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Geochemical survey and metalworking: analysis of chemical residues derived from experimental non-ferrous metallurgical processes in a reconstructed roundhouse

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Abstract: Geochemical survey is becoming a more frequently applied tool for site specific archaeological investigation. It has the potential to integrate site prospection and excavation data with post excavation artefact analysis, unifying two stages of the archaeological process. In the field of archaeometallurgy this is particularly relevant as sites of metalworking are liable to produce high geochemical loadings, related to the manufacture of metal goods and associated waste products such as slags. This paper describes the geochemical survey of an 'experiential' metalworking area within a reconstructed roundhouse, identifying geochemical enhancements associated with bronze and lead working. The geochemical survey of the roundhouse clearly defines areas of metalworking that can be related to recollected episodes of metalworking and quantifies the spatial distribution and absolute geochemical loadings from this activity. Consideration is given to how such geochemical enhancements should be archaeologically interpreted and whether geochemistry should be viewed as a micro-artefact and dealt with in a context specific way. It is suggested that geochemical survey can play an important role in defining evidence of metallurgy in archaeological investigations, particularly where such evidence remains elusive, e.g. the British Bronze Age.

Keywords: metallurgy, geochemistry, metal pollution, spatial survey, GIS

1.0 Introduction

Geochemical survey is becoming a more widely practised technique within archaeological research (Oonk *et al.* 2009a; Wilson 2009), which has the potential to identify evidence of anthropogenic activity that is otherwise invisible to conventional archaeological methods, i.e. the hidden site, context or landscape (Heron 2001). Despite this potential, geochemical survey has yet to establish itself as a technique that can consistently offer results demonstrably linked to human activities within the archaeological record (Oonk *et al.* 2009b**)**, partly due to the difficulty in interpreting multifaceted geochemical data; "because of the complexity of site use history and the effects of post depositional processes" (Wilson *et al.* 2008**)**. Archaeological geochemical survey has been applied on a variety of scales, ranging from landscape scale (Bintliff *et al.* 1992); to micro-landscape or wider site scale (James 1999; Entwistle *et al.* 2000; Linderholm and Lundberg 1994). It has been applied to identify activity areas within houses (Middleton and Price 1996) and intra-site organisation of space (Misarti *et al.* 2011; Vittori Antisari *et al.* 2013); intra site analysis of metalworking residues (Cook 2005; Carey and Juleff 2013), intra-feature analysis (Cook 2010) and intra feature analysis combined with soil micromorphology (Macphail and Crowther 2008).

Although multiple papers exist of geochemical surveys in archaeological research, there are different claims about what geochemical survey can achieve, which has led to ambiguity in the archaeological perception of its application. For example, geochemical survey has been used to attempt to identify low status sites not identifiable through other conventional forms of archaeological prospection (Aston 1998); as a general site prospection tool (Schleizinger and Howes 2000); identify agricultural and habitation residues (Entwistle *et al.* 1998) and identify functional areas of archaeological sites (Wilson *et al.* 2008; Parnell *et al.* 2002; Hjulström and Isaksson 2009). Whether geochemical survey is an effective tool for recognising low status archaeological sites or for identifying agricultural/habitation residues remains an open question.

However, a reoccurring theme within archaeological and environmental geochemical work has been the identification of metalworking residues through geochemical survey, such as the identification of metal contamination from historic lead smelting, e.g. Wild and Eastwood (1992) or identifying prehistoric copper contamination (Jenkins 2001) and copper and lead mining (Mighall *et al.* 2009) and historic iron mining (Bindler *et al.* 2011). Indeed, many of the papers investigating archaeological geochemistry relate to the identification of metalworking residues from antiquity, in both catchment wide (temporal) studies (Thorndycroft *et al.* 1999; Grattan *et al.* 2013) and localised site specific spatial scales (e.g. Cook *et al.* 2005**;** Carey and Juleff 2013).

This correlation of geochemical analysis and metallurgy can be interpreted as a function of the direct relationship between human activity and geochemical deposition, i.e. if a copper alloy is being worked, geochemical deposition will be in specific trace elements such as Cu, and elements associated with Cu in the ore or alloy, e.g. Sn, Zn, etc, at the foci of activities. Therefore, the nexus of cause (metalworking in the archaeological record) and effect (geochemical elevations in archaeological contexts) are easier to define. Arguably, for reasons of distribution patterns related to specific foci, e.g. hearths, and the degree of concentration of elements liable to be deposited in the archaeological record around the foci of activity (Banerjea 2008), it is likely that metalworking in antiquity will produce one of the most definable of all anthropogenic geochemical signatures. Such is the degree of contamination from metalworking that some geochemical signatures have been located at considerable distance from the foci of activity (Hong *et al.* 1994; Hong *et al.* 1996; Mighall *et al.* 2009; Meharg *et al.* 2012).

It is therefore surprising that geochemical survey has not seen greater development within the general sub-discipline of archaeometallurgy. The study of archaeometallurgy has developed from a strong empirical tradition for the analysis and cataloguing of metal artefacts (Ottaway and Roberts, 2008, 193-194) and increasingly utilises a barrage of scientific techniques that push the understanding of artefacts and materials connected to metal production. Examples include understanding metalworking infrastructure e.g. Computational Fluid Dynamics of wind powered iron furnaces (Tabor *et al.* 2005); the provenancing of ore deposits through isotope ratios of ores, slags and artefacts (Weeks *et al.* 2009); and the microscopic examination of hammerscales, slags, and blooms, to understand production and processing factors (Jouttijärvi 2013).

While this post-excavation phase of archaeometallurgical research has led to dramatic new insights, techniques for investigating the depositional environments of metalworking activities have seen relatively little development. This has created a disparity between the scientific, often micro-scale analysis of archaeometallurgical artefacts (e.g. furnace fabric, slags or metal) and the macro-scale prospection and excavation of metallurgical remains. It can be argued that geochemical survey has the potential to integrate the site excavation phase and the post excavation analysis of metalworking remains, although this relationship is currently untested. However, the potential exists to unite artefacts with production contexts via context geochemistry, and relate the use of space on archaeological sites to production processes through geochemical deposition. This paper looks to explore this relationship between spatial intra-site geochemical survey and metalworking, though focusing on the smaller intra-site scale of geochemical survey. A case study is given of experiential metalworking within a reconstructed roundhouse, which demonstrates how geochemical survey can be utilised to understand metalworking residues and the use of space in the archaeological record.

2.0 Geochemical survey, sample intervals and context specificity

In comparison to other forms of archaeological geoprospection, e.g. gradiometer survey (English Heritage 2008) there are no commonly accepted standards such as sample intervals for geochemical survey. However, with decreasing geochemical survey size comes a general decrease in sampling interval. With smaller sample intervals it becomes possible to relate geochemical samples to individual archaeological features/contexts, not wider landscapes. When samples are collected from non-excavated contexts, it is possible that multiple mixed archaeological contexts are being sampled together, either through homogenisation of soil and sediment systems (erosion/deposition/ploughing, etc) or through sampling with an auger or trowel across an intersection of contexts. Consequently, geochemical signals from different human activities can be merged. It has been argued that geochemical survey is best used within excavation, where samples are collected from specific contexts and geochemical survey can be related to human activities (Davis *et al.* 2012).

Some of the most successful interpretations of geochemical data have evolved through the ability to link geochemical signals to individual contexts, human activities and site taphonomy (Wilson 2009). With variation between archaeological sites/buildings/contexts identifiable through geochemistry (e.g. Oonk *et al.* 2009b), provenance and contextual specificity of a geochemical sample becomes a critical factor. Indeed as Davis *et al.* (2012) describe, it is a fundamental of archaeological excavation to understand the exact contextual relationship between excavated material and stratigraphy; geochemical survey is not an exception.

3.0 The experimental geochemical survey

3.1 Justification of methods

Trewortha Farm, Bodmin Moor, Cornwall, has several recently built ‘experimental roundhouses’ (Figure 1). Within one of these roundhouses a metal smith (Neil Burridge) used to cast (2002 – 2008) pewter and copper alloy implements, using technologies that are analogous to European prehistoric techniques. During this time he undertook multiple casting processes, providing an experimental location of known metalworking activities, which could be related to the use of space through interviewing Neil about his practices. A geochemical survey was undertaken of this ‘metalworking’ roundhouse to address the following questions:

- Could this recent metalworking be inferred through geochemical loadings within the floor samples?
- Could individual activity areas be defined within the roundhouse from the geochemical data?
- Could any geochemical patterning be used as a transfer model to aid in the identification of metalworking residues in the archaeological record?
- What are the limitations of this survey and its usefulness for investigating metalworking?

3.2 Geochemical survey methods

The Trewortha ‘experimental’ roundhouse is built on a brown earth soil, overlying granite, with a previous land use of unimproved pastureland. Within the experimental roundhouse the vegetation had been removed (died away after construction) leaving a dry brown-earth sediment (remnant A horizon after die-back of vegetation), which archaeologically is interpretable as the floor contexts of the roundhouse. For the ‘experiential’ metalworking Neil worked directly on this floor surface, using a portable furnace, c. 0.4m wide and 0.3m deep, made from a non-reactive modern ceramic. Two iron tuyeres were used to supply air to the base of the furnace, driven from hand bellows, and the metals to be cast were placed within a ceramic crucible in the centre of the furnace and surrounded with charcoal. When liquid the metals were poured into moulds, set onto the floor of the roundhouse. After casting the furnace was simply packed down and removed.

The survey used a regular 1m sample interval to collect small soil samples of c. 3g from the exposed floor and entrance of the roundhouse. A total sample population of 246 sediment samples were taken for analysis, with sample collection utilising a plastic spatula that was cleaned with distilled water between samples. At the time of sampling a multi-context archaeological plan was made of the roundhouse, with all sample locations recorded. The metal smith (Neil Burridge) was interviewed about his practices, his areas of casting and working, and his use of space. This remembered oral history was recorded onto the plan, with details such as the frequency, type and intensity of activities and this ‘remembered record’ identified 6 main foci within the roundhouse, with pewter casting and bronze casting as the main activities (Figure 2). Each casting used modern grade metals, which have very low impurity values, allowing cross referencing between geochemical samples and metalworking deposition. However, this also means that there would be no deposition of other elements associated with the metals, i.e. impurities from the ore sources, which will affect the multi-element spatial correlations which can be inferred for metalworking in prehistory (based on impurity compositions in metals and/or slags, e.g. Bray and Pollard 2012).

Within the laboratory each sample was freeze dried to remove moisture and homogenised using a pestle and mortar with any stone fraction over 2mm discarded. Approximately 1.5g sub sample was precisely weighed into a test tube and mixed with 6ml of HCl and 2ml of HNO_3, covered and left at room temperature for 15 minutes. The samples were transferred to a water-bath and left to react for 2 hours at 60^oC, with deionised water added as required to stop sample desiccation. Samples were removed and allowed to cool for 30 minutes before making up to a standard 50ml solution with deionised water. Subsequent dilution of samples took place at a ratio of 1:100 with deionised water before measurement of Cu, Pb, Mn, Co, Ni, Zn, As, Sn, and Pb using an Agilent 7700x quadropole ICP-MS and the multi-element standards of Agilent Multi-element calibration standard and Esslab ICP-MS Refractory Elements Standard. Measurement quality was ensured through reference to a certified reference sample (NCSDC73323GBWO7405) processed every fifty samples and an acid blank sample, using the acids for the extractions diluted with ultra-pure de-ionised water, processed every ten samples. The acid blanks did not have detectable levels of any metals in any sample and the reference material samples showed a high level of analytical precision between the published values (NACIS 2003) and the obtained measurement values.

The raw data values were converted from ppb in solution into mg/Kg in the sample and imported into a GIS system and surfaced for each element using a Kriging interpolation. The plan of the survey area, coupled with the oral history of the activity of the metalworking within the roundhouse, were digitised within the GIS, allowing comparison between the element concentrations and the foci of metalworking activity. The data was analysed using PCA (principal components analysis) with a correlation matrix, but no rotation, and components selected with eigenvalues over 1. From this analysis the PCA factor scores were imported into the GIS for components with an eigenvalue over 1 and surfaced, allowing the degree of association between sample (variable) and component (metalworking process) to be visualised.

The survey strategy utilised a continuous grid of sediment samples both within and outside the roundhouse. This sort of sampling method allows relative control of the survey data to be established, whereby lower values in the survey provide a relative control to the higher values. As the previously cited examples indicate (e.g. Hong *et al.* 1994; Hong *et al.* 1996) it is unlikely that any sediments deposited within the Holocene do not have some form of anthropogenic contamination within them. Consequently, within this study, the idea of relative controls relies on interpretation of the survey data to identify spatial anomalies caused by anthropogenic activities. The absolute values are one facet of the data for interpretation, which aid in the identification of anthropogenic geochemical anomalies. In each of the geochemical plots, the lowest sample concentrations give an indication of the relative scale. It is possible that all of the geochemistry within the roundhouse originates from some form of human activity, but critically in this example it is the relationship of specific geochemical anomalies to specific anthropogenic metalworking processes that is being investigated.

4.0 The experimental results

The data from the element distributions were displayed as coloured surfaces, with presentation of only the most significant of the elements in relation to metalworking discussed. The Cu distribution highlighted two key foci of activity (Figure 3). The first of these, Cu(1), had a copper elevation halo extremely close to a recorded bronze casting area, indicating a working area. Anomaly Cu(2) is located to the exterior of the building and closely correlates with an area of deposition of floor sweepings and some recorded cold working.

The copper concentrations were clipped within the GIS, with the Cu concentrations over 10,000mg/Kg removed from one level of analysis, which in effect removed two samples from the analysis (samples G155 and G344). Such high Cu concentrations over 10,000mg/Kg were localised and it was interpreted that such extreme values were caused by a small number of metal droplets (i.e. the droplets are distinct particles within the sample) and as such disguised subtler trends in the geochemical distribution. This removal of extreme outliers is analogous to clipping data in geophysical survey, promoting a better understanding of the mid-range data. This clipped Cu distribution identified 6 deposition halos (Figure 4). Cu(3) correlates with a bronze casting area and Cu(5) closely correlates with a second area of bronze casting. It is interesting to note that the recorded location of metalworking is adjacent to the anomaly centre, potentially an indication of where the working was ‘remembered’ in comparison to where it actually occurred. Cu(4) (clipped data) broadly correlates with anomaly Cu(1) (unclipped data), although one of the samples that created anomaly Cu(1) has been subsequently removed from the data set by clipping, yet both anomalies identify an area of bronze casting, indicating a more general halo of deposition around the metalworking activity.

Anomalies Cu(6) and Cu(7) are more difficult to interpret. Anomaly (Cu6) is located close to the area of bronze casting (x15), although the correlation is imprecise. It could represent a deposition halo from the working area. Cu(7) is a large anomaly partly located outside of the roundhouse and over a cobbled surface at the entrance. The reason for this anomaly is undefined, although a speculative interpretation could be of trample from movement of people depositing metal contaminated soil particles from the interior of the roundhouse to the entrance way, or another possible area of metalworking imprecisely recollected.

The surface produced from the Sn values (Figure 5) creates a similar image to the Cu distributions in Figure 2. Anomaly Sn(1) correlates with Cu(1), close to a bronze casting area, interpreted as a working area. Sn(2) correlates with Cu(2), an area of floor sweepings and cold working. Due to the exact correlation between these anomaly groups it is suggested that both anomaly spikes were caused by individual metal droplets within specific samples, so the Sn distributions were clipped, with Sn values over 10,000mg/Kg removed (Figure 6).

Sn(3) correlates with Sn(1), next to a bronze casting area, as does Sn(5) with Cu(5), again interpreted as a metalworking area for bronze casting. The anomaly Sn(4) correlates closely with an area of pewter casting on the cobbled entrance, again just off centre from the recorded area of working; although an area of Cu elevation was also recoded in this vicinity. Sn(7) is the halo around Sn(4) demonstrating elevated values at the entranceway to the roundhouse, potentially interpretable as trample from the interior of the roundhouse or another possible area of metalworking imprecisely recollected. Anomaly Sn(6) closely correlates with anomaly Cu(6) potentially indicating an unrecorded episode of metalworking. Significantly, whilst the unclipped and clipped distributions for Cu and Sn correlate strongly (Figures 3 and 5 and Figures 4 and 6), the clipped values for Cu and Sn also show some degree of variability. Significantly, anomaly Cu(3) is located within a recorded bronze working area and has no comparable Sn anomaly. Is this a product of 'misremembered' metalworking or does it reflect that some episodes of bronze metalworking are not definable through Sn deposition halos?

The Pb concentrations create four definable anomalies (Figure 7). Pb(1) partially correlates with Sn(5) and Cu(5), but it is located in an area of recorded bronze casting. It is possible that pewter casting also took place at this location and this was forgotten in the social documentation, but it is also possible that this elevation has another, unknown, explanation. Anomaly Pb(2) correlates precisely with Cu(2) and Sn(2), both located out of the roundhouse. The interpretation of this anomaly as residues included within floor sweepings is strengthened by all three elements have elevated values at this location, with distinct phases of pewter and bronze casting occurring within the roundhouse. Anomaly Pb(3) correlates closely with anomalies Cu(6) and Sn(6), an area with no 'remembered' evidence of metalworking. Again this either indicates an area of possible metalworking or of another undefined activity. Pb(4) shows a moderate concentration rise, but has no equivalent anomaly recorded for either Sn or Cu.

The PCA analysis of the data set provides considerable clarity to these univariable element distributions. PCI accounts for 50.5% of the variance within the dataset, its location heavily influenced by Co, Mn, Ni, Zn and As, elements that have no definable relationship to the metalworking areas. At the current level of analysis it is unclear what processes, whether natural or anthropogenic, caused the deposition of these elements. However, in respect of the processes documented within the workshop, these elements bear no definable relationship to metalworking, partly a result of the purity of the modern metals used in the casting experiments.

In comparison, PCII accounts for 29% of the variance in the data set and is strongly influenced by both Sn and Cu, both having 97% of their variance explained by PCII. The position of Pb is curious, as it shows a moderate relationship to PCI (0.49) and a stronger relationship to PCII (0.74) (Figure 8). The plotting of the original variables back onto the PCI and PCII axes provides a good visual definition of these relationships. PCII can be considered a metalworking axis and shows a strong relationship to Cu and Sn as one grouping, with PCI indicating a non-metalworking signature of Co, Mn, Ni, Zn and As. It must be re-emphasised that casting within the roundhouse used pure modern metals and consequently explains the high correlation between Sn and Cu, but no other elements in the bronze casting areas.

The PCII factor scores were surfaced to indicate the relative association of each sample to PCII, i.e. the influence of each sample on the positioning of the component. The interpretation of this data highlights the relationship of the working area identified as PCII(a) to the metalworking component PCII and also the residues in the floor sweepings, anomaly PCII(b) (Figure 9). The samples from these two areas are liable to have small metal globules contained within them, hence providing a strong correlation and exerting a strong influence on the positioning of PCII. A general elevation of PCII factor scores is visible in the roundhouse (PCII(c)) and potentially relates to the use of space within the roundhouse, with these areas of the roundhouse accessible for use/activities/movement, creating low level transportation of metal enhancement from the metalworking foci. However, it should be noted that although there is a high degree of incidence between the ‘remembered’ areas of metalworking and geochemical enhancements defined by PCII, the relationship is not exact; again potentially a product of imperfect recollection of events, although further research is required to substantiate such an interpretation.

5.0 Discussion of the experimental results

The data set has produced significant results related to metalworking geochemical signatures within an experimental roundhouse. Firstly, although distinct phases of pewter casting and bronze casting were orally recorded, evidence of bronze casting is much clearer in the geochemical data. By virtue of the relationship to Pb, both PCI (non-metalworking group) and PCII (metalworking group), it can be interpreted that Pb is deposited through multiple activities, one of which was pewter casting. PCII clearly defined direct and indirect evidence of metalworking with PCII(a) identifying residues directly from bronze casting, whilst anomaly PCII(b) defined indirect evidence of metalworking, probably derived from the floor sweepings. In this case the detected metalworking residues, PCII(b), originated from metalworking but were re-deposited in ‘antiquity’. In such a case relating geochemical values to archaeological contexts is essential; in this instance the sediments from this part of the site were from a different depositional environment to the samples from the interior of the roundhouse.

In addition to the interpretation of anomalies from the element and PCA spatial distributions, the absolute concentrations of the elements are significant. Both Cu and Sn have values peaking at over 10,000mg/Kg, which define a series of foci within the roundhouse that can be related to metalworking. Significantly, these analyses also indicate that depositional values from metalworking are liable to have been exceptionally high at the time of deposition in antiquity. This identifies considerable potential is utilising such techniques to define metalworking activities in the archaeological record.

However, defining the limitations of this study is also important. In this case, the geochemical residues were deposited within the roundhouse before the experiment geochemical survey design was constructed, with the planning and recording of activity reliant on an individual memory of events; memories which were not constructed from the point of view of data collation for the experiment design. Consequently, limitations in the reliability of this memory associated archive are inherent. Secondly, a range of metalworking activities had occurred within the roundhouse over a number of years and consequently there was a blurring of geochemical signals and human memories. This blurring was largely resolved by the PCA analysis, but it demonstrates the problems of sampling an experimental location with multiple processes and it can be expected that real archaeological surveys will display similar or greater levels of geochemical complexity.

Whilst the data presented raises questions about how to apply geochemical surveys to sites of metallurgy, the transferable functionality of this study to archaeometallurgical residues needs exploration. The element concentrations of Cu and Sn deposited by metalworking in this study were large, and as such allowed definition of metalworking within a recent survey area. However, if a transfer analogy can be applied between this survey and metalworking undertaken in antiquity, what concentrations can be expected from metalworking residues thousands of years old? Residual absolute concentrations will vary through many factors, such as intensity, frequency, repetition, skill level and raw inputs into the metalworking activity, and each of these factors will vary the level of absolute chemistry deposited and detectable. A situation can be hypothesised where a ‘clumsy smith’ would deposit similar concentrations in one casting to a skilled smith over several hundred castings, and so forth.

These variables need to be combined with taphonomic site formation factors, for the survival of geochemical residues. Such taphonomic factors include soil/sediment pH; archaeological context clay/organic/carbon content; cation-exchange capacity (CEC) of the soil/sediments, and later site disturbance such as ploughing. Primarily, metalworking residues will survive for longer in sediment matrices with a neutral or near neutral pH, which have a lower CEC, with cations being preferentially bound to clay and organic colloids (White 2006, 141). If site taphonomy effectively seals the deposit/s containing the metalworking residues, e.g. alluvial deposition, building collapse, etc, then loss of metallic cations over time is liable to be reduced, through removal of the archaeological deposit from the soil geochemical budget. Other factors affecting survival are levels of dissolved oxygen and fluctuations in the water table. As with other types of archaeological preservation, low levels of dissolved oxygen, consistent water tables and neutral pH are all conducive to better preservation, but anoxic conditions can lead to remobilisation of metal complexes (Cundy *et al.* 2008), with Maskall *et al.* (1995, 17) reporting that pH was the most significant factor for controlling vertical migration of metallic cations on sites of historic contamination.

Later disturbance, such as ploughing, will affect individual contexts causing blurring/homogenisation of the geochemical signature. It is possible that this will remove/reduce the effectiveness of the technique to identify activity zones, although this is currently unsubstantiated. The combination of these depositional and post-deposition factors renders prediction of concentration threshold levels and absolute geochemical signatures that can be taken as indicative of metallurgy as meaningless. Instead, consideration should be given to elevation, distribution, correlation between elements and spatial morphology of geochemical anomalies. Within such a framework, small elevations can potentially indicate significant results, but the spatial organisation of data is the most important factor, analogous to modern archaeological geophysical survey.

Further consideration needs to be given to the sampling procedure. If small sample intervals are to be used such as 1m or 0.5m, sampling individual contexts within excavation areas, then high sample numbers will result. This sampling procedure is made more complex by sampling structures/sites with multiple floors/contexts. It is suggested that sampling should be undertaken in a context specific way, always during excavation conditions. In cases of multiple floors and multiple contexts, it is considered necessary to sample each, even if this means repeated sampling within the same survey area. Therefore, sampling needs to be targeted and hypothesis driven to eliminate massive sample numbers across large excavation areas. Indeed, a firm stratigraphic understanding of the contexts is essential to identify contexts/features/structures of interest, suitable for geochemical analysis. The approach outlined here does raise issues for the use of geoprospection in wider landscape prospection surveys, where the context specificity and site/sediment taphonomic processes cannot be understood, creating ambiguity in interpreting geochemical residues.

6.0 Conclusion

This study has demonstrated two important issues regarding metalworking residues in the archaeological record. Firstly, at the time of deposition geochemical residues from metalworking can be extremely high and detectable through analysis of sediment samples. Secondly, the pattern of geochemical deposition can allow definition of metalworking activity in the archaeological record. Whilst the rate of degradation of geochemical signatures over time is not known, and will be site specific, the examples cited demonstrate that such residues are detectable from Bronze Age and Romano-British contexts. These combined factors indicate that geochemical survey can play a role in the identification of residues in the archaeological record, and this can be considered especially useful where evidence for the presence of metalworking is under-represented or elusive, e.g. the British Bronze Age. Simply put, could it be that this evidence of metalworking is not interpretable or visible on a macroscopic excavation level and instead requires the analysis of the microscopic artefact group of geochemical residues?

Geochemical survey has the potential to unite chemical analyses of ores and artefacts (archaeometallurgical analyses) with the identification and analysis of metal production sites (smelting/smithing/casting), at a prospection/excavation stage. It is acknowledged that further work needs to be undertaken to refine this technique and fully assess its potential to identify metalworking residues and relate these to post excavation analyses of ores and artefacts. However, the data presented from these results are unequivocal and highlight the potential of this technique to identify geochemical residues related to metallurgy. In particular, it is hoped that future application of this technique has the possibility of answering some important archaeological questions, e.g. evidence for a British Chalcolithic; evidence for small scale metalworking during the British Bronze Age, etc. More work is being undertaken on experimental sites to test the geochemical residues produced through smelting and casting of metals, allowing further testing of the technique’s viability.

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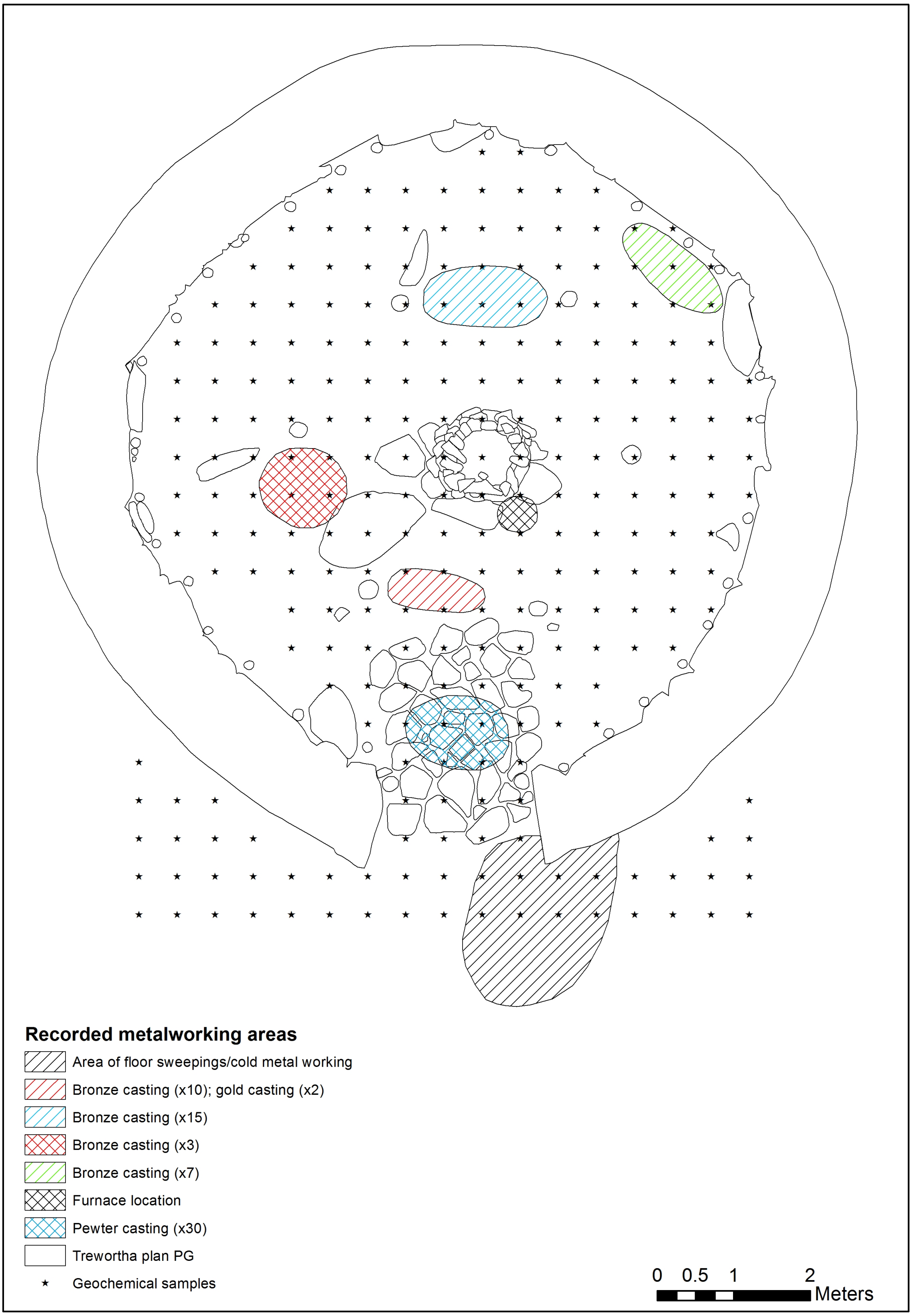
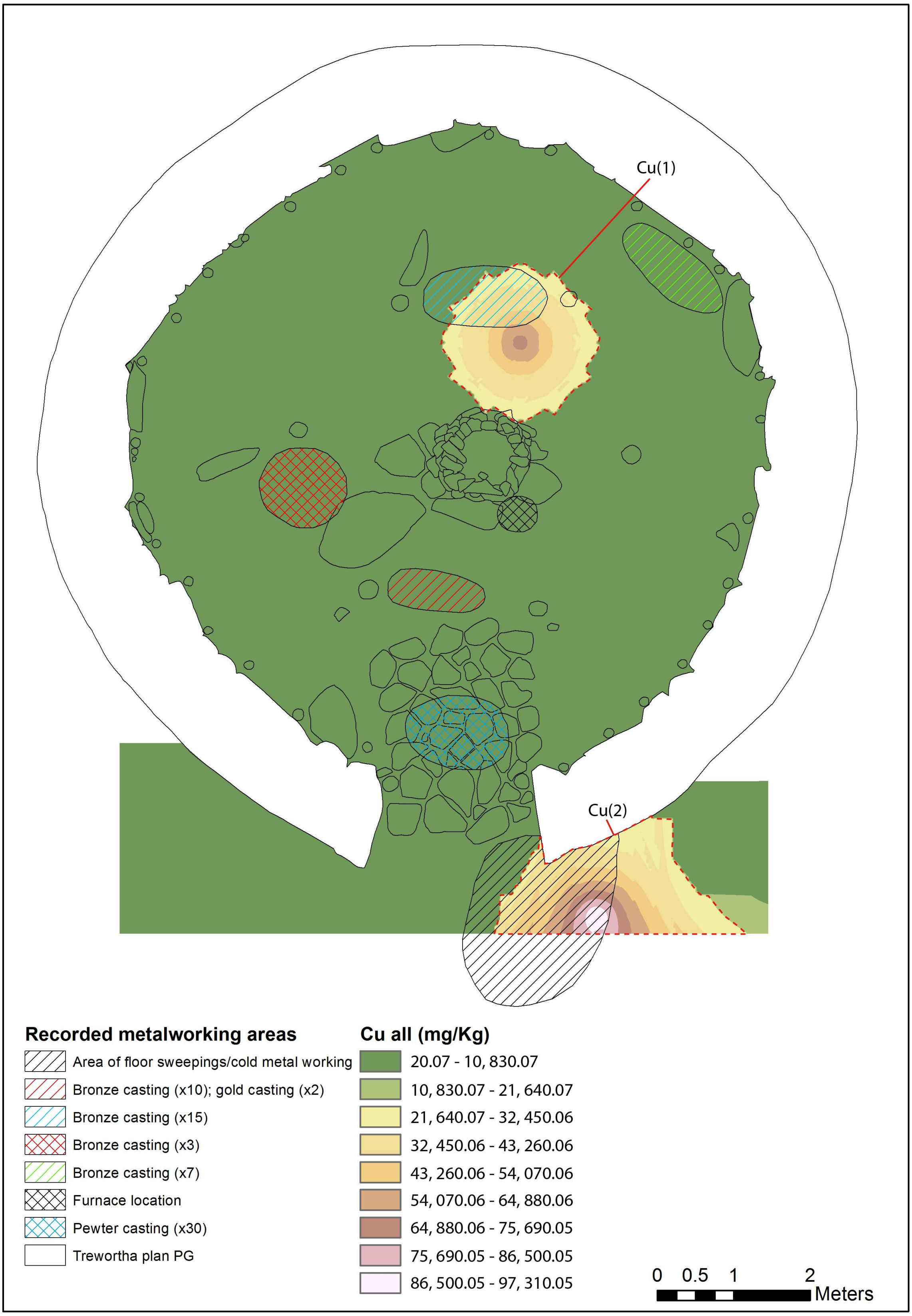
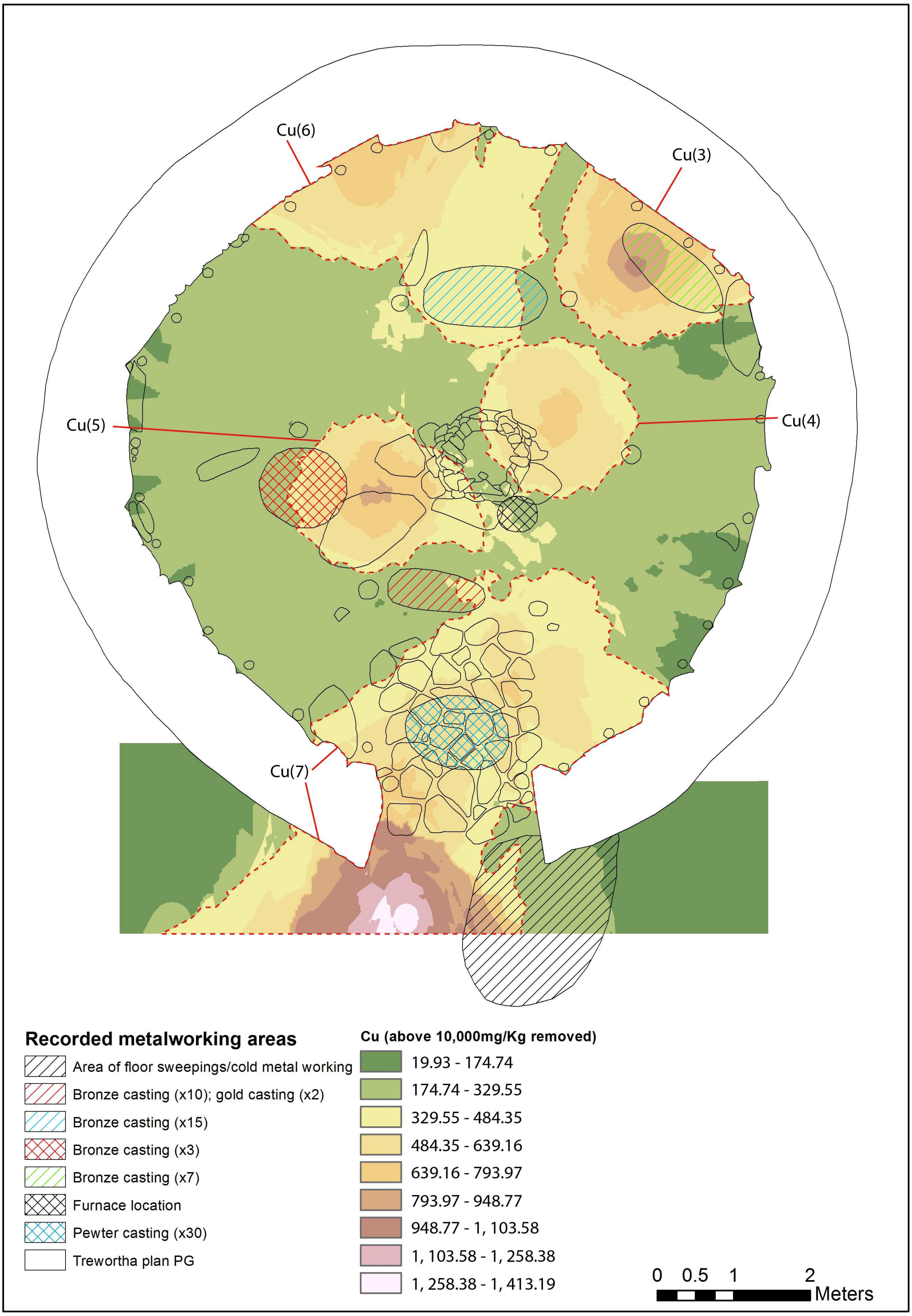
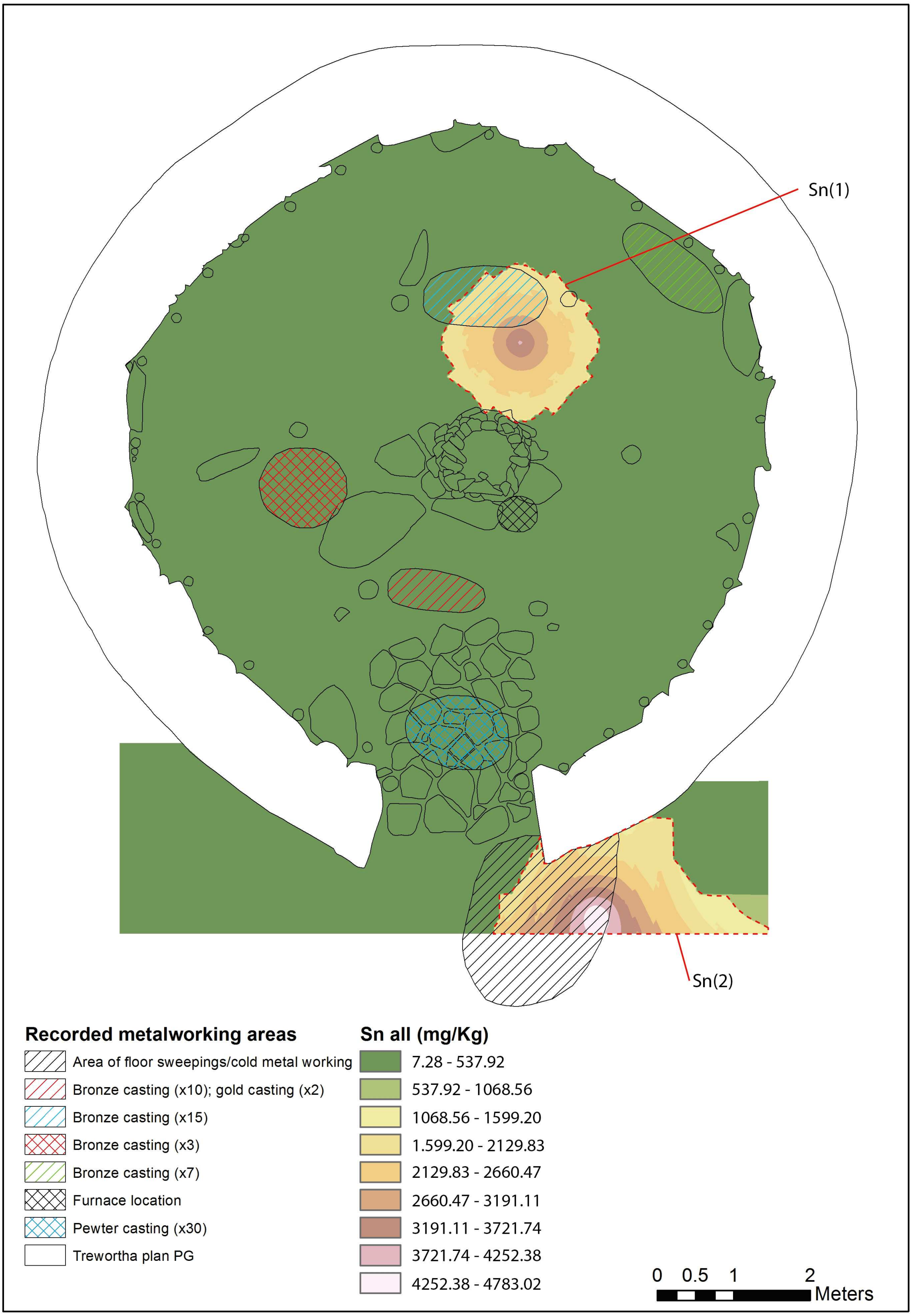
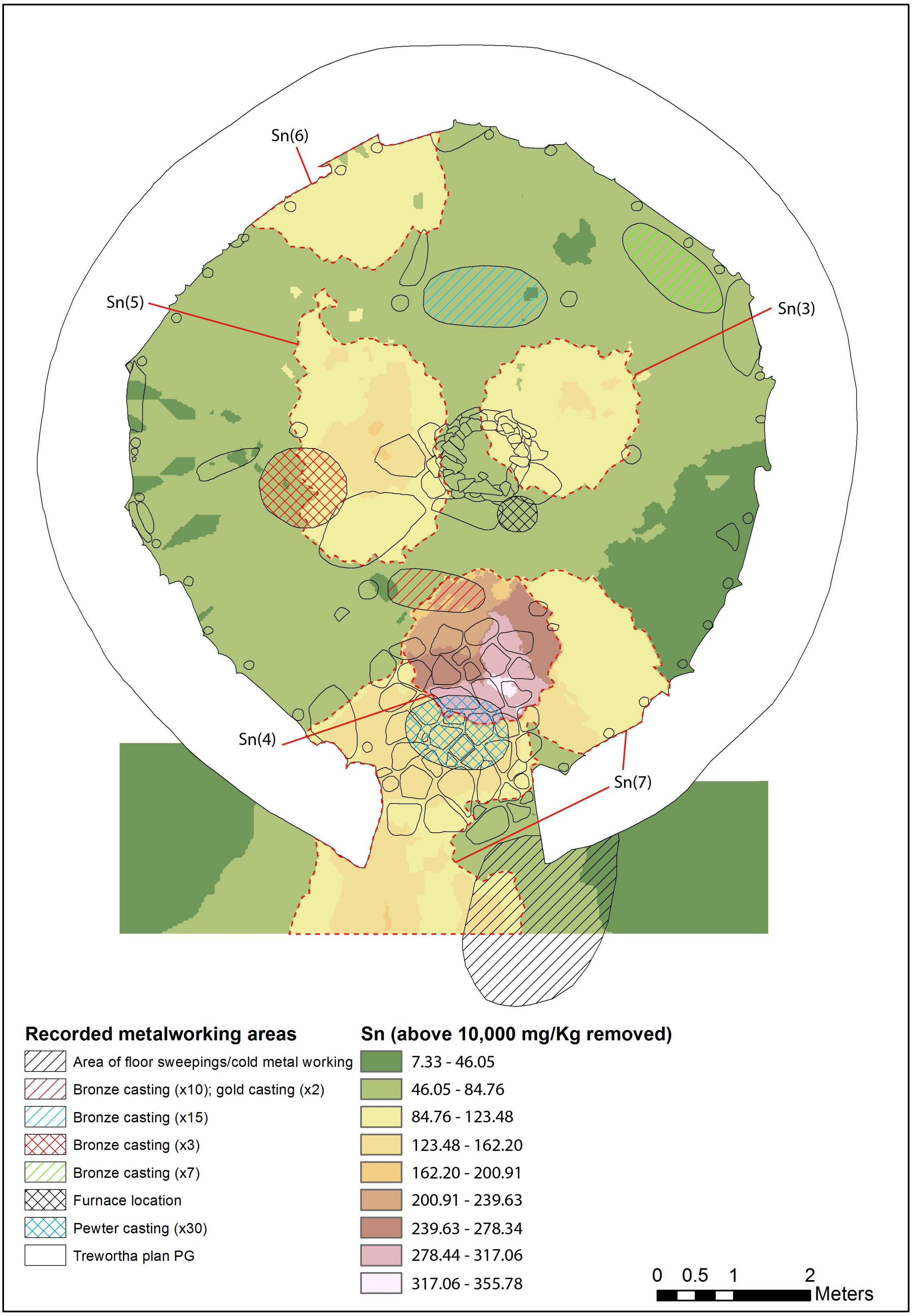
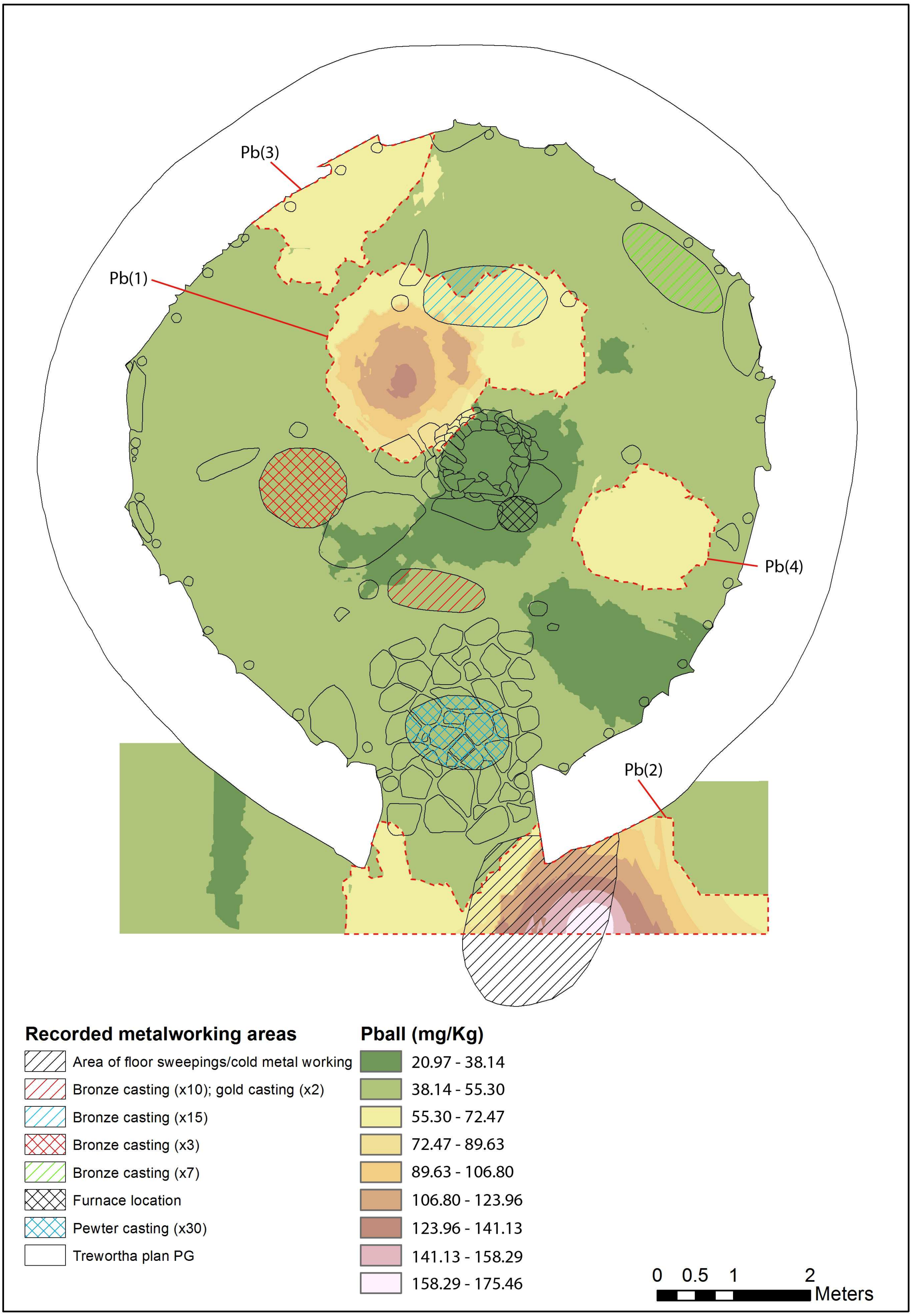

Recorded metalworking areas
Area of floor sweepings/cold metal working
Bronze casting (x10); gold casting (x2)
Bronze casting (x15)
Bronze casting (x3)
Bronze casting (x7)
Furnace location
Pewter casting (x30)
Trewortha plan PG
Geochemical samples
0
0.5
1
2
Meters


Cu(1)
Cu(2)
Recorded metalworking areas
Area of floor sweepings/cold metal working
Bronze casting (x10); gold casting (x2)
Bronze casting (x15)
Bronze casting (x3)
Bronze casting (x7)
Furnace location
Pewter casting (x30)
Trewortha plan PG
Cu all (mg/Kg)
20.07 - 10, 830.07
10, 830.07 - 21, 640.07
21, 640.07 - 32, 450.06
32, 450.06 - 43, 260.06
43, 260.06 - 54, 070.06
54, 070.06 - 64, 880.06
64, 880.06 - 75, 690.05
75, 690.05 - 86, 500.05
86, 500.05 - 97, 310.05
0 0.5 1 2
Meters


Cu(6)
Cu(3)
Cu(5)
Cu(4)
Cu(7)
Recorded metalworking areas
Area of floor sweepings/cold metal working
Bronze casting (x10); gold casting (x2)
Bronze casting (x15)
Bronze casting (x3)
Bronze casting (x7)
Furnace location
Pewter casting (x30)
Trewortha plan PG
Cu (above 10,000mg/Kg removed)
19.93 - 174.74
174.74 - 329.55
329.55 - 484.35
484.35 - 639.16
639.16 - 793.97
793.97 - 948.77
948.77 - 1, 103.58
1, 103.58 - 1, 258.38
1, 258.38 - 1, 413.19
0 0.5 1 2
Meters


Sn(1)
Sn(2)
Recorded metalworking areas
Area of floor sweepings/cold metal working
Bronze casting (x10); gold casting (x2)
Bronze casting (x15)
Bronze casting (x3)
Bronze casting (x7)
Furnace location
Pewter casting (x30)
Trewortha plan PG
Sn all (mg/Kg)
7.28 - 537.92
537.92 - 1068.56
1068.56 - 1599.20
1.599.20 - 2129.83
2129.83 - 2660.47
2660.47 - 3191.11
3191.11 - 3721.74
3721.74 - 4252.38
4252.38 - 4783.02
0 0.5 1 2
Meters

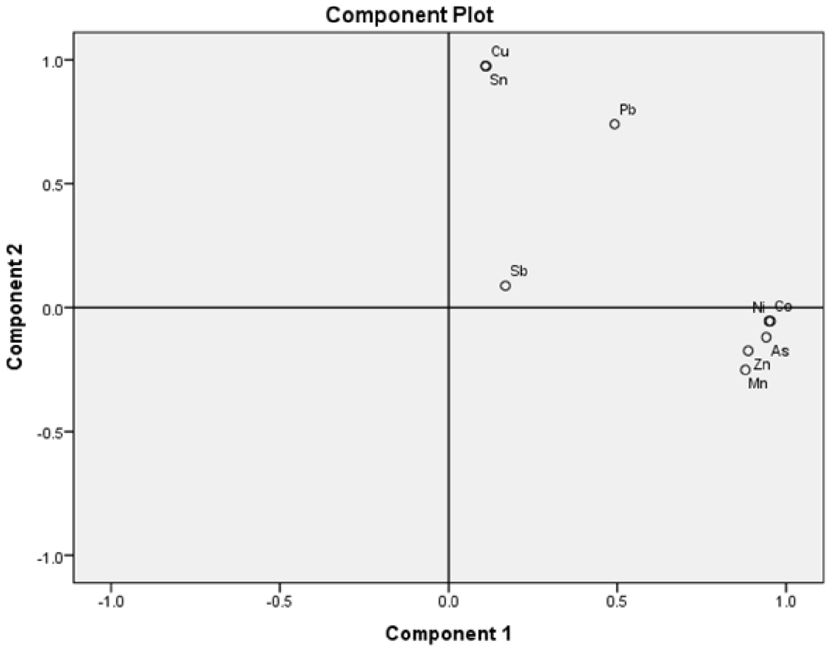

Sn(6)
Sn(5)
Sn(3)
Sn(4)
Sn(7)
Recorded metalworking areas
Area of floor sweepings/cold metal working
Bronze casting (x10); gold casting (x2)
Bronze casting (x15)
Bronze casting (x3)
Bronze casting (x7)
Furnace location
Pewter casting (x30)
Trewortha plan PG
Sn (above 10,000 mg/Kg removed)
7.33 - 46.05
46.05 - 84.76
84.76 - 123.48
123.48 - 162.20
162.20 - 200.91
200.91 - 239.63
239.63 - 278.34
278.44 - 317.06
317.06 - 355.78
0
0.5
1
2
Meters


Pb(3)
Pb(1)
Pb(4)
Pb(2)
Recorded metalworking areas
Area of floor sweepings/cold metal working
Bronze casting (x10); gold casting (x2)
Bronze casting (x15)
Bronze casting (x3)
Bronze casting (x7)
Furnace location
Pewter casting (x30)
Trewortha plan PG
Pball (mg/Kg)
20.97 - 38.14
38.14 - 55.30
55.30 - 72.47
72.47 - 89.63
89.63 - 106.80
106.80 - 123.96
123.96 - 141.13
141.13 - 158.29
158.29 - 175.46
0
0.5
1
2
Meters

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.553	50.584	50.584	4.553	50.584	50.584
2	2.570	28.560	79.143	2.570	28.560	79.143
3	.999	11.100	90.243			
4	.378	4.196	94.439			
5	.292	3.239	97.678			
6	.132	1.469	99.147			
7	.057	.629	99.776			
8	.019	.215	99.991			
9	.001	.009	100.000			

Extraction Method: Principal Component Analysis.

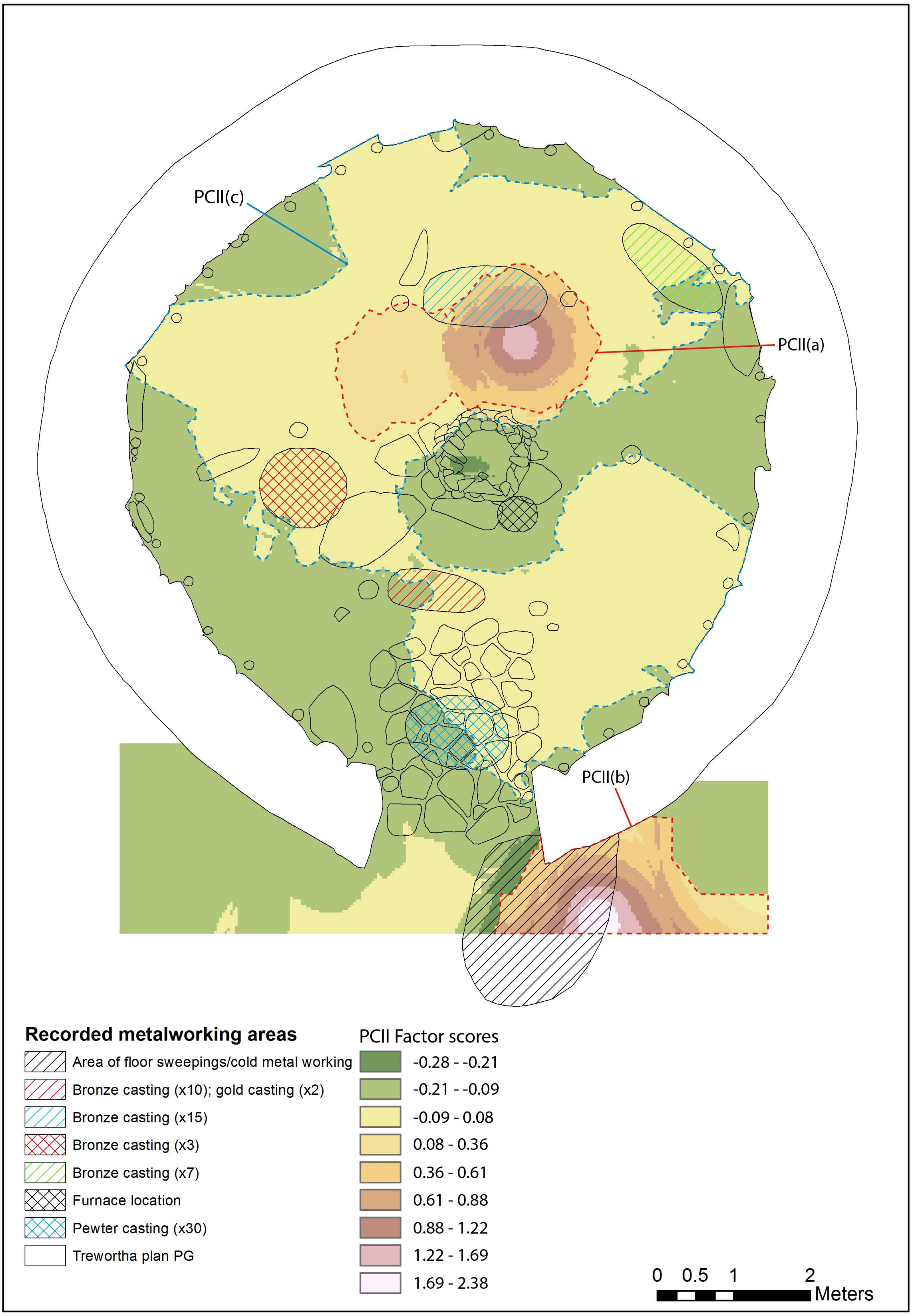


Component Matrix[a]

	Component	
	1	2
Mn mg/Kg	.879	-.251
Co mg/Kg	.949	-.055
Ni mg/Kg	.954	-.055
Cu mg/Kg	.108	.975
Zn mg/Kg	.888	-.175
As mg/Kg	.941	-.120
Sn mg/Kg	.112	.974
Sb mg/Kg	.168	.088
Pb mg/Kg	.492	.740

Extraction Method: Principal Component Analysis.

a. 2 components extracted.


PCII(c)
PCII(a)
PCII(b)
Recorded metalworking areas
Area of floor sweepings/cold metal working
Bronze casting (x10); gold casting (x2)
Bronze casting (x15)
Bronze casting (x3)
Bronze casting (x7)
Furnace location
Pewter casting (x30)
Trewortha plan PG
PCII Factor scores
-0.28 - -0.21
-0.21 - -0.09
-0.09 - 0.08
0.08 - 0.36
0.36 - 0.61
0.61 - 0.88
0.88 - 1.22
1.22 - 1.69
1.69 - 2.38
0 0.5 1 2
Meters

Highlights

- Geochemical survey of a roundhouse where ‘experiential’ metalworking occurred.
- Modelling of geochemical data within GIS to define specific areas of metalworking.
- Geochemical data related to recollected history of metalworking within the roundhouse.
- Discussion of the usefulness of geochemical data as a micro-artefact.
- Considers integrating prospection, excavation and post excavation data.