

Remote Sensing Investigation at Pipe Spring National Monument

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Final Report

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Research Report  
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NCARB

The Center for Cultural Sustainability (CCS) explores the continuity of the cultural systems of human existence. Cultural sustainability includes consideration, understanding and respect for heritage – identities and values that bind people to places.

The CCS provides academic research and services to benefit communities, completes large-scale research projects, provides research and educational opportunities for graduate students, and convenes leaders in the field for dialogue on global practices concerning sustainable development and construction.

The CCS is a research center of the University of Texas at San Antonio and is housed within the College of Architecture.

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## Project Abstract

The purpose of this project is to employ remote sensing technology in a non-destructive and non-invasive manner for analysis of potential archeological resources at Pipe Spring National Monument and provide educational opportunities for NPS staff, college students, and tribal members in the art, techniques, and use of remote sensing technology for managing cultural resources. Pipe Spring is interested in investigating floor deposits in the West Cabin, the Whitmore Dugout, and the original privy. Pipe Spring is planning treatment activities for these cultural resources that require knowledge of subsurface occurrences to mitigate any damage. Remote sensing methods have a long and proven track record of detection, delineation, and mapping of historical settlement sites and associated features. The results of the project will allow for the preservation of these cultural resources while still providing baseline documentation to guide treatment and management strategies.

Pipe Spring selected the University of Texas San Antonio Center for Cultural Sustainability (UTSA CCS) to assist in this endeavor and provide the remote sensing technology because it is a Colorado Plateau Cooperative Ecosystem Study Unit cooperator and has the staff, equipment, and experience in the geophysical experience necessary for this project.

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## Executive Summary

The CCS-NPS joint effort to assess cultural resources at Pipe Spring National Monument utilizes remote sensing techniques. Following a preliminary site visit (see Phase One Report dated 8/30/2012), Dr. Blake Weissling (geophysicist) conducted Ground Penetrating Radar (GPR) surveys of the West Cabin (East and West rooms) and Magnetic Gradiometry (MG) surveys of the conjectured locations of the Whitmore Dugout and Privy sites in the open areas between the main entry of the Fort (a.k.a. Winsor Castle) and the East Cabin.

Geophysical data collected during the Phase Two surveys were processed, analyzed, and interpreted off-site by Dr. Weissling in consultation with Professor Dupont. These data and subsequent descriptive analysis are presented in this report in both map and text form. Results indicate significant potential for undisturbed cultural resources in both the East and West rooms of the West Cabin, and at the conjectured location of the Privy site. Inconclusive results were obtained at the conjectured location of the Whitmore Dugout.

## Background and Purpose of Remote Sensing Investigation

### Background

Pipe Spring National Monument is a cultural resource managed by the National Park Service located north of the Grand Canyon in a remote area of Northern Arizona, close to the border with Utah. The size of the National Monument, consistent with the American Antiquities Act of 1906, is “confined to the smallest area compatible with proper care and management of the objects to be protected...;” in this case 40 acres. The square-shaped plot of land is bounded on all four sides by the Kaibab Indian Reservation. The site’s historic significance is related to the presence of an aquifer fed spring which flows up at multiple locations in the historic core of the site, in the otherwise arid landscape. For this reason the site has been continuously occupied and important to people who live in the region. The Mormons (Church of Jesus Christ of Latter-day Saints) built a fort in 1869-70, called Winsor Castle, directly atop the main spring to control the water. The history of the site has included disputes over control of the land which gives access to the water.

## Purpose

The purpose of the remote sensing investigation is to locate and document the presence of certain archaeological resources at Pipe Spring National Monument. The work is necessary prior to execution of a proposed soil stabilization treatment in one outbuilding, the West Cabin. In addition, remote sensing at two other locations – Whitmore Dugout and the assumed location of an outhouse – will be conducted to locate these resources, if possible.

## Context

The extant, historic buildings on site include the Winsor Castle (named after the builder and one of the first inhabitants of the structure, Bishop Anson P. Winsor), initially built as a fort, and two outbuildings. All of these were in partial ruin when President Harding declared the site to be a National Monument in 1923. Reconstruction and restoration ensued in the mid-1920s and on into the 1930s. Photographs, in the archives of the NPS office on site, show conditions prior to commencement of work. The Winsor Castle (a.k.a. the fort), with an approximate footprint of 68 x 43 feet, has thick walls constructed of large, red sandstone blocks, neatly dressed and laid with lime mortar in a coursed ashlar pattern. The two-story building has porch, floors and roof of wood frame construction. The topography slopes from northwest down to southeast, and the fort is built into the hill such that there is a door at grade on the upper level of the uphill side. The Winsor Castle is not a subject of the remote sensing investigation but is a key reference point for locating the other resources on the site.

## East and West Cabins

The two cabin outbuildings, east and west, have random-coursed walls of dressed red sandstone, double-hung wood windows and earthen roofs with wood beams and column supports. The floors are dirt. Due to the exceedingly arid climate, the dirt is friable. Dust is a problem for present day visitors as it was for past occupants. The East Cabin, first constructed 1867 - 1870, has an approximate footprint of 17 by 62 feet (two structures separated by a breezeway all under one roof), and is situated slightly downhill and approximately 80 feet east from the fort. The East Cabin is not part of the remote sensing investigation because it was thoroughly excavated by archaeologists in 1997 prior to addition of stabilized soil.

The West Cabin, first constructed c.1870, has an approximate footprint of 17 by 43 feet, and is situated on an elevated terrace 160 feet to the west of Winsor Castle with a commanding view to the west and south. The building is partially subdivided with a stone chimney and wall that contains two fireboxes, one facing into each of the two rooms that comprise the simple structure. Wooden furniture is displayed as part of the educational program. A wooden fence holds interpretive panels and defines a zone for visitors to move through the two period rooms. The dirt floors in the west outbuilding have not been stabilized or treated to control dust. Periodic watering is done, and various surface treatments are under consideration. The current plan is to treat the surface without removal of any soil that would disturb archaeological resources below.

## Whitmore Dugout

The Whitmore Dugout, constructed in 1863 and the earliest structure on site associated with use by the Mormons, is now a buried ruin. The structure was previously excavated in 1959 and then reburied. Unfortunately, it was not mapped in a plan of the site, so the precise location of the resource is no longer known.

## Original Privy

During the historic period of use, the site must have had at least one outhouse, and this is verified by an oral history account. A prior researcher (Fuller, 2005) suggests an outhouse location east of the Winsor Castle, "on the west side of the stone fence, four meters west of the southwest corner of East Cabin." This happens to be in an area greatly disturbed by post-1923 activity.

Fuller cites four sources for his opinion regarding the outhouse location:

"...confirmed by former PISP superintendent Leonard Heaton as the location of one of the historic outhouses used prior to NPS purchase of Pipe Spring (McKown 1959)..."

"...Dillworth Woolley also confirmed this location in interview with R.W. Olsen in 1965 (PISP archives, Vertical File – Woolley Family Histories: 46-52)..."

"...possibly shown in Tissandier's sketch of Pipe Spring (1885)"

"...it also appears to be shown in some of the early photographs of the fort."

Curious to be sure about the outhouse, Professor Dupont reviewed the archives working together with two NPS staff members. The Leonard Heaton reference in McKown (1959) was not found and we could not find an outhouse-type structure in any of the early photographs. Re-reading the oral history of Dillworth Woolley in the PISP archives (Vertical File – Woolley Family Histories) led to some confusion. The exact wording transcribed by R.W. Olsen places the outhouse 35 feet north of the east gate. The location Fuller suggests is approximately 85 feet northeast of the east gate. Finally, Tissandier's 1885 sketch of Pipe Spring does appear to include a small structure that could be an outhouse. To find the spot where Tissandier positioned himself to make the sketch, Dr. Weissling, accompanied by Professor Dupont, used building and landscape alignments. Approximating the location of the small structure in this manner revealed that it is much closer to the Winsor Castle than Fuller surmises. In fact, the location of the structure in Tissandier's sketch is consistent with the oral history account from Dillworth Woolley.

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1 For more information on the Tissandier sketch, see McCoy 2000

## Phase One

## Phase One Evaluation

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Photo 1

### West Cabin

Blake Weissling and William Dupont, representing the Center for Cultural Sustainability at the University of Texas at San Antonio, conducted a site visit at Pipe Spring National Monument, August 7, 2012, for the purposes of evaluating the applicability and feasibility of using the GPR remote sensing method for detection and mapping of near surface cultural resources associated with the east room of the Monument's West Cabin structure. GPR has an extensive and well-documented history for remote sensing of resources in archaeological contexts (Conyers, 2004). The selection of the method for near surface remote sensing (amongst other geophysical methods) is dependent on a variety of environmental factors that may contribute to both the success or failure of the technique to provide useful and meaningful results. GPR is unlike various other geophysical methods that do not require physical contact of the instrument with the ground surface. GPR stipulates that the system's radar antenna make solid ground contact at all times; hence a successful GPR survey is therefore dependent on a physical surface that is generally level and smooth, and completely free of impediments such as rocks, vegetation, structures, etc. Secondly, a successful GPR survey is contingent on the site's soil properties (NRCS, 2009), in particular on the soil's clay content. Most clay rich soils have been found to be unsuitable for the successful use of GPR, due to the energy absorbing nature of clays. These soil types severely attenuate the energy of the radar signal, and can be considered "opaque" to radar.

Both West Cabin floor surface and soils were evaluated during this site visit, and were found to be suitable for the use of ground penetrating radar, given some prep recommendations discussed later in this report. Site suitability was as-

sessed using a hand-held GPR instrument that is commonly used in engineering applications for imaging internal structure of concrete (photo 1). The instrument has a depth limit of approximately 50 cm, which was judged sufficient to image through and below the cultural resource zone of the site. The instrument's real-time data display, on several floor passes in the east and west rooms of the West Cabin, indicated clean, viable data through the top 30-40 cm of the soil with clear evidence of subsurface horizons. No significant energy attenuation due to soil clays was seen.

### Whitmore Dugout Site

The possible site of the Whitmore Dugout structure is located in a semi-vegetated area flanked by concrete sidewalks leading from the Fort's main gate to the East Cabin. Photo 2 depicts the site environment with the possible location of the Dugout. Our evaluation of environmental conditions at the Dugout site suggest that a second geophysical technique, most likely the Magnetic Gradiometry method, would be more suitable for the successful detection and mapping of the Dugout structure. Magnetic gradiometry, like GPR, is widely used in archaeological investigations, but does not require instrumental ground contact and can thus be deployed in more varied environmental conditions. The magnetic method is potentially sensitive to ground disturbances such as excavations as well as to anthropogenic "additions" to the natural environment such as stone foundations, post-holes/piers, and cultural detritus, all of which are likely present within and adjacent to the Whitmore Dugout.

### Privy Site

Prior to a re-assessment of photos and other documents at the Monument's archives, the suggested location of the fort's privy was above and within the south corner of the stone retaining wall behind the East Cabin. A review of the site's environmental conditions (for remote sensing) precluded the use of either GPR or magnetic gradiometry, due to an uneven and cluttered surface, with abundant modern metallic trash. However, the review of the archive's photo record indicated a more probable location of the privy, that being on the hill slope immediately northwest of the Fort's main gate and below the stone retaining wall. Photo 3 depicts the possible location of the privy at approximately the location of the wagon. This location, not unlike the Dugout location, is much more environmentally conducive to conducting a magnetic gradiometry survey. The likelihood of historical cultural trash in the privy excavation further increases the probability of a successful discovery of the privy site using magnetometry.



Photo 2



Photo 3

## Recommendations for Phase 2

The following site preparation recommendations were provided in order to enhance the Phase 2 survey objectives.

### West Cabin

- 1) All furniture in the east and west rooms of the West Cabin should be removed to allow for a complete, uninterrupted grid-based survey of the floor space.
- 2) The metal mesh that forms the visitor observation fence should be removed from the premises. It is not necessary to remove the fence posts however.
- 3) The floors in both east and west rooms should be rake-leveled if possible to facilitate a smooth, level surface
- 4) The floors should also be watered during the week prior to the GPR survey to facilitate a more compact surface and higher soil moisture levels. Slightly damp soils actually improve data quality.

### Whitmore Dugout

- 1) The northern half of the exposed soil area within the encircling sidewalks should be cleared of vegetation to facilitate collecting grid-based magnetic data. Vegetation should be cut to a height no greater than a few inches – this will allow for both clean access but also for vegetation regrowth. Vegetation should not be pulled up by the roots.
- 2) After vegetation clearing, the site should be surface inspected for modern cultural trash, especially ferrous metal trash. This material should be collected and removed.

### Privy

- 1) To facilitate surveying in the immediate area of the wagon and to avoid magnetic noise effects from wagon metal, the wagon should be relocated to a distance of at least 20 feet outside of the suggested survey area – the area bounded by the north wall of the fort, the sidewalk, the stone wall, and the East Cabin. The site should be cleared of vegetation (in the manner described above) and inspected for modern trash.



## Phase Two

## Phase Two Evaluation

### West Cabin

Blake Weissling, representing the Center for Cultural Sustainability at the University of Texas at San Antonio, conducted a remote sensing survey at Pipe Spring National Monument, November 7-9, 2012, for the purposes of evaluating the potential for intact near surface cultural resources within the East and West rooms of the Monument's West Cabin structure. The geophysical method or technique selected for this project, based on the Phase One site visit and reconnaissance survey, was Ground Penetrating Radar (GPR).

### Instrumentation and Methods

As described in more detail in this project's Phase One report (8/30/2012), GPR was selected for the West Cabin geophysical survey on the basis of the technique's extensive and well-documented history for remote sensing of resources in archaeological contexts (Conyers, 2004), and the evaluation of the technique in the context of the specific environmental factors of the West Cabin site, factors that typically govern to either the success or failure of the technique to provide useful and meaningful results

During Phase One of this project, it was determined that the soil composition of the West Cabin floors was suitable for radar data acquisition. No energy-absorbing clays, a common and significant impediment to GPR surveys, were detected. Tests of the "transparency" of the soil profile to radar energy indicated potential imaging depths of 30 – 50 cm, depths that were considered sufficient to image the cultural resources of potential interest. A second environmental constraint was likewise assessed during Phase One, and that was the condition and necessary preparation of the floor surface for the radar instrument. An

uneven and unlevel floor surface prevents the necessary ground contact of the radar instrument antenna. This ground contact is considered essential for the coupling and subsequent transmission of the radar waves into the subsurface. One recommendation of our Phase One assessment was that Park Service personnel prep the West Cabin floors prior to the final surveys. This recommendation included gentle raking/leveling of the floors and the application of sprinkler water to both reduce dust levels and to add soil moisture in the top 10 – 20 cm. Small amounts of soil moisture actually improve the radar energy coupling with the soil.

The GPR instrument selected for this survey was a GSSI Structure Scan Mini, an instrument most commonly deployed in the imaging of internal defects and structural anomalies in concrete (GSSI, 2013a). The instrument operates at a 1.6 gigahertz (GHz) frequency. Because the device is designed to be operated in contact with smooth concrete surfaces, given its wheeled configuration, it was necessary for the purposes of this survey to "drive" the device over a similar hard and flat surface (*Photo 4*). We achieved this end through the use of sheets of Hardibacker TM masonry board purchased at Home Depot. These sheets were of a size (36 x 60 inches) that were conducive to laying out over the dirt floor of the cabin in a grid system using guide strings. Furthermore, guide lines inscribed in the boards were ideal for positioning the radar device and for following grid-ded transects, as shown in *Photo 4*.

*Figure 1 (next page)* shows the layout of the data acquisition grids for both the East and West rooms. The grids were originally platted to align with the north and east walls of the East room and the north and west walls of the West room,



Photo 4

with a standoff of approximately 6 in from the respective walls. In the direction of the central dividing wall, the grids were extended to within 6 - 8 in of the flagstone hearth feature. In the direction of the south wall of the cabin, the grids were extended to within 2-3 in of the wood framing border of the visitor walkway. 208 individual radar transects were acquired in the East room, and 252 transects were acquired in the West room.

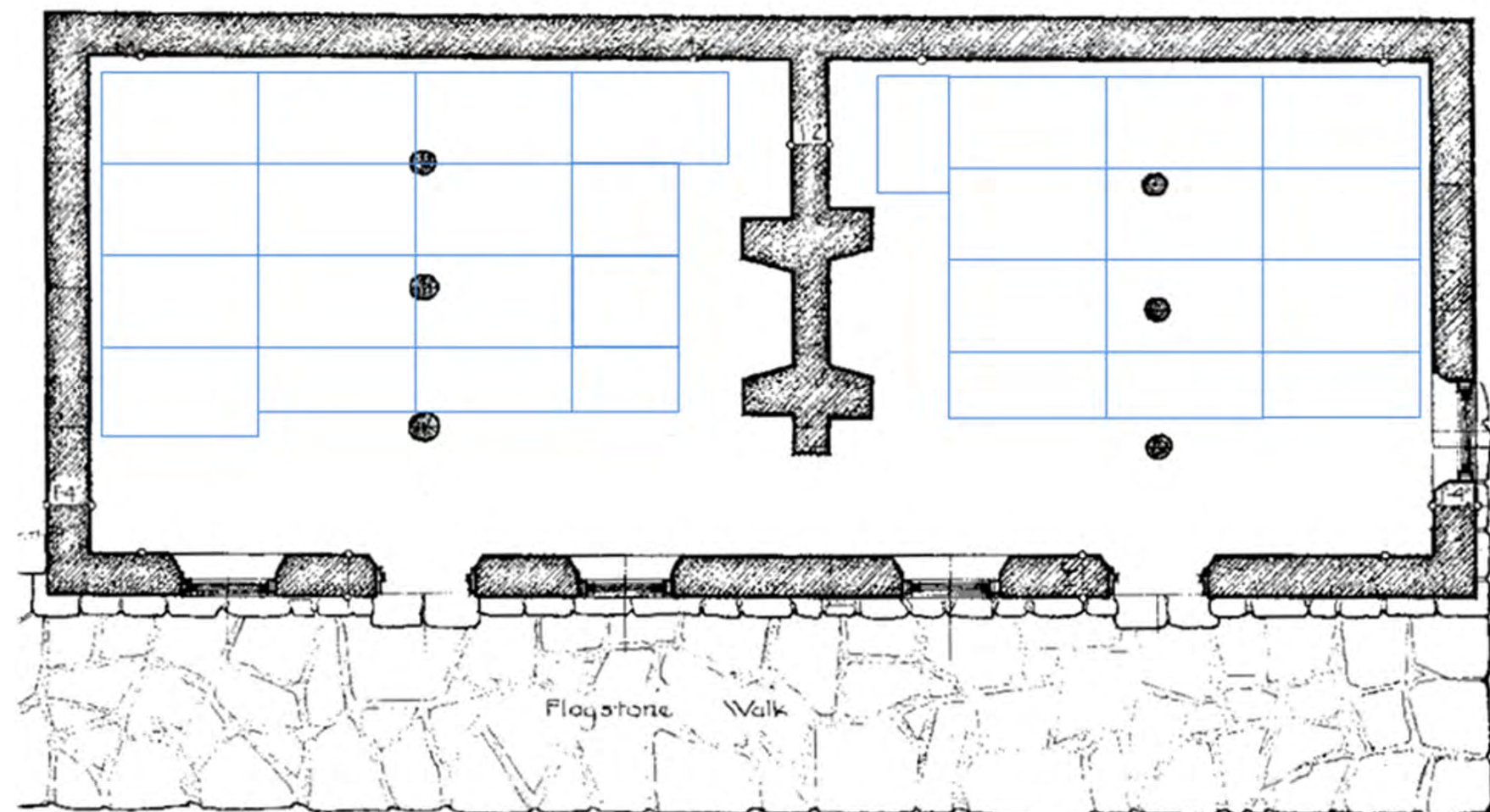


Figure 1. GPR data acquisition grids shown in blue lines overlaid on the 1949 HABS West Cabin floor plan.

## Data Processing

The first step in data processing involves the organization of all individual radar data transects into single acquisition grids (as shown in Photo 4 and depicted in Figure 1). Subsequently, all individual grids are mapped into an X-Y cartesian coordinate system, with an origin located in the northeast and northwest corners of the East and West rooms, respectively. The software utilized for this and all subsequent processing steps is RADAN for Windows, the GPR industry's leading data processing and analysis system (GSSI. 2013b). Based on the particular radar system deployed (e.g. antenna frequency), RADAN applies various filtering algorithms to reduce noise, boost signal gain, and remove various system phenomena common to GPR such as antenna "ringing". An additional processing step applied to all data from this survey was migration. Migration is a geometric technique that focuses radar returns from various discrete objects in the subsurface. This technique is especially useful when the final data are output as 2D map-view depth slices. However, in the more traditional 2D profile view of radar data, unmigrated data is often more useful in identifying specific discrete objects such as pipes.

All GPR data transects start as profile or cross-sectional views of the subsurface, where the X-axis is distance along the transect, and the Y-axis is time. To explain the latter, what a GPR system measures is the time (in nano or billionths of a second) it takes for a transmitted radar pulse to travel down into the soil, reflect off of objects or boundaries, and then travel upwards to the antenna, to be recorded. Hence the Y-axis of a radar profile is actually the two-way travel time of the pulse. In order to know the depth associated with radar reflections from subsurface objects, one must know the radar wave velocity in the media (e.g.

soils, rock, etc.). Few natural or man-made media (e.g. concrete) have specific radar velocities. In general, most media have ranges of possible velocities. The most direct way to determine a media's velocity is to acquire data over an object of a known depth. If such a situation is not available, then one must derive a velocity from indirect methods. One such way involves the migration technique mentioned above. For certain radar reflection geometries from discrete objects at varying depths, it is possible to derive approximations of radar velocity from this focusing technique. This method was applied to all final radar (profile and depth slice) products in this project.

The final step in the processing of radar data, in both profile and depth-slice formats, is the assignment of a color transform to the final data product. As radar data represents electromagnetic energy reflected off of subsurface objects or boundaries, it is actually the amplitude of the radar energy or waves that is being recorded in time. Therefore, one can choose how to symbolize the radar energy amplitude. Typically, radar profiles (or radargrams) are symbolized in grey-scale with white representing the highest positive amplitude and black the highest negative amplitude. Numerous color transforms exist and the most common ones were assessed for this GPR study, in order to best visualize the final results. The typical grey scale transform gave the best visualization of the subsurface cultural resources seen in the radar data.

### Interpretation Methodology

The two most common ways to construct depth slices are (1) to depth-vary a fixed width slice across the range of usable data (this was judged to be about 20 cm), and (2) to width-vary a fixed depth position slice. The first case represents the closest analog to an actual archaeological test pit excavation, where excavation proceeds downward in (usually) fixed thickness or width increments. For this GPR assessment, a series of depth slices of 2 cm fixed width from 4 cm to 20 cm depth (9 slices every 2 cm) were produced. A second series of depth slices (method 2) were produced by fixing the center of expanding width depth slices at 20 cm. The first slice is 2 cm in width, the second 8 cm, the third 14 cm, etc. The final slice has a width of 32 cm, which by being centered at 20 cm means it represents all radar data from 4 cm to 36 cm. While this latter depth slice series has no real analog in archaeological testing, it actually can be very informative in the context of cultural resources. The following graphic (*Figure 2*) depicts the design and arrangement of both sets of depth slices.

The analysis and interpretation of radar data, in either profile or depth slice format, can be approached from a geophysical perspective or any number of other perspectives (geologic, environmental, engineering, or archaeological), depending on the objective of the geophysical study. The first part of the results discussion will focus therefore on a geophysical interpretation of various anomalies seen in the data. In some cases, the interpretation may have a direct archaeological or cultural resource implication.

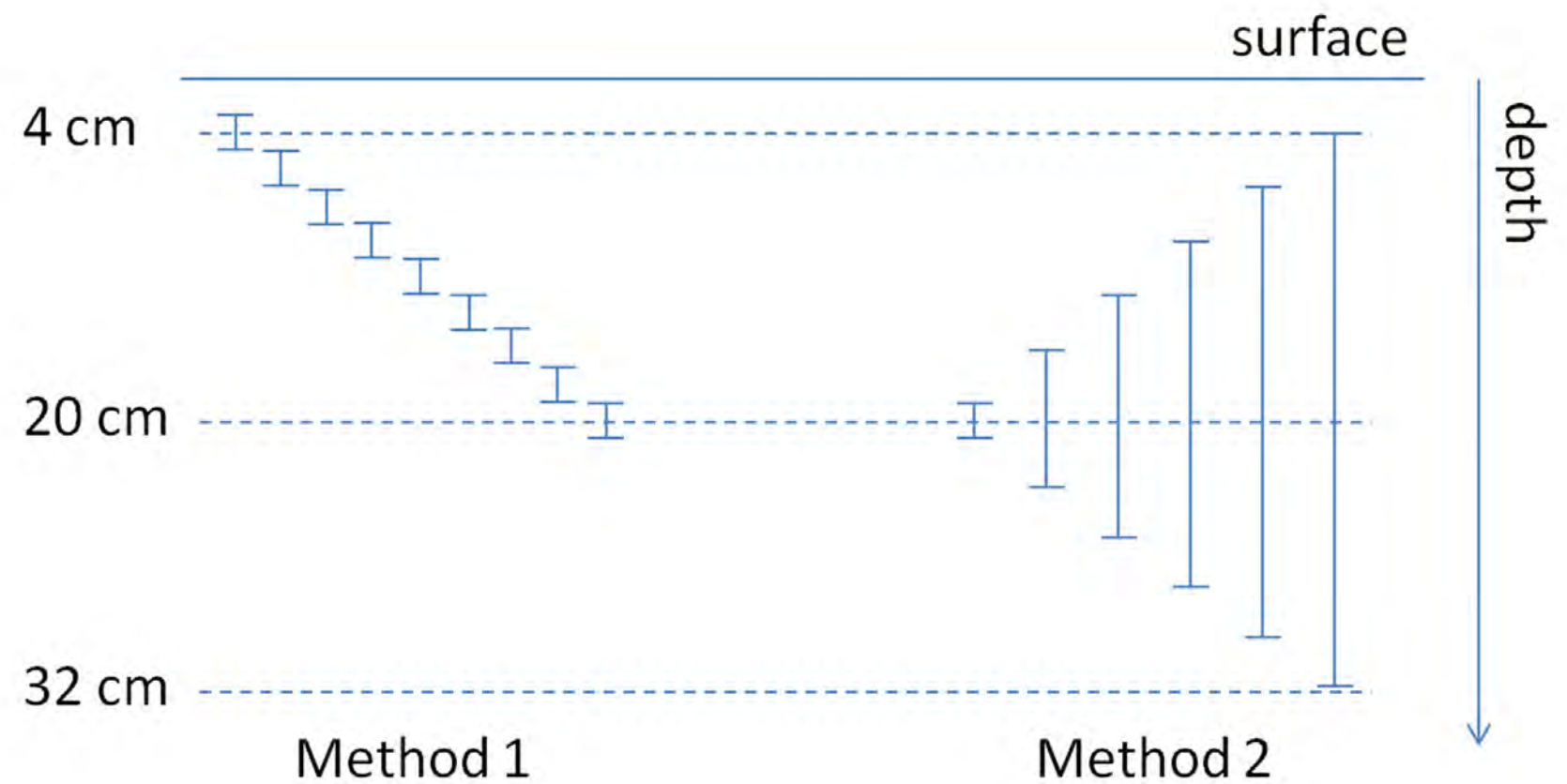


Figure 2. Depiction of the two methods utilized in this study for the generation of GPR depth slices. The position of each bar represents the respective thickness and depth for which GPR data is presented.

Radar profiles simply represent the time-based arrival of reflected radar wave energy from subsurface features or objects. For the most part, reflections of radar waves occur when a velocity change exists at the boundary of an object or feature. The more dramatic the velocity change, the stronger the reflection (e.g. amplitude) of the radar wave. Unfortunately, there are few subsurface objects, resources, or features (geological, archaeological, environmental, etc.) that have any type of characteristic signature. In other words, it would be impossible to make a definitive identification of most, if not all, subsurface cultural resources from radar data alone. The best one can do is to identify anomalies that, given the cultural context, could in a probabilistic sense relate to some resource.

There are a few exceptions to the uncertainty in identifying subsurface objects from radar data alone. The most common one, with a characteristic radar signature, is a piece of metal. Metal is considered a near-perfect reflector of radar energy. So much so that energy will reverberate between the object and the antenna, much like an echo in sound. This echo-like energy can be seen to propagate completely to the bottom of the radar profile record. Appendix 1a shows a radar profile collected from this survey that depicts the characteristic signature of a metal object. The actual size of the object can be as small as a coin, or a bit of wire. Actual identification of the object itself is not possible. A second common anomaly type that is seen on virtually any radar profile, regardless of resource, is the hyperbola anomaly. Appendix 1b shows a radar profile of this anomaly type along with a graphic illustrating the system geometry responsible for this characteristic shape.

## Results and Discussion

This section will focus primarily on the description and analysis of the map-view radar depth slices generated for both East and West rooms of the West Cabin. Where appropriate, specific radar profiles will be discussed in the context of anomalies in the depth slices. In order to better visualize the location and character of potential cultural resources as seen in these depth slice or radarmap datasets, it was necessary to overlay the radar data on a graphic of the West Cabin floor plan (from the 1949 HABS drawings). This was accomplished in a GIS, through a very careful spatial co-location of the radarmaps and the floor plan drawing. Known planar distances from the radar data were checked with distances measured in the geo-referenced HABS drawing. We are confident that the radar maps or depth slices are correctly positioned to within 2 – 3 cm (~ 1 inch) of their true as-surveyed location on the West Cabin floor plan.

### Fixed Width Depth Slice Results

Depth slice 4 cm (*Figure 3*) – The character of the data in this first shallow depth slice is more strongly influenced by the coupling of the radar wave with the ground surface rather than by actual reflections from subsurface features. Typically, ground coupling effects are a result of a changing antenna-ground separation (due to air gaps between the backer board and ground) as well as changes in soil moisture, soil compaction, and composition. The mottled appearance of the data is common. The only anomalous feature in this first depth slice is in the west room, in the corner above the fireplace (marked A). The feature is clearly too linear and regular to be due to the ground coupling effect just discussed.

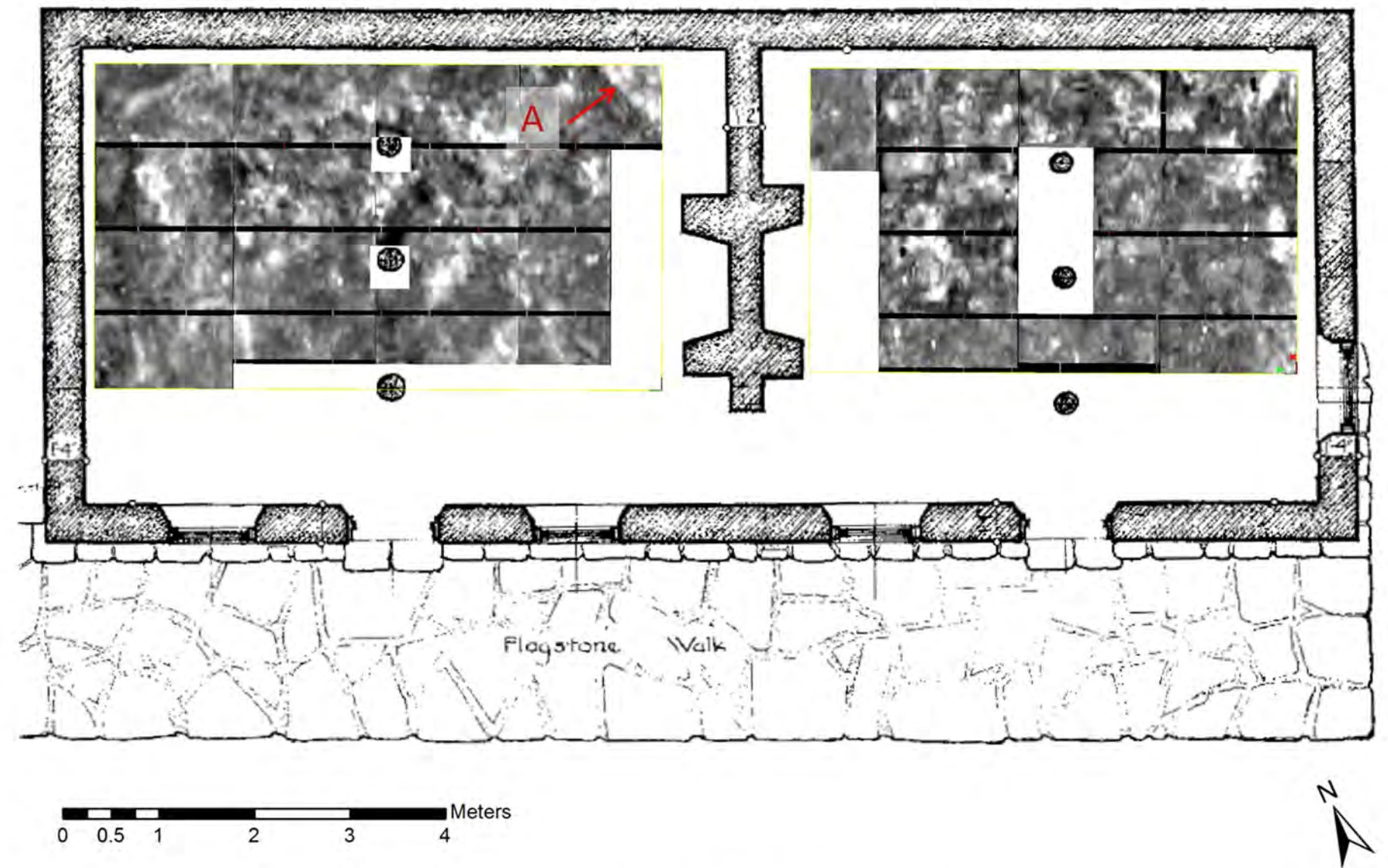
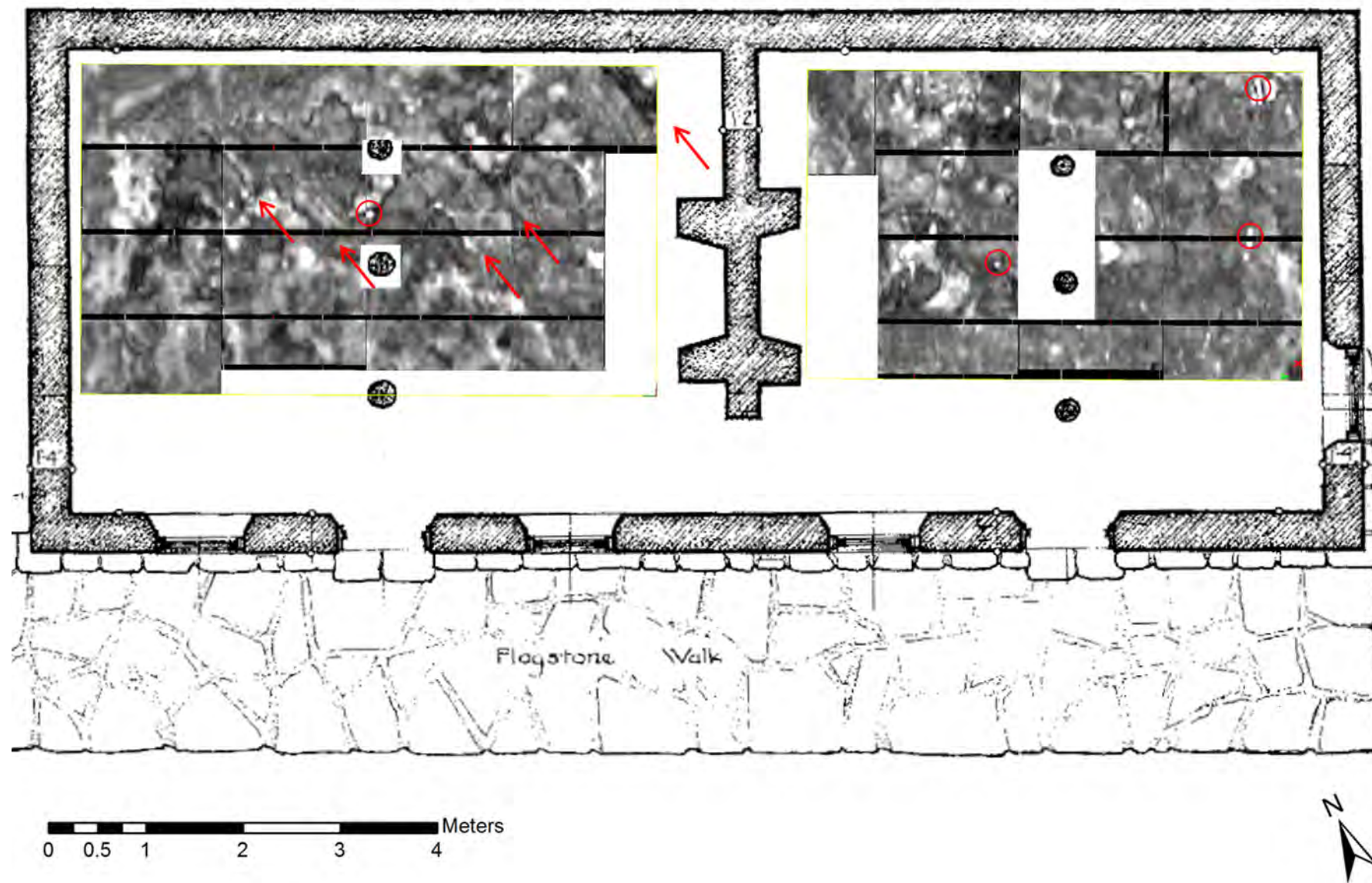


Figure 3. Radar depth slice (2 cm thick) centered at 4 cm.

## West Cabin GPR Survey



### Depth slice 6 cm

(Figure 4) – Although this depth slice shows a considerable amount of the mottled coupling effect discussed above, some interesting patterns begin to emerge, especially in the west room. The angled feature seen in the 4 cm slice, above the fireplace, is even more prominent in this view. In fact a number of subtle but evident striations, that appear to run parallel to this feature, can now be seen in the west room (marked with red arrows). In the east room, nothing particularly of interest is emerging yet. Although, several small bright point anomalies are visible (as marked with red circles) that can be positively attributed to small pieces of metal (e.g. a nail, small piece of wire, etc.).

Figure 4. Radar depth slice (2 cm thick) centered at 6 cm.



### Depth slice 8 cm

Depth slice 8 cm (Figure 5) – Several anomalous features in this depth slice of likely cultural origin are quite obvious in this depth slice. First, the striations in the west room are becoming more evident. A second very unusual anomaly has appeared along the far west wall of the west room (marked as B). This unmistakably rectangular feature, being parallel to the wall, suggests a possible stone structure. In the east room, two noticeably bright anomalies (marked as C and D), are likely related to reflections from shallowly buried flagstone. The feature at C is immediately adjacent to the exposed flagstone between the two roof support posts. A very subtle line anomaly that runs parallel to the north wall of the east room is significant (marked as E). A similar line feature in the west room can barely be discerned at the same relative position to the north wall as that in the east room.

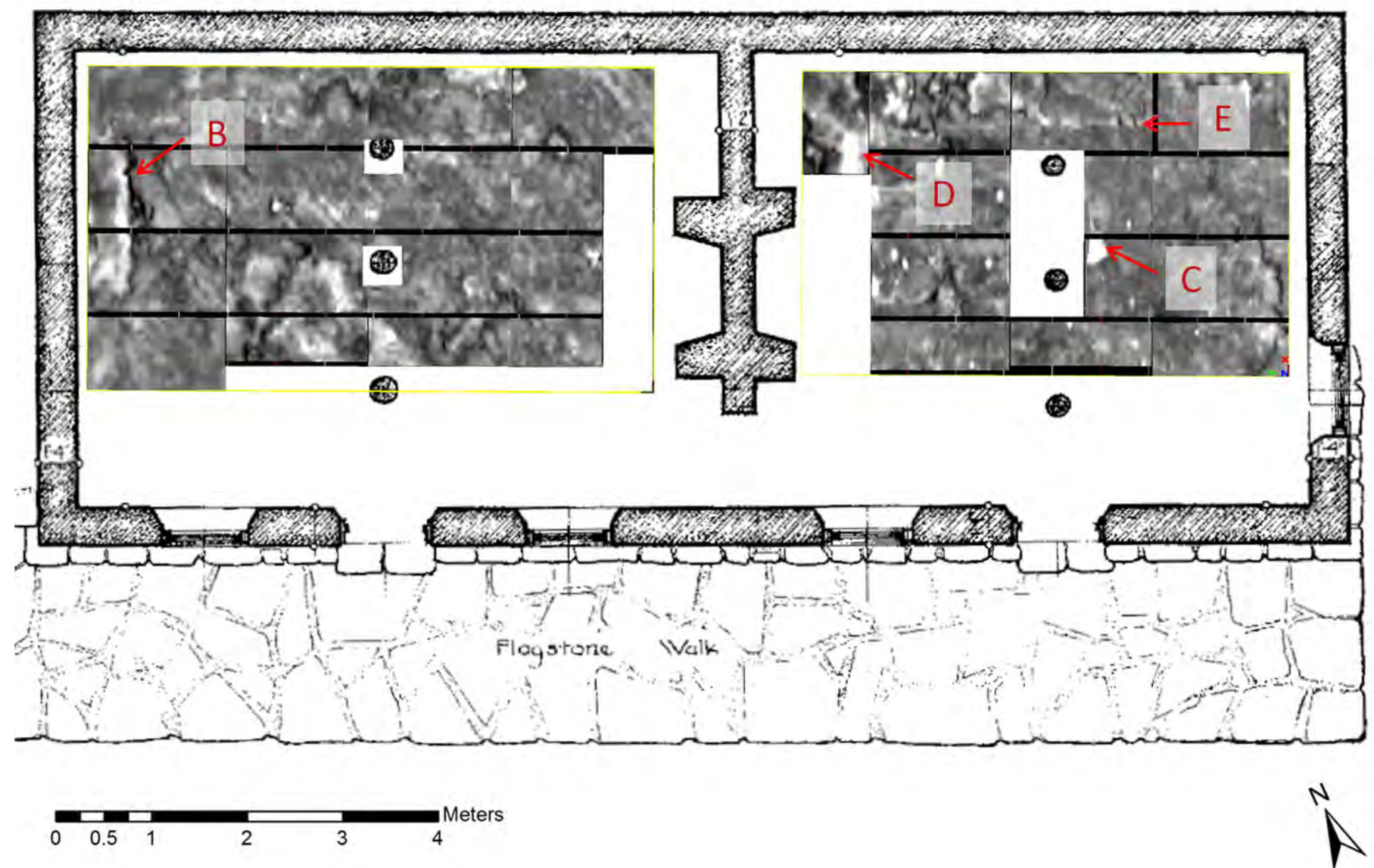
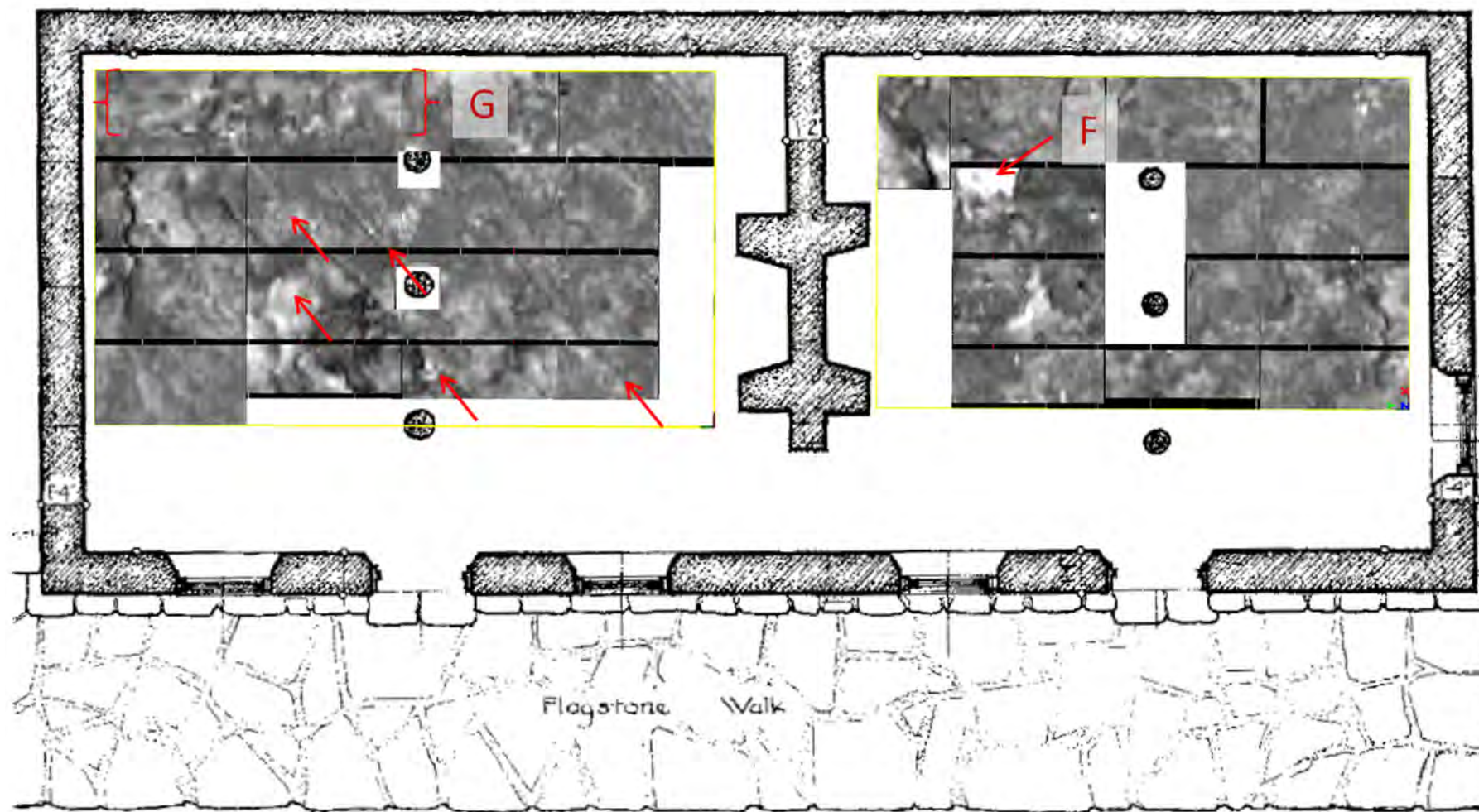


Figure 5. Radar depth slice (2 cm thick) centered at 8 cm.

Note that the striations in the central part of the room appear to stop abruptly at the feature marked G (bracketed)

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### Depth slice 10 cm

(Figure 6) – In the east room, a large very bright feature (marked F) has emerged between the roof support posts and the fireplace hearth. Its shape and position are consistent with the subsurface flagstone located and mapped in the 1989 archaeological testing. The west room striations are still quite evident (marked with red arrows). Another interesting observation concerning these striations is that they do not extend past the location of the line anomaly described above. In fact, the character of the radar changes immediately above this line, enough to describe this as another rectangular anomaly (marked G) like that seen in depth slice 8 cm (Figure 5).

Figure 6. Radar depth slice (2 cm thick) centered at 10 cm.

### Depth slice 12 cm

(Figure 7) – In the west room, this depth slice is one of the more revealing about possible cultural resources. The striations are most evident, showing an unmistakable regularity in spacing and orientation. While they extend to the edges of the survey area along the south side, they clearly end at a position approximately 0.75 m from the north exterior wall (Feature G). The yellow horizontal line in Fig 7 shows the location of the specific profile view (Inset). The 3 striations marked (red arrows) are clearly identified with three dipping radar reflections seen in the profile view. They appear to extend to about 20 cm below the surface. In the east room, some anomalous radar activity is evident between the support posts and the fireplace (identified by orange dashed polygon). There is no particular structure or shape, however, to these features at this depth level. The subsequent depth slices will reveal more potential subsurface flagstone here.

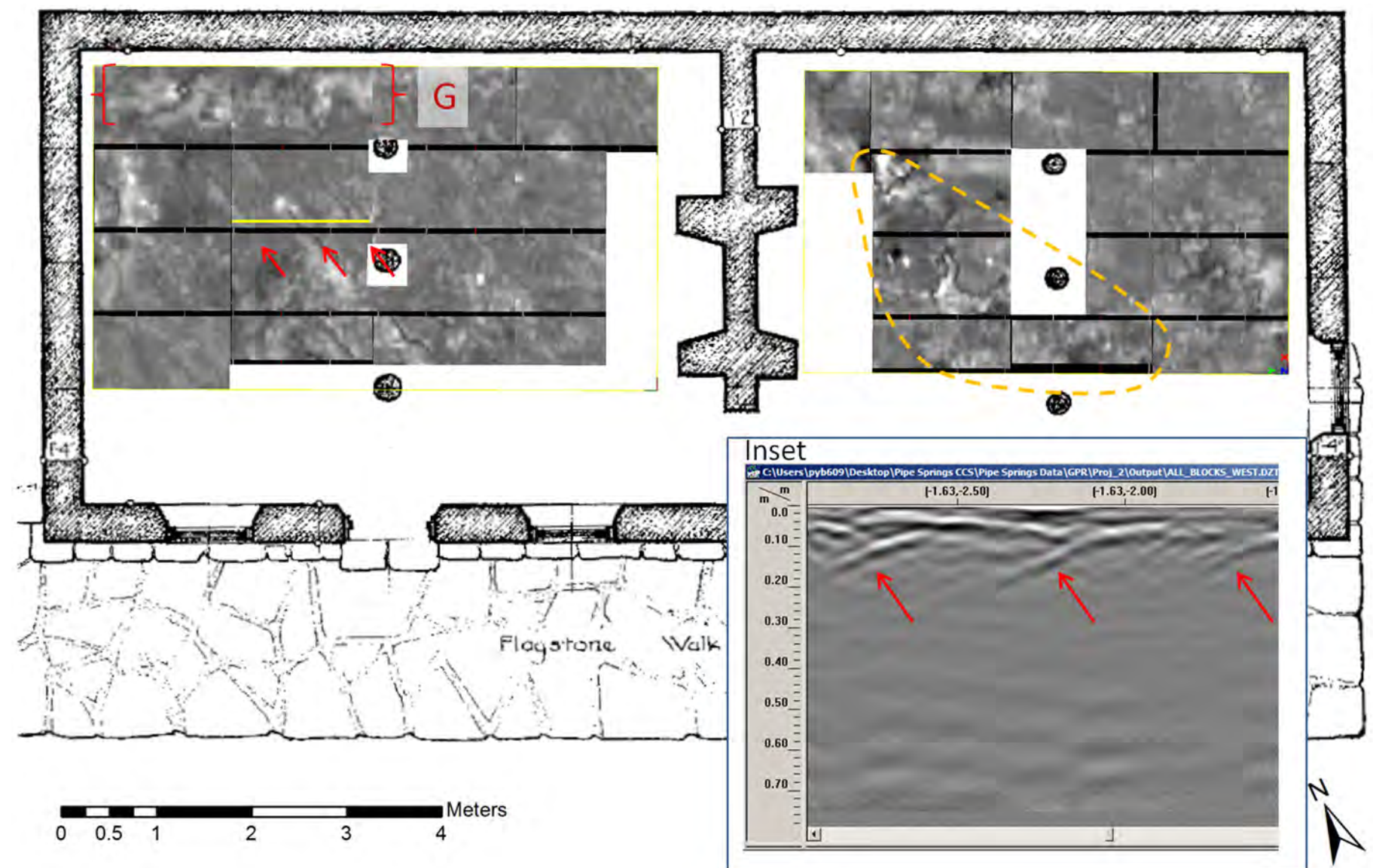
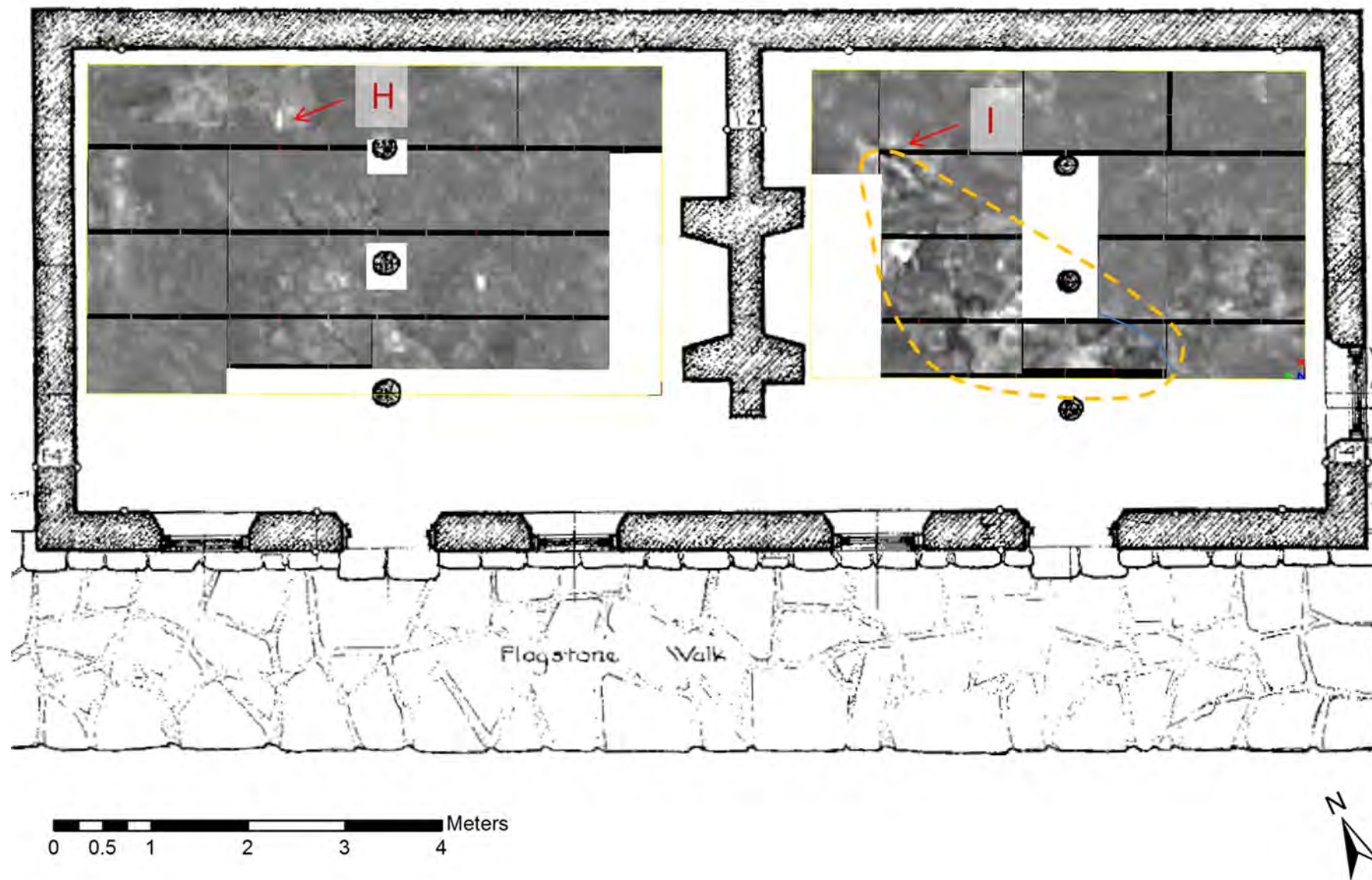


Figure 7. Radar depth slice (2 cm thick) centered at 12 cm. Yellow line indicates position of radar profile (inset). Note that the orientation of the profile is reversed (E-W).



Depth slice 14 cm

(Figure 8) – The view of the west room at depth slice 14 is very similar to that of slice 12, although a new feature is just emerging (marked at position H). This feature is much more prominent in the subsequent slices and so will be discussed there. The southwest corner of the east room is beginning to show some interesting features. An angular feature at a similar orientation to the striations in the west room has emerged at the position marked I. Between this feature and the south edge of the survey area, a rather mottled area has emerged (identified by orange dashed polygon), suggestive of the mottled character of the coupling zone discussed in the first depth slice. At this depth, this radar character could indicate some disturbance to this zone that might relate to soil moisture or soil compaction. It will become more evident in the next depth slice.

Figure 8. Radar depth slice (2 cm thick) centered at 14 cm.

West Cabin GPR Survey

### Depth slice 16 cm

(Figure 9) – This depth slice is perhaps the most interesting and most revealing, in terms of potential cultural resources. In the east room, a clearly evident striation or line has appeared in the northwest corner of the room (marked as I) that is almost parallel with the west room striations. Below where this line appears to terminate is an elliptical-shaped bright feature that is consistent with another piece of buried flagstone (marked as J). The mottled area described above is even more pronounced in this slice and appears to take on a triangular shape (delineated with orange dashed lines) that expands in size moving south from the terminus of the striation. In the west room, a clear line feature has emerged (again marked as H) that runs north-south parallel to the west wall of the room. As this feature is considerably more evident in the set of expanding thickness depth slices, it will be discussed in more detail in that section.

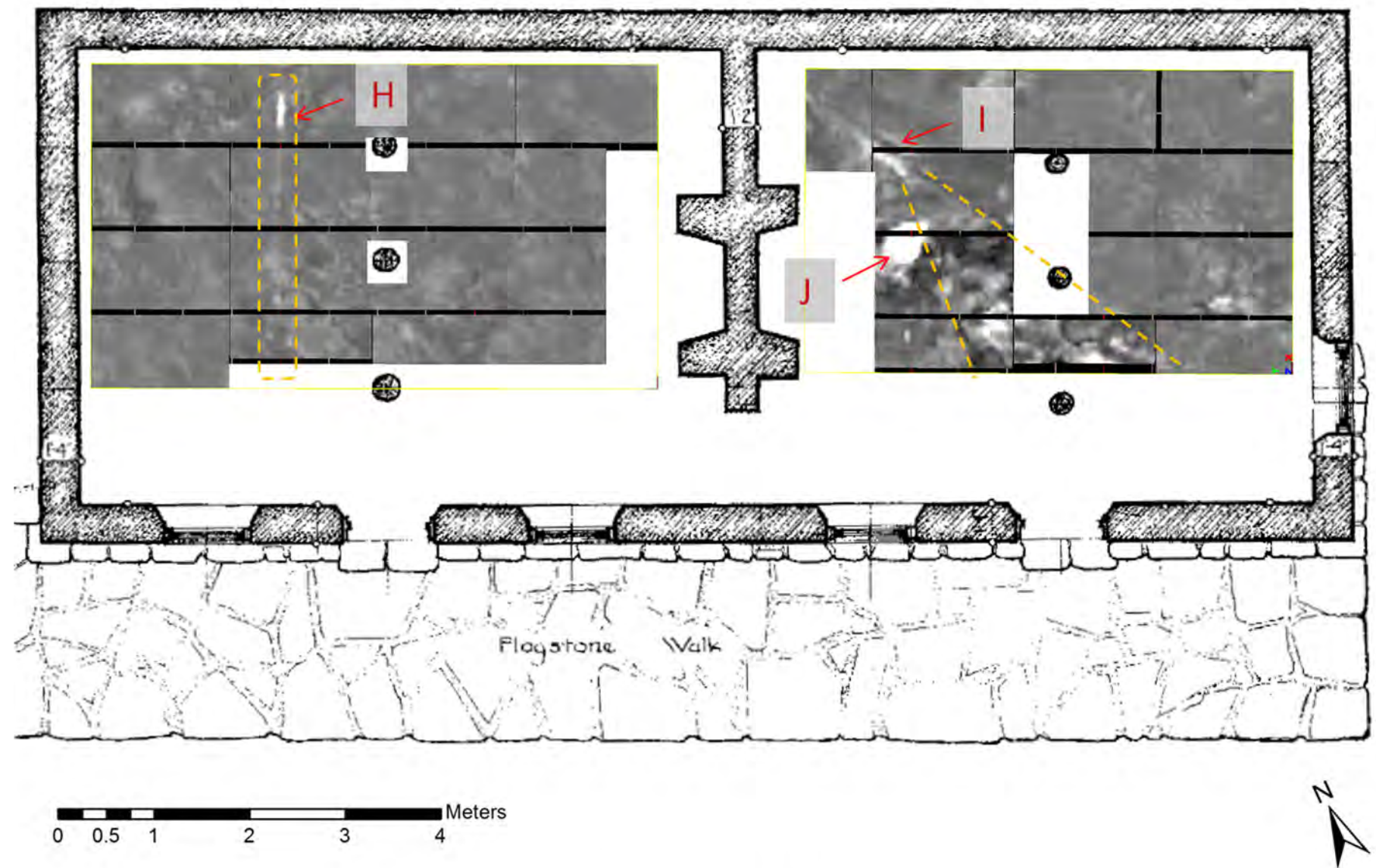
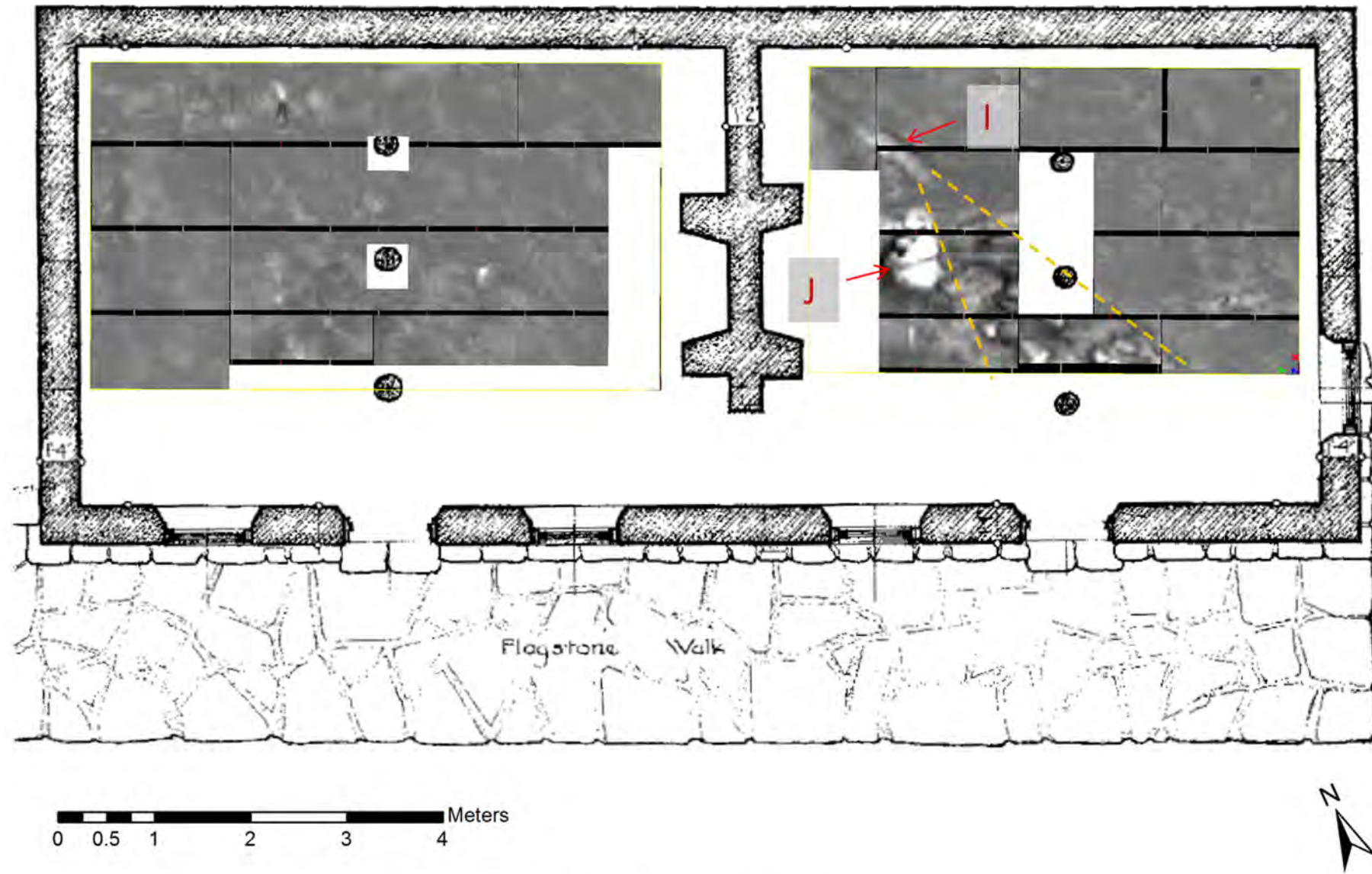


Figure 9. Radar depth slice (2 cm thick) centered at 16 cm.

West Cabin GPR Survey



Depth slice 18 cm

(Figure 10) – The west room, in this slice, appears very similar to the preceding slice with no noteworthy changes. In the east room, the conjectured flagstone anomaly (marked J) has appeared to split into two separate features. The angled striation feature is still quite evident along with the mottled zone below.

Figure 10. Radar depth slice (2 cm thick) centered at 18 cm.

West Cabin GPR Survey

### Depth slice 20 cm

(Figure 11) – In the west room, the north and south ends of the line feature (marked H) discussed in slice 16, are much more prominent than in the preceding slices. In the east room, the striation, flagstone, and mottled zone features are fading from view. No other features of any significance are emerging at this level or at levels below 20 cm. This suggests that the depth of potential cultural resources has been reached at approximately this 20 cm level.

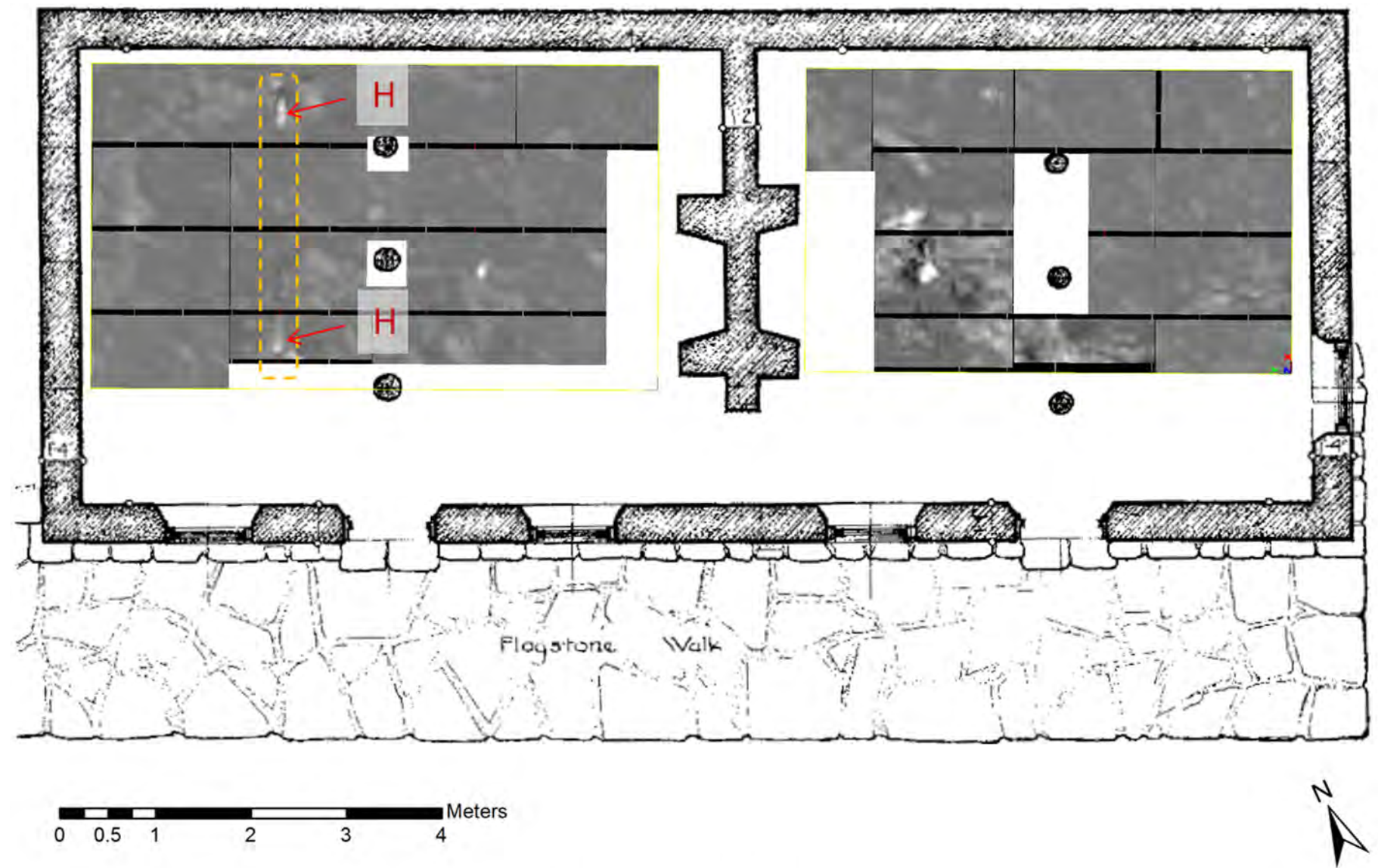
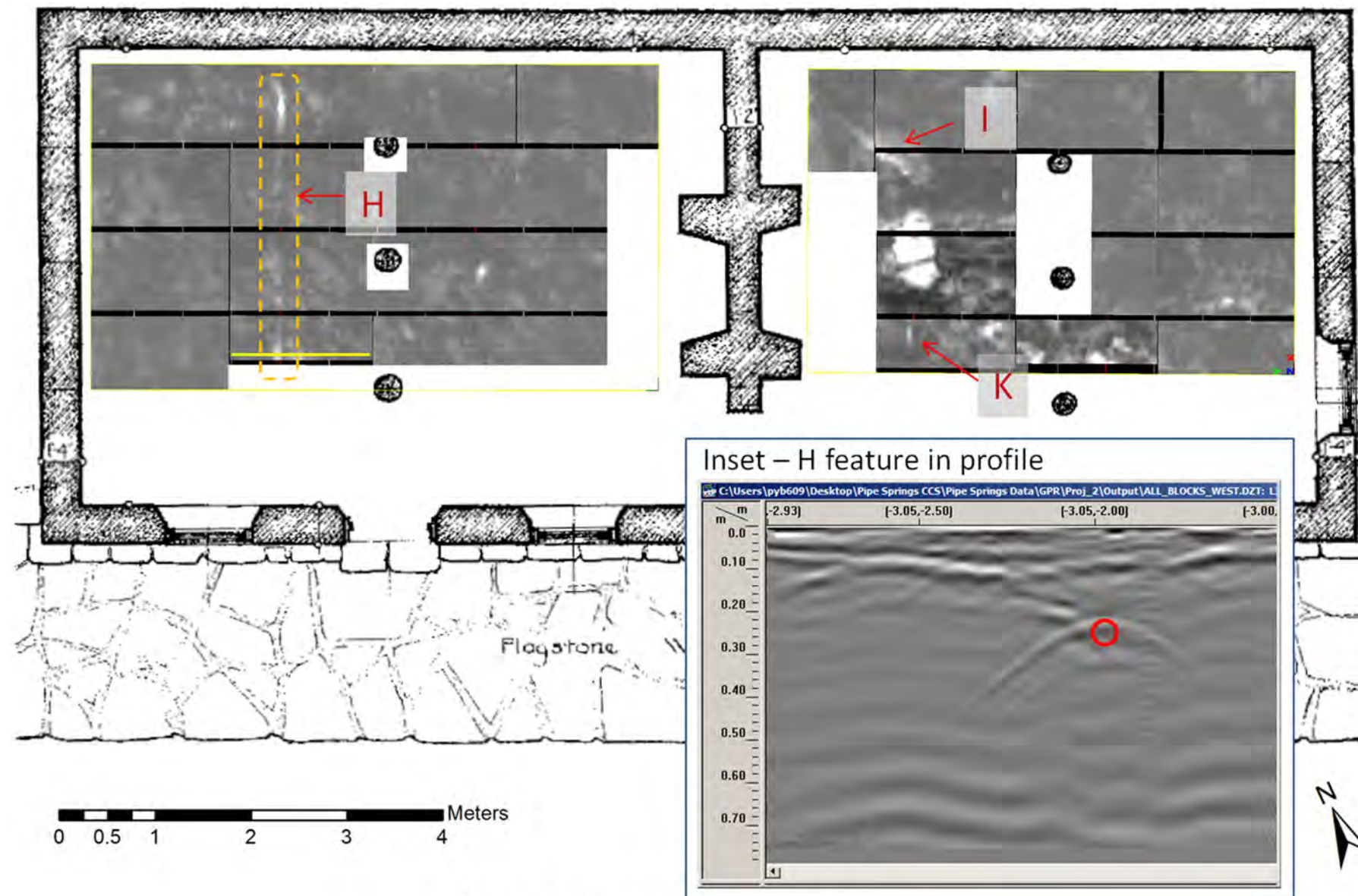


Figure 11. Radar depth slice (2 cm thick) centered at 20 cm.

### West Cabin GPR Survey



West Cabin GPR Survey

## Expanding Width Depth Slice Results

### Depth slice 2 cm centered at 20 cm

This depth slice is identical to that shown in Figure 11, so no additional discussion is warranted.

### Depth slice 8 cm centered at 20 cm

(Figure 12) – In the west room, the feature previously marked H is clearly visible as a continuous line that begins approximately 0.38 m (~ 15 in) from the north wall and ends at the edge of the survey area. As mentioned before, the feature is clearly parallel to the west wall with a standoff of 2.1 m (6.9 ft). The top of the feature appears to curve slightly toward the west. The yellow horizontal line in Fig. 7 shows the location of the specific profile view (Inset). In profile view, there is clearly a classic hyperbola reflection from some subsurface linear object. In the figure inset, the red circle shows the approximate location of the object with the top of the object being approximately 0.25 m (~ 10 in). The depth to the top of this feature is slightly greater at the south end (2-3 in) than at the north end. The character of the overlying radar reflections also suggest a depression or excavation associated with this linear object. In the east room, the feature previously marked I shows a very similar character to the west room linear object. In profile view, the I feature also presented a similar hyperbola reflection at a similar depth to the H feature.

Figure 12. Radar depth slice (8 cm thick) centered at 20 cm. Yellow line indicates position of radar profile (inset). Note that the orientation of the profile is reversed (E-W).



### Depth slice 14 cm centered at 20 cm

(Figure 13) – Below the I feature there is another linear feature (marked K) that likewise presents a hyperbola reflection anomaly in profile view (Inset). Not unlike the situation at H in the west room, the overlying reflections indicate a depression that may be related to an excavation associated with this object. Coincidentally, the position of the K feature relative to the south end or apparent terminus of the I feature, if connected, places this I-K object parallel to the central wall and to the H object.

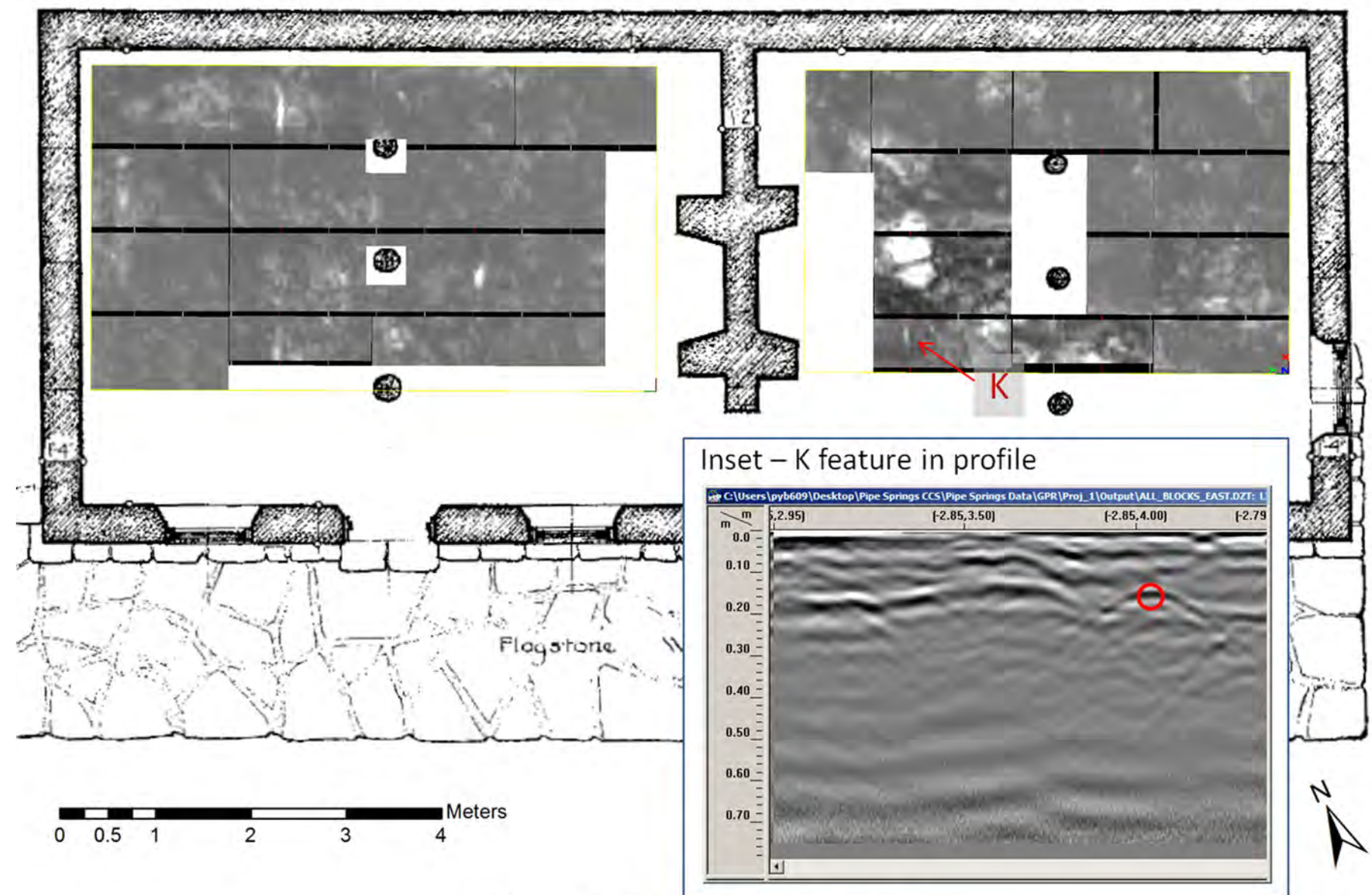
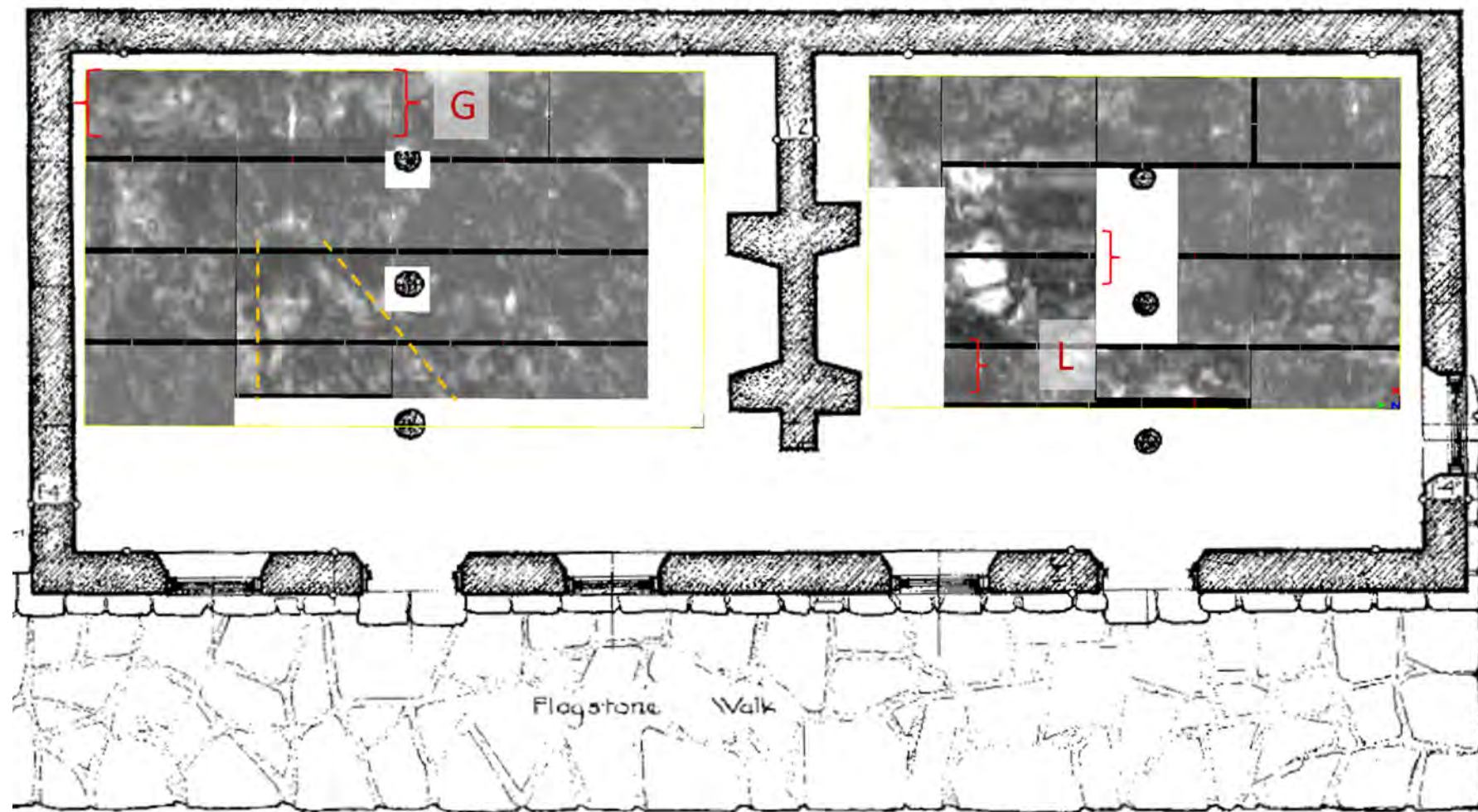


Figure 13. Radar depth slice (14 cm thick) centered at 20 cm.

### West Cabin GPR Survey

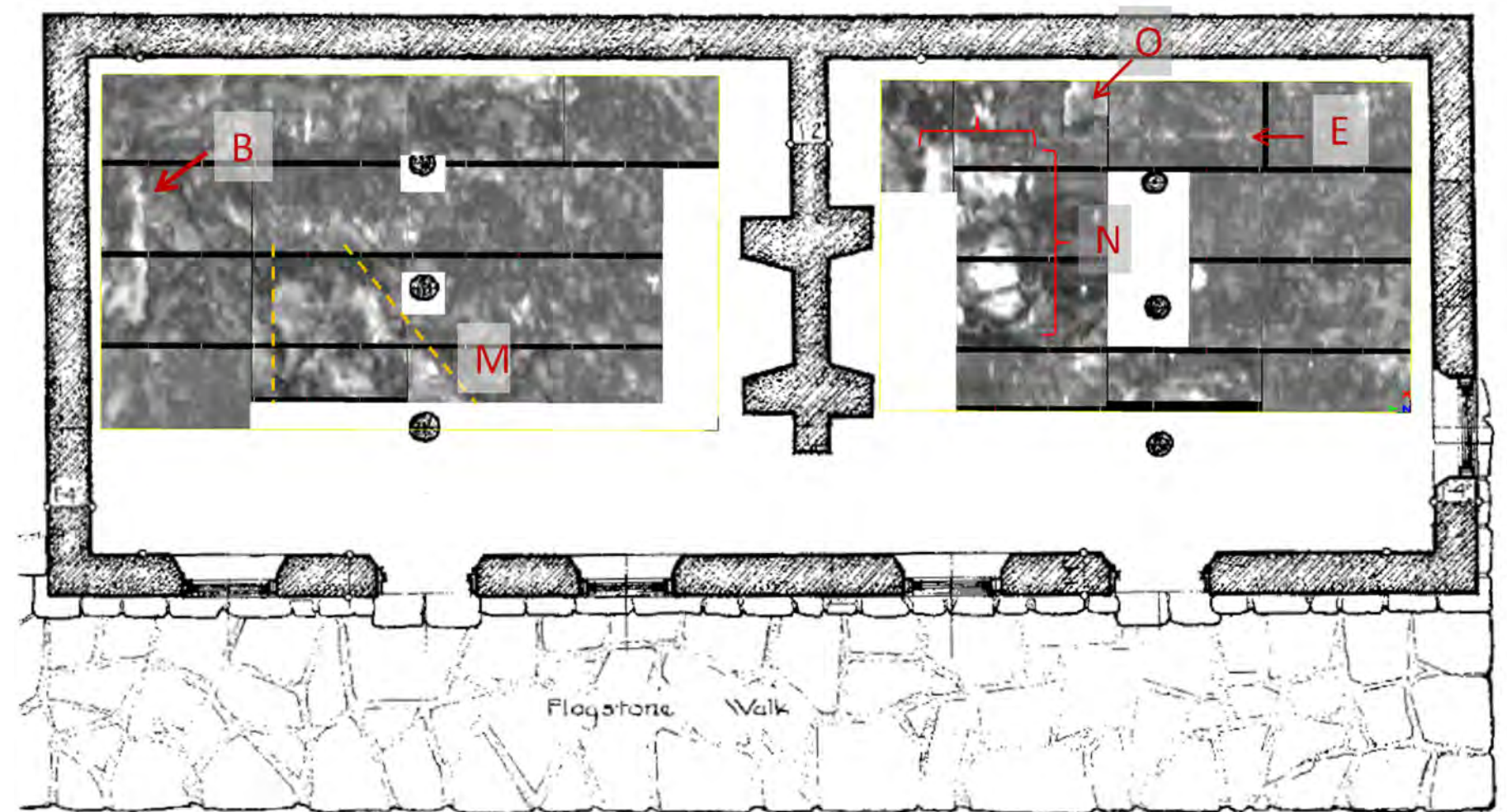


Depth slice 20 cm centered at 20 cm

(Figure 14) – In the west room, the feature previously marked G, as the rectangular feature that abuts the north and west walls, is particularly evident in this depth slice. The orange dashed lines in the west room denote a feature that is strikingly similar to the triangular shaped, mottled character feature that was seen in the east room of depth slice 16 (also denoted by the orange dashed lines). This feature is more evident in the next slice, so will be discussed in more detail there. In the east room, this depth slice shows well the pattern and positioning of the subsurface flagstone (previously marked F and J), both conjectured and confirmed by the 1989 archaeological survey (Figure 15). The small red brackets in the east room mark the locations of the 1989 survey test pits (marked as L). Both pits were 1 m x 0.5 m. In this depth slice, the edges of the pits can be discerned by a change in the radar data texture and brightness.

Figure 14. Radar depth slice (20 cm thick) centered at 20 cm.

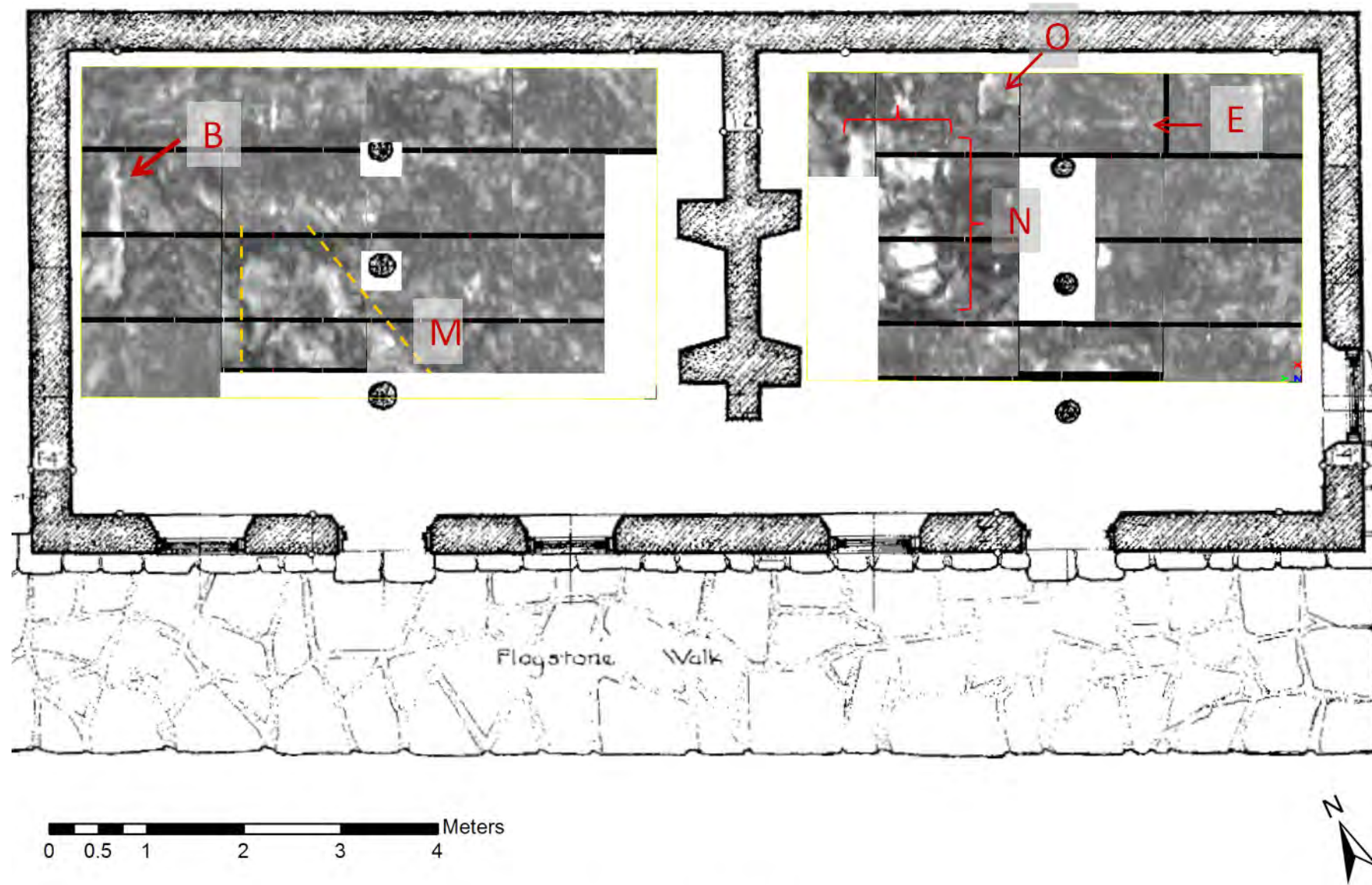
West Cabin GPR Survey



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Figure 15. Overlay of the 1989 Archaeological Testing results (east room) on the 1949 HABS floor plan.

### West Cabin GPR Survey



Depth slice 26 cm centered at 20 cm

(Figure 16) – In the west room, the feature previously marked B is quite visible and evident again. The triangular feature in the west room is most clearly defined in this depth slice (marked as M). In the east room, the assemblage of features that are likely flagstone can be seen most clearly. Framed by the red brackets (as shown) this assemblage has taken on an overall rectangular shape (marked as N). In addition the top of this rectangular shape at N matches quite well with the previously described linear feature (at E). Finally, there is another feature in this same vicinity that shows most well in this depth slice, and that is the feature marked O. This feature matches quite well in position and size to a feature described in the 1989 archaeological testing of the east room.

Figure 16. Radar depth slice (26 cm thick) centered at 20 cm.

West Cabin GPR Survey

Depth slice 32 cm centered at 20 cm

(Figure 17) – The final depth slice encompassing all data from 4 cm to 36 cm is not particularly revealing of any features presented and discussed thus far.

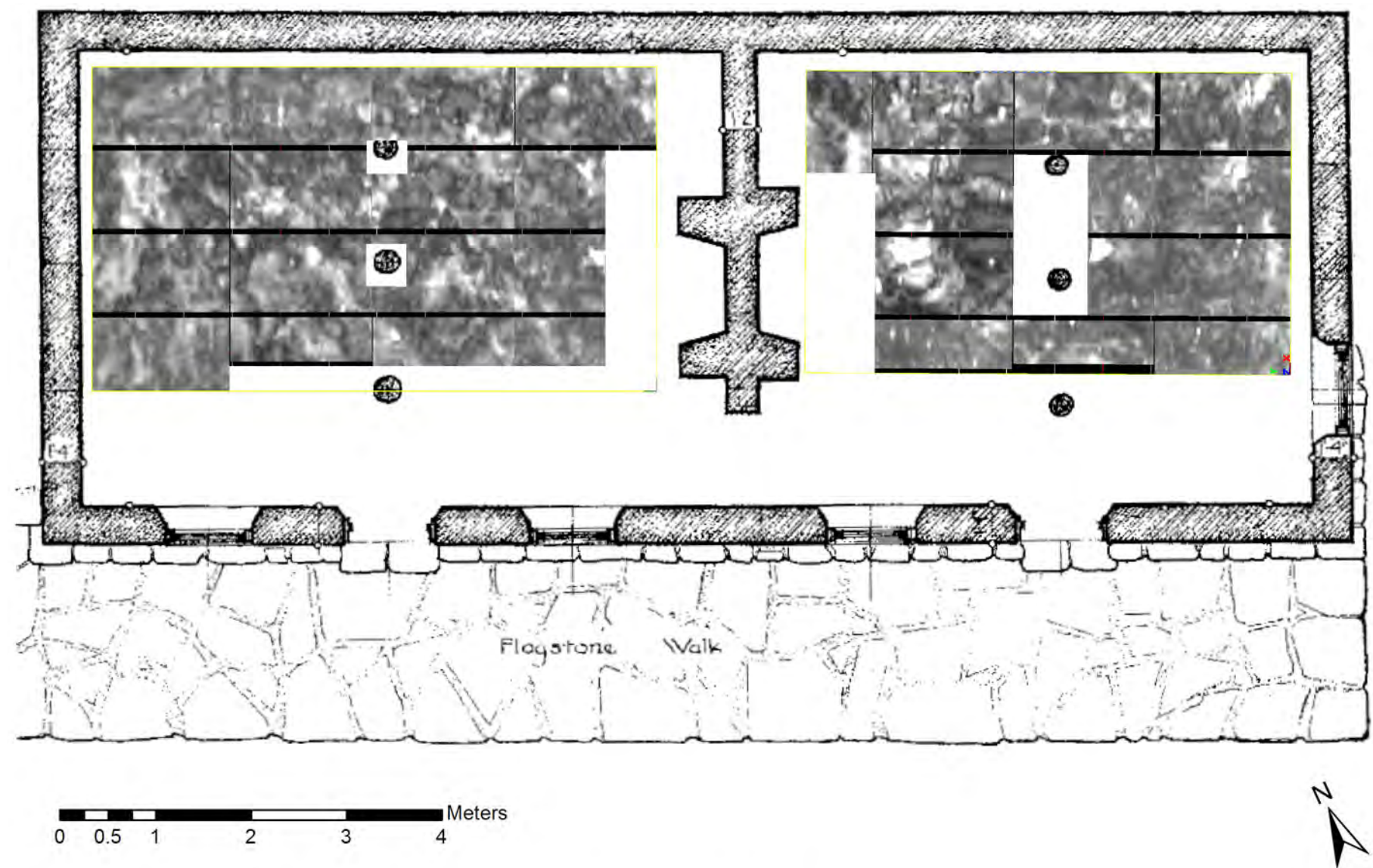


Figure 17. Radar depth slice (32 cm thick) centered at 20 cm.

West Cabin GPR Survey

## Summary Interpretation of Radar Results

Figure 18 presents a summary of anomalies encountered in both east and west rooms of the West Cabin and our interpretations of these anomalies in a historical/cultural context.

The striation features seen primarily in the west room remain somewhat of a mystery. Clearly there is something structural and/or morphological to these features, as evidenced by the radar profiles. The general strike of these features is north-south, with dip to the east. The feature spacing, at 0.5 – 0.6 m (~ 2 ft) would not be inconsistent with agricultural furrows or terracing. If related to some type of land use practice, likely related to the adjacent springs, then most definitely the features would have to pre-date the West Cabin structure. At this time we have no other plausible explanation – natural or cultural – for these features.

The anomalies that we are interpreting as radar reflections from buried flagstone are for the most part confirmed by the spatial match of the anomalies with the flagstone mapped during the 1989 archaeological testing. It must be noted that there does appear to be some spatial error in the 1989 map, as the best fit of the map to the HABS floor plan places the support posts some 20 cm to the left (and slightly north) of their HABS positions. We are more confident in the HABS map accuracy, in that the post positions matched much better with our radar survey maps. This 20 cm offset also is consistent with a spatial shift of the exposed flagstone that is currently situated between the 2 most northern posts. Two anomalies that we are interpreting as pieces of flagstone (or assemblages) were not shown on the 1989 testing map and are shown on our anomaly map as the darker shade of brown.

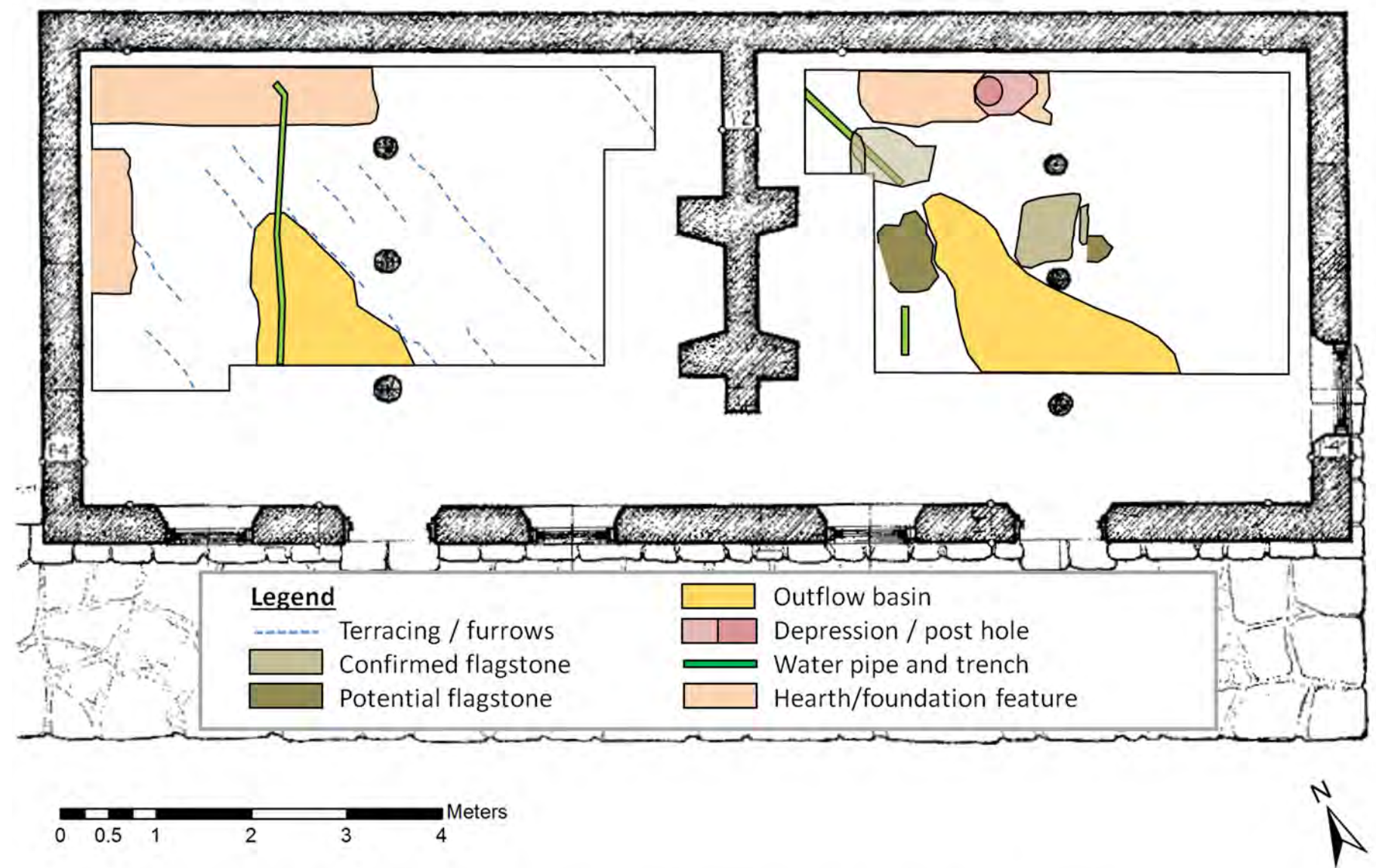
The rectangular-shaped anomalies (2 in the west room, and 1 in the east) we are tentatively interpreting as possible foundation-related features, perhaps related to buttressing structures of the existing cabin walls, or perhaps to an earlier phase of construction of the West Cabin. The shorter of the two features in the west room, could also be related to a wall buttressing structure. Another possibility, due to its size, shape and its somewhat central position along the west wall, is that it is related to a hearth associated with an earlier building phase of the West Cabin. While the east room anomaly does not have quite the same rectilinear sides, it is curiously aligned with the west room structure. Moreover, it had a similar radar data character.

The anomaly along the north wall of the east room, that we are interpreting as a posthole feature with an associated depression, is entirely consistent with the feature discussed as Feature #1 in the 1989 testing. It matches quite well spatially with the 1989 mapping of same. In the radar profile view, the depression is evident. The brightness anomaly seen in the radar depth slices is likely associated with either a piece of flagstone at the base of the depression, or perhaps compacted soil.

Finally, the last two anomaly types to discuss could perhaps be the most significant from a cultural perspective. There is no doubt, from a geophysical perspective, that there is some linear physical object that extends from almost the north wall to the south edge of the survey and that this object is parallel to the end walls of the room and that this object is approximately 25 cm in depth (~ 10 in). Moreover, we are confident that the depth to this feature increases slightly from north to south. The similarity, from an anomaly morphology

perspective, of the linear features detected in the east room, suggests these sets of features are related. The 1950 West Cabin rehabilitation letter, copied in the 1989 West Cabin Stabilization report, mentions the presence of a small spring near the northwest corner of the building. It is our interpretation, therefore, that these features seen in the radar data are evidence of some piping structure that conveyed water into the two rooms of the cabin. With the existing radar data evidence, we do not feel that this pipe is metallic (e.g. lead or iron), but is perhaps a clay pipe or conduit. In Figure 18, we also show two large triangular shaped anomalies (colored orange) that appear in the deepest depth slices. The north ends of both of these anomalies seem to be spatially associated with the pipe features just discussed, and fan out to the south – which happens to be the direction of the local hillslope gradient. We are interpreting these features as vestiges of spring water outflow from one or more terminal points of the piping system. The mottled character of the radar anomalies is consistent with mineralogical changes and/or soil compaction changes associated with long-term soil wetness or saturation. This phenomenon is commonly seen in surface radar studies of soil moisture and compaction.

Figure 18. Summary interpretation of radar anomalies.



West Cabin Radar Anomaly Summary Map

## Whitmore Dugout and Privy Sites

The purpose of the Whitmore Dugout and Privy sites surveys were to geophysically assess the conjectured locations of the two sites based on the best available spatial information from historical photos, maps, and written documentation. The best information for the probable location of the Dugout site, from a 1959 photo taken during the last excavation effort (Photo 5), was based on the spatial position of the excavation with respect to the East Cabin, visible in the upper left of the photo. This would place the most likely location of the Dugout within the perimeter of the existing walkway (sidewalks) that connect the East Cabin with the Fort and to the path to the Visitor Center, in the approximate location of the historical information sign at the juncture of the 3 sidewalks. (Photo 2, page 7). The potential location of the privy site (or sites) was less certain given the absence of any photographic documentation. Our selection of a geophysical survey site was based on the two pieces of historical evidence described in the Phase 1 report, the small “outhouse-looking” structure in Tissandier’s 1885 sketch and the 1965 oral history account from Dillworth Woolley, that placed it 35 ft north of the east gate of the Fort. We therefore designed the size and position of two rectangular survey areas to coincide with the conjectured site locations. The graphic (photo 6) shows the possible privy structure from the Tissander sketch (circled in red) and the corresponding location drawn on a recent photograph (grey box structure).

The geophysical method selected for these cultural resource surveys was gradient magnetometry. Magnetic gradiometry, like GPR, is widely used in archaeological investigations (Kwame 2006), but does not require instrumental ground contact and can thus be deployed in more varied environmental conditions. The magnetic method is potentially sensitive to ground disturbances such as excavations as well as to anthropogenic “additions” to the natural environment such as stone foundations, post-holes/piers, and cultural detritus, all of which are likely present within and adjacent to the Whitmore Dugout and Privy sites. The requested vegetation clearing and prep of the site, by Park Service personnel, was conducted in the days preceding the geophysical surveys.

Two rectangular survey areas were staked and subsequently geolocated using submeter accuracy GPS. The Dugout survey area was a 10.5 m x 12 m (34 ft x 40 ft) grid aligned along its west side with the central axis of the Fort (center of east gate). The grid was approximately centered within the previously vegetated area bounded by the visitor walkways. The Privy survey area was an 8.5 m x 9 m (27.5 ft x 30 ft) grid aligned with its south edge parallel to the east wall of the Fort and its SW corner aligned with the NW corner of the Fort, with a 2 m standoff.



Photo 5

Excavation of Whitmore Dugout, 1959.





Tissandier 1885 sketch



photo 6

### Instrumentation and Methods

The geophysical method selected for these cultural resource surveys was gradient magnetometry. Magnetic gradiometry, like GPR, is widely used in archaeological investigations, but does not require instrumental ground contact and can thus be deployed in more varied environmental conditions. The magnetic method is potentially sensitive to ground disturbances such as excavations as well as to anthropogenic “additions” to the natural environment such as stone foundations, post-holes/piers, and cultural detritus, all of which are likely present within and adjacent to the Whitmore Dugout and Privy sites. The requested vegetation clearing and prep of the site, by Park Service personnel, was conducted in the days preceding the geophysical surveys.

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Modern magnetometers can measure the most subtle change or perturbation in the earth’s ambient magnetic field due to the influence of near surface magnetized objects. Magnetometers can detect weak magnetic fields arising from some archeological resources to less than one part in a half million of the strength of the earth’s field (Geometnics, 2013). A magnetometer in gradiometer mode employs two separate but identical magnetometers, mounted and

aligned on a carrying apparatus at a fixed distance apart (usually 0.5–1 m). As the magnetic field strength of a magnetized object falls off as a function of the cube of the distance, magnetization changes in the near surface environment will influence the bottom sensor more than the top sensor. The difference of the two measurements is the basis of the gradiometer. A significant advantage of the gradiometer is the cancellation of any magnetic noise that is likely to affect both sensors equally such as natural fluctuations in the earth’s magnetic field. Subsurface cultural resources that are most likely to be detected by the magnetometer would be ferrous and some non-ferrous metal objects, some burials and their associated excavations, historical middens, privies, and potentially excavations and building walls/foundations. In the case of all non-metallic objects, the instrument’s ability to detect weak magnetic fields is due to the presence of magnetic minerals present in some soils, rocks, and building materials.



photo 7

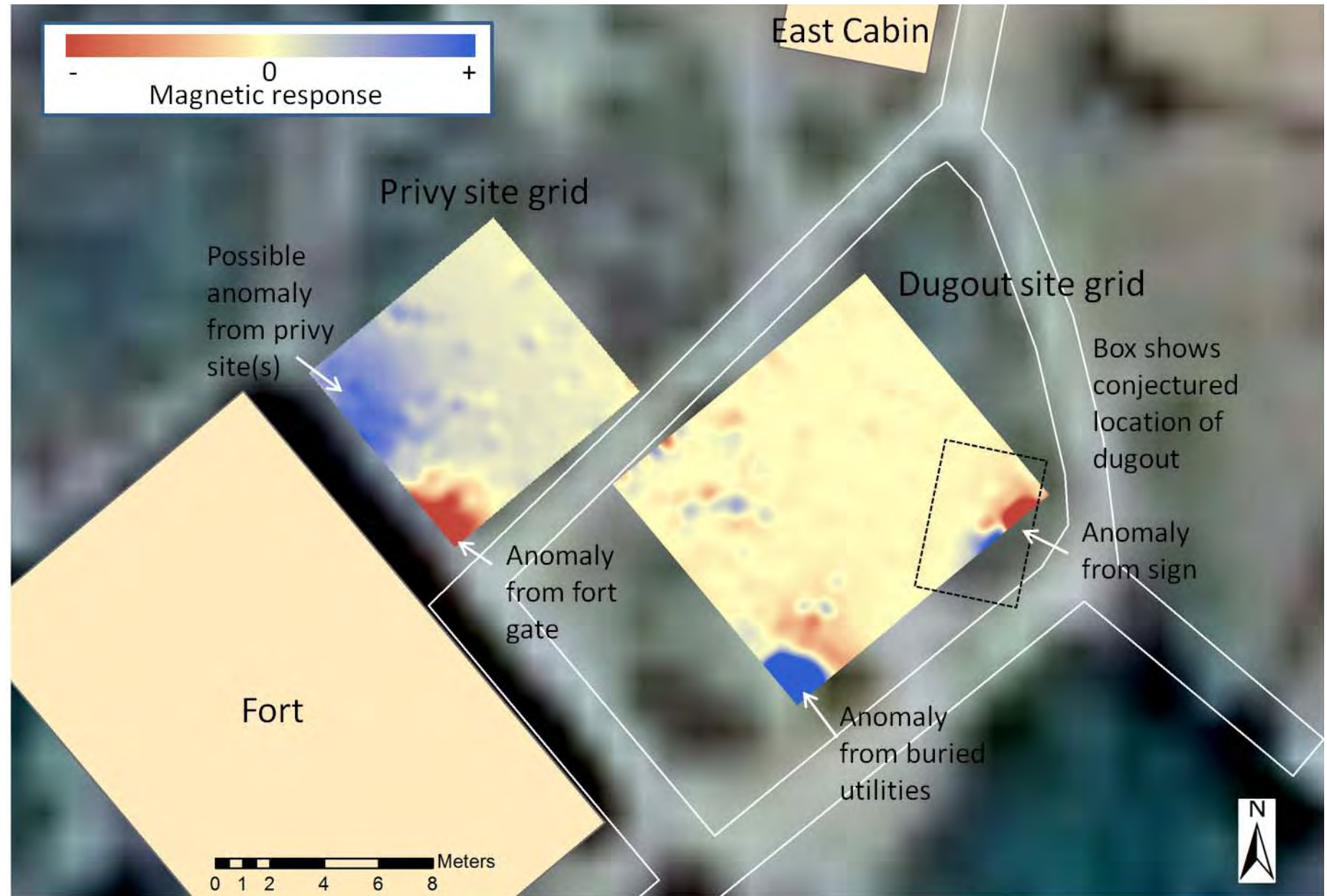
## Data Processing and Interpretation

Data was acquired in both grids on a 0.5 m sample spacing and transect spacing. Both survey operator and the Park Service assistant were checked for magnetic “cleanliness” prior to the start of the surveys. Even small amounts of metal on a person can negatively affect the quality of the data. Also, as a quality assurance measure, both sites were checked prior to the survey for all visible metallic clutter. An overhead wire above the Privy site survey area was taken down to avoid potential magnetic noise. Data collection is rather straightforward as it involves only a single instrument reading at each sample location (photo 7). Data processing of magnetometer data is rather straightforward as it involves only the spatial registration of individual numerical readings. Initially, this is done in an X-Y local coordinate system established in table format (e.g. spreadsheet). This data is first checked for noise spikes and various other artifacts and then imported into a GIS for subsequent global coordinate registration of the grids and interpolation of the gridded datapoints to a continuous raster-based surface. All magnetometer data is thus plan-view. No profile or depth information is possible with this particular technique.

The interpretation of magnetic data is not so straightforward due to the nature of the physics of magnetic fields as well as to whether the fields from the targeted objects are induced by the earth’s ambient magnetic field, or are remanent (e.g. permanent) fields. In general, induced fields are usually much stronger than remanent fields. The only cultural resources that typically present an induced field are iron or ferrous objects. Most other cultural resources, if they contain any magnetic field at all, are considered remanently magnetized. In regards to anomalies seen in magnetic surveys, induced fields are usually dipolar in nature.

In other words, the anomalies display both a positive and negative magnetic response (see Appendix). Dipole anomalies also are commonly aligned with the earth’s field, so that a line drawn between the positive and negative centers of the anomaly generally points north-south. Remanent anomalies seldom present as dipoles, but rather single polarity anomalies (either negative or positive). Unless cultural ferrous objects (e.g. trash) were left within the Dugout excavation site, we do not expect any induced or dipole effects. The most likely effect will be weak magnetic remanence, either from the disturbance to the natural soil environment (during original construction or subsequent excavation) or from magnetic remanence in the building stones used in the original construction. On the other hand, the most recent excavation may have “scrambled” any significant magnetic response from the site. While we cannot rule out the possibility that the Privy site contains significant ferrous objects, and thus may induce various dipole anomalies, the more likely situation will be some combination of a remanent and minor induced magnetization effects due to the associated excavation and/or to the diverse cultural contents within.

The graphic of the dipole anomaly shown in the appendix is presented in a standard grey scale format. To better illustrate the subtleties of the results from the dugout and privy surveys, the ensuing survey results map has been given a color transformation where red depicts strongly negative magnetic response, blue strongly positive, and shades of pale yellow depicting weak response.



Dugout and Privy Sites Magnetometer Survey

Figure 19. Summary interpretation of magnetic anomalies.

## Results and Conclusions

## Results and Discussion

Two very strong anomalies, with peak values of  $\pm 1000$  nanoteslas/meter (nT/m), were seen in the Dugout survey grid (Figure 19, page 36). The anomaly in the east corner of the grid near the junction of the sidewalks is most certainly associated with the metal associated with the interpretive sign, or metal (iron rebar) within the concrete base of the sign. The large anomaly in the south corner of the grid is most likely associated with the buried utilities that are known to exist in that area. A few weak point scale anomalies appear mostly in the west half of the grid. With the exception of the two large anomalies discussed above, the east half of the grid is exceptionally quiet. Based on the 1959 photo of the dugout excavation, it is the east corner of the grid where we might expect to see a response from the dugout. The absence of any magnetic anomaly suggests either (1) there is no measurable remanent effect from the dugout resource, or (2) the strong magnetic response from the sign has effectively “drowned out” any weak response from the dugout, or (3) the location of the dugout is further to the east, off-grid, and likely under the existing sidewalk.

One very strong anomaly, with a peak value of  $-600$  nT/m, was seen in the far south corner of the privy site survey grid. This negative anomaly, as part of a larger dipole anomaly, is most likely associated with the iron hinges and hardware of the east gate of the fort. The positive side of the anomaly is closer to the gate itself and just off the grid. Anomalies of this magnitude are almost always associated with induced effects from significant iron objects. It would be rare to have a remanent effect with a magnitude greater than about  $\pm 50$  nT/m in a cultural resource context. The majority of archaeological resources, assessed by this geophysicist in numerous surveys, have anomaly magnitudes less than 20 nT/m. The west corner of the survey grid, therefore, merits attention. A somewhat diffuse but clustered set of positive magnetic anomalies is clearly evident. No dipole effects are seen in this cluster. The peak values of magnetization within this cluster are on the order of 100 – 150 nT/m, with background values of 50 – 75 nT/m. These values would be considered high for purely remanent effects. However, considering the likelihood that multiple privy pits were utilized and that these pits may have also seen use as trash dumps, the combined remanent and induced effects could perhaps explain this anomaly. The location of this anomaly is in fact consistent with the location of the object seen in the Tissandier sketch. It is also consistent with where the oral history account places it with respect to the east gate of the fort. The center of this anomaly is  $\sim 30$  ft from the center of the gate.

## Summary Conclusion

Our purpose was to use remote sensing technology in a non-destructive and non-invasive manner for analysis of potential archeological resources at Pipe Spring National Monument. The immediate concern and thus the focus of this work was the West Cabin. Because the NPS staff expect to execute soil stabilization efforts to control dust within the West Cabin, this project was a necessary and appropriate due-diligence effort to discover the sub-surface resources prior to the work in order to mitigate potential for damage. The findings conclusively and accurately locate cultural resources buried within the West Cabin. The results provide baseline documentation to guide treatment and management strategies, plus the findings allow for the preservation of these cultural resources.

The project had two secondary objectives, also involving remote sensing technology – to locate the Whitmore Dugout and try to find the location of a former privy. The seemingly straightforward task, to locate the Whitmore Dugout last exposed in 1959, proved to be largely inconclusive. There was too much electrical field disturbance from nearby objects -- an interpretive sign and a new sidewalk – and not enough signal from the cultural deposits.

Location of the privy, a speculative task expected to produce no result, was a surprise success. Using the primary source archival information (available on site with the help of knowledgeable staff), the team targeted a location to search. Cultural deposits were located, providing baseline documentation for future management and long-term protection. Should the need arise for future archaeological investigation, that work will be well guided by this report.

## Bibliography

Conyers, L. B. (2004). Ground penetrating radar for archaeology. Walnut Creek, CA: Altamira Press.

Geometrics, Inc. (2013). Geometrics G-858 magmapper cesium vapor gradiometer. Retrieved from <http://www.geometrics.com/geometrics-products/geometrics-magnetometers/g-858-magmapper/>

Ground penetrating radar soil suitability maps. (2009). National Resource Conservation Service (NRCS). Retrieved from <http://soils.usda.gov/survey/geography/maps/GPR/>

Kwame, K., (2006). Magnetometry: nature's gift to archaeology. In J.K. Johnson (Ed.), Remote sensing in archaeology: An explicitly North American perspective (pp. 205-233). Tuscaloosa, Alabama: University of Alabama Press.

McKoy, K. L. (2000). Cultures at a crossroads: An administrative history of Pipe Spring National Monument. No. 15 cultural resources selections, intermountain region. Denver, CO: U.S. Dept. of the Interior, National Park Service, Intermountain Region.

RADAN 7: The most advanced GPR data processing software optimized for Windows 7. [Brochure]. (2012). Salem, NH: Geophysical Survey Systems, Inc., Retrieved from <http://www.geophysical.com/Documentation/Brochures/GSSI-RADAN7Brochure.pdf>

StructureScan series systems: concrete inspection systems by GSSI. [Brochure]. n.d. Salem, NH: Geophysical Survey Systems, Inc. Retrieved from <http://www.geophysical.com/Documentation/Brochures/GSSI-StructureScanSeriesSystems.pdf>

### Other References

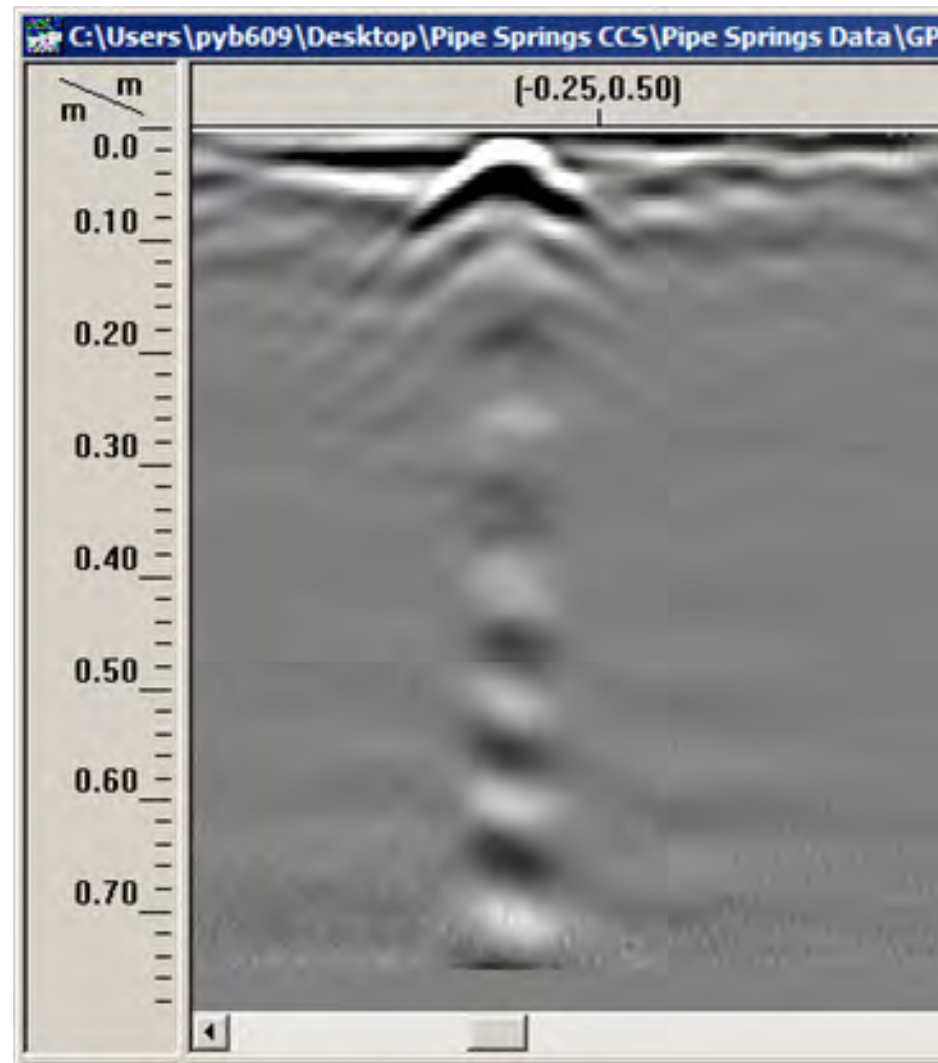
Fuller. (2005) Historic Outhouse. Unpublished report, Pipe Spring National Monument. Fredonia: Arizona

Tissandier, Albert (1885). Photocopy of 1963 photograph of original 1885 pencil sketch provided by Pipe Spring National Monument. See McKoy.

Woolley family histories. n.d. Vertical File, Pipe Spring National Monument Archives. Fredonia: Arizona.



## Appendix Ground Penetrating Radar

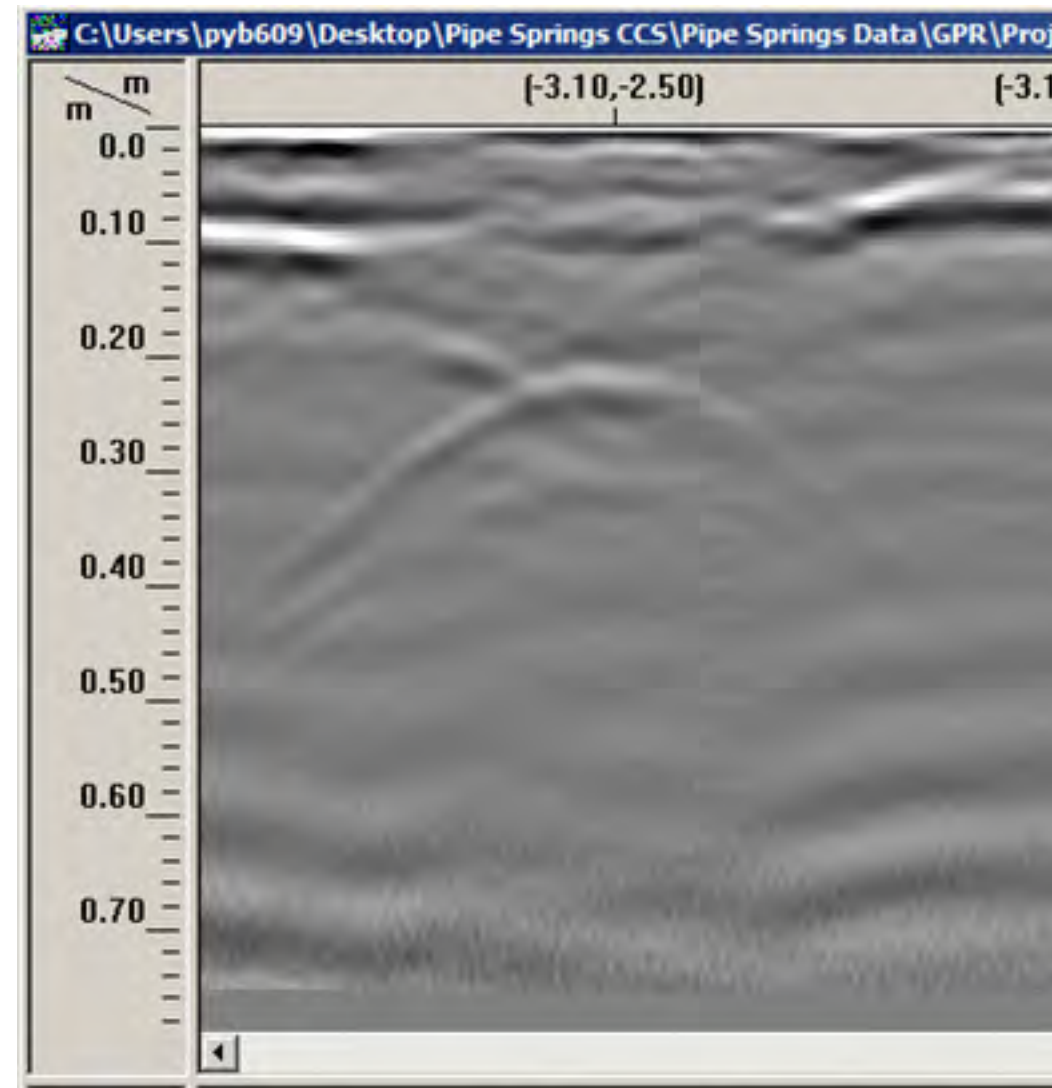


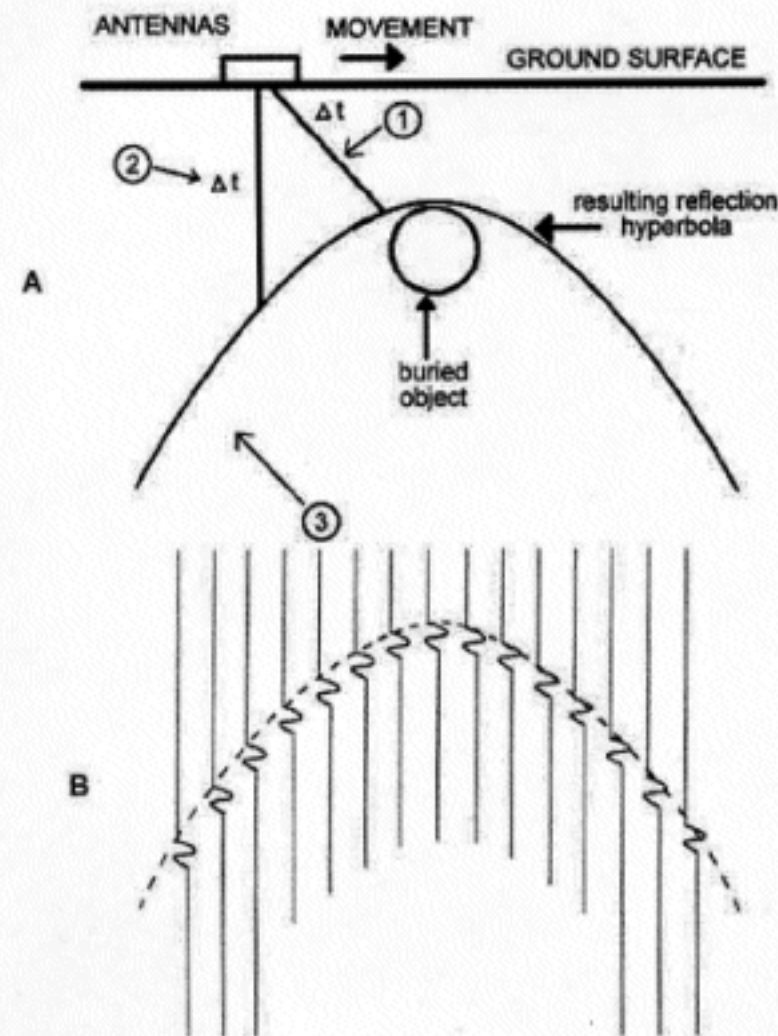
### “Ringing” metal object anomalies

Example of the characteristic signature of a small metal object, in this case very near (within a couple centimeters) to the surface. Note the reverberating echo of the radar energy that propagates to the bottom of the profile. The small red circle on the graphic denotes the location of the metal object.

### Hyperbola anomalies

Example of a discrete (likely non-metallic) object producing a hyperbola-shaped anomaly. Such anomalies can be produced from an object like a stone, or from a linear object such as a pipe. In the latter case, the hyperbola is best seen when the pipe is crossed at right angles. Positive ID of a linear object is usually confirmed when the hyperbola is seen multiple parallel transects. The red circle denotes the location of the object. The following graphic explains the geometry inherent in the generation of these hyperbola anomalies.





As the surface antenna moves closer to a buried point source, the receiving antenna will continue to record reflections from the point source prior to arriving directly on top of it, and continue to "see" it after it has passed. A reflection hyperbola is then generated because the time it takes for the energy to move from the antenna to the object along many oblique paths is greater the farther the antenna is away from the source of the reflection. As the antenna moves closer to the buried object the reflection from it is recorded closer in time until the antenna is directly on top of it. The same phenomena is repeated in reverse as the antenna passes away from the source, resulting in a hyperbola where only its apex denotes the actual location of the buried source, with the arms of the hyperbola creating a record of reflections that traveled the oblique wave paths.

From Conyers (2004)

## Magnetic Gradiometry

### Magnetic dipole anomaly

Plan or map view of a magnetic dipole anomaly produced from a ferrous (iron) object. In this case, the anomaly was induced by a medium-sized nail. Note that a line between the + and - poles aligns approximately with north. The red circle shows the estimated location of the near surface object

