Illuminating the darkness: Using geochemical survey in archaeological reconnaissance and evaluation for major infrastructure developments.

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Introduction

While geophysical prospection is a long established and recognised method employed by archaeologists, geochemical prospection has not been utilised in a similar manner. The high cost and lengthy sample preparation and analysis times associated with traditional lab-based soil analysis has meant that it has not been readily deployed on sites and, when it has, it is often only for a limited number of samples (Figure 1).

Figure 1. A geochemical analysis being undertaken in the field using a portable XRF instument (© Fusion JV).

Developments in portable analytical equipment, particularly pXRF, now allow for the economical and rapid in-situ analysis of soil samples making higher resolution geochemical survey an additional technique in the archaeologist’s arsenal. The speed of, and reduced costs, per analysis mean that thousands of analyses can be conducted across a site or landscape allowing for the detailed spatial mapping of chemical variation. The rapidity with which data is returned means that the results of geochemical survey are now available almost instantaneously and can be conveniently used to inform evaluation and excavation strategies in real time. While in-situ soil analyses have been deployed in a number of research-based projects the technique has, up to now, made little impact in professional or development-led archaeology.

In this paper, the background to the approach and the method for prospection alongside the results from a case study are presented.

The approach

Geochemical survey relies on mapping the chemical variability across a site or landscape with areas of enhancement exhibiting as ‘structured anomalies’ against a background of lower levels, sometimes below levels of detection. Unlike geophysical prospection which tends to quantify a single property (i.e. magnetic flux or electrical resistance), geochemical prospection relies on the detection of up to 34 chemical elements, each of which is independent of geophysical properties. This means that geochemistry offers an independent method of prospection that simultaneously detects a number of independent elements with the potential to provide information relating to a wide-range of human activities. While geochemistry can offer a novel and independent means of prospection, it is best deployed in tandem with geophysics and/or other techniques such as fieldwalking, multi-spectral imaging or DSMs generated, more recently, from drone-based LiDAR (see Goodchild *et al*. this session).

Geochemical survey is a sensitive technique that can detect subtle variability in soil chemistry brought about by a range of human activities. Anthropogenic enhancement of soils arises when communities undertake a range of activities in a locale such as burning, craftwork, middening, habitation, burial, manuring, animal processing and craft activities. Trace elements may relate to anthropogenic processes and/or local geology/lithology (Wilson *et al*. 2009). Trace element indicators and the potential activities giving rise to them are set out in Table 1.

Table 1. Origins of key trace elements in geochemical analysis

Origin	**Elements**	**Comments**	**References**
Geology/Lithology	Na, Al, Ti, Sc, Zr, Nb, Cd, Cs, Hg	Na, K -soil mobility	Khan *et al.* 2013 Effect of slope position on physico-chemical properties of eroded soil. soil and Enviroment. 31. 22-28.
Anthropogenic	P, Mg, Ca, Cu, Zn, Ni, Mn, Sr, Pb, Sn, K, S, Ba	P, Ca -middens, burials, livestock, food processing[1]. P, Mg-Wood burning[2]. Cu, Pb, Zn (Main anthropogenic indicators) + Cr, Mg, Mn, Ni, P, Se, Sn, Sr and Zn[3] (Cu, Pb, Mn-at elevated levels >300ppm craft working i.e. metallurgy[4])	[1] Lutz, 1951; Parsons, 1962; Cook and Heitzer, 1965 [2] Heidenreich and Navratil, 1973 [3] Bethell and Carver, 1987; Ottaway and Matthews, 1988 [4] Pyatt *et al.* 1999; Pyatt *et al.* 2002, Davies *et al.* 1988; Wilson *et al.* 2009
Uncertain	V, Rb, Al, Cl, As	Local geological system dependency	Wilson *et al.* 2009

Studies undertaken by Dungworth (2014) and Aston *et al*. (1998) have addressed the relationship between elemental variation and depth on archaeological sites concluding that there are strong correlations between surface and sub-surface analyses. The high sensitivity of pXRF instrumentation and its ability to detect trace elements at very low levels (ppm) means that chemical signatures across a site can be established from non-invasive surface analyses. This fact allows for rapid and cost-effective surveys such as those that may be deployed on infrastructure projects where efficient and rapid results are required.

Since geochemical data is not coupled to corresponding geophysical data, geochemistry acts as a complementary and independent dataset to geophysics, cropmark data or Lidar data. While geochemical anomalies can enhance the interpretation of geophysical ones, geochemistry can also act as a test of “blank areas” as defined by geophysical, aerial and Lidar surveys. This can be particularly useful in mitigating risk to cost and programme and reassuring clients about the potential for encountering undetected archaeological remains during construction works.

Blank Area Testing

It is very unusual to use geochemical survey to undertake largescale archaeological evaluation using geochemistry and even more rare for such an approach to be deployed in a commercial archaeological context. The results to date that have been forthcoming from a number of projects have been compelling, showing a clear correspondence between certain key elements including phosphorous, zinc, copper and potassium and the areas of archaeology as identified by geophysics and cropmarks, and similarly low counts where such surveys identified little or no archaeology (Figure 2).

Figure 2 A geophysics interpretation plot(left) with archaeological anomalies highlighted in green with the results for phosphorous (P) overlain in purple showing the measurements for samples taken from the surface as well as from the top of the substrate.

The extensive geochemical survey approach was selected for a large infrastructure project because it offered a rapid, sensitive, non-invasive and cost-effective method. It was introduced and honed in an environment open to innovation and eager to address long-standing archaeological issues relating to testing blank areas and identifying ‘hard to find’ archaeology, specifically Stone Age and early medieval archaeological remains.

The elemental range produced by portable XRF analysis can provide data that indicates a range of practices including burning (Mg, K, P), burial and disposal of animal remains (Ca, P), craft-working, especially metalworking (Cu, Sn, As, Pb), and a broad range of domestic activities (P, Cu, Zn, Pb).

In this way the geochemical approach provided an appropriate method for rapidly and accurately assessing large land parcels in advance of a national infrastructure development that required a high level of information to inform the mitigation strategy. Another benefit of using this technique was that it minimised impact on the surviving buried archaeology which meant key relationships remained intact until the mitigation phase.

The technique has provided the ability to identify geochemical anomalies and to target these with test pit survey, fieldwalking and ultimately targeted strip, map and sample excavation supported by geoarchaeological trenching. The results of test pitting have shown good correlation between geochemcial anomalies and Early Prehistoric flint scatters (Upper Paleolithic and Mesolithic) which are otherwise very hard to prospect for using traditional remote sensing techniques.

The technique has also shown utility in helping to delimit the extent of buried archaeological remains at known sites (i.e LIA/Roman Ladbroke) and revealed evidence for spatial signatures that indicate zoning and the differential use of space across a site.

Conclusions

Given the speed, accuracy, spatial precision and cost-effectiveness of applying this technique in this way, it shows considerable promise for wider use in pre-determination evaluation works where it could be ideally applied alongside geophysics and/or fieldwalking in advance of highly targeted evaluation trenching, or being sufficient to inform the type and extent of any necessary mitigation works. Its ability to produce results across a range of geologies, soil types and environments support its use globally in addressing matters of World Heritage.

Beyond prospection, its use during open area excavation or strip, map and sample excavations, provides a further context of use at the site-based scale where greater detail can be produced and questions addressed in relation to the specific use of key structures, buildings and spaces across a given site. The utility of geochemical survey in archaeology is only just beginning to be tapped and its potential and roll out in a commercial archaeological context is an exciting prospect that will bring benefits to clients, archaeologists and the public.

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Conflict of Interests Disclosure

There are no conflicts of interests apparent to the authors.

Author Contributions

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