Field Survey of Evaporite Karst along New Mexico Highway 128 Realignment Routes

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ABSTRACT.—The phase 2 realignment study of alternate routes for State Highway 128 in Eddy County, New Mexico, considered the local effects of karst as well as other processes. Within parts of secs. 3–6 and 10, T. 22 S., R. 30 E., karst and related surficial features include caves, alluvial sinkholes, alluvial dolines, collapse valleys, springs, and lineaments. Cave features and alluvial sinkholes show that karst processes are active, and springs may be indicating some of the hydrological conditions within the karst system. Many of the alluvial dolines have relatively stable surfaces, based on soils and vegetation, indicating that internal drainage and sediment transport are relatively restricted and unable to cope with available sediments. Collapse valleys are interpreted as a consequence of coalescing sinkholes or dolines along relatively linear trends. Caves and alluvial sinkholes occur within collapse valleys, indicating that the karst system is still active within the valleys. Surface linear trends can be interpreted along these collapse valleys as well as between other features, such as alluvial dolines. Although not proven, we suggest that these lineaments are related to both bedding surfaces within the Permian Rustler Formation and fracturing trends created by subsidence after dissolution of salt from the upper Salado Formation.

Alluvial sinkholes appear to form in alluvial dolines where drainage concentrates runoff. As a consequence, some areas just north of the present right-of-way, particularly in sec. 4, should probably be avoided for highway construction. In addition, drainage from alluvial dolines and collapse valleys crossed by a new grade should be maintained or enhanced, whereas drainage into these same locations should be minimized or avoided. This should help avoid developing new alluvial sinkholes under a new grade.

INTRODUCTION

The western end of State Highway 128 (NM 128) in southeastern New Mexico has been studied for possible realignment to avoid or lessen maintenance problems mainly from brine lakes along the current route (Fig. 1). Evaporite karst presents one possible construction and maintenance issue along alternate routes. Although Nash Draw (Fig. 1) is known as a locality where sinkholes and collapse features have formed (e.g., Bachman, 1981), areas along the current and proposed alternate rights-of-way weren't surveyed in any detail to identify specific features. For this study, a preliminary surface geological survey was conducted in 1999 along the more likely areas to identify specific features, assess the current level of karst activity, and suggest mitigating efforts. There have been no field geotechnical studies for the realignment since phase 2 was completed (1999).

For this geological survey, resources included reports on Nash Draw, standard topographic maps, contact prints from aerial photographs of October 1976, and printed images from digital records of aerial photographs taken in 1999. In the field, features were lo-

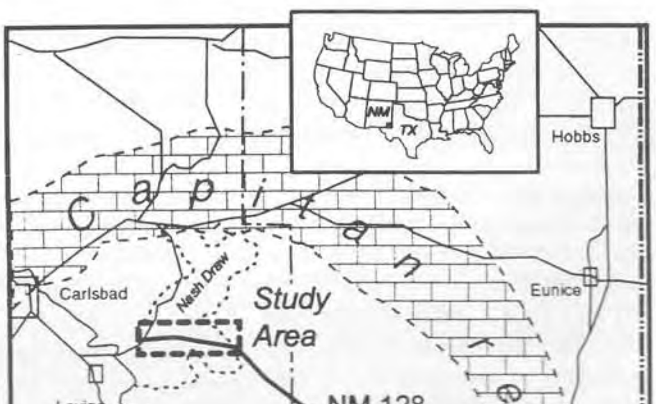

Figure 1. General location map of study area for realignment of western end of State Highway 128 (NM 128) in southeastern New Mexico.

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cated mainly through using the photographs; Dave Belski used his personal Global Positioning System (GPS) equipment for some of the field survey, which was quite helpful.

Based on previous field experience, most of the observable evaporite karst features of significance were expected to be east of Laguna Cuatro along outcrops and subcrops of the sulfate beds of the Tamarisk Member of the Permian Rustler Formation (Fig. 2). While the gypsites of the Tamarisk Flats area should also be susceptible to karst formation, surface features do not appear to have developed to the same degree. Trenching for the El Paso Energy pipeline across the Tamarisk Flats (Fig. 3) did not show significant features (Powers and others, 1997). Most of the field survey was conducted east of Laguna Cuatro and included areas both north and south of the present NM 128 right-of-way.

Field time focused on forming an overall impression of evaporite karst in this area and was limited. A detailed survey will no doubt yield additional features through this area, and this study by no means covers the extent of karst in Nash Draw. Nevertheless, it is possible to propose a course of action for geotechnical field activities to help in the final decision about the location and design of the realignment.

BACKGROUND ON NASH DRAW EVAPORITE KARST

In 1925, Willis T. Lee examined this area as part of his broader studies of karst and caves in the region around Carlsbad Caverns. Sinkholes and small caves in central and northern Nash Draw (Fig. 1) were identified by Lee (1925), and he proposed a general theory of solution and fill to account for the development of the draw. Drilling in the late 1920s revealed potash minerals just north of Nash Draw, and further drilling resulted in development of the first potash mine in the early 1930s. Though this drilling focused on Nash Draw and the immediate surroundings, very shallow geology was not well studied. Robinson and Lang (1938) mapped some of the springs and the shallow hydrology, indicating that salt was being removed from the evaporites and that the overlying ground was subsiding in response. Vine (1963) also pieced together more of the geology and concluded that dissolution had affected the outcropping formations sufficiently so that it was difficult to make sense of the stratigraphic sequence. Vine also noted sinkholes in the central part of Nash Draw.

The most comprehensive theories of solution and fill or evaporite karst were developed by George Bachman (1974, 1976, 1980, 1981, 1985) for much of this area. Bachman (1981) mapped the Nash Draw area in more detail, identifying numerous areas of sinkholes or collapsed sinks. He also proposed (Bachman, 1980) that alluvial dolines observed just east of Livingston Ridge (well north of the NM 128 right-of-way) provided local catchment and feeders to

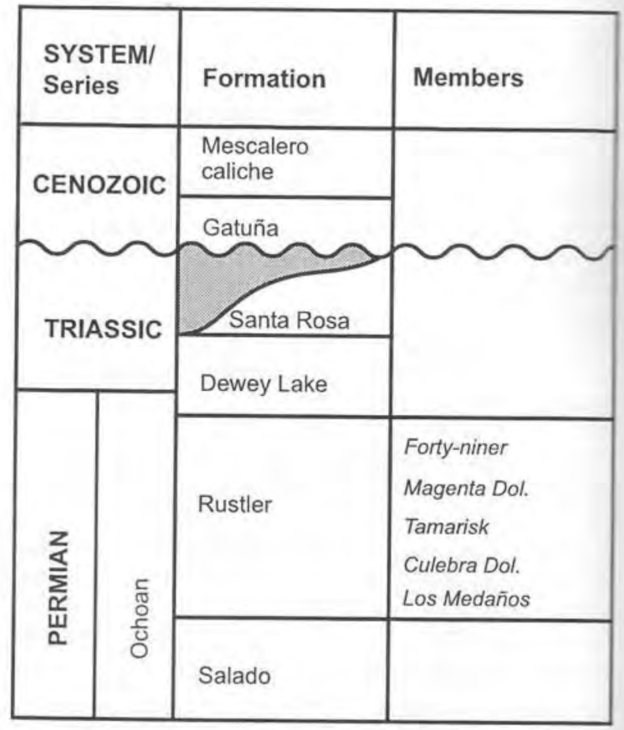

Figure 2. Simplified stratigraphic chart of the study area. Surficial deposits, including gypsite, dunes, and soils, are not shown.

Nash Draw at one time and developed local spring deposits on the eastern side slopes of Nash Draw. Bachman (1981) shows a few sinkholes in the general vicinity of proposed realignment routes for NM 128, but his studies were more general.

SPECIFIC SURVEY FEATURES

Based on analysis of photos, topographic maps, and field surveys, features are grouped into six more-general categories that have utility for the realignment study:

1. Caves, which include a variety of shapes and sizes, but all are developed in gypsum rock or well-lithified gypsite.

2. Alluvial sinkholes, in which soft or unlithified alluvium has collapsed and should indicate a cave opening for drainage below the sinkhole.

3. Alluvial dolines, which are shallow depressions with alluvial fill in the depression. Cave or alluvial sinkholes may or may not be observable in an alluvial doline.

4. Collapse valleys or swales, postulated to develop as a series of dolines or caves connect and an area collapses after dissolution.

5. Springs, which feed some of the local lakes and may be fed by karst recharge.

6. Lineaments, which show apparent trends to a variety of features.

The first three features are individual and more objectively identified. The collapse valleys or swales

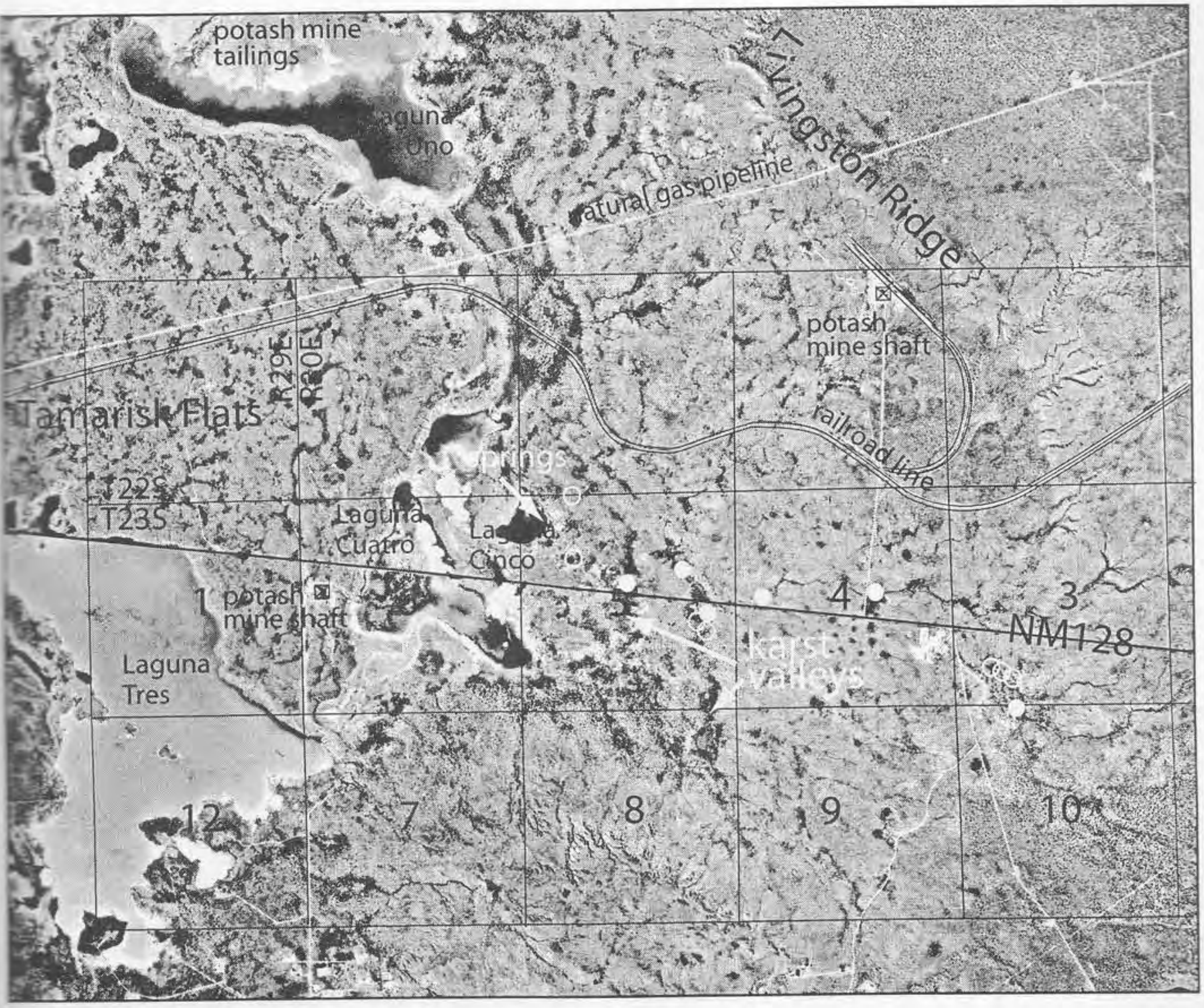

Figure 3. Aerial-photograph underlay of part of the study area, with NM 128, potash mines, brine lakes, and some township, range, and section lines. Open white circles show general locations of caves described in the text. Solid white circles show the general locations of sinkholes in alluvium or alluvial dolines. Small, round, dark areas in the photo commonly indicate alluvial dolines. Karst valleys probably developed from coalescing subsidence, and they may follow stratigraphic boundaries of gypsum beds in the Tamarisk and Forty-niner Members of the Rustler Formation. More linear trends are observable in this aerial photograph; no lines have been drawn that would obscure the features. The aerial-photograph source of the underlay is image NAPP 9611-51, dated 10/22/1996, from the EROS Data Center, Sioux Falls, South Dakota.

are identifiable as features, but their origin is more speculative in some cases. Although the springs are clearly identifiable, their relationship to karst is possible but speculative. Lineaments are yet more subjective groupings of features.

Caves

At least five larger caves are within ~300 m of the existing or proposed rights-of-way that may be large enough to be entered (open white circles in Fig. 3). Around some of these caves are smaller drop holes or subsidiary entrances that are not separated for discussion.

Los Medaños caves (Zone 13: UTM ~606000 mE, 3577250 mN) are in a large area of caves and alluvial sinkholes developed in outcrops or over subcrops of the upper sulfate bed of the Tamarisk Member. This area is in the SW¼ sec. 3, T. 23 S., R. 30 E., just southeast of the intersection of NM 128 with Mobley Ranch Road (Fig. 3). The area is southwest of a vegetative-study plot adjacent to NM 128.

Thornbush cave (new name) is near the northern boundary of the NW¼ sec. 5, T. 23 S., R. 30 E. (UTM 602942 mE, 3578571 mN) (Fig. 3). A secondary cave is present near Thornbush cave. Thornbush cave (Fig. 4) is developed in surficial gypsite that likely overlies the upper sulfate bed of the Tamarisk Member.

Saltbush cave (new name) is near the center of the

NW¼ sec. 5, T. 23 S., R. 30 E. (UTM 602772 mE, 3578111 mN) (Fig. 3). It is in a large, heavily vegetated alluvial doline near the crest of a small hill. This cave entrance is relatively large (Figs. 5, 6), and it is also developed in gypsite. Although the Tamarisk Member likely underlies this site, there are no nearby outcrops to determine possible depth.

Goldenrod cave (new name) is in the SE¼ sec. 5, T. 23 S., R. 30 E. (UTM 603827 mE, 3577475 mN) (Fig. 3). The surficial deposits appear to be gypsite, but the Tamarisk sulfate beds must be shallow, as they are exposed at the mouth of nearby Acacia cave. The Goldenrod cave entrance is also relatively large (Fig. 7).

Acacia cave (new name) is in the SE¼ sec. 5, T. 23 S., R. 30 E. (UTM 603747 mE, 3577528 mN) (Fig. 3). It has the largest observed entrance (Fig. 8), and some notable rattlesnakes guarding the entrance. Acacia cave has nearby subsidiary unnamed caves, and it is in an area with several alluvial sinkholes in a broad collapse valley or swale.

Figure 4. The entrance to Thornbush cave is developed in surficial gypsite that likely overlies the upper sulfate bed (15+ m thick) of the Tamarisk Member. Dave Belski provides scale.

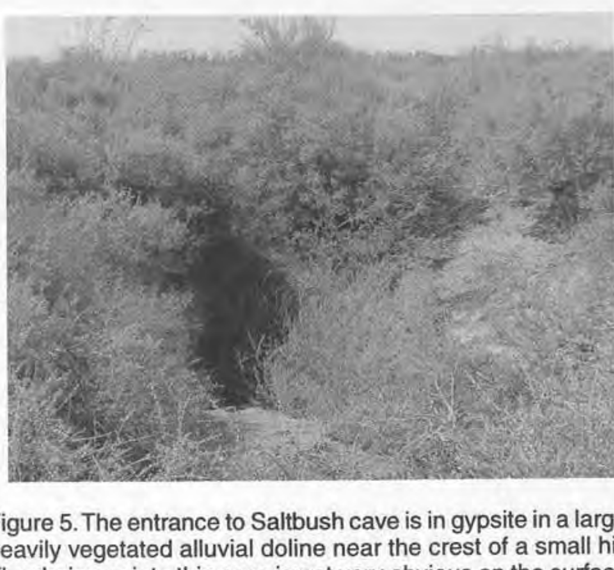

Figure 5. The entrance to Saltbush cave is in gypsite in a large, heavily vegetated alluvial doline near the crest of a small hill. The drainage into this cave is not very obvious on the surface.

A small, shallow series of caves occurs slightly west of the center of the NE¼ sec. 5, T. 23 S., R. 30 E. (UTM ~603350 mE, ~3578175 mN). These caves developed in gypsite along a north-northwest trend and show no significant drainage into them.

The rocks and lithified gypsite around cave entrances surveyed here commonly display some dip to bedding and fracturing. The dip is often at odds with the regional dip of about 1° to the east, no doubt caused by movement of the rocks after solution of underlying sulfate or Salado Formation halite (Powers and others, 2003). The fracture trends have not been mapped.

Exploration in the area of these caves will surely show additional caves and alluvial sinkholes. In view of the topography and drainage patterns, there should be additional caves to be found south and east of the localities given here. Though these caves and features would be of general interest in understanding the development and status of evaporite karst along the realignment routes, the survey of features was conducted in the more immediate vicinity of the routes.

Alluvial Sinkholes

The term *sinkhole* generally refers to a small area of collapse at the surface in bedrock and soil. In this area, small cave openings occur in lithified gypsite or gypsum rock. Generally circular and local collapse of unlithified alluvium occurs within a larger alluvial doline. This collapse of alluvium is called here an *alluvial sinkhole*. For the most part, more lithified units that allow drainage are not observed in the bottom of an alluvial sinkhole. It is probable that, if the drainage is adequate, the alluvium is washed out, leaving an observable cave.

Six larger alluvial sinkholes were found in the area of the survey (solid white circles in Fig. 3). Numerous very shallow depressions in alluvial dolines or collapse valleys have been observed, but they were not documented if they appeared not to be active. Significant alluvial sinkholes are located as follows:

1. Near the center of sec. 5, T. 23 S., R. 30 E., at approximate UTM coordinates of 603250 mE, 3577925 mN. This alluvial sinkhole is near the current right-of-way, and it is within a major collapse valley or swale.

2. Near the southern boundary of the NE¼ sec. 5, T. 23 S., R. 30 E., at approximate UTM coordinates of 603625 mE, 3577975 mN. This alluvial sinkhole is developed along the edge of a major collapse valley or swale, and it also would be approximately on line from Thornbush cave through some other unnamed small caves.

3. North of the center of the SE¼ sec. 5, T. 23 S., R. 30 E., at approximate UTM coordinates of 603800 mE,

3577600 mN. There are at least two larger alluvial sinkholes and a number of small depressions. These alluvial sinkholes may have small areas of rock outcrop and may just be covering some cave entrances related to Acacia and Goldenrod caves.

4. Near NM 128 and the western boundary of sec. 4, T. 23 S., R. 30 E., at approximate UTM coordinates 604200 mE, 3577780 mN. This alluvial sinkhole (Fig. 9) developed in a large alluvial doline just up-drainage from a narrow arroyo cut through gypsite and into the top of the upper Tamarisk gypsum bed. Given the porosity observed in the gypsite in the arroyo, it seems likely that part of the drainage into the alluvial sinkhole feeds the arroyo at its head.

5. Slightly southeast of the center of sec. 4, T. 23 S., R. 30 E., and just east of the road to the former Western Ag Minerals surface facilities, at UTM coordinates 605139 mE, 3577814 mN. There are several major alluvial sinkholes here, at the north side of a large alluvial doline.

6. Near the northern edge of sec. 10, T. 23 S., R. 30 E., at UTM coordinates of 606160 mE, 3576964 mN. This alluvial sinkhole shows general evidence of a deep soil profile that likely indicates relatively rapid and uniform accumulation of alluvium before developing the soil profile from the surface down. The A and B horizons appear to be moderately developed (Fig. 10).

Several alluvial sinkholes are near the present right-of-way or preferred alternate routes. They indicate that these areas are still active in draining runoff through karst conduits that are of sufficient size to pass alluvium through without plugging.

Alluvial Dolines

There are numerous alluvial dolines in the area, and they are commonly visible on the aerial photograph (Fig. 3) as small black dots owing to vegetation. Good examples occur at Saltbush cave in the NW¼ sec. 5, T. 23 S., R. 30 E., and at the alluvial sinkhole near the center of sec. 4, T. 23 S., R. 30 E. These alluvial dolines are relatively shallow depressions with a

Figure 6. Detail of the entrance to Saltbush cave shows debris indicating water inflow, and a packrat nest indicating that flow has not been too recent or deep. Rock hammer for scale.

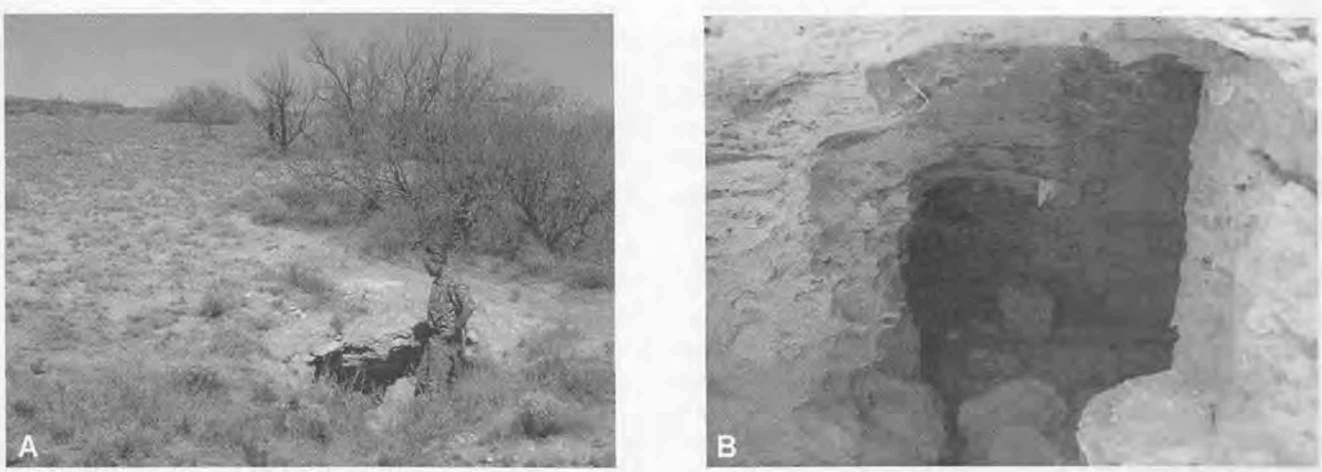

Figure 7. (A) Entrance to Goldenrod cave in gypsite deposits overlying Tamarisk Member gypsum. Goldenrod cave, like Acacia cave (Fig. 8), lies in the eastern of two apparent karst valleys (Fig. 3). Lewis Land provides scale. (B) Close-up of entrance to Goldenrod cave, showing some planar boundaries along fractures believed related to subsidence as Rustler gypsum, and possibly upper Salado halite, was dissolved.

Figure 8. Entrance to Acacia cave in Tamarisk Member gypsum. This cave has the largest entrance observed in the caves along the study area. Several subsidiary caves in the area are likely interconnected. Acacia cave lies in the eastern of two apparent karst valleys trending approximately north–south and crossing the NM 128 right-of-way (Fig. 3).

Figure 9. Large sinkhole developed in an alluvial doline south of Los Medaños caves. This sinkhole appears relatively stable, as grasses have developed, along with a few annuals.

fill of alluvium. There are many small alluvial dolines with no obvious alluvial sinkhole, cave, or other specific drainage points for water coming into the doline. Smaller alluvial dolines (~50–150 m across) tend to have limited arroyos or channels upslope, and they very commonly develop a single channel or arroyo somewhat downslope. Larger alluvial dolines are more likely to show a direct channel draining downslope.

The vegetation in many of the alluvial dolines consists of mesquite, creosote, and gramma grasses or sacaton. Because these species are perennial, these dolines would appear to have rather stable surfaces, not subject to significant sedimentation. It may also be that these dolines receive less inflow. Other alluvial dolines show a variety of annual species, including ragweed or other "weeds" that are characteristic colonizing species. This vegetation may be growing in fresh alluvium or in areas that appear to be subject to more recent flooding. It seems likely that these species indicate relative instability of the surface of the dolines they inhabit.

Alluvial dolines are important recharge points, as is obvious where an observable alluvial sinkhole or cave has developed within a doline. The dolines without specific drainage points are also likely to be important recharge points, but they may also provide some storage, allowing longer periods of steadier recharge to the system. This is speculative without some direct hydrological observations in this area. It may be helpful in some areas, however, to provide surface drainage for alluvial dolines to limit or avoid the possibility of unplugging an alluvial doline to create a large alluvial sinkhole under a right-of-way.

Collapse Valleys or Swales

Two larger valleys or swales intersect the right-of-way in sec. 5, T. 23 S., R. 30 E. (Fig. 3). They tend to be 100–200 m wide and up to ~1 km long. Vegetation is heavy, consisting of larger mesquite, some creosote, and a variety of grasses. Local areas are covered with annuals, indicating surface instability owing to sedimentation or flooding or both.

Figure 10. The soil profile developed in the alluvial doline (Fig. 9) is relatively thick for an arid climate, and it indicates a significant period of relative stability. The white arrow indicates the boundary between a grayish, more organic-rich A horizon above and a reddish-brown B horizon below it. Neither soil horizon appears well developed.

These valleys or swales include caves and alluvial sinkholes, showing that evaporite solution has occurred and is occurring. In addition, the outlines of these valleys tend to have small scallops or arcs, indicating that they were alluvial dolines. As a result, it appears most likely that these valleys or swales formed from coalescing alluvial dolines and collapse.

It is possible that Laguna Cuatro represents a larger version of a collapse valley or swale, but there is no direct evidence or obvious features that indicate this origin.

These collapse valleys or swales can't be avoided along the preferred routes for realigning NM 128 through this area. One of the important design and construction efforts should be to provide some reasonable surface drainage through the right-of-way across collapse valleys. Water has covered the highway at these points in the past, and debris caught in fences and vegetation show that surface-water flow has been considerable. There is no obvious means of diverting water that accumulates in the valleys or swales. It is preferable to make sure that the water doesn't accumulate at the right-of-way and possibly redevelop conduits under the right-of-way, causing alluvial sinks.

Springs

There are several springs around the eastern and northeastern margin of the lake (Laguna Cinco) in the NW¼ sec. 5, T. 23 S., R. 30 E. (Fig. 3). Two smaller springs may be providing flow on the order of 10 liters/minute, while the larger spring on the northeastern edge may be flowing many tens of liters/minute.

This lake appears to be accumulating some subaqueous sulfate minerals but no subaqueous halite. Some of the water must seep from the brines in Laguna Cuatro, but the springs and runoff are probably more important. The water chemistry has not been tested, but it is likely that these springs are fed from karst-recharged zones in the area.

There is no apparent direct effect on the realignment from these springs. They likely indicate that the karst system is active and also that water may be encountered at rather shallow depths in some areas.

Lineaments

In the area examined for karst features, the alluvial dolines and collapse valleys appear to be arranged along some persistent trends. Much of the drainage that has developed also tends to be linear and commonly about perpendicular to some of the trends of the dolines and collapse valleys.

A recent (1996) National Aerial Photography Program (NAPP) aerial photograph (Fig. 3) of this area illustrates these trends (photo is not marked, to avoid obscuring the trends). Some linear trends along the major collapse valleys trend about north–south. Most of the other linear trends of alluvial dolines and drainage trend between about east–west and about southeast–northwest. As might be expected, caves, alluvial sinkholes, and springs can also be related to these trends, though there are too few of these features mapped to develop the trends on that basis alone.

At this time it is not possible to demonstrate the source of the linear trends in this study area. There are, however, two likely contributors. A study of the underlying Salado thickness in this general area shows that the upper Salado thins rather abruptly owing to dissolution, and the thinning increases from northeast (edge of Nash Draw) to southwest (Powers and Holt, 1995; Powers and others, 2003). Subsidence of the overlying Rustler rocks as dissolution continues is likely to produce some fracturing oriented perpendicular to the thinning trend—i.e., in the range from about east–west to about southeast–northwest. In addition, the bedding within the Rustler tends to crop out along the same trend in part of the area and along a trend more nearly north–south in some parts of the study area. The Rustler is not exposed very well, however, so these general trends can't be related in a straightforward way to the surface lineaments. Although fractures caused by subsidence after dissolution and bedding are the most likely contributors to the lineaments, the relationship should be considered speculative at this time.

GENERAL CONCLUSIONS REGARDING KARST

Several types of evaporite-karst features have developed mainly in the sulfate beds of the Rustler Formation or in the more recent gypsite that commonly blankets much of the Rustler gypsum outcrop. Caves and alluvial sinkholes clearly demonstrate that the karst is still active, whereas alluvial dolines and collapse valleys indicate that karst processes have continued for much longer, though the length of time is poorly bounded. Although it is likely that the hydrologic system that produces local springs is connected to the local karst, the springs also indicate that the system has some storage capacity. Most karst conduits drain rapidly.

The principal concern with road construction and maintenance related to karst through this area is to avoid sudden collapse into either an unknown cave or from "unplugging" an alluvial doline to produce an alluvial sink. The potential for collapse is real and can be demonstrated by the past rerouting of the Mobley Ranch road, <0.5 mi south of NM 128, around a collapse in an area with alluvial dolines and caves. Although the date of the collapse is not clear, it occurred after 1976, on the basis of aerial-photo inspection.

In view of the collapse valleys and apparent trends to karst features, it is most likely that existing features and existing trends will be followed as karst continues to develop. Conduits that are already developed will most likely continue to develop over the lifetime of a road. Given that geologically short period of time, a "new" sinkhole or doline is less likely to develop from collapse into a cavernous system; it is more likely that an existing doline or collapse valley will be locally reactivated. Existing trends should be given priority during field investigations for final design.

The significant alluvial sinkholes found during this survey tend to be in alluvial dolines where surface drainage is connected over larger areas and appears to concentrate more runoff. This is most apparent in the drainage north of the current right-of-way through sec. 4, T. 23 S., R. 30 E. It is appropriate to avoid this drainage system, and it is also appropriate to minimize surface inflow to alluvial dolines intersected by the road grade.

GENERAL DESIGN CONSIDERATIONS

Given the features already found in a basic field survey, it is highly probable that the existing NM 128 road grade was constructed across areas with active cave systems in evaporite rocks. The road grade has not failed because of karst processes. At least one localized collapse in this vicinity, however, caused the Mobley Ranch road to be rerouted in the last 24 years. Geologic inspection of the area suggests that the NM 128 route selection and design consider three recommendations.

The first is that the route through sec. 4 may be better if it stays on or slightly south of the existing road grade. The reason for this is that alluvial sinkholes appear to be developed in alluvial dolines along the drainage not far north of the existing right of way. This drainage apparently collects more water to flood the dolines, which may be the factor that develops the alluvial sinkholes. The sinkhole near the Western Ag Minerals access road is very large and is to be avoided. Some alluvial dolines south of the existing road grade may be aligned with this larger sinkhole and may be part of the same system, but they do not appear to be active at this time.

The second recommendation is to avoid concentrating road runoff and ditch drainage into alluvial dolines under the grade. At the same time, surface drainage out of any alluvial doline crossed by the grade should probably be enhanced or at least not hindered.

Third, grades crossing the larger alluvial valleys, especially in sec. 5, should provide adequate cross-grade drainage to eliminate unnecessary ponding in the low areas and possible activation of alluvial sinkholes. As practical, ditches may need to be designed to divert flow or minimize concentrations of flow into these areas.

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