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Boden Vean, St Anthony in Meneage, Cornwall: Report on Geophysical Survey, October 2003

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Summary

A Ground Penetrating Radar GPR survey was conducted over the remains of a rediscovered Cornish souterrain or fogou at Boden Vean, Manaccan, St Anthony in Meneage, Cornwall. The fogou, last seen over 70 years ago, was relocated during the laying of an agricultural water main by the land owner in 1991 and became the subject of an extensive programme of geophysical survey, including a microgravity survey to identify any extant buried voids. The current GPR survey was conducted to complement this original work and better define the structure and location of the fogou indicated by the microgravity anomalies in advance of trial excavation proposed by the Cornwall Archaeological Unit. Despite a subdued response, the GPR survey has successfully identified a number of significant anomalies related to both the fogou and the surrounding round enclosure.

Keywords

Geophysical Survey
Ground Penetrating Radar

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BODEN VEAN, St. ANTHONY IN MENEAGE, Cornwall.

Report on geophysical survey, October 2003.

Introduction

The remains of an undisturbed buried chamber or fogou were rediscovered at Boden Vean during the laying of an agricultural water main by the landowner, Mr Chris Hosken, in 1991. These remains consisted of a 3m deep, stone-lined pit or well to the N and the remains of a partially collapsed fogou, relocated to the S through probing with an iron bar, consistent with the last known observation of the structure, approximately 70 years before the current rediscovery. Subsequent geophysical survey (Linford, 1998) confirmed the location of a number of void type anomalies, identified during a microgravity survey, at a distance of ~15m from the collapsed fogou remains. The presence of a rectilinear Iron Age 'round' enclosure, commonly associated with other similar sites throughout Cornwall (Christie, 1979) was also confirmed during a magnetic survey.

Subsequent to the initial investigation of the site, one of the void anomalies identified by the microgravity survey 15m NE of the observed fogou collapsed, under the weight of agricultural machinery, to reveal a subterranean chamber apparently formed from two deeply excavated passageways (Figures 1 and 2). This suggested the survival of an extensive souterrain type structure extending from the observed remains of the fogou to the area of possible voids identified through the microgravity survey.

Following the submission of a project design from the Cornwall Archaeological Unit (CAU) to English Heritage for the invasive archaeological evaluation and necessary conservation of the site, an additional geophysical survey using Ground Penetrating Radar (GPR) was conducted. GPR was not available at the time of the original survey but it was hoped that results from this technique would further complement the available geophysical survey data. In addition, the likelihood of extant, sizeable voids (e.g. Figure 2) over the site posed a potential health and safety risk during the machine excavation of the proposed evaluation trenches. It was hoped that the GPR survey would provide further information pertinent to the location of any plant machinery to avoid such void type anomalies and minimise the risk of further collapse.

The site (SW 768 240) occupies an elevated (70m above OD) position on a slight southerly slope a little below the summit of a gentle hill, commanding extensive southerly views of the surrounding landscape. A 300m wide band of Devonian Conglomerate overlies a broader outcrop of crush breccia (Menage crush zone) bordered to the S by hornblende-schist. Spilite lava outcrops are indicated immediately

S of the conglomerate as intrusions within the underlying breccia (British Geological Survey, 1974). Well drained, fine loamy soils of the Denbigh 2 association have developed over the site that, due to the elevation of the site, are unlikely to be affected by groundwater (Soil Survey of England and Wales, 1983).

Weather conditions during the acquisition of the GPR data were mixed, alternating from bright and dry to a period of heavy rain and gale force winds. Field conditions were good with a firm surface of short stubble left fallow following the harvest of a cereal crop.

Figure 1 Photograph of the collapsed void facing E towards the prominent apple tree, originally used by the landowner to relocate the remains of the fogou.

Figure 2 Photograph of the subterranean passageway or creep heading SE observed from the collapsed void shown in Figure 1 taken during the GPR survey.

Method

The Ground Penetrating Radar (GPR) survey was conducted with a Pulse Ekko PE1000 console and both 450MHz and 225MHz centre frequency antennas. The 225MHz antenna was selected as the most suitable centre frequency for obtaining the optimum depth of penetration and lateral resolution required to image the expected archaeological targets (Figures 3 and 5). Attempts to estimate the velocity of the radar wavefront in the subsurface through a common mid-point (CMP) velocity analysis conducted in the field suggested an average subsurface velocity of ~0.11m/ns. This latter velocity was adopted as a reasonable average value for processing the data from this site and for the estimation of depth to reflection events in the recorded profiles.

A 60m square survey grid was established over the site, using a Trimble kinematic differential global positioning system, to allow data to be collected from parallel EW traverses separated by 0.5m (Figures 3 and 4). Individual traces along each profile were separated by 0.05m and recorded the amplitude of reflections through an 80ns time-window. Post acquisition processing involved the adjustment of time-zero to coincide with the true ground surface, removal of any low frequency transient response (dewow), noise removal and the application of a suitable gain function to enhance late arrivals.

Owing to antenna coupling of the GPR transmitter with the ground to an approximate depth of $\lambda/2$, very near surface reflection events should only be detectable below a depth of 0.49m, if a centre frequency of 225MHz and a velocity of 0.11m/ns are assumed. However, the broad bandwidth of an impulse GPR signal results in a range of frequencies to either side of the centre frequency which, in practice, will record significant near-surface reflections closer to the ground surface. Such reflections are often emphasised by presenting the data as amplitude time slices. In this case, the time-slices were created from the entire data set, after applying a 2D-migration algorithm, by averaging data within successive 2ns (two-way travel time) windows (David and Linford, 2000; Sensors and Software 1996). Each resulting time slice, illustrated as a greytone image in Figure 6 represents the variation of reflection strength through successive ~0.11m intervals from the ground surface.

Results

The response to GPR survey over the site was subdued although an acceptable degree of penetration, to a depth of approximately 2.0m, was achieved. The slightly disappointing nature of the GPR response was not surprising given the previous earth resistance data that failed to identify the course of the round enclosure ditch, but did identify a high resistance anomaly in the vicinity of the excavated fogou (Figure 6). It is possible that both the original earth resistance survey and the GPR survey have been adversely affected by extreme soil moisture conditions at the site. The earth resistance survey was conducted in the midwinter, when the soil conditions were fully saturated, and the current GPR data was collected at the end of a dry summer with little significant rainfall. As both techniques, to a certain degree, rely on a contrast in soil moisture more optimal seasonal conditions might well improve the recorded geophysical response.

However, trial 30m GPR profiles, conducted immediately S of the collapsed passage way with both 225MHz and 450MHz centre frequency antennas, successfully identified anomalies associated with the visible void features (Figure 5). The agricultural water supply trench has been detected to the east of the trial profiles with responses to the known voids appearing approximately 5m from the field boundary. The 225MHz centre frequency antenna has, apparently, defined both the "roof" of the void (~0.8m from the ground surface) and the floor of the structure (~1.7m from the ground surface). This is, no doubt, due to the greater penetration depth afforded by the lower frequency antenna although at a reduced lateral resolution in comparison to the near-surface data recorded with the 450MHz antenna. Additional anomalies found approximately 10m E of the visible collapse correspond with the known location of the previously excavated fogou remains and a possible second passage way or creep 10m further to the E again.

Amplitude time slices

Following the trial GPR profiles a detailed survey of a 60m × 60m area (Figure 3) was conducted using the 225MHz centre frequency antenna to produce the amplitude

time slices shown in Figure 6. From the estimated velocity of the radar wave front at the site (~0.11m/ns) each grey scale plot in Figure 6 represents the variation of relative reflector strength within successive 0.11m thick slices through the subsurface. To assist with the interpretation of the data a graphical summary of significant anomalies is provided in Figure 7.

The near surface time slices (0 to 16ns) provide evidence for a number of anomalies due to recent features, such as the surface plough patterns [1] and the agricultural water main [2] running along the E edge of the survey grid. An amorphous area of high magnitude reflections following the course of the water main to the S may well indicate water leaking from this supply into the pipe the trench.

High amplitude reflections are also recorded over the known location of the excavated fogou [3] and the collapsed passage way [4] where the presence of a temporary plywood sheet cover allowed the antenna to be traversed directly over the exposed void (Figure 8). However, both [3] and [4] are more completely described in the deeper time slice data.

The location of an anomaly associated with the round enclosure ditch [5] becomes partially visible within the 14 to 16ns time slice. Later time slices, 22 to 40ns, reveal a more complete anomaly that correlates directly with the magnetic response to this feature from the original survey. Whilst the initial GPR reflections from the round enclosure ditch appear to originate from a depth of approximately 0.8m the later time slice data suggests a response from a greater depth in excess of 1.5m. Samples recovered during the original magnetic survey over the location of the enclosure ditch confirmed that the enhanced magnetic soil extended to a depth of approximately 0.8m (Linford, 1998: Fig 3). This suggests the GPR is, perhaps, responding to the base of the ditch-feature rather than magnetically enhanced topsoil accumulating within the near-surface layers.

Of greater interest is the high amplitude reflection [6] found along the course of the enclosure ditch (from 18 to 40ns) in the vicinity of the postulated entrance to the round suggested by the magnetic data. Anomaly [6] is apparently circular in shape with a diameter of ~5m and may well represent a more substantial stone-built structure, possibly associated with an additional pair of responses [7] at a similar depth immediately E of the proposed entrance to the round.

Returning to the remains of the known fogou, the GPR survey has provided additional information to complement the previous geophysical results from the site. The anomaly at [3], over the location of the excavated portion of the fogou, suggests a N-S orientated feature approximately 3m wide sloping from the N for a length of approximately 10m. The deepest reflection from [3] occurs in the final time slice (42 to 44ns) at the southern extent of the structure, although there is some suggestion of an additional, perhaps partially collapsed, passage way [8] extending from the S. An additional, curvilinear response [9] follows a similar NS orientation parallel to the axis of [3] but the GPR data does not fully support any direct association between the two anomalies.

To the N of [3] there is evidence for a right–angled passageway heading E towards the location of the current collapse at [4]. This concurs with visual evidence viewed from the ground surface into the void that suggests two apparent passage ways, the first heading SW towards [3] and the second heading SE following the course of the anomaly suggested by [4] towards the field boundary to the E (*cf* Figure 2). The GPR data also supports the continuation of [4] N beyond the current open void terminating at the confluence between [4] and the N circuit of the round enclosure [5]. This suggests material covering the collapsed void has fallen into the passageway to the N partially blocking the continuation of this structure.

One final area where the GPR data suggests added complexity over the original geophysical survey results is found at [10]. This was previously identified as an area of amorphous magnetic disturbance but a more intriguing structure is suggested by the GPR survey. Anomaly [10] first becomes apparent in the 14 to 16ns time slice and with increasing depth appears to separate into a more complex response bounded within an approximately oval region of disturbance. The response continues to a similar depth as the other reflections [3] and [4] associated with the known fogou (32 to 34ns) and it is possible that [10] represents a similar souterrain-type feature or buried chamber.

Figure 8 A temporary plywood sheet cover was established over the collapsed void to allow the sledge mounted GPR antenna to pass unhindered over the site.

Comparison with the previous geophysical survey

As noted above, the original earth resistance survey produced disappointing results and failed to identify any significant anomalies, beyond the location of the excavation trench opened over the partially collapsed fogou following its initial rediscovery (Figure 6). Whilst the poor earth resistance results may well have been due to excessive soil moisture conditions, it is surprising that the strong conductivity contrast expected between the extant void spaces of the fogou and the surrounding subsoil were not detected. However, a far greater degree of success was achieved through magnetic survey with a wealth of significant anomalies, including the response due to the rectilinear 'round' enclosure ditch, being recorded.

The GPR survey has certainly proved more successful than the earth resistance survey and has replicated many of the anomalies identified within the original magnetic data, albeit with a reduced magnitude of response. It is unclear whether the success of the GPR survey, compared with the earth resistance data, is due to more favourable soil moisture conditions or the influence of the magnetic properties of the soils. This might well be due to the strong quadrature phase susceptibility recorded during the electromagnetic survey of the site with a Geonics EM38 that dominated the conductivity response of the soil (Linford, 1998).

Many of the magnetic anomalies have been replicated by GPR reflections from a more considerable depth. Whilst this may indeed reflect the geophysical response to the varying physical contrast of the features with depth, it is possible that, in part, these represent partially collapsed passageways or chambers. In this case, the lower lying base of the feature is likely to be composed of the collapsed wall stones or roofing lintels of the fogou, resulting in a detectable GPR reflection. Closer to the surface enhanced magnetic topsoil will have accumulated in the depression created by the collapse, producing the near-surface magnetic anomalies recorded by the fluxgate gradiometer survey.

Perhaps of greater interest is a comparison between the GPR data and the void type anomalies identified by the microgravity survey (microgravity anomalies marked as G1, G2 and G3 on Figure 7). The predicted negative microgravity response G2 was subsequently proven by the partial collapse of the void following the survey (Figure 1) and corresponds to the location of anomaly [4] within the GPR data. However, the GPR data has, apparently, provided a more complete description of the underlying causative feature. The positive gravity response G3 is found in the vicinity of GPR anomaly [3], close to the known location of the partially excavated fogou, and G3 was originally interpreted as a response to the buried stone work in this region. From the GPR data it would appear that G3 is located slightly to the W of [3], suggesting the microgravity anomaly may not, necessarily, be directly associated with the excavated remains of the fogou.

No significant GPR response was found to correspond with the location of G1, a negative void-type microgravity anomaly located immediately N of the round enclosure ditch.

Conclusion

Despite a subdued response, GPR survey over the site has proved fruitful revealing a number of significant anomalies associated with the remains of the buried fogou and the ditch of the 'round' enclosure. This informed the location of trenches for the subsequent excavation and mitigated the Health and Safety risks associated with working close to a known void structure. In particular, the extent of the passageways to the N of the excavated fogou, discovered through the partial surface collapse, has been clarified. The fogou itself would now appear to be formed from a central, stone-lined chamber approximately 3m wide following a NS orientation parallel to the rectilinear enclosure ditch for a length of at least 10m. A curvilinear passageway may also exist to the W of the central structure, although there is no evidence to fully support a confluence between the two. To the N of the central fogou chamber there is evidence for a right-angled passageway, sloping gently upwards to the E towards the location of the observed surface collapse. At this latter point the GPR survey has revealed an additional passageway approximately 12m in length running on an approximately NW-SE alignment. This passageway apparently extends towards both the 'round' enclosure ditch to the N, beyond the area of partial collapse visible from the surface, and along the observed passageway heading to the present day field boundary to the E.

Beyond the location of the fogou the GPR survey suggests the presence of a more substantial structure along the course of the 'round' enclosure ditch to the W in the vicinity of the postulated entranceway, as interpreted from the magnetic data. In addition, an area of amorphous magnetic disturbance found beyond the NW corner of the 'round' enclosure reveals a more complex structure of subsurface GPR reflectors that may, possibly, represent the remains of a second subterranean feature.

Surveyed by: N Linford
L Martin

Date of survey: 1-3/10/2003

Reported by: N Linford

Date of report: 28/01/2004

Archaeometry Branch,
English Heritage Centre for Archaeology.

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List of enclosed figures

Figure 1 Photograph of the collapsed void facing E towards the prominent apple tree, originally used by the landowner to relocate the remains of the fogou.

Figure 2 Photograph of the subterranean passageway or creep heading SE observed from the collapsed void shown in Figure 1.

Figure 3 Location of the Ground Penetrating Radar survey superimposed over the base OS map (1:2500).

Figure 4 Linear greytone plot of the 20 to 40ns (1.1 to 2.2m) GPR time slice superimposed over the magnetic data and base OS map (1:2500).

Figure 5 Trial GPR profiles collected adjacent to the location of the exposed fogou passageway.

Figure 6 GPR amplitude time slices together with relevant extracts from the previous magnetic and earth resistance surveys (1:1500).

Figure 7 Graphical summary of significant GPR anomalies together with the location of identified archaeological remains and anomalies G1, G2 and G3 identified during the microgravity survey (1:1000).

Figure 8 A temporary plywood sheet cover was established over the collapsed void to allow the sledge mounted GPR antenna to pass unhindered over the site.

ENGLISH HERITAGE

CENTRE FOR ARCHAEOLOGY SURVEY WITNESS FORM

Site Name: BODEN VEAN **Station ID:** PERMA1

Project code: A3649 **Station marker type:** Permamark

Station text description:
Permamark set in flush with ground, with yellow disk labelled "EH 2003". Less than two metres out from 'dog-leg' on southern edge of field, ~30m west of south gate.

Co-ordinates: OSGB/~~arbitrary~~ (site or trench based?)

Eastings	Northings	Height	Checked to OSBM? Yes/no
176847.644	023982.250	70.114	N

Date established: 2/10/03 **Surveyors:** Neil Linford
Louise Martin

Method: GPS (processed OSTN02 using precise ephemeris data)

Sketch and photo (indicate direction of north):

Facing SE.
Ranging rod in right of image indicates location of permamark.

Facing SW.
Ranging rod in centre left of image indicates location of permamark.

ENGLISH HERITAGE

CENTRE FOR ARCHAEOLOGY SURVEY WITNESS FORM

Site Name: BODEN VEAN **Station ID:** PERMA2

Project code: A3649 **Station marker type:** Permamark

Station text description:
Permamark set in flush with ground, with yellow disk labelled "EH 2003". At base of hedge ~10-15m west of north gate.

Co-ordinates: OSGB/~~arbitrary~~ (site or trench based?)

Eastings	Northings	Height	Checked to OSBM? Yes/no
176797.248	024161.861	75.581	N

Date established: 2/10/03 **Surveyors:** Neil Linford
Louise Martin

Method: GPS (processed OSTN02 using precise ephemeris data)

Sketch and photo (indicate direction of north):

Facing NNE.
Ranging rod in centre left of image indicates location of permamark.

Figure 3

BODEN VEAN, CORNWALL
Location of GPR Survey, October 2003

0 90m
1:2500

Ground Penetrating Radar (GPR) survey
Location of trial GPR transects (Figure 5)
Location of perma-marker

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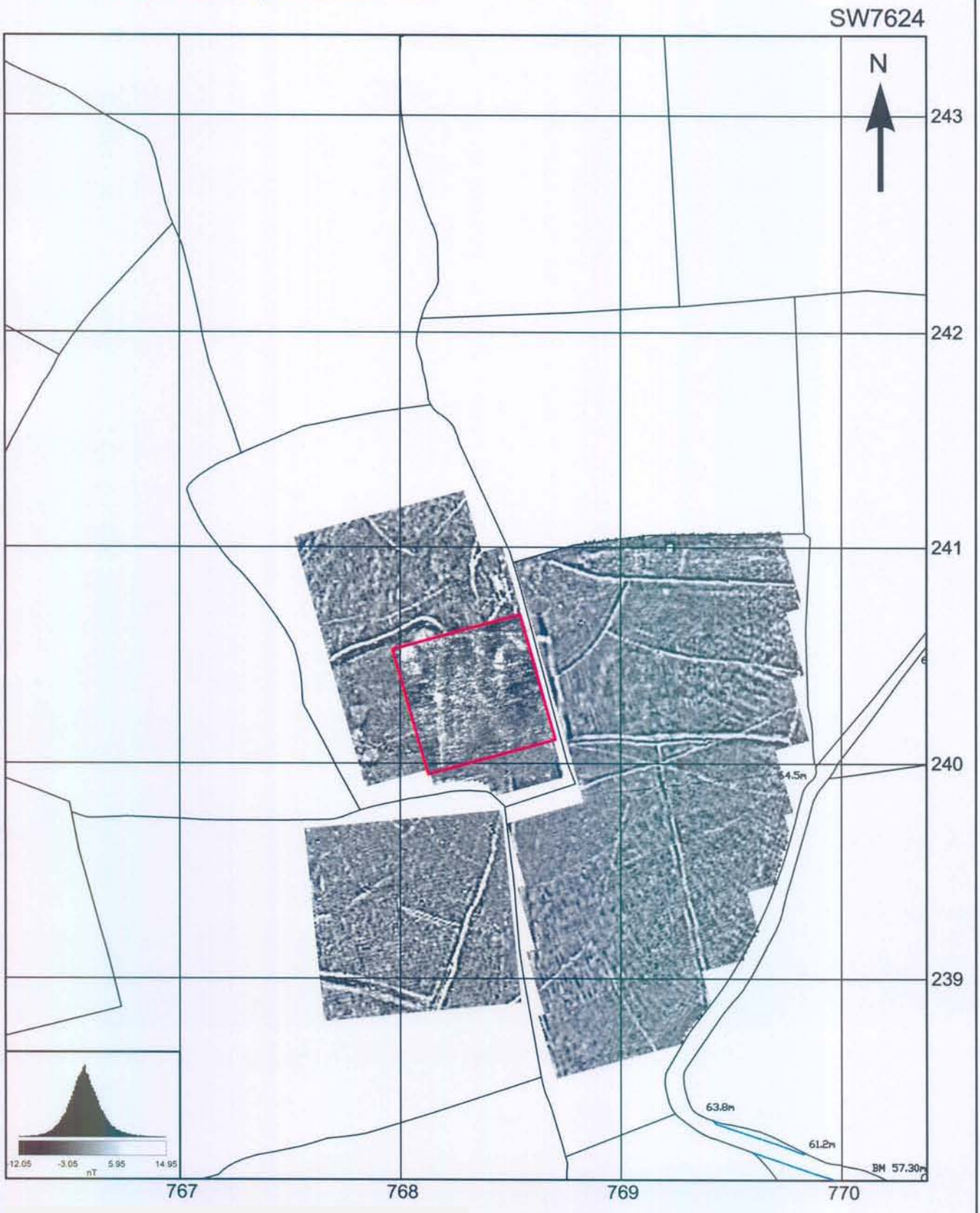
Figure 4

BODEN VEAN, CORNWALL
Location of GPR Survey, October 2003



Ground Penetrating Radar (GPR) survey 20 to 40ns time slice superimposed over fluxgate magnetometer data

0 90m
1:2500

English Heritage Centre for Archaeology 2003

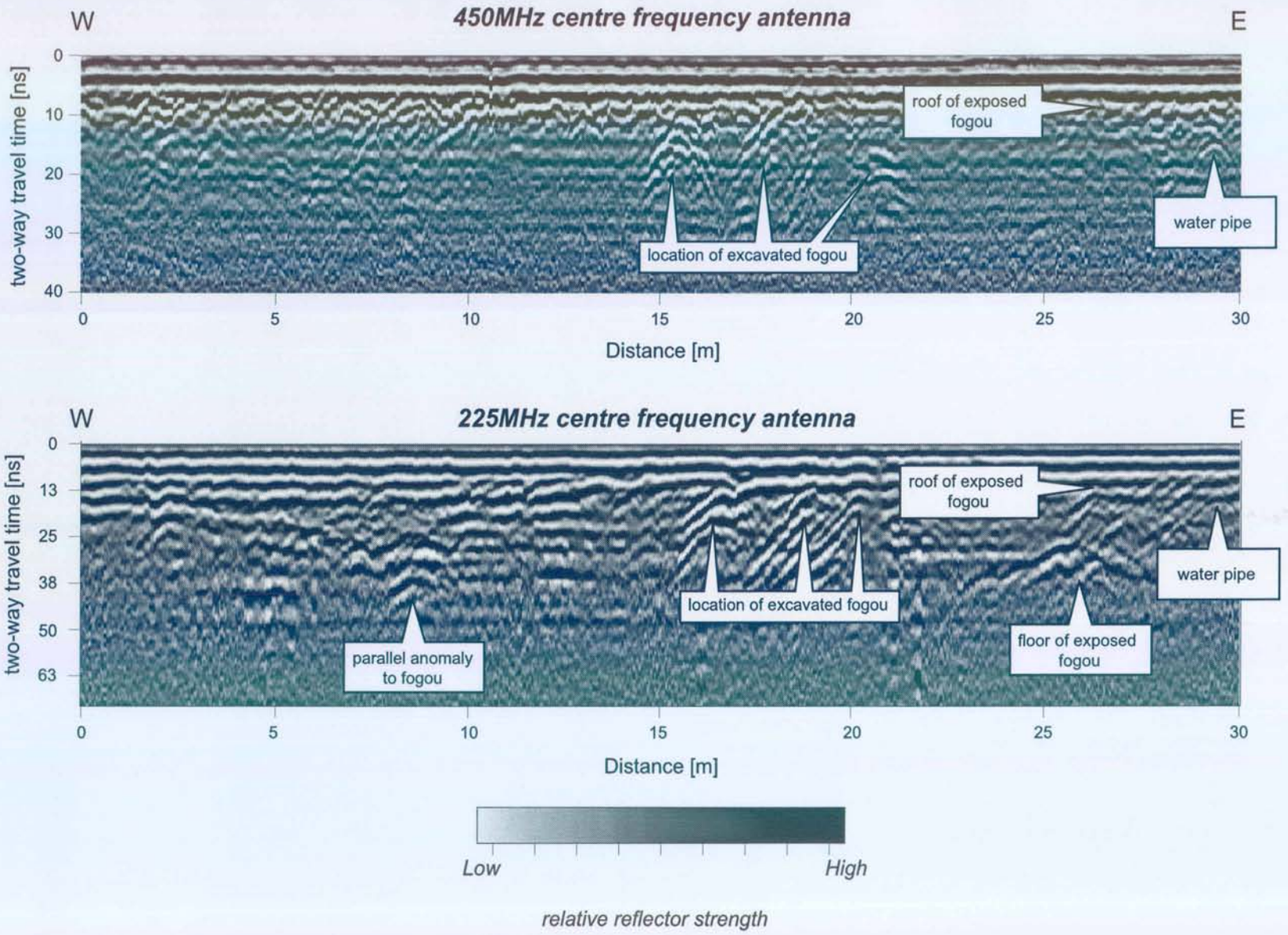
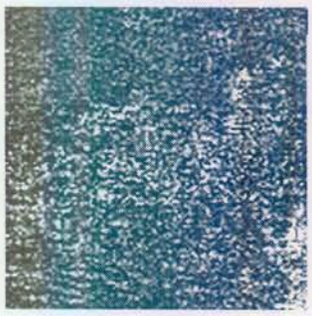


Figure 5; Boden Vean, Cornwall; *trial GPR profiles collected adjacent to the location of the exposed fogou passage way.*

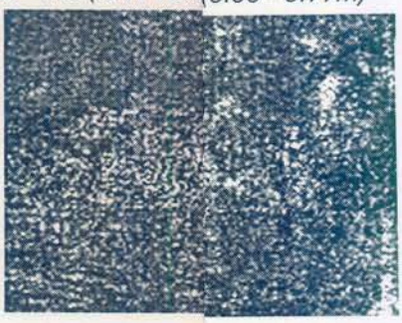
BODEN VEAN, CORNWALL.
GPR Amplitude Time Slices

Figure 6

0 - 2ns (0.0 - 0.11m)

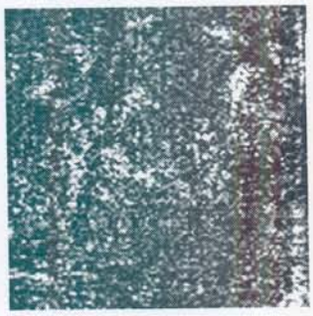


2 - 4ns (0.11 - 0.

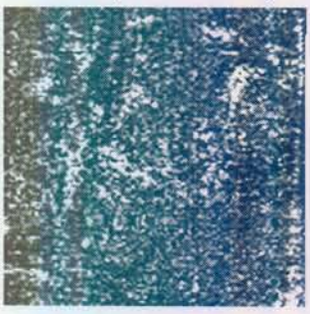


(0.66 - 0.77m)

14 - 16ns (0.77 - 0.88m)



16 - 18ns (0.88 - 0.99m)

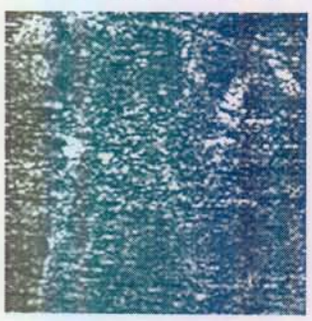


18 - 20ns (0.99 - 1

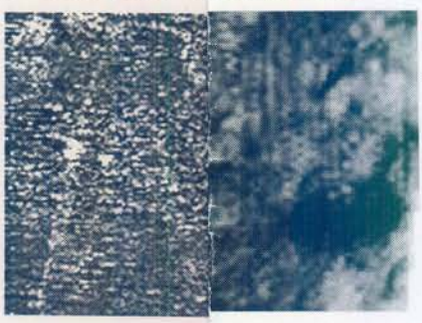
1.54 - 1.65m)

30 - 32ns (1.65 - 1.76m)

32 - 34ns (1.76 - 1.87m)

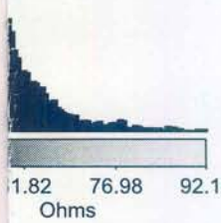


34 - 36ns (1.87 - 1

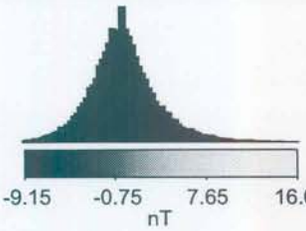


sistance data

magnetic data



1.82 76.98 92.15
Ohms



-9.15 -0.75 7.65 16.05
nT

BODEN VEAN, CORNWALL.

GPR Amplitude Time Slices

Figure 6

0 - 2ns (0.0 - 0.11m)

2 - 4ns (0.11 - 0.22m)

4 - 6ns (0.22 - 0.33m)

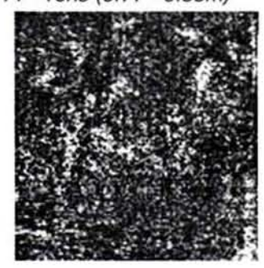
6 - 8ns (0.33 - 0.44m)

8 - 10ns (0.44 - 0.55m)

10 - 12ns (0.55 - 0.66m)

12 - 14ns (0.66 - 0.77m)

14 - 16ns (0.77 - 0.88m)



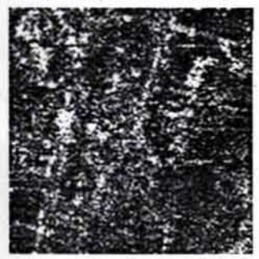
16 - 18ns (0.88 - 0.99m)

18 - 20ns (0.99 - 1.10m)

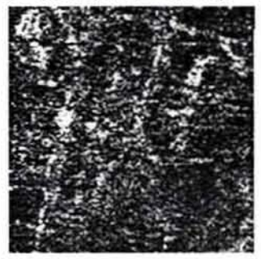
20 -22ns (1.10 - 1.21m)

22 - 24ns (1.21 - 1.32m)

24 - 26ns (1.32 - 1.43m)

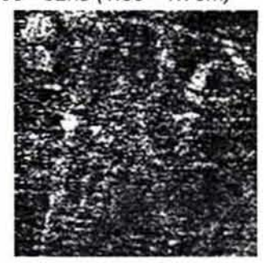


26 - 28ns (1.43 - 1.54m)



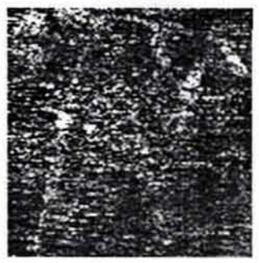
28 - 30ns (1.54 - 1.65m)

30 - 32ns (1.65 - 1.76m)

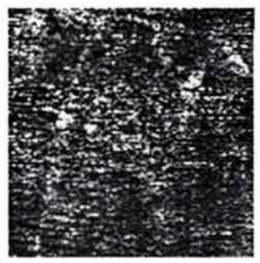


32 - 34ns (1.76 - 1.87m)

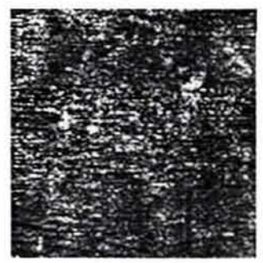
34 - 36ns (1.87 - 1.98m)



36 - 38ns (1.98 - 2.09m)



38 - 40ns (2.09 - 2.20m)



40 - 42ns (2.2 - 2.31m)

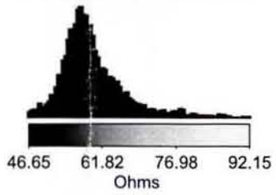
42 - 44ns (2.31 - 2.42m)

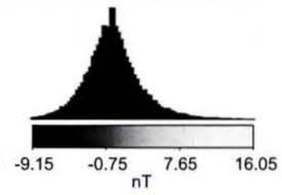
earth resistance data

magnetic data

low *high*

relative reflector amplitude





0 ——— 90m

1:1500

English Heritage Centre for Archaeology 2003

Figure 7

BODEN VEAN, CORNWALL
Summary of significant geophysical anomalies