NCKRI REPORT OF INVESTIGATION 5

# ELECTRICAL RESISTIVITY SURVEYS, JOHNSON ESTATE DRILL SITE, LOVING COUNTY, TEXAS

National Cave and Karst Research Institute

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# ELECTRICAL RESISTIVITY SURVEYS, JOHNSON ESTATE DRILL SITE, LOVING COUNTY, TEXAS

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National Cave and Karst Research Institute

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Cover photo: Aerial view of the Red Bluff Reservoir Area, where the Johnson Estate Drill Site is located and which influences groundwater conditions at the site (imagery from Google Earth, 2014).

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## NCKRI Organization and Mission

NCKRI was created by the US Congress in 1998 in partnership with the State of New Mexico and the City of Carlsbad. Initially an institute within the National Park Service, NCKRI is now a non-profit 501(c)(3) corporation that retains its federal, state, and city partnerships. Federal and state funding for NCKRI is administered by the New Mexico Institute of Mining and Technology (aka New Mexico Tech or NMT). Funds not produced by agreements through NMT are accepted directly by NCKRI.

NCKRI's enabling legislation, the National Cave and Karst Research Institute Act of 1998, 16 USC. §4310, identifies NCKRI's mission as to:

1) further the science of speleology;
2) centralize and standardize speleological information;
3) foster interdisciplinary cooperation in cave and karst research programs;
4) promote public education;
5) promote national and international cooperation in protecting the environment for the benefit of cave and karst landforms; and
6) promote and develop environmentally sound and sustainable resource management practices.

## NCKRI Report of Investigation Series

NCKRI uses this report series to publish the findings of its research projects. The reports are produced on a schedule whose frequency is determined by the timing of the investigations. This series is not limited to any topic or field of research, except that they involve caves and/or karst. To minimize environmental impact, few or no copies are printed. Electronic copies of this and previous reports are available for download at no cost from the NCKRI website at www.nckri.org.

# TABLE OF CONTENTS



# LIST OF FIGURES

# Electrical Resistivity Surveys, Johnson Estate Drill Site, Loving County, Texas

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## Introduction

BHP Billiton Petroleum (BHP) is conducting an extensive drilling program in Culberson and Loving counties, Texas, to develop unconventional oil reserves in the Wolfcamp and other shale reservoirs. Some of the operator's wells have intersected cavities formed in the gypsum bedrock, resulting in significant lost circulation problems and troublesome surface cementing jobs. Possible worst case scenarios are blow-out conditions that can damage or destroy a drilling rig, and endanger personnel and the environmental integrity of the project if not mitigated properly. The cavities are reported to range in depth from about 50–335 m below ground level.

In an attempt to avoid future drilling hazards, BHP contacted the National Cave and Karst Research Institute (NCKRI) to conduct electrical resistivity (ER) surveys for subsurface cavities at the proposed Johnson Estate Drill Site in northwest Loving County, Texas, near Red Bluff Reservoir. NCKRI's work on this project will reduce the potential for drilling into a cave that could compromise the safety of the drilling operation, personnel, and the environment. However, it is critical to stress that this study cannot assure that no cavities or associated hazards will be encountered, such as by cavities smaller than the resolution of the ER methods employed.

NCKRI is conducting this project in part to support improved safety for drilling operations. Additionally, because the cavities that may be encountered by this and other drilling operations are isolated from direct human access and investigation, NCKRI is conducting this research to develop a database to better evaluate cave development, hydrogeology, and risk assessment in these otherwise unstudied areas.

## Geologic Setting

Many of the BHP wells are sited in a physiographic region known as the Gypsum Plain, a large expanse of upper Permian evaporites that crop out in southeastern New Mexico and west Texas (Stafford, 2013). The Gypsum Plain is located within the west-central section of the Delaware Basin, a large hydrocarbon producing sedimentary basin in west Texas and southeastern New Mexico (Land, 2003). Barnes (1976) mapped the geology and shows Quaternary alluvium covering the study area. Outcrops of Triassic age Dockum Group shales and siltstones, and Permian age Dewey Lake Redbeds of siltstone, sand, and clay, occur immediately to the east. Gypsum observed at the site, where not covered by alluvium, is probably from the Permian Rustler Formation, a roughly 50 meter thick sequence of limestone, siltstone, and sandstone with interbedded clay and gypsum.

BHP reports that cavities are not expected to occur deeper than about 120 m, with a minimum likely depth of approximately 67 m. These depths correlate to the Castile Gypsum, a major cave forming unit in the area. All of the bedrock units are essentially flat-lying and undeformed, but with a pronounced fracturing trending slightly north of east. However, Stafford (2013) identified major subsidence features in the study area.

## Methods

The basic operating principal for ER surveys involves generating a direct current, or an alternating current of very low frequency, between two metal electrodes implanted in the ground, while measuring the ground voltage between two additional implanted electrodes. Given the current flow and measured voltage drop between two electrodes, differences in subsurface electrical resistivity can be determined and mapped.

Resistivity profiles detect vertical and lateral variations in resistivity in the subsurface. The presence of water or water-saturated soil or bedrock will strongly affect the results of a resistivity survey. Air-filled caves or air-filled pore space in the vadose zone are easy to detect using the ER method, since air has near-infinite resistivity, in contrast with more conductive surrounding bedrock. By contrast, subsurface voids filled with brine or brackish water would be indicated by zones of low resistivity (e.g., Land and Veni, 2012; Land, 2013).

NCKRI staff originally proposed conducting two parallel surveys, 6 m apart, centered on the proposed well site, and oriented north-south perpendicular to the regional fracture trend and likely orientation of major caves. The purpose of the parallel lines was to provide greater confidence that a single line didn't slightly miss a cavity that might pose a hazard to the drilling operation, as well as to reinforce the interpretation of the results. However, well site infrastructure and construction activity prevented this configuration. We therefore conducted two surveys (JE1 and JE2) sub-parallel to each other in a northeast orientation (Figure 1). JE1 was conducted on 26 February 2014 and JE2 on 27 February 2014.

The depth of investigation for an ER survey is directly related to length of the array of electrodes—the longer the array, the greater the penetration that can be obtained. For the Johnson Estate survey, electrode spacing was 6 m, and the full array length for each survey line was approximately 666 m. A standard dipole-dipole array configuration was used to survey each ER line to depths of about 80 m. To achieve a greater depth of investigation, an infinity electrode was attached to an 18 gauge wire and extended in the direction of the JE1 array to collect data from depths greater than 120 m in a pole-dipole configuration. However, the wire was damaged in the field and rendered unusable. Consequently, a pole-dipole survey was only accomplished the next day for the JE2 array using an infinity electrode at the end of a shorter-than-preferred 500 m 18 gauge wire so a depth of only 100 m was surveyed.

The number of data points collected in the field is a function of array configuration and number of electrodes. Because we employed both dipole-dipole and pole-dipole arrays for the JE2 survey line, we were able to use EarthImager 2D software to merge the data from the two array configurations to maximize both resolution and depth of investigation. One advantage of this procedure is that it yields several thousand data points. Thus, even when a noisy data set requires removal of a large number of data points (15–25%) during the iterative process, a substantial amount of data remain for interpretation.

While resistivity data were collected, NCKRI personnel used the survey-grade Topcon GR3 global positioning system (GPS) equipment to collect survey-grade GPS coordinates for each electrode in the arrays (Figure 1). Elevation data collected during these surveys was used to correct the resistivity data for variations in topography at the survey site.

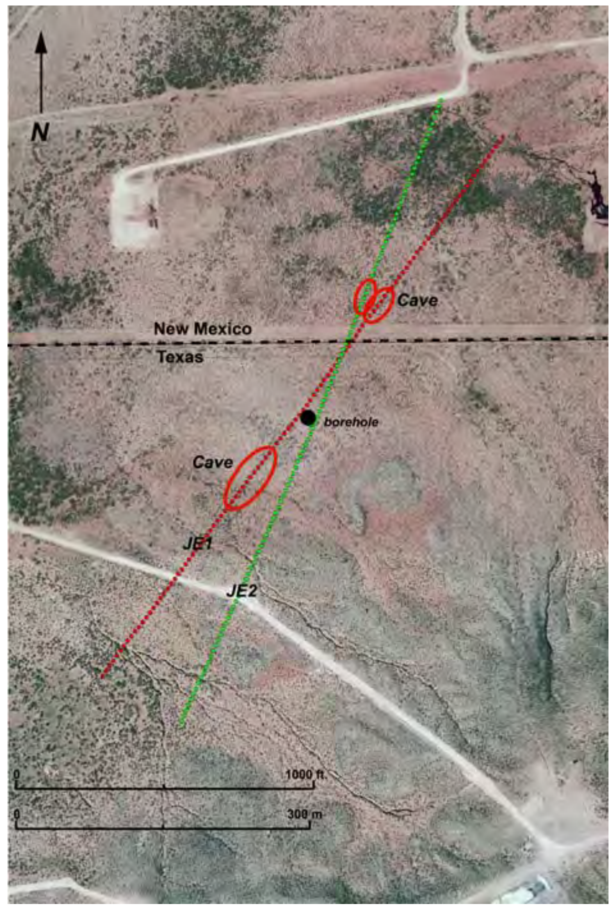


***Figure 1**. Map of Johnson Estate survey area, showing locations of JE1 and JE2 resistivity survey lines, proposed borehole location, and probable caves identified by higher resistivity zones. Red and green dots indicate locations of electrodes.*

Electrical resistivity surveys, as with any geophysical method, yield non-unique solutions. We may interpret isolated zones of relatively high resistivity as subsurface cavities in the phreatic zone filled with fresh to slightly brackish water. However, a similar signal could be produced by a cavity filled with water-saturated sediment, or by a water-saturated breccia zone that may have resulted from a collapsed cave. In addition, because the surveys documented in this report are twodimensional, they cannot image possible subsurface voids that are not directly beneath the survey line. For these additional reasons, we recommend conducting two parallel or sub-parallel resistivity surveys to better ensure that cavities will not be encountered while drilling.

NCKRI personnel for this project consisted of:

- Dr. Lewis Land, karst hydrogeologist, and Principal Investigator for the study
- Dr. George Veni, NCKRI Executive Director and karst hydrogeologist
- Lasha Asanidze, NCKRI student intern

BHP provided the following personnel:

- John Theriac, operations geologist
- Ted Lee, graduate geologist
- Alphie Wright, graduate geologist

Madron Services was subcontracted by NCKRI to provide field support with conducting the surveys. Madron personnel assisted with deploying electrical cable, installing electrodes, loading and unloading equipment, and repairing damage to cable connectors.

## Results

Based on the absence of distinct electrical resistivity anomalies on the JE1 and JE2 survey lines (Figure 2), it is unlikely that significant cavities are present directly beneath the proposed borehole location at the Johnson Estate Drill Site to depths of 100 m. Figure 2 includes the ER profiles in default mode, which are at different resistivity scales to better highlight the relevant features, and, at BHP's request, at similar scales for more direct comparison. The area beneath the proposed borehole location on both profiles is dominated by low to moderate resistivity indicative of water-saturated bedrock. This is confirmed by a relatively horizontal zone of low resistivity at an elevation of about 860 m in both arrays. The water level in Red Bluff Reservoir, which partially wraps around the site from 700 m to the west to 2.1 km to the south and southeast, was at an elevation of 857.6 m during the time of the surveys (Texas Water Development Board, 2014). This represents the lowermost elevation of the water table in the study area during this investigation and is consistent with the resistivity data, which show a transition from vadose to phreatic groundwater conditions.

Line JE1 shows a thin high resistivity layer near the surface beneath the well pad, which may result from the presence of air-filled porosity in the fill material used to construct the pad. A small, distinct resistivity anomaly is present on the JE2 profile between 450 and 467 m ~12 m below ground level (Figure 2B, C, and D). The resistivity of this anomaly (3,500-3,700 ohm-m) suggests it is probably a cavity filled with relatively fresh water. This feature coincides with a lower-resistivity zone present beneath 461 m on the JE1 survey line (Figure 2A). The JE1 anomaly probably represents a sideswipe of the cave detected on JE2, hence its lower resistivity and less well-resolved geometry. The presence of a pipeline could produce a similar resistivity anomaly. Line JE2 does cross a pipeline, but the high resistivity zone is ~5 m north of the pipeline crossing and probably too deep to be caused by a pipeline.

A large resistivity anomaly is clearly visible between 200 and 280 m on line JE1, ~20 m below ground level beneath the southwest corner of the well pad (Figure 2A). Its high resistivity values (~180 to 600 ohm-m), compared to the surrounding surveyed area, could result either from void space filled with relatively fresh water or from a water-saturated breccia interval; the lateral extent of the cavity is not clear. However, the data suggest it is very likely that a substantial cave is present at this location. This interpretation is consistent with observations by a local driller who reported losing circulation at 20 m depth at two wells within ~300 m of the drill site.

## Conclusions

Resistivity surveys at the Johnson Estate Drill Site do not show evidence of any obvious subsurface cavities directly beneath the proposed borehole location. However, the data suggest that two caves are present, one northeast and one beneath the southwest corner of the well pad. The southwest resistivity anomaly on line JE1 is consistent with the presence of a large cave, yet no obvious ER anomaly is present on line JE2, <15 m to the east. We therefore recommend that future surveys employ a minimum of two parallel or sub-parallel resistivity lines to better ensure that any cavities can be detected.

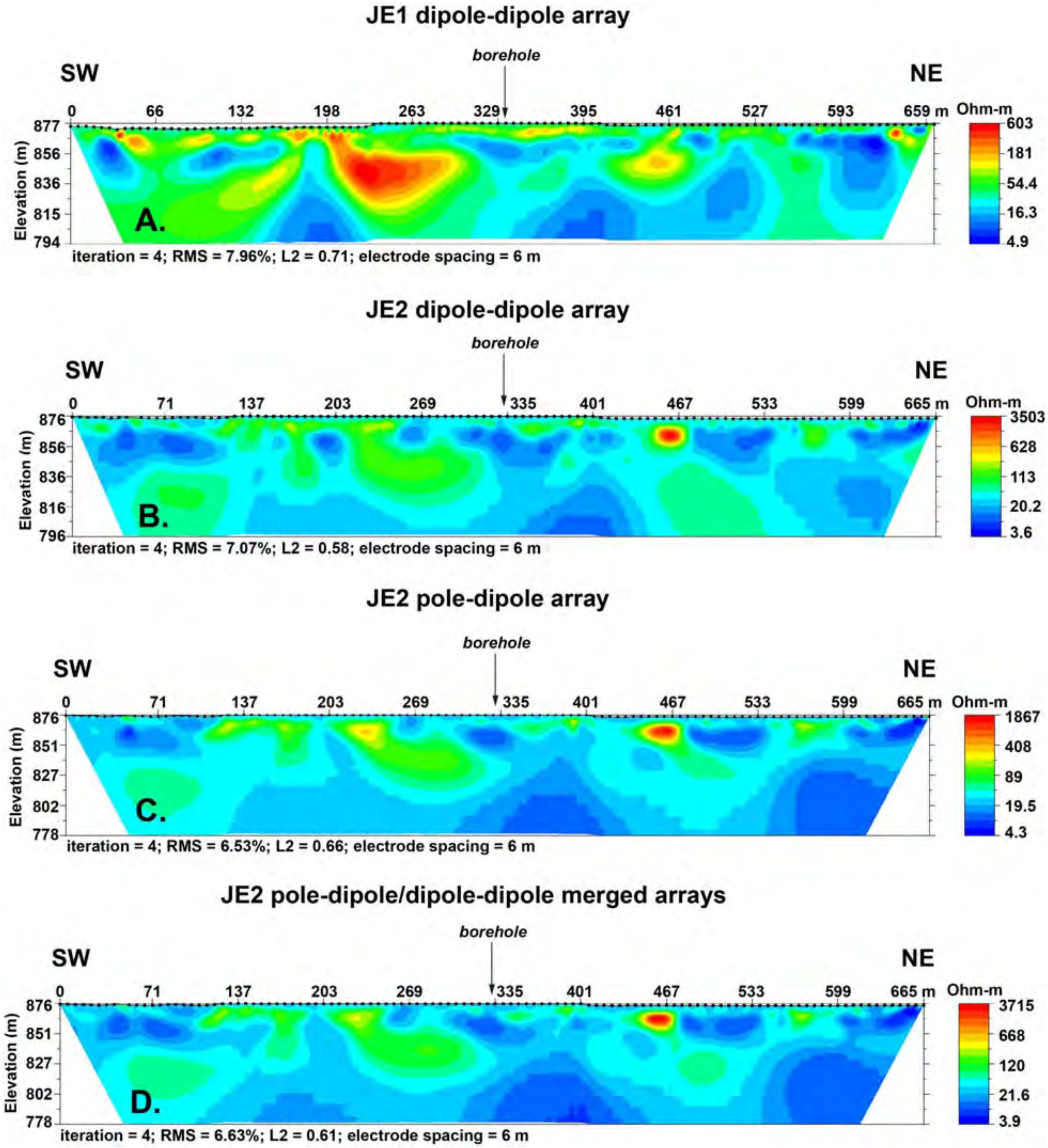


***Figure 2.*** *Resistivity profiles at the proposed borehole.*

*A. JE1, dipole-dipole array. A probable cave is indicated by a higher resistivity zone beneath the southwest corner of the drill pad, ~20 m below ground level between 210 and 281 m. A smaller cave is indicated at 461 m ~20 m below ground level.*

*B. JE2, dipole-dipole array. The small cave identified north of the drill pad on line BHP1 is more sharply defined on line JE2 at 467 m.*

*C. JE2, pole-dipole array.*

*D. Merged data from JE2 dipole-dipole and pole-dipole arrays.*

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