ROLLALONG RESISTIVITY SURVEYS REVEAL KARSTIC PALEOTOPOGRAPHY DEVELOPED ON NEAR-SURFACE GYPSUM BEDROCK

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Abstract

Following flooding in September 2013, several areas in northern Eddy County, New Mexico (NM) were damaged by multiple sinkhole collapses. We conducted rollalong electrical resistivity (ER) surveys for subsurface cavities parallel to roads within and near the community of Lakewood, NM to guide road repairs. The rollalong method allowed us to generate exceptionally long, continuous ER profiles of the survey area. ER surveys attained a maximum exploration depth of 55 to 62 meters over a lateral extent of ~1000 meters, revealing an unconformable surface developed on gypsum bedrock, punctuated by shallow depressions. Subsurface stratigraphy, including clay-rich valley fill sediments, and mudstone and gypsum of the underlying Seven Rivers Formation, can be identified by vertical and lateral variations in electrical resistivity. The irregular bedrock surface of the Seven Rivers Formation reflects paleotopography developed on that surface prior to its burial by floodplain sediment. Some of the negative paleotopographic features are probably filled sinkholes, which may be associated with shallower karstic features not imaged on the profiles.

Background

In the aftermath of flooding in September 2013, several areas along Lakewood Road and Lake Road within the village of Lakewood, NM (Figure 1), were damaged by multiple small (1-2 m depth) sinkhole collapses (Figures 2 and 3). The National Cave and Karst Research Institute (NCKRI) was contracted to conduct electrical resistivity (ER) surveys parallel to the roads in an effort to identify subsurface cavities and guide road repairs.

The sinkholes in the study area, cover collapse sinkholes, form by the piping of soil and alluvium into underlying karstic cavities. Their position along the two roads is probably the result of drainage channels along both

Figure 1. Regional map of southeastern New Mexico, showing location of Lakewood study area.

shoulders of the roads, which have promoted groundwater recharge in these linear areas for many years. The piping of unconsolidated materials created cavities in the alluvium that slowly stopped up toward the surface and into the soil. Heavy rains and flooding in September 2013 focused substantially greater flow down into the soil in the channels until the cavities became sufficiently large and unstable, causing them to collapse and breach the surface.

Geologic Setting

Effective remediation of cover collapse sinkholes requires accurate characterization of piping zones and

Figure 2. Small sinkhole formed on north shoulder of Lakewood road. First author's foot for scale.

Figure 3. Lakewood, NM study area. ER survey lines parallel to Lake and Lakewood roads are indicated by red and blue symbols; each symbol represents one electrode in the array. Yellow filled circles show locations of sinkholes and other karst features photographed during resistivity surveys.

depth to bedrock. Stratigraphic units in the Lakewood area that are relevant to this investigation include a surface layer of topsoil 0 to 5 m thick, which grades into underlying clay, sand, and gravel of the Pecos River floodplain. The thickness of floodplain deposits

is highly variable because of paleotopographic relief developed on the underlying bedrock. Bedrock in the study area is represented by the Seven Rivers Formation, the middle unit of the Permian-age Artesia Group, which is composed of interbedded reddish-brown mudstone, siltstone, dolomite and gypsum. The Seven Rivers Formation is exposed along the McMillan Escarpment on the eastern margin of the Pecos River valley, where it is capped by dolomites of the Azotea Tongue (Kelley, 1971).

Subsurface dissolution of gypsum within the Seven Rivers Formation and other members of the Artesia Group has caused local and regional subsidence and has profoundly influenced topography along the margins of the Pecos River Valley. The presence of these highly soluble rocks has also contributed to the formation of sinkholes and caves (Land, 2003; Stafford et al., 2008). Lake McMillan, less than one kilometer east of Lakewood, was ultimately abandoned because of loss of water through karstic conduits within the underlying Seven Rivers Formation (Cox, 1967).

Based on a survey of well records in the area, depth to the top of the Seven Rivers Formation in the vicinity of Lakewood ranges from 26 to 49 m. One well intersected a cave within the Seven Rivers Formation at a depth of ~60 m.

Methods

The basic operating principal for electrical resistivity imaging involves generating a direct current between two metal electrodes implanted in the ground (current electrodes) in order to create a potential field. This potential field is sampled at multiple locations between two additional implanted electrodes (potential electrodes) in order to measure distortions around subsurface targets. The structure shown in 2D resistivity profiles and 3D models allows geologic and hydrologic interpretation and comparison with ground truth data derived from boreholes or other direct investigations. Previous work (e.g., Land and Veni, 2012; Land, 2013) has shown that resistivity imaging is one of the most effective methods for identifying water-filled and air-filled voids due to their strong contrast with surrounding bedrock.

Modern resistivity surveys employ an array of multiple electrodes connected with electrical cable. Over the course of a survey, pairs of electrodes are automatically measured

by means of a switchbox and resistivity meter. The depth of investigation for a typical ER survey is approximately one-fifth the distance between the furthest measuring electrodes (effectively, the length of the array of cable in 2D surveys). NCKRI staff conducted six electrical resistivity surveys parallel to Lake and Lakewood Roads (Figure 3), using 112 electrode arrays at a 3-m electrode spacing, for a maximum deployment length of 333 m per array and an anticipated depth of investigation of approximately 65 m. This spacing and target penetration depth were selected to determine if substantially larger cavities occur in the subsurface than were indicated by the size of the observed sinkholes. Resolution of an ER survey is estimated by taking one half of the electrode spacing. The 1.5m resolution of this array is finer than typically used in engineering studies over karst terrains. This degree of resolution was chosen to better define both small and large voids formed in the gypsum bedrock that were of particular concern.

Four of the surveys employed a rollalong method to increase the length of the resistivity profiles. After data were collected for each 112 electrode array, the first half of the array was shifted forward to the far end for a 50% overlap. Although this method does not increase the depth of investigation, it permits a nearly seamless ER profile much longer than the length of the main array. While resistivity data were collected, a survey-grade global positioning system (GPS) survey was conducted of all electrode positions for each array. The elevation

data were used for advanced processing to correct for variations in topography along the survey line. We used an Advanced Geosciences, Inc. (AGI) SuperSting R8/ IP/SP electrical imaging system to collect the data and EarthImager-2D™ software to process the data.

Results and Discussion

Lakewood Road, East of Railroad

Two rollalong resistivity surveys were conducted parallel to Lakewood Road, one on each shoulder, extending west from the intersection of Lake and Lakewood Roads to the Burlington Northern and Santa Fe (BN&SF) railroad tracks (Figure 3). These surveys achieved a maximum depth of investigation of 62 m below ground level. Variations in electrical resistivity are influenced by subsurface stratigraphy and facies variations (Figure 4), and by the presence of subsurface cavities. Our interpretation of the resistivity data is informed by subsurface records from area water wells, including an augmentation well drilled by the New Mexico Office of the State Engineer (NM OSE) in 2006, located approximately 3.2 km southwest of the survey area.

Three distinct stratigraphic units can be identified on the resistivity profiles. A thin zone of relatively high resistivity occupies the uppermost ~5 m of the section and extends almost continuously across the profile from west to east. This high resistivity layer most likely represents air-filled porosity in unsaturated soil and gravel.

Figure 4. Electrical resistivity profiles conducted along north and south shoulders of Lakewood road, east of BN&SF railroad tracks.

Underlying this high resistivity layer is an interval ~30 – 50 m thick of generally lower resistivity (5 to 30 ohm-m). This layer probably represents a more clay-rich section of alluvial material of the Pecos River floodplain. Clays typically have lower resistivity than more coarse-grained sediments.

A zone of moderately high resistivity extends across the profiles ~40 to 50 m below ground level. Based on well records in the survey area, we interpret this interval to represent mudstone and gypsum of the Seven Rivers Formation, which crops out along the McMillan Escarpment on the opposite side of the Pecos River. Undulations in the top of the Seven Rivers Formation reflect the paleotopography of the unit prior to burial by floodplain alluvium. A prominent depression in the top of the Seven Rivers is visible on the north shoulder profile between 138 and 165 m. This feature may represent a buried sinkhole filled with more electrically conductive clay, as indicated by a pod of very low resistivity material above it.

Lakewood Road, West of Railroad

Because of the presence of the railroad tracks, it was not possible to conduct continuous rollalong surveys on Lakewood Road. For this reason two separate surveys were conducted on the north and south shoulders on the west side of the railway (Figure 5). These surveys achieved a maximum exploration depth of 60 m.

A thin layer of high resistivity is also present on the profiles west of the railway, reflecting air-filled pore

space in sand and gravel of the soil horizon. This layer is underlain by 40 – 50 m of generally lower resistivity material of the Pecos River floodplain. However, several lenticular bodies of higher resistivity are also present within this section. One distinctive high-resistivity lens is present on the south shoulder profile between 110 and 140 m, ~15 m below ground level. A more laterally extensive high resistivity layer occurs beneath the west end of the north shoulder profile. Subdued reflections of both of these features are also present on the opposite shoulder profiles. Because of their geometry and their presence within the alluvial section, we interpret these features as lenticular bodies of coarse sand and gravel in the unsaturated zone; it is unlikely that they represent caves. In spite of the presence of several small sinkholes along the shoulders of Lakewood Road west of the railway, no obvious subsurface cavities are visible on the ER profiles.

The top of the Seven Rivers Formation is poorly defined in the resistivity survey data collected west of the railway. It is possible that the top of the Seven Rivers dips locally to the west and exceeds our depth of investigation in this area. Although regional dip is to the east, the topography of the Pecos Valley has been strongly influenced by local and regional subsidence due to subsurface gypsum dissolution (Bachman, 1984; Land, 2003), resulting in the presence of a number of sediment filled basins along the western margin of the river valley (Lyford, 1973).

Figure 5. Electrical resistivity profiles conducted along north and south shoulders of Lakewood road, west of BN&SF railroad tracks.

Lake Road

Two rollalong resistivity surveys were conducted along the west and east shoulders of Lake Road, extending north about one kilometer from the intersection of Lake and Lakewood Roads. Both surveys attained a maximum depth of investigation of 55 m.

The near-surface, high resistivity soil horizon is not as well defined on the Lake Road ER surveys. However, the lower resistivity, clay-rich alluvial section is clearly visible, extending along the entire length of both profiles (Figure 6). The Seven Rivers Formation is clearly defined by a high resistivity zone beneath the northern half of the profile ~25 m below ground level, and appears to be dipping gently to the south.

The top of the higher resistivity section that represents the Seven Rivers Formation is interrupted in several places, reflecting paleotopography developed on the top of the formation. One of these breaks occurs on the west shoulder profile between 600 and 650 m, where a sag in the top of the unit most likely represents a filled sinkhole. Subsidence over this feature appears to have caused a local near-surface accumulation of coarser sediment, as indicated by an overlying lenticular high resistivity zone. This feature is also visible on the east shoulder profile between ~630 and 670 m. Several less well-defined breaks in the Seven Rivers profile may also represent filled sinkholes.

A small but well defined pod of higher resistivity occurs at 305 m on the east shoulder profile, ~5 m below ground level, overlying a depression in the bedrock surface. A second high resistivity pod occurs directly beneath the first at ~20 m below ground level. These features are likely to represent subsurface cavities partially filled

with sediment, or two segments of a fissure adjacent to or extending beneath the roadway. A 4-m long soil fracture was identified near this section of the ER profile during the February, 2014 reconnaissance survey (Figure 3, number 16).

The ER profiles show no unambiguous near-surface (<5 m) resistivity anomalies that would indicate shallow subsurface cavities, in spite of the presence of several shallow sinkholes and earth fissures along both shoulders of Lake and Lakewood roads, immediately adjacent to the survey lines. We attribute the absence of such anomalies to the array configuration and electrode spacing, which was designed to detect larger cavities at greater depths.

Conclusions

Electrical resistivity surveys conducted parallel to Lakewood and Lake roads near the community of Lakewood, NM attained a maximum exploration depth of 55 to 62 m. Subsurface stratigraphy, including a near-surface soil horizon, clay-rich alluvium of the Pecos Valley floodplain, and mudstone and gypsum of the Seven Rivers Formation, are indicated by vertical and lateral variations in subsurface electrical resistivity. The irregular surface of the Seven Rivers Formation on all profiles reflects paleotopography developed on that surface prior to its burial by floodplain alluvial sediment. Some of the negative paleotopographic features are almost certainly filled sinkholes, which may be associated with shallower karstic features not imaged on the profiles. The absence of a well-defined Seven Rivers section on ER profiles along Lakewood road west of the railroad tracks may be due to a broad zone of subsidence caused by subsurface dissolution of evaporites, accompanied by a thicker accumulation of overlying floodplain alluvium.

Figure 6. Electrical resistivity profiles conducted along west and east shoulders of Lake road.

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