ridge is deformed across the escarpment and fractured parallel to the escarpment, evidence that dissolution occurred after the pedogenic calcrete formed ~0.5 Ma (Bachman, 1980). Additional subsidence and regrading is younger than this time.

South of this area lies the maximum depression (below 800 m amsl) on upper Salado halite (Fig. 3A), with contours paralleling a slight embayment of Livingston Ridge. West of Livingston Ridge, however, there is no surface depression adjacent to the escarpment overlying the depression on halite. Instead, silt and fine sand have formed a sediment apron with near-linear shallow arroyos, perpendicular to the escarpment, that disappear in a shallow depression 1–2 km west of the escarpment (Figs. 3A, 5). At the south end of this area, larger arroyos cut Livingston Ridge at an acute angle to the escarpment and lead out of the map area.

Available drillhole control indicates that closure on the south end of the depression on upper Salado halite is 10–20 m. Easy outflow may no longer exist for brine sitting on the upper Salado here, a likely partial explanation for the surface features we see.

We infer that the closed depression below 810 m amsl represents additional solution of upper Salado halite, relative to areas north and south. There is no other practical mechanism known for subsidence or lowering of this horizon at this location. The modest embayment on Livingston Ridge is a response to dissolution advancing from the more general trend of the ridge. Nevertheless, such a closed depression is likely to retain more dense brine, effectively limiting dissolution until the brine can be diluted or moved. A well-developed alluvial apron is filling the subsiding area, and the straight drainage courses indicate that it is still grad-

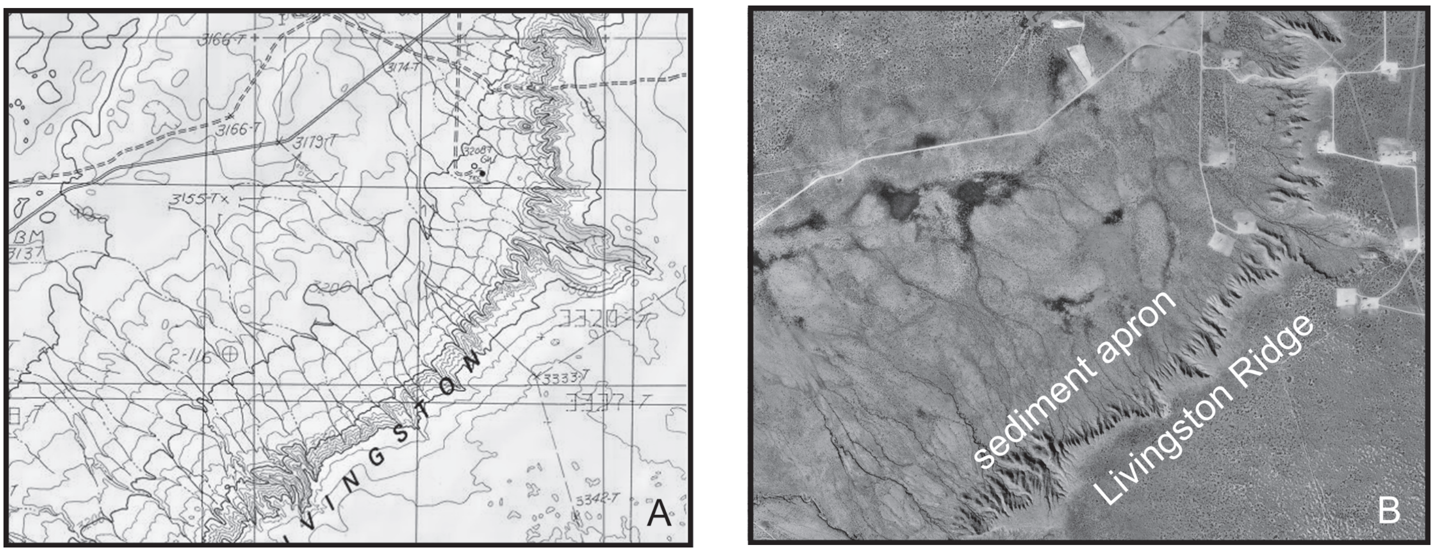

FIGURE 5. Topographic map segment (A) and equivalent segment of an aerial photograph (B) (NAPP frame 9610-248, dated 10/22/1996) illustrating the embayment on Livingston Ridge, sediment apron, and straight arroyos leading to a shallow depression.

ing to the base level. Inadequate field detail exists to determine if there is a more recent subsidence event in this depression that might have changed base level, similar to the depression along Livingston Ridge farther north.

If solution has created a closed depression, with brine now limiting further dissolution, the hydraulic system had to have been different in the past. Earlier, wetter climates could have provided recharge with sufficient fluid flow to create localized depressions on upper Salado halite. The details could be unraveled with additional studies of the alluvial slope sediments, pedogenic soil development, and any faunal and floral record preserved in the sediment apron and depression fill.

Drainages developed south of the embayment are longer, better integrated, and they are responding to base-level changes further into the draw. Some of them respond to capture by sinkholes in Rustler sulfates. At this time, not enough detailed field work has been done to evaluate timing of these broader features.

Laguna Grande de la Sal

Laguna Grande de la Sal (Laguna Grande) has previously been interpreted to have formed in a depression that developed as upper Salado halite dissolved. A saturated unit of brine developed in the residue as well. More detailed data indicate stronger relationships between topography and halite dissolution and suggest trends for brine aquifer movement toward the Pecos River.

Top of Salado halite

Drillholes around Laguna Grande provide data on the first encounter of halite in the Salado, with the same sources of variation as along Livingston Ridge. Nevertheless, the surface elevations of these data (Fig. 6) provide broad evidence that Laguna Grande lies over a depression in the salt surface. Halite is at an elevation of 810 m amsl at the north end of Laguna Grande, and it is below 810 m at the south end of the lake. Robinson and Lang (1938) reported top of Salado halite at 817 m in a drillhole in the western central part of the lake at approximately the point labeled "USGS #4" on Figure 6. This is consistent with contouring exclusive of this datum. Interpolating contours across the lake suggests an elevation low that connects from north to south. The relief on halite is ~30 m (840 m to 810 m) from 2 km east of Laguna Grande to the middle of the lake.

South of the lake, drainage traces reveal a complicated karst surface terrain with numerous small, internally drained basins (Fig. 6). Some display well-developed centripetal patterns, while others have more complex sets of drainage. Various intersections suggest drainage capture and some level of integration by coalescing depressions. The drainages are generally most complex within the area encompassed by the 800-m contour. More detailed topography, not shown on this figure, also reveals that sequential valleys trend along the approximate axis of the 800-m contour and then swing west toward the Pecos near the southern map margin.

We suggest the low on the upper Salado halite indicates a practical pathway for brine from the "brine aquifer" to follow. The brine can move towards lower areas (800 m) and may follow a path along the general trend of valleys shown on the surface south of Laguna Grande, as they are inferred to indicate deeper dissolution of upper Salado halite along a narrower trend.

The brine aquifer may also drain more southwesterly through the low divide (known as Scoggin Flat) between Laguna Grande and the Pecos River (Fig. 6). The Miocene-Pleistocene Gatuña Formation, as well as later alluvium and other coarse-grained deposits, form this divide. Little detail is available, however, to indicate depth of these more permeable deposits or the elevation of halite. Mercer (1983) provided general contours of the potentiometric surface, corrected for specific gravity, on the brine aquifer that indicate this southwesterly flow direction, but Mercer included no data from the Laguna Grande area.

East of central Laguna Grande, the 830-m contour line on Salado halite shows two southeastward swings underlying surface drainage patterns (Fig. 6). Even smaller topographic features may reflect Salado halite dissolution, but drillholes are spaced too far apart to be conclusive.

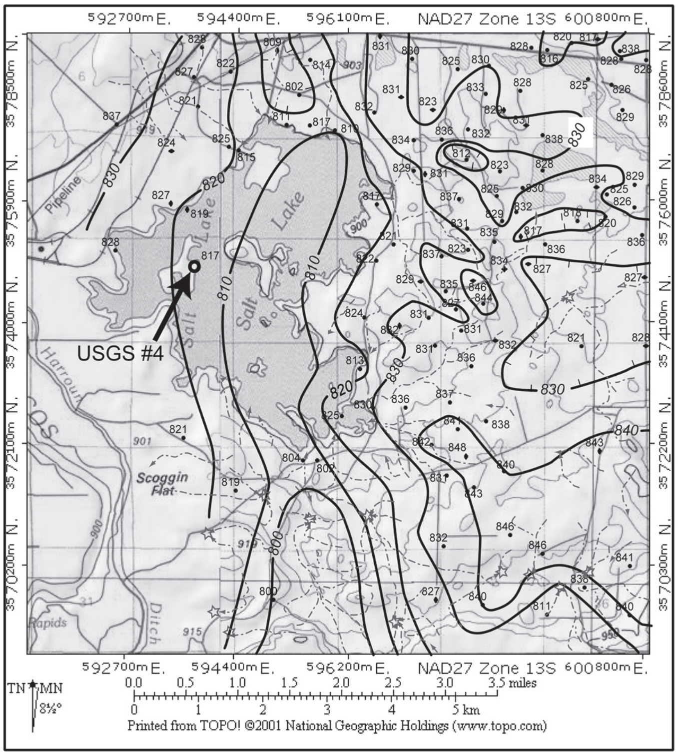

FIGURE 6. Topography of Laguna Grande de la Sal, with superimposed contours (m amsl) and values for the elevation of the top of halite in the Salado. "USGS #4" is the location of a borehole reported by Robinson and Lang (1938) with the elevation of halite. Drainages not visible at this map scale have been traced with arrows at the downstream end and star patterns at low points. A possible pathway for brine follows a series of enclosed valleys south of Laguna Grande along the inferred low on the surface of Salado halite.

DRAINAGE BASIN CHARACTERISTICS AND RECHARGE

Much of Nash Draw exhibits no significant integrated surface drainage, while certain areas (e.g., south of Laguna Grande) show small, internally drained basins with a sink or doline. Some larger areas with integrated drainage can be considered for their recharge potential. These larger basins constitute a fraction of the total ~400 km^2 area of Nash Draw.

Red Lake Drainage Basin

Red Lake is an ephemerally flooded area with artificial tanks or dugouts that commonly contain water. The area is covered by red silt and clay that shows little obvious soil development in arroyos. Well-developed arroyos drain the northwest arm and the northern side of the northeastern arm of Nash Draw. The drainage course from the northeast is relatively straight, and headward erosion has created a deeper embayment in the escarpment. This is the largest area of integrated drainage in and around Nash Draw, with an estimated surface area of about 70 km^2. This estimate does not include upland areas without obvious drainage or areas with extensive sand dunes. Some alluvium along the margins reveals narrow arroyos that are eroding headward at sharp nickpoints up to 2 m deep, indicating that the surface hydraulic gradient has recently changed. The change may reflect recent subsidence, the development of unobserved swallow holes, or some other process that has lowered the hydraulic base level and can accommodate sediment being eroded in these arroyos.

Drillhole reports from Red Lake have not yielded information on the top of Salado halite. Soluble sulfates in the Rustler may be dissolved. In this general area, long-wall mining of potash and subsequent surface subsidence up to 1 m have also affected drainage patterns, but the major features of the drainage and Red Lake predate mining. Lee (1925) considered this area to be a sink that was choked with sediment, and this interpretation may be correct.

Because of the relative size of the catchment, efficiency of the drainage, and sediment fill in the low area, the flats at and around Red Lake are likely a point or area of recharge to the shallow subsurface in the northern Nash Draw. There are few hydrologic data for shallow groundwater in this area.

Laguna Grande de la Sal

The integrated drainage around Laguna Grande covers an area of ~50 km^2, and Laguna Grande covers ~13 km^2. Most of the integrated drainage occurs north of Laguna Grande, extending to the Quahada Ridge area. Several ponds in Nash Draw with brine effluent from potash refining drain into Laguna Grande through man-made channels and some near-surface seepage.

Robinson and Lang (1938) tested chemistry and hydraulic heads of wells at various depths within Laguna Grande and deeper horizons. They concluded there was little vertical infiltration or connection between these units because of the low permeability of halite and other sediments in the lake. Lake brines may be infiltrating at shallow depths and laterally at the south end of the lake, but they are unlikely to dissolve any significant rock volumes. Runoff into Laguna Grande becomes saturated with respect to halite through evaporation and dissolution of halite in the lake substrate.

Remuda Basin

Remuda Basin is a smaller, but well-developed basin with about 6 km^2 of integrated drainage area in the southern part of Nash Draw. Arroyos are relatively straight and incised, and they drain to a common low. Some small benches inside the arroyos indicate temporary base-level stability. Nevertheless, the overall pattern of straight, incised drainages into fine sediment and little soil development are indicators of a recent, lowered base level or of continuing subsidence. Fractures and small-scale faulting observed on the east side of the basin have arcuate patterns parallel to general basin topographic contours.

Remuda Basin exposes coarse to fine Gatuña Formation sediments that Powers and Holt (1993) assign to facies related to fluvial and local eolian environments. The basin post-dates most, if not all, Gatuña sedimentation.

SURFACE KARST FEATURES IN GYPSUM

Within central and southeastern Nash Draw, numerous collapse sinks, caves, solution-subsidence troughs, and blind valleys of various sizes have been found developed mainly in the sulfate beds of the Rustler (e.g., Lee, 1925; Vine, 1963; Bachman, 1981; Powers and Owsley, 2003). Gypsite is common in some areas as fill, eolian sediment, or weathered surfaces over subcrops of Rustler gypsum. Some of these sinks or caves at least start at the surface in gypsite, but they likely lead into Rustler gypsum beds. Here we review some of the features in Rustler sulfate beds in the southeastern arm of Nash Draw and provide an overview of the apparent recharge system.

Following Bachman (1987), we are not commonly using the terms doline or alluvial doline in this article because depressions appear to be caused by collapse rather than solution on a surface.

Collapse sinks

Collapse sinks in the southeastern arm of Nash Draw seem to be best developed on sulfate beds within the Forty-niner Member of the Rustler and on the upper, thick sulfate bed of the Tamarisk Member. Two basic forms have been observed: sinks with vertical walls and no alluvial fill, and sinks that form broader depressions with an alluvial floor.

Collapse sinks with vertical walls are not common, but they are found where the top of the Rustler is exposed by erosion of the overlying Dewey Lake Formation. A well-exposed example west of Livingston Ridge (Fig. 7) shows some trends that may have fracture control roughly parallel to the Livingston Ridge escarpment. At this time, there has been no exploration to determine if a cave exists at the base of this unit. From stratigraphic data, the mudstone unit at the base of this sulfate (see Powers et al., 2006,

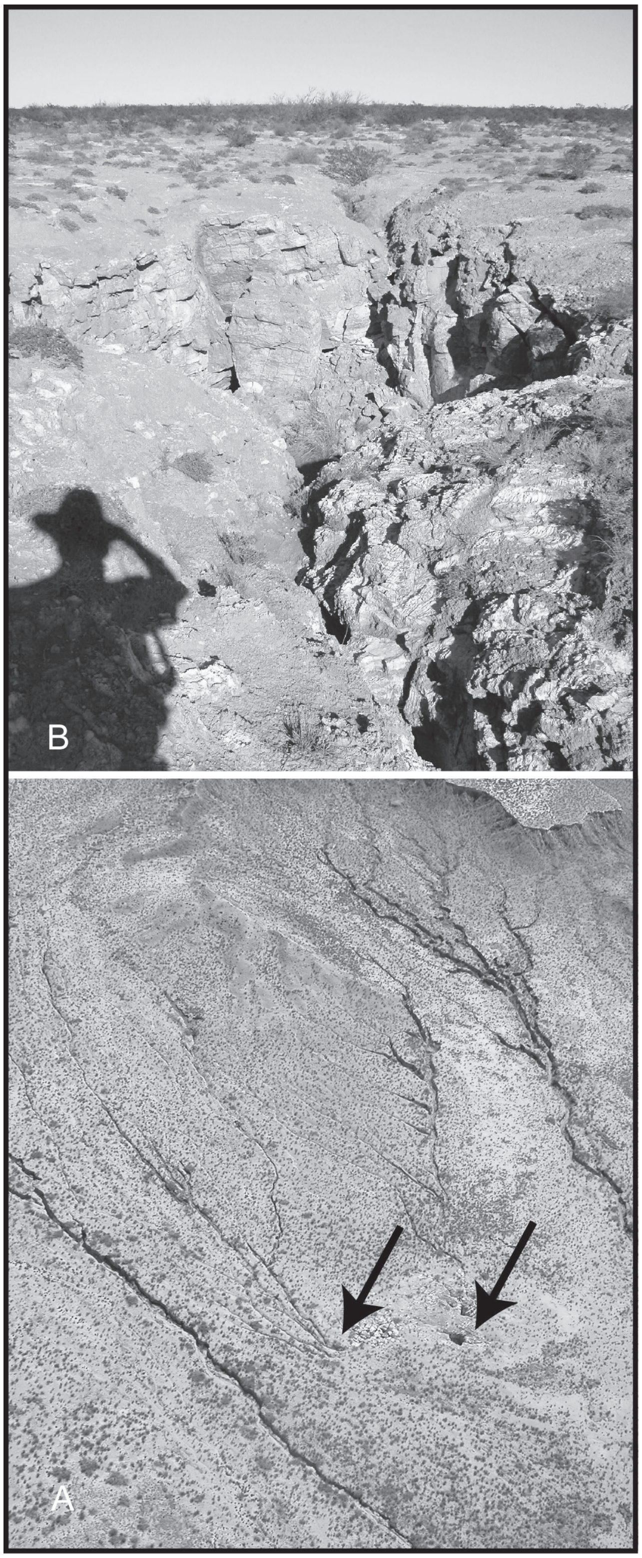

FIGURE 7. A. Low-angle aerial photograph of vertical-walled collapse sinks (arrows) that have captured local drainage. The left sink is shown in B and is more linear, along fracture trends. The southern (right) sink is circular, but vertical-walled. The escarpment of Livingston Ridge at the top right corner of the photograph is the Dewey Lake Formation of Permian or Triassic age. B. Surface photograph of northern (left) collapse sink in A. The sink developed in exposed uppermost gypsum (A-5) of the Forty-niner Member of the Rustler Formation.

figure 1) may be accepting runoff, although there also may be cavernous porosity developed at the base of this sulfate or the top of the next lower sulfate. An aerial view of this feature (Fig. 7A) indicates local capture of drainage. The vertical walls (Fig. 7B) of these collapse sinks suggest that they are relatively recent. They are also located near the base of the retreating escarpment (Livingston Ridge), and the overlying sediment has been more recently removed compared to locations farther into the draw. This area is also subject to subsidence from dissolution of upper Salado halite, creating fractures parallel to the escarpment that allow infiltrating waters and shape the sink.

Farther from the escarpment, and developed in both sulfate beds of the Forty-niner, collapse sinks tend to have low relief, walls of sloping gypsum, and alluvial fill (Fig. 8). These are closest in form to alluvial dolines, but they apparently have developed from collapse rather than from solution at the surface of the sulfate bed. These features are aligned to some degree along strike, indicating stratigraphic control, and they can form as a series connected by arroyos that run generally perpendicular to strike. The alluvium seldom shows signs of an open sink that can become a swallow hole. Instead, grasses and perennial plants are common rather than invasive annual species, and eroded sections can show some soil development. These "alluvial" collapse sinks are relatively stable, and the fill provides some storage for collected runoff. Some arroyos also end in these features; they are usually not deep or well-developed, and there is no cave at the end of the drainage that would qualify them as blind valleys or "blind arroyos." Whether they were blind valleys or blind arroyos at some time is not clear, but they do not resemble other blind valleys in the area.

The upper sulfate bed (A-3) of the Tamarisk Member of the Rustler Formation is thick, and it is exposed farther from Livingston Ridge than stratigraphically higher sulfates (e.g., A-4 and A-5), at or near topographic lows. Collapse sinks tend to develop in weathered A-3 or gypsite covering A-3 along these lows. They range from open to largely debris-filled; field evidence shows they become swallow holes when runoff accumulates in the collapse sink depressions. There is a common association with larger features described below as karst valleys.

Blind valleys

Blind valleys in this area end in caves (Fig. 9) that commonly developed in the thick upper sulfate of the Tamarisk Member or base of the overlying Magenta Dolomite. The drainage system for these blind valleys is better developed than for most areas. Deeper stratigraphic position and dip of these upper Rustler beds indicate they are located farther from the draw margin than are the more common areas of alluvium-filled collapse sinks.

Blind valleys may have developed before alluvium-filled collapse sinks by virtue of earlier exposure of the rocks by erosion, but they are not an apparent step in an evolutionary sequence. Instead, blind valleys appear more likely to have occurred because the Magenta is less subject to either erosion or solution than are sulfate beds in this environment. The Magenta is mechanically stable, resisting collapse and protecting solution channels at the top of the Tamarisk, in A-3.

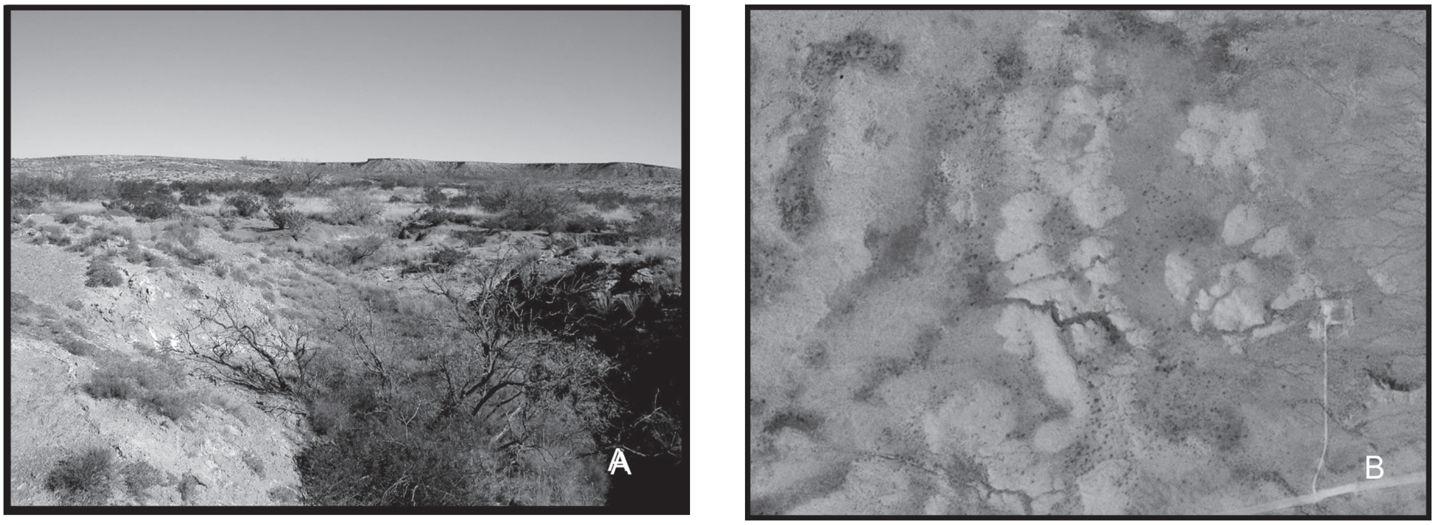

FIGURE 8. A. Surface photograph of collapse sink with sloping sides of gypsum and alluvial fill. B. Segment of aerial photograph (NAPP frame 9611-50, dated 10/22/1996) showing this same sink and the drainage that connects such features.

Caves and swallow holes in gypsum

Powers and Owsley (2003) reported concentration of caves in the vicinity of NM Highway 128 that extended the reports of Vine (1963) and Bachman (1980). These caves have not been explored, so their lateral extent and connections are unknown. Caves are generally developed within the upper Tamarisk sulfate bed or in gypsite that veneers this sulfate bed. Entrances are small and show evidence of fallen angular blocks. Cave walls exposed at the surface have more planar than rounded surfaces (e.g., Powers and Owsley, 2003, figure 7). These features indicate at least local control by fractures, but no preferred orientation of fractures has yet been determined. Caves tend to occur along strike, showing some stratigraphic control, but this doesn't rule out grosser fracture control on the km scale.

Caves are generally observed along the sides of what are here called karst valleys (see next section). It is possible caves exist within these valleys but are obscured by, or filled with, debris. They become swallow holes when the karst valley fills sufficiently with runoff. It is undetermined whether some of them may perform as springs if the water table increases, but there are no apparent recent spring deposits.

A few caves occur at the end of blind valleys, as described above. They are developed at the top of the same stratigraphic unit (Tamarisk A-3) as the caves described here along karst valleys.

Karst valleys

Nash Draw itself is called a karst valley by Bachman (1987). The smaller features here called karst valleys have an uncertain history of formation. In the southeastern arm of Nash Draw, karst valleys are a few km in length and ~100–200 m wide. Their common features are closed depression, alluvial fill with generally stable perennial vegetation, caves along the margin, and collapse sinks within or along the margins. Debris and alluvium tends to choke the features nearer the low points of the depression or valley. Powers and Owsley (2003, figure 9) also reported a sinkhole in alluvium along one of these valleys, and soil developed in this alluvium indicated periods of stability. Similar features have been found elsewhere in the southeastern arm of Nash Draw.

FIGURE 9. Blind valley with cave developed in uppermost sulfate (A-3) of the Tamarisk Member of the Rustler Formation. The Magenta Dolomite Member is above the cave, and this configuration characterizes the active blind valleys found so far.

The best interpretation of these features is that they formed mainly by coalescing collapse along a stratigraphic trend; erosion probably initiates the process, but the history is obscured by subsequent collapse.

Field evidence shows these karst valleys can accumulate significant runoff. For example, the valley developed in the SE ¼ sec 5, T23S, R30E (Fig. 10) is at the low point of a drainage basin that is 23 km^2 in area, the largest basin with significant integrated drainage in the southeastern arm. Physical evidence in the field shows that the sinkholes and caves become swallow holes (Fig. 11), and silt-stained mesquite, strandline debris, and stranded dry cow patties (Fig. 12) reveal that runoff can accumulate to depths of ~1 m in this depression.

RECHARGE AND DISCHARGE IN THE SOUTHEASTERN ARM OF NASH DRAW

Some elements of the hydraulic system within Nash Draw can be broadly inferred from our observations and previous data, including the gradient and flow of brine in the brine aquifer above Salado halite to the south-southwest toward the Pecos River. Another element is that effluent from potash refining affects shallower hydrology in Nash Draw, based on the chemical signature from dissolved potassium (e.g., Ramey, 1985). Another inference is that Laguna Grande and other depressions with halite substrates are probably not locations for regular vertical recharge because of the low permeability of these halite beds.

Portions of the southeastern arm of Nash Draw form effective modern drainage basins, separated topographically and served by integrated drainage that can focus runoff in smaller areas with collapse sinks and caves that become recharge points. Within these larger drainage basins, alluvium-filled collapse sinks form smaller locations where runoff can accumulate and saturate the alluvium. The sinks and valleys with alluvium likely provide a means of slower, more constant recharge to the shallow hydraulic system in southeastern Nash Draw. Local springs that discharge year-round require storage somewhere within the system.

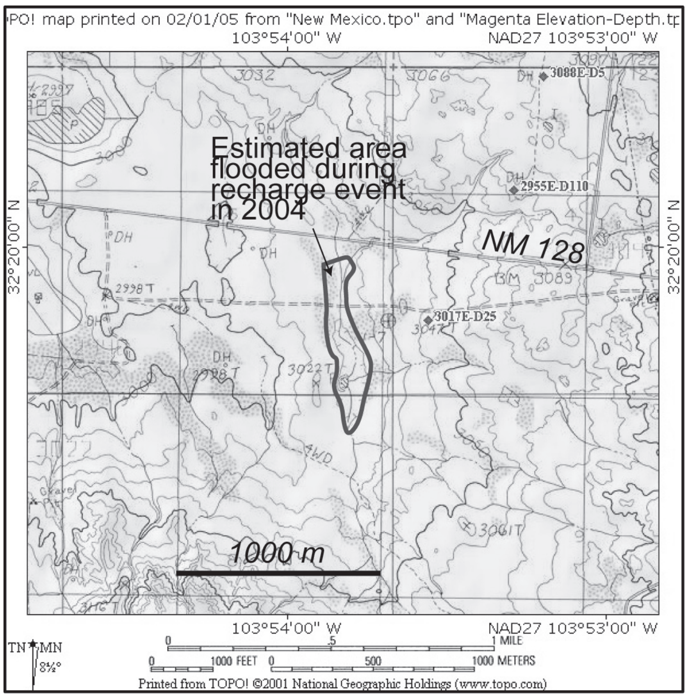

FIGURE 10. Segment of topographic map showing the approximate boundary of a smaller karst valley in section 5, T23S, R30E that developed from coalescing karst features.

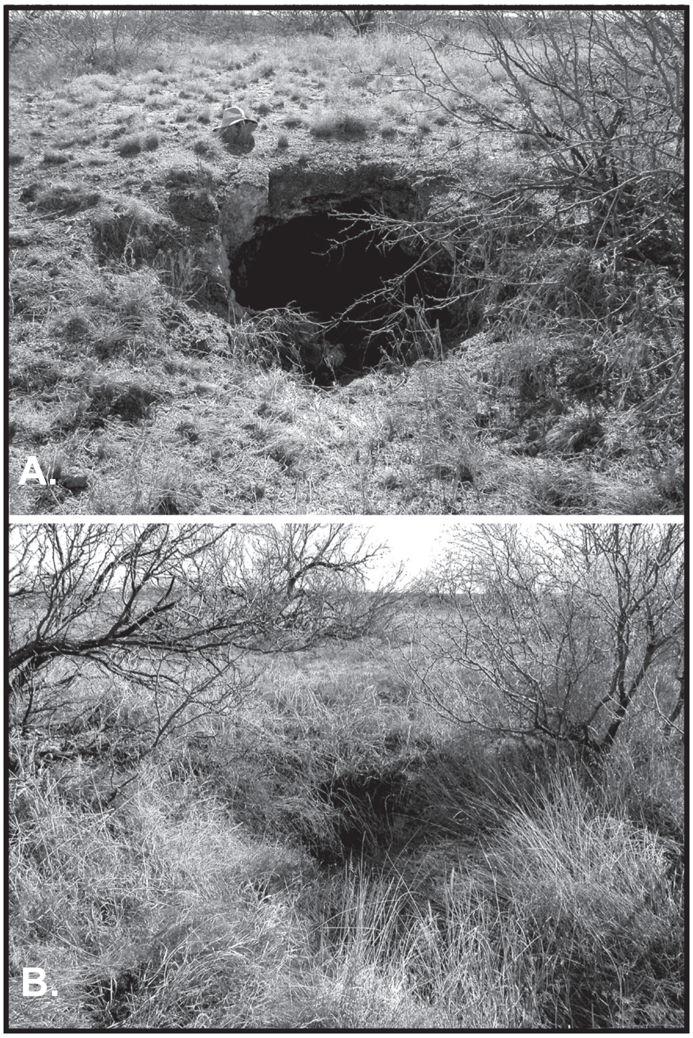

FIGURE 11. Examples of caves and sinkholes that become swallow holes when runoff accumulates in the karst valley in Figure 10. A. The sinkhole is in the lower part of the valley, with perennial grass around and within. Sediment probably restricts flow into this sinkhole. B. The debris strandline is just above the top of this cave (at the hat) along the west side of the valley, indicating the cave was below water level.

Springs discharge within two of the brine lakes located in the southeastern arm of Nash Draw (Fig. 13). These can be differentiated by specific gravity data and temperatures in a recent survey (December 2005).

The springs and seeps discharging into Laguna Dos discharge high-specific-gravity water (> 1.19); spring water has low temperatures (~10 °C) and the seeps are warmer (~20 °C). There is only one known source of such high-specific-gravity water,

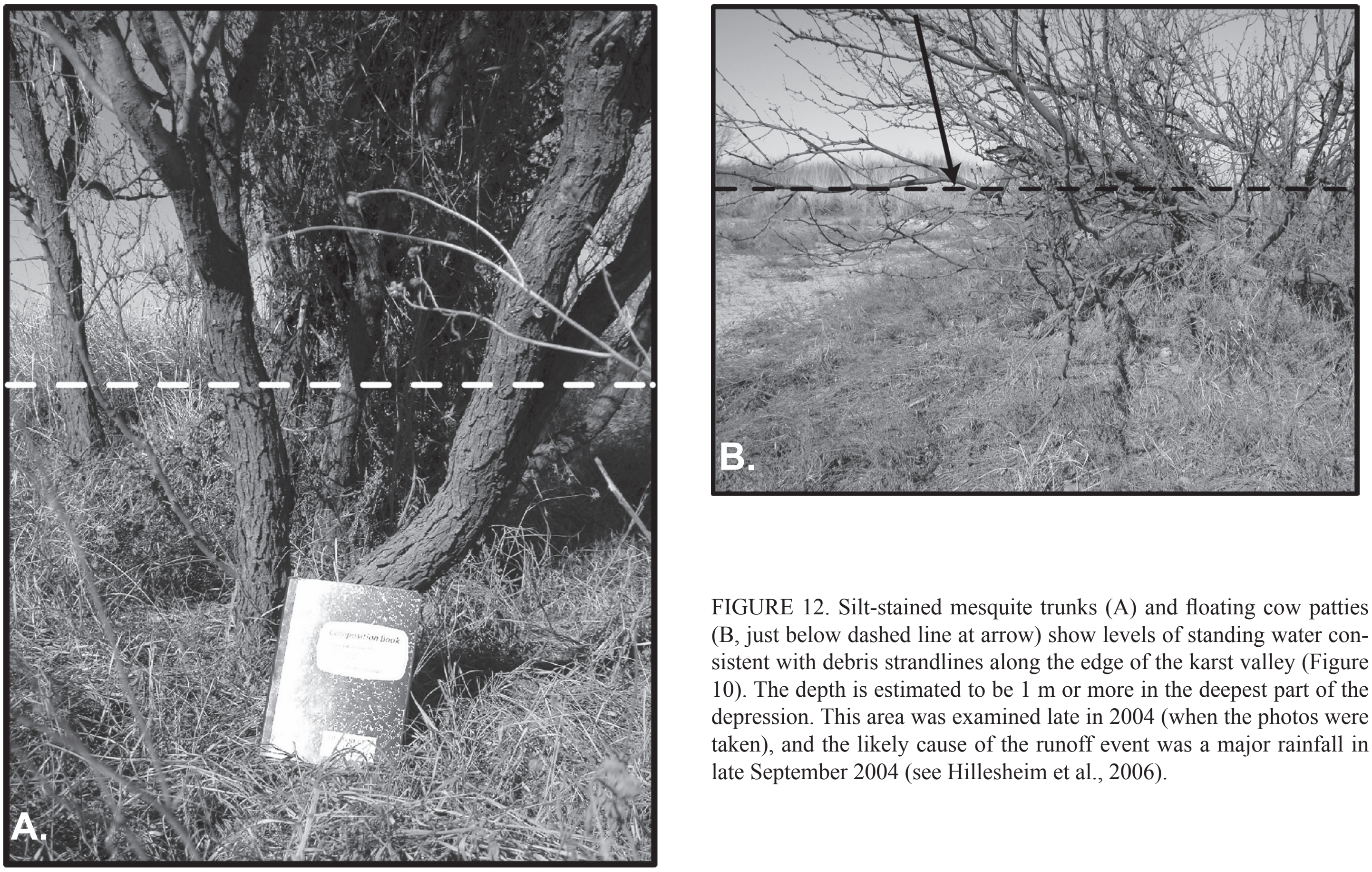

FIGURE 12. Silt-stained mesquite trunks (A) and floating cow patties (B, just below dashed line at arrow) show levels of standing water consistent with debris strandlines along the edge of the karst valley (Figure 10). The depth is estimated to be 1 m or more in the deepest part of the depression. This area was examined late in 2004 (when the photos were taken), and the likely cause of the runoff event was a major rainfall in late September 2004 (see Hillesheim et al., 2006).

Laguna Uno to the northwest, which is higher and receives the effluent from refining potash ore. In the future, this effluent will be redirected to Laguna Grande by pipeline, changing the near-surface hydrology and chemistry.

The springs discharging into Laguna Cinco along the east and northeast sides of the lake have been measured for specific gravity several times, and the values have never exceeded 1.125. The lake substrate is gypsum, and the gypsum crystallinity varies during the year, depending on environmental conditions. During greatest evaporation in the early summer, the substrate displays well-formed, coarse gypsum crystals. During times of greater runoff or rainfall in the area, the gypsum tends to degrade to sand and small, poorly defined crystals.

The springs in Laguna Cinco are fed by systems in contact with gypsum, such as those described in southeastern Nash Draw. These springs require upgradient storage, which is not a characteristic of high-porosity cavern systems. The alluvium-filled valleys and collapse sinks are proposed as a significant storage system.

DISCUSSION

Nash Draw is a complicated geological feature whose origins, history, and processes have been broadly outlined by previous investigations. Powers and Owsley (2003) provided additional details of karst features in the southeastern arm of Nash Draw, and many of the features reported there are discussed or described further here. Some of the approaches taken here will be extended elsewhere in the draw.

Upper Salado halite was dissolved to form a distinct margin along Livingston Ridge and the eastern margin of Nash Draw. Drillhole control is not as dense, however, in most other areas, and the precise control and details of the history would be more difficult to extract elsewhere. We can be reasonably confident that, by analogy, much of the eastern margin of Nash Draw develops by similar processes, although perhaps at differing rates and times. Sulfate was also removed from the Rustler in Nash Draw, although data on structure and well logs indicate this is not the dominant process along the Livingston Ridge at the Cabin Lake Field. Data on upper Salado halite have not been developed in comparable detail along the western margin of Nash Draw, and we cannot evaluate the relationship between upper Salado halite dissolution and that very distinctive margin. The fact that the western margin can be drawn along different escarpments suggests an even more complicated history. Nevertheless, based on additional data, we feel more confident than Vine (1963) about the relationship between Nash Draw topography and upper Salado halite dissolution.

The data on upper Salado halite around Laguna Grande are consistent with a low along a north-south axis of the lake that may provide, or have provided, a pathway for brine movement southward out of the area under the lake before migrating further

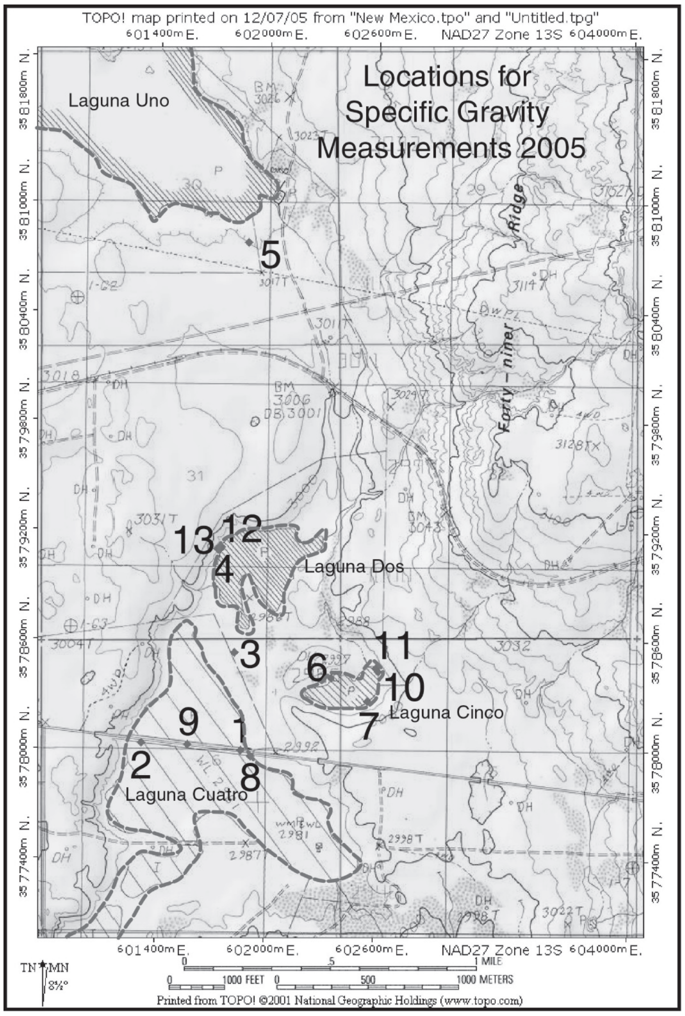

FIGURE 13. A. Topographic map segment showing the location of lakes near the mouth of the southeastern arm of Nash Draw where specific gravity measurements were taken in 2005 to differentiate waters. (see also Figure 1 for locations). B. Surface photograph from December 2005 of the upwelling sulfate-rich northern spring in Laguna Cinco (near location 11 in A). The upwelling spring is about 30 cm in diameter. Photograph view is toward the southeast.

south and southwest toward the Pecos River. The elevation on the top of halite, as shown by a few wells in this area, indicates more halite removal, and the rocks at the surface have developed internally-drained, elongate valleys as well as small, circular basins over this area in response. There are some indications that more localized topography, including some drainages east of Laguna Grande, have developed in response to local differences in halite dissolution. This inference will likely remain very tentative since it is unlikely that significantly closer spacing of drillhole data will be obtained.

The array of surface karst features that developed on gypsum beds and gypsite in the southeastern arm of Nash Draw show evidence of stratigraphic control and reveal some aspects of their evolution. Sharply defined, vertical-walled collapse sinks are more common on upper Rustler beds, but they also are more recently exposed by erosion. Similar beds, lower stratigraphically and exposed farther from the edge of the draw, show more collapse and fill. These features likely show some steps in the evolution of karst with time in this setting. Blind valleys are, at least now, associated with the Magenta Dolomite and upper Tamarisk gypsum. They do not resemble collapse sink development; rather it appears that the less-soluble carbonate over gypsum is an important factor in maintaining the cave system instead of collapsing. The features we call karst valleys, however, may be a later step in collapse sink development, where they coalesce into a longer feature. Because the karst valleys developed in lower stratigraphic units than do the more individual collapse sinks described here, it is not certain what role stratigraphy plays in the evolutionary timing of these features.

Springs near the mouth of the southeastern arm of Nash Draw are dominated by sulfate-rich water. Moderate specific gravity and gypsum formation from the evaporating water differentiate these springs from those with high specific gravity and brines that precipitate halite. The brines precipitating halite undoubtedly flow through very shallow gypsum karst, but the brine source is a lake maintained by potash refinery effluent. The sulfate-rich springs are part of the karst hydraulic system in the southeastern arm of Nash Draw, which is developed mainly on beds of sulfate and gypsite. Given the year-round flow in an area with strong seasonal differences in rainfall, the system has considerable storage. Because we cannot quantify what proportion of the fluid flow in this arm of Nash Draw goes to this spring, and have not quantified flow from the springs into Laguna Cinco, it is not practical to estimate how storage occurs there. Subsurface fluids are likely stored in the alluvium that fills some sinks and valleys. Thin (~3–5 m thick) mudstones between Rustler gypsum beds and Rustler dolomites may also provide storage. Hillesheim et al. (2006) suggest recharge reaches the Culebra Dolomite (which is significantly deeper than the near-surface features described here). The Culebra is not storage for these springs, however, as the hydraulic heads for the Culebra are not sufficient to reach the surface here. The systems that discharge to the springs are quite likely feeding open porosity that is locally strata-bound. The degree to which the shallow system in the southeastern arm of Nash Draw is connected to deeper beds, such as the Culebra, is not yet established. Hillesheim et al. (2006) show that heavier precipitation across Nash Draw does affect water levels in the Culebra. Local gradients and flow toward the springs at Laguna Grande, as described here, is not evidence that the Culebra follows a similar local flow path.

SUMMARY

Nash Draw is a prominent evaporite karst feature formed by erosion and solution processes. These processes are active today, although not necessarily uniformly. The more soluble rock units include halite in the upper Salado and gypsum beds of the Rustler. The eastern margin of Nash Draw is related to dissolution of Salado halite, while halite data remain insufficient to demonstrate firmly such a link for Nash Draw in general. Changing base levels for surface drainage and fractured caliche indicate that the margin has been actively dissolving in the last 0.5 Ma. Brine from this dissolution exists over much of the draw, and hydraulic gradients and brine seeps in the Pecos indicate that the Pecos is a discharge point.

Rustler gypsum has developed more specific features, such as collapse sinks, blind valleys, and karst valleys. These features show stratigraphic control as well as some evolution of features. The features appear to focus runoff locally and recharge near-surface units, and some of this sulfate-rich water discharges into closed lakes with gypsum substrates.

ACKNOWLEDGEMENTS

We thank Mike Hillesheim, Rick Salness, Doug Edmiston, Mark Rigali, Steve Kouba, Daryl Mercer, and Sandy Halliday for reviewing the article. Dave Belski, Lewis Land, Mary-Elena Martell, Bruce Baker and Glen Garrett are among those who examined features in the field with Powers and discussed their significance.

This research is funding by WIPP programs administered by the Office of Environmental Management (EM) of the U.S. Department of Energy.

Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

REFERENCES CITED

Bachman, G.O., 1980, Regional geology and Cenozoic history of Pecos region, southeastern New Mexico: U.S. Geological Survey, Open-file Report 80-1099, 116 p.

Bachman, G.O., 1981, Geology of Nash Draw, Eddy County, NM: U.S. Geological Survey, Open-file Report 81-31, 10 p.

Bachman, G.O., 1985, Assessment of near-surface dissolution at and near the Waste Isolation Pilot Plant (WIPP), southeastern New Mexico: Albuquerque, NM, Sandia National Laboratories, SAND84-7178, 33 p.

Bachman, G.O., 1987, Karst in evaporites in southeastern New Mexico: Albuquerque, NM, Sandia National Laboratories, SAND86-7078, 82 p.

Hale, W.E., Hughes, L.S., and Cox, E.R., 1954, Possible improvement of quality of water of the Pecos River by diversion of brine at Malaga Bend, Eddy County, New Mexico: Pecos River Commission, 43 p.

Hillesheim, M.B., Beauheim, R.L., and Richardson, R.G., 2006, Overview of the WIPP groundwater monitoring program with inferences about karst in the WIPP vicinity: New Mexico Geological Society, 57th Field Conference Guidebook, p. 277-286.

Lee, W.T., 1925, Erosion by solution and fill, *in* Contributions to the Geology of the United Sates, 1923-24: U.S. Geological Survey Bulletin 760-C, p. 107-121.

Lorenz, J.C., 2006, Assessment of the geological evidence for karst in the Rustler Formation at the WIPP site, New Mexico Geological Society, 57th Field Conference Guidebook, p. 243-252.

Mercer, J.W., 1983, Geohydrology of the proposed Waste Isolation Pilot Plant site, Los Medaños area, southeastern New Mexico: U.S. Geological Survey, Water-Resources Investigations Report 83-4016, 121 p.

Powers, D.W., 1996, Tracing early breccia pipe studies, Waste Isolation Pilot Plant, southeastern New Mexico: A study of the documentation available and decision-making during the early years of WIPP: Albuquerque, NM, Sandia National Laboratories, SAND94-0991, 70 p.

Powers, D.W., and Holt, R.M., 1993, The upper Cenozoic Gatuña Formation of southeastern New Mexico: New Mexico Geological Society, 44th Field Conference Guidebook, p. 271-282.

Powers, D.W., and Owsley, D., 2003, A field survey of evaporite karst along NM 128 realignment routes, *in* Johnson, K.S., and Neal, J.T., eds., Evaporite Karst and Engineering/Environmental Problems in the United States: Oklahoma Geological Survey Circular 109, p. 233-240.

Powers, D.W., Holt, R.M., Beauheim, R.L., and McKenna, S.A., 2003, Geological factors related to the transmissivity of the Culebra Dolomite Member, Permian Rustler Formation, Delaware Basin, Southeastern New Mexico, *in* Johnson, K.S., and Neal, J.T., eds., Evaporite Karst and Engineering/Environmental Problems in the United States: Oklahoma Geological Survey Circular 109, p. 211-218.

Powers, D.W., Holt, R.M., and Beauheim, R.L., and Richardson, R.G., 2006, Advances in depositional models of the Permian Rustler Formation, southeastern New Mexico: New Mexico Geological Society, 57th Field Conference Guidebook, p. 267-276.

Ramey, D.S., 1985, Chemistry of Rustler fluids: Santa Fe, NM, Environmental Evaluation Group, EEG-31, 62 p.

Robinson, T.W., and Lang, W.B., 1938, Geology and ground-water conditions of the Pecos River valley in the vicinity of Laguna Grande de la Sal, New Mexico: New Mexico State Engineer, 12th and 13th Biennial Reports, p. 79-100.

Snyder, R.P., and Gard, L.M., Jr., 1982, Evaluation of breccia pipes in southeastern New Mexico and their relation to the Waste Isolation Pilot Plant (WIPP) site, with section on drill-stem tests: U.S. Geological Survey, Open-file Report 82-968, 90 p.

Vine, J.D., 1963, Surface geology of the Nash Draw quadrangle[,] Eddy County[,] New Mexico: U.S. Geological Survey, Bulletin 1141-B, 46 p.


Stop 1
Day 3
2005
Jordan

PLATE 16: EVAPORITE KARST AT BOTTOMLESS LAKES STATE PARK

PLATE 16A. Lazy Lagoon, formed in an abandoned channel of the Pecos River, appears to be a single body of water when water levels are high. The lake actually consists of three sinkholes with a maximum depth of > 25 m. Notice the large rotated slump blocks on the Seven Rivers Escarpment near the center of the image.

PLATE 16B. Overview of Lazy Lagoon during the summer months, when water levels are low due to increased irrigation pumping from the Artesian Aquifer.