January 2009

GPR Report, 2009 Ground Penetrating Radar Surveys Near Big Manhole Cave

Ron Lipinski
Carl Pagano
Steve Peerman

Follow this and additional works at: https://digitalcommons.usf.edu/kip_data

Recommended Citation
Lipinski, Ron; Pagano, Carl; and Peerman, Steve, "GPR Report, 2009 Ground Penetrating Radar Surveys Near Big Manhole Cave" (2009). KIP Data Sets and Technical Reports. 82.
https://digitalcommons.usf.edu/kip_data/82

This Text is brought to you for free and open access by the Karst Information Portal at Digital Commons @ University of South Florida. It has been accepted for inclusion in KIP Data Sets and Technical Reports by an authorized administrator of Digital Commons @ University of South Florida. For more information, please contact digitalcommons@usf.edu.
Ground Penetrating Radar Surveys Near Big Manhole Cave

Ron Lipinski, Bob Straub, Jacqui Thomas, Steve Peerman,
George Veni, Jeff Bach, Carl Pagano
May 10, 2009

A set of brief Ground Penetrating Radar (GPR) surveys was made inside Big Manhole Cave (BMC) and over the entrance room on March 24-28, 2009 to determine the distinguishing features of a GPR image of a cave and to help determine whether passages might exist close to existing passages. This report summarizes the results. The chronological sequence of GPR measurements was

1) Floor of the entrance room (3/25/09),
2) Northeast dig branch at the bottom of the dig (from survey point W17 to W19) (3/26/09),
3) Southeast dig branch at the bottom of the dig (near survey point W23) (3/27/09)
4) Surface survey over the cave just south of the gate

However, the results will be presented starting with the surface survey and working downward since it makes interpretation of the data easier.

Description of the Cave and Dig Passages

Figure 1 shows a vertical profile of the cave and dig passages oriented 40° relative to magnetic north. This orientation captures the dig passages which are primarily in a vertical plane at that angle. The dig passages stay close to the southeast wall of the entrance room (which is filled with breakdown). Figure 2 shows a plan view of the entrance room. GPR survey lines and dates are shown in green. The entrance room has a ceiling that is about 35 to 40 feet above the floor. There is about 20 feet of bedrock from the ceiling of the room to the surface. The dig is in the southeast corner of the room. The floor is flat on the south side of the room, partly because of the fill from past digs, and partly because of the wash from rainwater and mud entering the crack during severe weather. The rainwater drains to the west at the end of the 3/25 survey in Figure 2.
Figure 1. Profile of Big Manhole Cave at 40° Orientation (0 Elevation is Surface)
Description of Equipment

The GPR unit used was a PulseEkko bistatic radar (Sensors & Software, Inc., Mississauga, Ontario, Canada) with a 100-MHz antenna on loan from Prof. Catherine Snelson of New Mexico Tech, Socorro, New Mexico. Figure 3 shows the setup of the data acquisition system (excluding the antennas) from a previous trip. The wagon was not used for this expedition due to the rugged nature of the terrain. The yellow box is the data control electronics. It sends signals along a fiber optic cable to a transmitter, shown in Figure 4. The transmitter is attached to a 100-MHz (quarter wavelength) antenna. It generates a pulse of electromagnetic waves and transmits them into the ground. The pulse of waves is reflected at discontinuities in ground conductivity, such as bedding planes, deposits of clay or water, or large voids. The reflected signals are detected by the receiver antenna and amplified and converted to light before being sent back to the data control electronics along a second fiber optic cable.
Figure 3. Pulse Ekko 100 GPR Equipment

Figure 4. GPR Transmitter (left), Receiver (right) and Attached Antennas (on ground)
The control electronics determines the time difference between the transmitted and reflected signals, as well as the amplitude and sign of the signal, and transmits that information to a laptop computer via an RS-232 cable. The computer stores all the information and also has software for real-time visualization of the results (similar to what is shown later in this paper). The control electronics is powered by a 12-V lead-acid car battery or marine battery. The transmitter and receiver have their own set of 12-V sealed lead-acid batteries. The computer uses its own lithium-ion batteries but can be run off the car battery via an inverter and power supply (but this is very wasteful of battery power). The system can run for about a day of data acquisition if careful power management is observed. For example, the computer should be dim and turned off when not needed. The control electronics, transmitter and receiver should be turned off when not needed.

**GPR Velocity and Penetration Measurements**

The GPR velocity in rock and penetration measurements were obtained on a previous expedition in July 2008. Those results are reproduced here for completeness. The first measurement was a common midpoint measurement (CMP) to determine the speed of propagation of the GPR electromagnetic waves through the ground at this site. It was made on the rocky jeep road at the trailhead to the cave. The road had exposed bedrock (limestone) and thus had very little attenuation from surface material before bedrock was encountered. In a CMP measurement, the two antennas of the GPR are separated in a series of steps symmetrically about a fixed point. Figure 5 shows the results. The topmost region represents the electromagnetic waves traveling through air. The measured speed is 2.98 x 10\(^8\) m/s (0.298 m/ns, or 0.977 ft/ns). This is in close agreement to the speed of light, as expected. The next region shows the waves propagating through the ground just below the surface. The measured speed is 1.01 x 10\(^8\) m/s (0.101 m/ns, or 0.331 ft/ns). This also is in agreement with typical speeds in limestone. This number enables us to convert the round trip time of a signal into depth.

Figure 5 also shows reflections at numerous depths. Clear reflections are seen down to 250 ns for a round-trip time. This corresponds to about 12.5 m (41 ft). This measurement was obtained at 100 MHz with a stack of 64 pulses at each station.

Figure 6 shows the effect of using more or fewer pulses stacked up at each station. The first column shows five stations at a single location, each with just four pulses stacked together. The second column shows the same location with 128 pulses stacked together. The 4-stack data becomes difficult to distinguish from noise at a depth of 9 m (30 ft) (180 ns round trip). The 128-stack data seems to be clear beyond 14 m (46 ft) (280 ns round trip), although the plot does not extend beyond that depth. Statistically, the signal to noise ratio should increase with the square root of the number of stacks. This helps overcome the signal attenuation with depth of penetration.
Figure 5. Common Midpoint Measurement

Figure 6. Comparison of 4 stacks and 128 stacks
Surface GPR Survey Across the Cave Entrance (3/25/09)

A surface survey was done across the top of the cave entrance on March 28, 2009 to better define the characteristics of a cave passage when viewed via GPR. The starting and end points are given in Table 1 in UTM Coordinates Datum NAD1927, Zone 13 (using a GPS unit from G. Veni). The coordinates for the brass benchmark above the cave gate is included for reference.

<table>
<thead>
<tr>
<th>Location</th>
<th>Location</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start</td>
<td>548600</td>
<td>3562374</td>
</tr>
<tr>
<td>Finish</td>
<td>548616</td>
<td>3562357</td>
</tr>
<tr>
<td>Brass Benchmark</td>
<td>548597</td>
<td>3562388</td>
</tr>
</tbody>
</table>

The survey line followed the surface of the ground, was fairly level, passed through lechuguilla, sotol, scrub juniper, and rugged rock. There was very little dirt, clay or gravel overlying the bedrock. Figure 7 shows the terrain close to the start of the survey. There is an 8-foot sharp drop south of the survey line which starts about 30 ft south of the line at the start of the survey, swings out to about 60 ft south of the line at the cave entrance, and then swings back to about 15 ft south of the line at the (west) end of the survey. Figure 8 shows the survey as it passes south of the cave gate (which is directly above the entrance drop of about 60 feet to the entrance room floor). Figure 9 shows the survey near the end. A caver in the background at the left of the picture in Figure 9 shows the location of the cave entrance. Figure 10 shows the cable management technique needed to preserve the optical cables in the challenging environment. The antenna were held as nearly horizontal as possible for each shot, even if that mean levitating one end or the other. Occasional junipers, lechuguillas, ocotillos, and cacti added to the challenge. Figure 11 shows the control center setup located among the lechuguilla (foreground) and ocotillo (background). Figure 12 shows a sunshade technique for viewing the computer screen in the bright desert sunlight.

The antennas were aligned perpendicular to the path of travel, as can be seen in Figure 7 and Figure 8. A step size of 25 cm was used between shots, using a tape measure lying on the ground for reference. At each station 128 pulses were taken and stacked up electronically to reduce signal noise and increase penetration. This took about 4 seconds per shot; moving to the next shot location usually took a comparable amount of time. A 400-ns acquisition window was used to assure collection up to 20 m if available. The antennas were kept 1 m apart. The transmitter was in the lead (west of the receiver). AGC gain was 500.

Because the length of the survey exceeded twice the length of the fiber optic cables, and to reduce the risk of loss of data from unanticipated battery depletion, the survey was saved into two separate sequential files. Figure 13 shows the combined survey results.
Figure 7. Near the Start of the Surface Survey

Figure 8. Survey Passing just South of the Cave Gate
Figure 9. Near the End of the Surface Survey

Figure 10. Cable Management in the Rough Terrain
Figure 11. Control Center Setup

Figure 12. Sunshade for Viewing Computer Screen
Figure 13. GPR Surface Survey across Top of Big Manhole Entrance Room, SE to NW at 298° (Magnetic)
The surface survey figure has been reversed from the normal display so that it is oriented approximately from northwest to southeast (left to right). This places it approximately in the same orientation as shown previously for the plan view in Figure 2. Thus, the view is looking approximately northeast, and the two GPR surveys (BMRE110 and BMRE111) progressed from right to left in the figure. The brass cap at the top of the figure indicates where the entrance crack is located. The approximate locations of the room walls as traversed by the survey are also shown in the figure, as well as the location of the dig passages. The location of the floor will be discussed shortly.

Some discussion of how GPR data are plotted is needed to interpret this figure. The GPR antenna sends out a hemispherical wave into the ground and measures the time of the return signal. Return signals are obtained from all directions, not just directly below. The return signals are plotted in a vertical line in the graph with sign and intensity indicated by different shades of white or black. Each shot is plotted in a vertical line offset horizontally by the same fixed amount. By taking data at a series of locations the return signals can be interpreted.

For example, as the transmitter and receiver pair approaches the vertical wall of the entrance room from the right in the figure, a return signal is obtained from it with a round trip travel time for the pulse that is equal to twice the slant-range distance divided by the speed of the electromagnetic wave in rock (0.101 m/ns, or 0.33 ft/ns). As the transmitter and receiver pair get closer, the slant range distance decreases, so the plotted time at each location decreases. This results in a plot of a line trending upward at an angle. This is precisely what is seen from 155 ft to 130 ft in the figure: a diagonal line that decreases in delay time from 240 ns to 140 ns on the right vertical axis. This is the southeast wall of the entrance room. A similar diagonal line is seen from 30 ft to 60 ft. This is the northwest wall of the room.

There are numerous horizontal black and white lines in the top region of the figure. A distinctive pair occurs at a depth of about 19 feet. A horizontal line is indicative of a bedding plane in the limestone. As the antenna pair is moved along, the minimum round-trip time of flight remains fixed. Hence the signal builds into a horizontal line. Note that this horizontal line coincides with the top ends of the two diagonal lines that represent the room walls. The bedding plane marked by the horizontal line becomes the ceiling of the room when it is between the walls. The match is not precise because the walls bend inward as they approach the ceiling. The thickness of the limestone over the top of the room is about 20 feet, which agrees with survey measurements through the entrance crack.

The location of the room floor is about 35 to 40 ft below the ceiling. However, when the electromagnetic waves travel through air in the room, they travel at three times the speed they do in limestone (0.30 m/ns instead of 0.10 m/ns). Hence, the floor of the room would be plotted about 12 to 13 ft below the ceiling rather than 35 to 40 ft because the plotting program does not compensate for propagation in voids. Indeed, there is a distinct horizontal line plotted 13 ft below the ceiling (at a total depth of 33 ft). This is the floor of the room. This level is indicated by dashed lines in the figure. Note that the floor level yields a fairly strong signal where it is flat. This may be due to the very strong reflection caused by the air-rock or air-dirt interface there.
The region between the ceiling (20 ft depth) and the room floor (33 ft depth) is full of reflections. These may be due to the sloping breakdown pile and flowstone shown previously in Figure 1 and Figure 2. The breakdown pile gets within about 10 ft of the ceiling.

Note that the total penetration into the ground increases as the antenna pair pass over the void of the entrance room. This is due to lack of absorption of the electromagnetic wave as it passes through air instead of limestone. When the electromagnetic waves reach the floor of the room, they still have sufficient intensity to penetrate into the breakdown of the floor. It appears that the waves probe about 25 feet into the breakdown. One would have expected them to penetrate only an additional 10 feet, based on the behavior to the right and left of the room. Perhaps the additional range is due to a significant porosity in the breakdown. It is also possible that these signals are coming from reflections within the room, but these should occur with a periodicity corresponding to multiples of 13 ft (which is the room height divided by three). Such periodicity is not apparent.

From this survey, four distinguishing characteristics of a cave in a GPR survey are revealed:

1) A sloping line plateaus for a distance and then slopes back down (due to approaching and receding from vertical cave walls)

2) The plateau coincides with a horizontal bedding plane line (due to likely ceiling determination by a bedding plane)

3) The depth of penetration increases in the plateau region of the survey (due to no attenuation in the void of the cave)

4) A large reflection signal occurs somewhat below the plateau (due to the air-rock interface at the cave floor)

These features may be used to help interpret future GPR surface surveys as well as in-cave surveys.

**GPR Survey on the Entrance Room Floor (3/25/09)**

A GPR survey of the Entrance Room floor was done on March 25, 2009. The survey is shown in Figure 2 and extended from just above the dig (14 ft from the wall along the line of the survey), along the flat level portion of the floor (fill) to where the mud meets the wall near the natural drain of the room. Figure 14 shows the setup and location of the first shot for the survey. Figure 15 shows the data acquisition setup. Figure 16 shows the survey as it passes by an historical barbed wire and stick ladder. When the antennas were near this location there was a resonance type anomaly in the signals. Figure 17 shows the end of the survey. The survey was brought all the way to the wall at the end. Figure 18 shows the plotted results of the survey. The plot has been reversed from the usual display so that it has the same orientation as in Figure 2.
Figure 14. First Shot for Entrance Room Survey
Figure 15. Data Acquisition Setup

Figure 16. Cable Management near Historical Barbed Wire Ladder

Figure 17. Placing the Tape at the End of the Survey
There is an obvious artifact reaching down to a “depth” of 60 ft in the center of the picture. It is not known what causes these artifacts, but they have been seen in past surveys. Possibly there is a low-strength resonance that is causing this; it is too weak to disturb the shallow data but appears down deep. (The return signal strength is enhanced with depth by the software to compensate for absorption in the ground.)

The ceiling is about 36 ft above the floor, so one should be cautious with any signal that has a round trip time of flight less than or equal to 72 ft / 1.0 ft/ns = 72 ns. This corresponds to a “depth” of 12 ft in the plot. There is a line at a depth of about 13 feet that might be the ceiling reflection.

A slanted line can be seen rising up from east to west and appearing to level off at about 15 ft from the west end of the survey and 17 feet under the floor. Perhaps there is a small void at that location, although there is no obvious increase in penetration depth there so it would not be a large one. It also is possible that the anomaly is off to the side of the survey rather than under it.
There is much less penetration between 47 ft and 70 ft than between 0 and 47 ft. Possible reasons might be a larger void fraction in the breakdown below the west half of the survey or more clay in the east half.

Within a cave there is a potential for reflections off the walls and the ceiling. To help elucidate the potential for this a set of measurements was made at 8 ft from the start of the floor survey (which corresponds to 61 ft on the bottom axis of Figure 18). The results are shown in Figure 19. There were five orientations of the antennas, which are described in the caption below the figure. Each orientation had four shots, so the results are distinct horizontal bars. The first is simply a repeat of one of the measurements in the Entrance Room survey, and the agreement with the data at that location is excellent, demonstrating good reproducibility. (Figure 19 is the same scale as Figure 18 to simplify comparison of the two bar patterns at the 61-foot mark).

A = Antennas on floor, perpendicular to survey path, as in the room survey
B = Antennas on floor, parallel to survey path
C = Antennas oriented vertically and aimed toward the southeast wall (9 ft away) and perpendicular to path
D = Antennas oriented horizontally but aimed directly up toward the ceiling, and perpendicular to path
E = Antennas oriented vertically and aimed to the northwest, toward the breakdown pile, and perpendicular to path

Figure 19. Measurements at One Location (61 ft from West End)
The second orientation (B) had the antennas on the floor pointing downward, but they were rotated 90° about the vertical axis so they were parallel to the original survey path. The results would be identical to the first orientation if the antennas were truly symmetrical. But that is not the case. The antennas detect objects aligned with the length of the antennas better than objects off to the side if the objects are in the same plane as the antennas. We were unable to determine explicit reasons for the differences between orientations A and B.

For orientation D (antennas at shoulder height and pointing directly upward at the ceiling 30 feet above the antennas), there were return signals for a longer delay time. This is as expected since the waves are not being attenuated when they are traveling through air. Thus we would expect about 60 ns greater total delay time in the return signals at the limit of penetration. That is approximately the case between orientation A and D. There are many more bands of reflections. This may be due to reflections from walls, ceilings, and the breakdown pile within the room since the antennas are not touching the ground or the wall. The same can be said for orientation C, which is aimed at the southeast wall, 9 feet away. There are fewer reflections for orientation E which faces the breakdown pile; perhaps the slope directs the reflections away from the antennas. Or perhaps there are fewer monolithic features in the breakdown to provide reflections.

The two main conclusions from this rotational survey are:

1. Changing the orientation of the antennas for a ground traverse from perpendicular to the path to parallel to the path can lead to significantly different results.
2. It is difficult to interpret results from a single shot at one position; a series of shots as the antenna location moves is needed.

**GPR Survey at the Northeast Bottom of the Dig (3/26/09)**

The GPR survey equipment was moved deeper into the cave to the northeast end of the dig at the lowest available level. The computer and console were placed about 20 feet above the passage where the antennas were placed (between W10 and W11). A pair of traverses were made in the horizontal passage near W18 ending at W19. The first traverse was with the antennas on the floor and parallel to the direction of travel; the passage was not wide enough for the antennas to be perpendicular to the path. The second was with the antennas against the southeast wall, again parallel to the path. In both cases the separation was about 0.5 m due to space limitations.

Figure 20 shows the antennas at the start of each survey. The antenna with a single fiber optic connected is the transmitter. So the transmitter was closer to the wall on the first survey and closer to the floor on the second survey.
Figure 20. Antennas for Surveys at the Northeast Bottom of the Dig (3/26/09)

Figure 21 shows the results of both traverses. The traverses were both about 10 ft long. The third picture in the figure shows the second traverse flipped horizontally so that the end points of the two surveys (near W19) are adjacent. In both traverses there are numerous slanted lines.

Figure 21. Survey at the Northeast Bottom of the Dig (3/26/09)
The slanted lines could be either anomalies (e.g. a cave passage) or bedding planes that are at a slight angle to the surveys. The difference in depth of the reflected signal from the start to the end of the survey is only about 1 foot. By geometry, any point anomaly would need to be at least 25 feet below, to the side, or above the antennas in order for the reflected signal to change by only one foot from one end of the survey to the other. Most of these lines are closer than 25 feet. Hence, the most likely explanation is that these are all bedding planes. (For example, the bedding planes could all be level and the survey may have lowered by a foot from one end to the other.)

Figure 20, described previously, shows that the receiver moved about 1.5 feet closer to the wall and 1.5 feet upward between the two surveys. Some of the deeper bedding planes show such a shift in the third image in Figure 21. This suggests that they are below the antennas rather than above.

Following these two surveys, a number of shots were taken with the antennas in various orientations. The orientations of the antennas will be presented later in a table. No useful information was gleaned from these shots (see below).
GPR Survey at the Southwest Bottom of the Dig (3/27/09)

The GPR survey equipment was moved to the southwest end of the dig at the lowest available level (near W22). The computer and console remained about 20 feet above the passage. This passage was even tighter and more restricted than the northeast end. The first survey was along the wall that ran from NE to SW and ended at the dig shaft. The antennas were aimed into the wall and oriented horizontally. The second survey continued after turning about 45°. It was along the wall that ran from E to W. The antennas were aimed into the wall again and oriented horizontally. They were situated about six feet lower than the previous survey. The results are shown in Figure 23.

![Survey at the Northeast Bottom of the Dig (3/27/09)](image)

Figure 23. Survey at the Northeast Bottom of the Dig (3/27/09)

In the first survey (NE-SW) there appears to be a slanted line running from 18 feet to 16 feet in depth. This change of about 2 feet occurs as the antennas are moved a distance of about 5 feet. Geometrically, this is approximately consistent with a point anomaly at a distance of 16 feet from the antennas at the 5-foot point in the survey. This part of the survey is within a few feet of the Jacker Crack that go into the wall and occasionally have airflow coming from them. The survey has numerous artifacts that obscure the rest of the interpretation. For the E-W survey, there are no obvious features.
Figure 24 shows the results of the rotational survey in the dig shaft at the SW end of the dig. Interpretation is difficult.

![Rotational Survey in the Shaft at the Northeast Bottom of the Dig (3/27/09)](image)

**Summary of the GPR Surveys**

The table below gives a summary of the GPR surveys. GPR surveys were made across the top of the cave on the surface, on the floor of the entrance room, at the NE end of the bottom of the dig, and at the SW end of the bottom of the dig. The survey across the top of the cave led to distinguishing marks for a cave: diagonal lines that turn horizontal coincident with a bedding plane (the cave ceiling), greater penetration at the cave itself (due to reduced attenuation in the cave void, and a large reflection from the floor of the cave. Surveys inside the cave resulted in a possible anomaly at the SW end of the bottom of the dig; that anomaly appears to be about 16 feet into the wall, but the evidence is sparse.
### Table 1. Summary of the GPR Surveys

<table>
<thead>
<tr>
<th>Filename</th>
<th>Date</th>
<th>Location</th>
<th>Shots</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMRE12</td>
<td>3/25/09</td>
<td>Entrance Floor</td>
<td>All</td>
<td>From dig to wall along flat floor</td>
</tr>
<tr>
<td>BMRE13</td>
<td>3/25/09</td>
<td>Entrance Floor</td>
<td>1-4</td>
<td>22 ft from start of BMRE12, perpendicular to path as before</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5-7</td>
<td>Parallel to the path</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8-10</td>
<td>Perp. to path but aimed horizontally to wall 9 ft away</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11-13</td>
<td>Aimed at ceiling (30 ft above antenna)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14-15</td>
<td>Aimed horizontally to pile NW of path</td>
</tr>
<tr>
<td>BMRE14</td>
<td>3/26/09</td>
<td>NE bottom of dig</td>
<td>1-14</td>
<td>SW end to NE end, aimed down, parallel to path, 0.5 m separation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15-62</td>
<td>Aimed horizontal, 0.5 m separation, circle survey at 30 deg intervals, 4 shots per direction, start due north</td>
</tr>
<tr>
<td>BMRE15</td>
<td>3/26/09</td>
<td>NE bottom of dig</td>
<td>1-4</td>
<td>Horizontal, flat on the wall</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5-8</td>
<td>Horizontal, aimed in opposite directions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9-12</td>
<td>Aimed up (room 3 ft tall)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>13-16</td>
<td>Aimed down but 1 ft above floor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>17-20</td>
<td>SW end of room, antenna aimed horizontally into wall but oriented vertically, 1 m apart</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>21-end</td>
<td>SW to NE path, antenna aimed horizontally into wall, oriented horizontally</td>
</tr>
<tr>
<td>BMRE16</td>
<td>3/27/09</td>
<td>SW bottom of dig</td>
<td>2-11</td>
<td>NE to SW end, antenna aimed horizontally into wall, oriented horizontally, 0.5 m apart, transmitter on the floor, stopped where the wall turned west, last two shots only the receiver moved (we ran out of hands).</td>
</tr>
<tr>
<td>BMRE17</td>
<td>3/27/09</td>
<td>SW bottom of dig</td>
<td>2-9</td>
<td>W to E after turning corner, antenna aimed horizontally into wall, oriented horizontally, 0.5 m apart, transmitter below the receiver, about 6 feet lower than BMRE16, starts in the vertical shaft at the</td>
</tr>
</tbody>
</table>
corner of the wall

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>BMRE18</td>
<td>3/27/2009</td>
<td>SW bottom of dig</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-36</td>
</tr>
</tbody>
</table>

360 degree rotation with 30 degree increments, antennas aimed into the walls, oriented vertically on R. Straub’s shoulders, started facing directly away from the SW-NE wall.

Acknowledgments

The authors wish to thank Prof. Catherine Snelson and the New Mexico Institute of Mining and Technology for the use of the equipment and Mr. Jim Goodbar of the Bureau of Land Management for his continued support.