Archaeological investigations using geophysics at Chimney Rock Great House, Colorado
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SUMMARY
In this talk, we present results from a geophysical investigation at the Chimney Rock Great House using magnetics, electromagnetics, and DC resistivity. Our data is focused on a grid southwest of the Great House, where we use geophysics to detect potential buried walls. These walls may be covered by 1 to 3 m of fill as a result of nearby excavations in the 1920s, and should be approximately 0.5 m thick. Using geophysics, we were able to identify several potential targets in the multiple datasets, which are consistent with sketches from earlier archaeological digs. Through our investigations, we have likewise gained a better understanding of the geophysical responses of buried walls at Chimney Rock.

INTRODUCTION
The Chimney Rock area, which can easily be recognized by the iconic shape of the towering sandstone formations, is located about twenty miles west of Pagosa Springs, CO. The area has at least seven Native American settlements but our prime interest is the Great House located at one of the highest points. Surrounded by cliffs on every side, the Great House offers protection and views of the entire valley. Much of the Great House has been excavated throughout the 20th century and a 1920s map of the settlement depicts the structure. However, some of the walls indicated in this map are not currently visible at the site (see Figure 1).

Chimney Rock was inhabited by the ancestors of the modern Puebloan tribes during the late 11th century to the early 12th century. These ancestral Puebloans were characterized by their subsistence farming regimen, construction of dwellings, production of tools and crafts, use of storage rooms, and integration of cultural structures. This particular settlement is connected to the practice of astronomy. The two pinnacles, Chimney and Companion Rocks, were most likely used for the observation of lunar standstills. Once every 18.6 years, the moon is seen to rise directly between the two rocks (Richardson, 2006).

In 2009, researchers at the University of Colorado at Boulder reduced fill in advance of stabilization and conducted limited tests to determine depth to the sandstone bedrock in two rooms of the Great House. These tests also help to determine whether or not the walls are built directly on the sandstone bedrock or if there is an amount of soil separating the bedrock and the wall foundations. A sketch showing rooms on the western side of the mesa prompted the researchers to ask for a geophysical investigation to determine whether these rooms really exist.

The geology of the Chimney Rock area is part of a larger area called the Mesaverde Group (Chronic, 2001). The rock that composes Chimney Rock is a Cretaceous shoreline deposit, an artifact of the ancient sea that used to cover most of Colorado. The sedimentary cap at Chimney Rock is Pictured Cliffs Sandstone (about 70-100 million years old) while the dark gray sediments below are Lewis Shale (CRIA, 2009). When looking at the Chimney Rock area, it becomes clear that the sandstone, of which the two pinnacles are comprised, is more resistant to erosion than the underlying shale. Over time, these structures will also erode away. The Native American structures at Chimney Rock were built using local material. We will show that geophysics can be used to distinguish between the local rock used to build houses and the soil that fills and covers the structures.

BACKGROUND
A few elements were considered before deciding which geophysical methods would be most appropriate. The Chimney Rock Great House was built using local materials, which could make it difficult to distinguish the walls from the surrounding soil. Because the Great House is situated on top of a mesa, we had to consider instrument size and weight. The survey grid size was maximized to cover as much area as possible. Because of these limitations, we chose the survey grid as shown in Figure 2, which shows the GPS locations of our survey grid, the trail on the mesa, and the locations of the existing walls. The grid location was also based on Figure 1, which shows predictions for the buried walls. We also needed to consider the half-space assumption associated with many geophysical methods.
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Figure 2: A section of the aerial map of the Chimney Rock Great House with the GPS points shown along the walls (green) and the GPS points of the survey grid (red). Turquoise points show the location of the trail while blue points depict the location of the dipole-dipole line. Colored points in the northeast portion of the image show the base station location.

methods, as errors in the data would arise from the proximity of the cliffs. We chose to collect electromagnetic and DC resistivity data based on the similarities in geology and native history to Chaco Canyon, where these methods proved successful (Martinez et al., 2009). We also chose to collect magnetic data since fire-damaged walls can have a significant magnetic response. Burn marks were evident on some of the excavated walls, further convincing us to utilize this method.

Using the basic geology of the area, a simple model was created to describe the setting of the buried walls. The walls, more porous than the sandstone bedrock due to the mortar, are presumed to be built directly on top of the sandstone bedrock. This means that the walls are more conductive than the bedrock but more resistive than the soil that fills and covers the rooms. It is also likely that, as a result of wall collapse, there are unconsolidated piles of rubble on either side of the walls. These rubble piles are assumed to be more conductive than the walls or the fill. This model can be used to provide an initial idea of the expected geophysical response of buried walls. An initial model for the shallow subsurface is crucial to the interpretation process.

By utilizing geophysical methods, we can learn more about the shallow subsurface and detect whether or not there are walls of the Great House covered by soil within the survey grid. Geophysics is a great way to do this as the methods we chose to employ are non-invasive and can provide an extensive understanding of the area. The methods we decided to use are: electromagnetics, magnetics, DC resistivity dipole-dipole, and DC resistivity middle gradient. Next, we discuss the data collection using these methods, the processing involved with each dataset, and our interpretations of the results.

GEOPHYSICAL METHODS

Survey grid and GPS
The survey grid spanned 42 m in the NE-SW direction and 23 m in the NW-SE direction (see Figure 2). Stations were separated by 1 m and the line separation was also 1 m. GPS points were collected at each station. Continuous GPS data was collected along the top of the exposed walls and along the trail.

Magnetics
We collected magnetic data using the Geometrics Cesium 858 magnetometer with a sample rate of 5 Hz. Line spacing was 1 m and we collected along NE-SW lines. The data were collected in a vertical gradient mode, with a top and a bottom sensor. The bottom sensor was approximately 0.37 m above the ground surface and the separation between the two sensors was 0.75 m.

Electromagnetics
Electromagnetic data was collected along NE-SW lines and NW-SE lines with the Geonics EM31-MK2. The line spacing was 1 m and the GPS was tied to the EM31 so position information was simultaneously collected for greater accuracy in the location of the data points.

DC resistivity: dipole-dipole
A 2D dipole-dipole array was collected along a NE-SW line in the middle of the grid (see Figure 2). The current electrodes were spaced 1 m from one another and the potential electrodes were also spaced 1 m from another. The two sets of electrodes were spaced 1 m from one another along first profile. Further profiles were collected with the current electrode pair and potential electrode pair spaced at 2 m, 3 m, and 4 m from each other to increase the depth of penetration.

DC resistivity: middle gradient
The middle gradient data were collected in two sets: the northernmost section had an current electrode spacing of 30 m and the middle section had a current electrode spacing of 36 m. The potential electrodes were spaced 1 m apart throughout both grids. This data gives us a map of the resistivity of the area, which compliments the dipole-dipole data well.

PROCESSING AND INTERPRETATIONS

Magnetics
The magnetic data was decorrugated using a wavelength of 2 m to remove the heading errors and a smoothing filter was applied to remove some of the high-frequency noise. This filtered data from the top sensor is shown in Figure 3. The boundary between the region of high response and lower response correlates well with the location of the predicted walls.

We calculated the total horizontal gradient of this filtered data, which, for the top sensor, is shown in Figure 4, and shows an increased response close to the exposed walls. This response could be due to both the presence of subsurface walls and possible burning of these walls. There are two notable linear features identified in Figure 4: the first is close to the westernmost
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Figure 3: Magnetic data from the top sensor. The data were decorrugated and filtered to remove heading errors and high-frequency noise. Notice the distinct transition between the northeast region of the plot (magnetic high) and the rest (magnetic low). The transition between relative high and low susceptibility is abrupt, linear in shape, and aligned with the westernmost predicted wall in the sketch.

The vertical gradient was calculated by subtracting the data from the top sensor from the bottom sensor data and normalizing by sensor separation. Often this provides a better image of near-surface targets since it minimizes the influence of larger regional trends and better constrains the location of small anomalous targets. This result is shown in Figure 5 and provides greater information on the magnetic response, thus further supporting our conclusions from the other magnetic datasets.

Electromagnetics

We decorrugated the electromagnetic (EM) data using a wavelength of 2 m to remove heading errors and smoothed the data slightly using a low-pass filter. Electromagnetic data were collected in the same orientations as the magnetic data. Figure 6 shows the quadrature component of the EM data collected along NW-SE lines. The EM data shows the conductivity trend over the whole survey grid, with the highest conductivity areas in the south and the more resistive areas in the north.

The same filtering was done for a second set of EM data collected along NW-SE lines (not shown). Although a distinct linear feature is detected following the westernmost wall of the kiva, the large discrepancy in this region between the two EM data sets causes us to question the validity of the NW-SE dataset.

DC resistivity: dipole-dipole

One 32 m dipole-dipole line was collected from approximately NE to SW, transecting the survey grid (refer to Figure 2). The array had an AB separation of 1 m and a value n=1 to n=4. We inverted the apparent resistivity data to produce the 2D model shown in Figure 7. The model shows a distinct region of high resistivity near the surface at approximately 13 m (local coordinates). The location of this structure correlates with the linear feature described in the magnetic data (Figure 3).

Based on the model that the walls are built directly on the sandstone bedrock, we expect to see a resistive anomaly surrounded by more conductive features to represent the wall and the fill, respectively, in the inversion. This expectation is supported by the actual inversion result (Figure 7). Again, the anomaly location aligns with the feature seen in the magnetic data and wall locations in the sketch, reinforcing our interpretation.

DC resistivity: middle gradient

The two DC resistivity middle gradient datasets were combined and plotted together for both the apparent resistivity and the potential. Figure 8 shows a map of the potential distribution across the survey grid. As in the magnetic data, there is a sharp boundary aligned with the westernmost exposed kiva wall. The feature has a high potential value, which relates to a high resistive value. This interpretation matches the anomaly detected in the inversion results, although we are looking at different locations. The middle gradient data, along with the wall of the kiva while the second is approximately 10 m west of the first feature and lies directly beneath the westernmost predicted wall in the sketch. These features align with the projected walls in the sketch.
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Figure 6: Quadrature component of the EM data, collected along NE-SW lines. This plot shows the general conductivity distribution across the survey grid.

Figure 7: Inversion results of the DC resistivity dipole-dipole data. The large anomaly matches with the smaller linear feature seen in the magnetic total horizontal gradient data (Figure 4).

Figure 8: A map with the potential gradient values from the middle gradient data. Notice the linear trend aligned with the westernmost wall of the kiva. This trend is also seen in the magnetic datasets.

CONCLUSION

In this talk, we presented the results of an archaeological investigation using several geophysical methods to identify potential buried walls at the Chimney Rock Great House in Colorado. Specifically, we used magnetics, electro-magnetics, and two types of DC resistivity surveys. The magnetic data showed linear features that aligned with the predictions from the sketch and the electromagnetic data provided the regional conductivity trend at Chimney Rock. The dipole-dipole inversion and the middle gradient data narrowed down the signature of potential structures, giving us the ability to further constrain our interpretation. Combining these methods has allowed us to interpret two locations where walls may be buried. These structures have a high magnetic signature and are more resistive than the surrounding fill. The first wall is an extension of the westernmost exposed kiva wall and the second wall is located approximately in the center of the survey grid, parallel to the first wall. Both of these structures align very well with the original sketch depicting possible locations.

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