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Authors: C.A. Wilson, D.A. Davidson, M.S. Cresser

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An evaluation of the site specificity of soil elemental signatures for identifying and interpreting former functional areas.

Wilson, C.A.[1*], Davidson, D.A.[1], and Cresser, M.S.[2]

1. School of Biological and Environmental Sciences, University of Stirling, Stirling, FK9 4LA, UK. Corresponding author, c.a.wilson@stir .ac.uk
2. Environment Department, University of York, Heslington, York, YO10 5DD, UK.

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Abstract

Soil multi-element analysis is now a routine technique employed to help answer questions about space use and function in and around archaeological sites. The pattern of enhancement of certain elements, including P, Pb, Ca, Zn, and Cu, has been shown by numerous studies to correlate closely with the archaeological and historical record. Interpretation of these soil signatures, however, has generally been more problematic. One approach to the problem has been the use of ethnographic or “known” sites to guide interpretation, but how confidently can results from one site be extrapolated to another? This study of abandoned farms tests the site specificity of soil multi-element signatures of past space use through the use of discriminant models. Data analysis suggests that one to one comparisons of similar sites are much less accurate (38% accuracy) than comparisons based on a wider range of sites (59.3% accuracy), even when the latter have contrasting geology. The results highlight the importance of individual anthropogenic practices

during occupation and abandonment in the development of diagnostic soil geochemical signatures.

Background

The atmospheric deposition of metals from modern and historic industrial activity is an obvious effect of anthropogenic processes on soils (e.g. Mighall et al., 2002; Norton, 2007; Rawlins et al., 2006; Sabin and Schiff, 2008). However, soils may also preserve more localised evidence of past human activity as a result of material inputs, either deliberate or accidental, from a range of domestic, agricultural, and industrial processes (e.g. Davidson et al., 2006; El Khalil et al., 2008; Murray et al., 2004; Nicholson et al., 2006). The resulting chemical signatures, in the form of enhanced soil element concentrations, are increasingly being used as an interpretational tool to aid archaeological site prospection (Aston et al., 1998; Eckel et al., 2002; Schlezinger and Howes, 2000), map patterns of past space use (Cook et al., 2006; Entwistle et al., 1998; Entwistle et al., 2000; Sullivan and Kealhofer, 2004; Wells, 2004), and identify former functional areas (Cook et al., 2005; Knudson et al., 2004; Middleton and Price, 1996; Terry et al., 2004).

Recent research into multi-element concentrations in the soils around abandoned farm sites with a known history of use (Wilson et al., 2005; Wilson et al., 2008), has shown there is a remarkable consistency in the suite of elements that are enhanced, and also of the pattern of enhancement. Concentrations of barium (Ba), calcium (Ca), copper (Cu), phosphorus (P), lead (Pb), strontium (Sr), and zinc (Zn) were found to be enhanced in the soils at each site studied. These elements have also been identified in elevated concentrations in archaeological soils of many periods and from around the world (see for example, Aston et al., 1998; da Costa and Kern, 1999; Linderholm and Lundberg, 1994; Middleton and Price, 1996; Pierce et al., 1998; Wells et al., 2000).

The generalised pattern of enhancement in the abandoned farms included peak concentrations of P in the byres (animal houses) whilst the peak concentrations of the other elements were often associated with the hearth and kitchen areas. Pb isotope analysis has confirmed the hearth as the source for a significant proportion of Pb loadings on such sites (Meharg et al., 2006; Wilson et al., 2006a). Element concentrations were at lower levels in the byre (except P), midden (dung hill), garden and arable fields. Besides this core suite of element enhancements, site specific patterning in a range of other elements was also identified (Wilson et al., 2005) and the between site effects for all elements were highly significant. However, elements such as titanium, vanadium, aluminium and zirconium showed virtually no correlation with the archaeological remains on these abandoned farms and variations in their concentration were thought to reflect geological differences (Wilson et al., 2005). A combined discriminant model based on soil geochemical patterns associated with six comparable abandoned farm sites in the UK was found to be accurate in identifying functional areas (from a choice of eight alternatives) in more than 75% of instances (Wilson et al., 2008).

These similarities in suites and patterns of elemental enhancement suggest that it should be possible to interpret space use and function at one site based on known evidence from another using discriminant type analyses. However, in practice the interpretation of elemental concentrations on sites where archaeological evidence is limited, is extremely problematic. Often, interpretations are limited to the location of areas of interest, or tentative identifications of activities are made based on element associations and groupings from a known context or ethnographic site (for example, Barba and Ortiz Butrón, 1992; Barba et al., 1995; Fernández et al., 2002; Knudson et al., 2004; Middleton and Price, 1996; Terry et al., 2004). One reason interpretation of soil element concentrations is so difficult is the effect of post-depositional soil processes, such as differential leaching and adsorption of metals (Ottaway and Matthews, 1988; Wilson et al., 2008). However, the immense diversity of potential human activities and individual practices could also complicate extrapolation of results from modern or neighbouring sites.

This paper presents the results of a study to test the efficacy of discriminant models of soil element concentration in identifying past space use, and assesses the importance of site specific factors in the expression of elemental soil loadings. This is accomplished through the analysis of soils from two neighbouring post-Medieval abandoned farm sites, Balnreich and Tombrek. These two historic rural settlement sites have comparable geological, environmental and socio-economic settings; hence it is hypothesised that a discriminant model built from the site data of one should be accurate in predicting function from the soil geochemistry at the second. The data from Balnreich and Tombrek were then compared with that for five other previously studied sites; Olligarth, Grumby, Auchindrain, Far House and Cwm Eunant (Wilson et al. 2008). These five sites, however, have contrasting soil types, geologies and geography. The aim was to assess whether models of soil geochemistry from known sites could reliably be used to identify areas of former function on sites with a similar history of use. The results of this work have implications for the application and interpretation of multi-element soil analysis in archaeological research.

Methods

Study sites

In total, seven historic rural settlement sites from across the UK are included in this study. Six of these sites (Balnreich, Olligarth, Far House, Cwm Eunant, Auchindrain and Grumby) had been previously sampled (2002 and 2003) and the results are presented in Wilson et al. (2008). One site (Tombrek) was sampled subsequently (2006) and was chosen so as to be directly comparable with the previously studied site of Balnreich in North Tayside, Perthshire, Scotland (Figures 1 and 2).

This area of North Tayside suffered significant depopulation through the late 19th and early 20th Centuries and as a result the relatively fertile land along the loch side has many abandoned townships and farms of the type described by Entwistle et al. (2008). The soils in this area of LochTayside are dominated by histosols and spodosols formed in glacial drift deposits derived from the Dalradian schist that underlies both Balnreich and Tombrek. Both sites are in areas of relatively free-draining soils and occupy a terrace landform that runs along the loch edge at ca. 200 m AOD. The John Farquharson 1769 survey map of North Lochtayside (McArthur, 1936) confirms the historical similarity in site layout and farming practice at the two sites.

The other five sites, used for comparison purposes in this study, are located across Scotland (Olligarth, Papa Stour; Grumby, Sutherland; Auchindrain, Argyll), England (Far House, N. Yorkshire) and Wales (Cwm Eunant, Powys) on a range of contrasting geology (limestone, sand, mica schist, shale, rhyolite, and gneiss) and consequently soils. Each site is of a comparable size and was farmed traditionally until abandonment between the mid 19th Century and 1940 (see Wilson et al., 2005 and Wilson et al., 2008 for further site details).

At each farm soil samples were taken from a range of comparable functional areas identified on the basis of standing and archaeological evidence and documentary evidence. The functional areas sampled were: hearth, house, byre, midden, garden, arable fields and grazed fields as well as “off-site” reference soils. The grazed fields were not sampled at Tombrek as they are located at some distance from the main settlement and in an area of contrasting geology, thus negating the aim of keeping background conditions identical between Balnreich and the later sampled Tombrek site. Also, no midden contexts were identified at either of these two sites. Within the buildings samples were taken over a 1 m grid from the upper 5-15 cm of the soil that had accumulated since the abandonment of the buildings (overburden). Test pits (1 m x 1 m) were excavated within the buildings to expose the uppermost (most recent) floor surface. Samples of the overburden were taken from the pit sections and samples from the floor layers were taken from between the exposed cobbles and flags of the floor layers. Five replicates were taken from each horizon or 20 cm depth increments. In the field areas the topsoil – upper 5-15 cm or less depending on horizonation - was sampled using auger grid surveys (grid size 8 m x 6 m) with a 2 m sampling interval (minimum 12 samples). Test pits (0.6 m x 0.6 m) were excavated to the parent material. Five replicate samples were taken from each horizon or 20 cm depth increments depending on the horizon differentiation within individual soil profiles. Samples of the parent material were also taken from each test pit.

Analysis

Five grams of air-dried, less than 2 mm soil was digested in 5 ml of Aristar concentrated nitric acid at 120^{o}C for 1 hour. The digest was filtered through Whatman No. 2 filter paper and the filtrate made to 100 ml volume using deionised water. Samples were analysed using a Perkin-Elmer 3300RL ICP-AES spectrometer. Loss-on-ignition (405^{o}C), soil pH (1:5 soil:water), particle size distribution (laser diffraction LS230 Coulter Counter), and cation exchange capacity (1M KCl leaching method) were also determined to provide background soil conditions for each functional area. This digestion method was chosen as giving the best recovery of anthropogenic signals versus the geological background (Wilson et al., 2006b).

Data Analysis

Data were normalised using a logarithmic transformation and four samples with extreme outliers (quartiles +/- 3 x interquartile range) were removed. Stepwise discriminant analysis was used to model elemental differences between functional areas. Models were generated for (1) the Balnreich site only, and (2) a composite model of six abandoned farm sites from across the UK (Balnreich, Olligarth, Grumby, Auchindrain, Far House and Cwm Eunant). These models were then used to predict functional area based on the elemental composition of the samples from Tombrek. Note that the generic model includes grazed field and midden contexts whilst the directly comparable model of Balnreich and Tombrek excludes these contexts because of differences in geology and absence respectively.

Results

Comparison of settlement remains at Tombrek and Balnreich

The buildings at Tombrek and Balnreich were constructed from stone rubble stabilised by clay mortar, with roof crucks supporting turf thatch. At Tombrek the hearth consisted of a large (ca. 1 m x 0.8 m) raised hearth stone placed centrally in the building, to the west of which may have been a wooden partition. The hearth stone itself showed evidence of heating but had evidently been cleaned at or following abandonment as no charcoal or ash deposits were found. Samples from the hearth were taken from cracks in the hearth stone where ash may have accumulated, and from the floor immediately around the hearth. This contrasts with the hearth at Balnreich where carbonised deposits were found in-situ. The floors in both houses were of flag stones, and the byre floors were cobbled. There had clearly been some reuse of the house section of Tombrek after its abandonment as a poorly constructed stone wall had been inserted across the building.

The garden area at Tombrek contains a deepened soil profile with an Ap/A horizon 0.6 m thick containing charcoal, glazed pottery, and bone fragments indicating intensive past manuring of this area. An auger survey across a 1 m grid around the pit produced samples from the upper 5-15 cm of the soil. At Balnreich the garden soil showed no evidence of deepening (ca. 0.3 m deep); nor did it contain any visible anthropogenic inclusions.

The arable areas at both sites were identified by reference to the Farquharson map of north Loch Tayside dating to 1769. The arable field areas at both Tombrek and Balnreich were shallow (ca. 0.3 m) and contained no visible evidence of charcoal. The outfield areas to the north of the Tombrek site were not sampled as the previous analysis at Balnreich had revealed geological changes on the slopes of Ben Lawers; hence only the fields close to the steadings were felt to be suitable controls for comparison.

Soil geochemical results

Comparison of Balnreich and Tombrek

The mean pH, cation exchange capacity (CEC), and percentage organic matter (OM), sand, silt and clay content for each functional area are summarised in Table 1 for both Tombrek and Balnreich. The reference soils of both sites have a very similar sandy clay loam texture and acid pH (reference soils pH 5.7 and 5.6). However, organic matter content and CEC are consistently higher on-site at Balnreich than at Tombrek. This suggests that CEC, and hence the ability of the soils to retain metal cations, is strongly influenced by soil organic matter content.

The sub-soils (C horizons) provide background parent material element concentrations, thus allowing comparison between Tombrek and Balnreich (Figure 3). With the exception of potassium (K), iron (Fe), aluminium (Al), and titanium (Ti), there are no significant differences (p 0.05) in the geochemistry of the glacial drift parent materials at Balnreich and Tombrek.

Table 2 summarises the pattern of significant differences (one-way ANOVA, $p < .05$) in individual elemental top-soil concentrations between functional areas on Tombrek and on each of the six other sites used in the models of function. Elements with one star show a generalized pattern of enhancement in the built settlement (house, hearth, byre and garden) relative to the surrounding fields, whilst those with two stars also show significant differences in element concentrations between the contexts of the built settlement. It can be seen that Ba, Ca, K, Na, P, Pb, Sr, Cu and Zn, all show significant differences in soil concentration across Tombrek. With the exception of sodium this suite of enhanced elements is similar to that seen at the other sites studied previously. No significant differences in the concentrations of these elements were identified between the samples taken from the floor layer and those from the overlying (overburden) material. Henceforth, concentrations refer to the floor samples in the buildings (hearth, house and byre) and the topsoils (5-15 cm) in the fields; as this was found to give the most effective separation of functional areas.

Figure 4 shows the pattern of concentration of Pb, Ca, P, Cu, and Zn in topsoils and floor layers across the sites of Tombrek and Balnreich. These elements had been highlighted during the study of Balnreich as potentially discriminating between the different functional areas of hearth, house, byre, garden, and arable fields (Table 2) and as being substantially enhanced relative to the off-site reference soil (As can be seen in Figure 4). This shows that at both sites Pb concentrations are significantly higher than in the local soil parent materials. The hearth contains the highest Pb concentrations followed by the house and byre. The garden and arable fields at Balnreich were not enhanced relative to the reference sub-soil; however, at Tombrek these soils do contain significantly more Pb. The pattern of Ca enhancement shows greater differences between the two sites. At Balnreich the hearth showed very strong enhancement of Ca with significant, but much lower levels of enhancement in the house, byre, garden and arable fields (still limed by farmer). By contrast at Tombrek the house contains the highest levels of Ca followed closely by the hearth and byre. The garden and arable fields show no significant enhancement of Ca as confirmed by analysis of variance and Tukey's Honest Significant Differences (Table 3). At both Balnreich and Tombrek, P is significantly enhanced in the soils surrounding the township compared to the parent material. At Balnreich the highest P concentrations were found in the byre, whilst at Tombrek the garden soils contain the highest levels of P, though the hearth, house and byre also contain relatively high concentrations.

At Balnreich both Zn and Cu were strongly concentrated in the hearth area; whilst the hearth at Tombrek is enriched in these two elements (particularly Cu), the level of enhancement is much lower than at Balnreich.

One-way Analysis of Variance of log transformed soil concentrations from Tombrek shows significant differences (p value $< .000$) in soil concentrations by functional area (Table 3). Tukey's post-hoc analysis shows that P was concentrated in the byre, garden, house and hearth areas, Ca, Sr and K in the hearth, house and byre, and Pb in the hearth.

Discriminant model results

The regionally specific discriminant model built using only data from Balnriech is presented in Table 4. Note that the elements used in the model do not include the full suite of “anthropogenic” elements. This is because a stepwise discriminant model was used due to the strong cross correlation between elements; thus, P, Pb, Zn and Ba best summarised the discriminating power of the “anthropogenically interesting” elements. Entering the Tombrek floor and topsoil data into the regionally specific discriminant model built with the data from neighbouring Balnreich resulted in 38.0% of the samples being correctly classified (Table 5). Identification of house and garden samples was good (69.1% and 90.9% respectively), but all the hearth, byre, arable and reference soils were incorrectly identified. Ignoring functional areas and classifying samples according to site was highly successful, with correct classification of independent samples (not used in the model) in a minimum of 97.1% cases (Table 6).

The discriminant model built using the data from Balnreich, Olligarth, Cwm Eunant, Far House, Grumby and Auchindrain is presented in Table 7. Note the greater number of elements used in the model compared with the regional model (Table 4); this reflects the lower levels of cross correlation between elements in this larger, multiple site data set. Entering the Tombrek data into the generic model based on all the other six farm sites, resulted in 59.3% of the samples being correctly classified (Table 8). All the hearth samples were incorrectly identified, predominantly (92.3%) as from the house. In total, 85.3% of house samples were correctly identified, the remainder of the samples being assigned to byre; 70.4% of the byre samples were correctly identified and all the garden samples were correctly assigned. However, 96% of the arable field samples were incorrectly assigned either to garden or grazed field samples, and all the reference sub-soil samples were incorrectly assigned.

Discussion

The parent materials at Balnreich and Tombrek have been shown to be effectively identical in terms of their elemental composition. The soils at the two sites also have similar soil clay contents and pH. Given the similar geomorphological, hydrological and land use settings of the two sites, we could expect, therefore, that unamended soils would have similar elemental compositions and this expectation is borne out by the results. Thus, we can be confident that these two sites are directly comparable in terms of background soil element loadings.

The high pH in the reference sub-soil reflects the natural level of base cations that have been progressively leached from the topsoils. The higher pH in the hearth areas is probably the result of additions of peat ash. Organic matter content and consequently cation exchange capacity are higher at Balnreich than at Tombrek. This means that loadings of elements such as calcium, barium and strontium, which are predominantly held in the exchangeable soil fraction (Wilson et al., 2006b) and hence are vulnerable to leaching in the wet Scottish climate, may have a lower residency time at Tombrek than at Balnreich. However, there was no evidence of any significant differential leaching effect over the 100-150 year time scale since abandonment at these two sites.

A similar suite of elements (Ca, Ba, Sr, Zn, Pb, P, Cu and K) shows enhancement in and around Tombrek as at the previously studied abandoned farms. Previous studies of reference materials (Davidson et al., 2007) and Pb isotopes (Wilson et al., 2006b) suggests that at other historic rural settlement sites the hearth and the process of combustion is the main process of element concentration; these loadings then are spread further across the site through middening and manuring. The pattern of contamination at Balnreich supports this with the hearth containing the highest levels of lead, calcium, zinc and copper. At Tombrek too, the hearth contains the highest recorded levels of lead, zinc and copper, and amongst the highest concentrations of phosphorus, calcium, potassium, sodium, and strontium. However, the level of enhancement is much lower because, unlike at Balnreich, the hearth at Tombrek had been thoroughly cleaned prior to abandonment.

The garden at Balnreich was somewhat atypical compared to the other Scottish townships as it contained a shallow soil profile, with none of the signs of deepening or inclusions such as charcoal and pottery that were found in the garden soils at Tombrek. This suggests a more sustained manuring effort at Tombrek than at Balnreich, and this is reflected in the higher phosphorus levels in the Tombrek garden. The byre at Tombrek, however, contains lower phosphorus levels than that at Balnreich, and of the other sites analysed previously. This may be due to cleaning of the byre at Tombrek (and likewise the hearth) prior to its abandonment.

These site-specific differences in anthropogenic history influence the soil chemistry. As a result the model of space use based on soils from Balnreich was able to correctly predict functional area for only 38% of samples. Prediction rates of house and garden samples were good (69.1% and 90.9% respectively), but no hearth, byre, arable or reference samples were successfully identified.

The generic model based on the results of all six sites from the former study (see Wilson et al., 2008), produced a respectable 59.3% success rate for function prediction from the soils at Tombrek. Compared with the regionally specific model, the generic model was better at predicting both house and garden samples (85.3% and 100% respectively), and additionally successfully identified more than 70% of byre and 4% of arable field samples. Because the Tombrek hearth had been cleaned out, no hearth samples were correctly identified based on the chemistry of the charcoal-rich residues recovered from the other six sites. Nor were any of the reference soils correctly identified, though this is to be expected from a model developed from six geologically diverse (limestone, sand, mica schist, shale, rhyolite, and gneiss) locations. Identification of individual field areas is also poor, probably because of lower levels of enhancement that will mask background variation less well. The importance of site-specific factors, other than geology, is borne-out by the strong site discrimination of soils on the basis of their elemental concentrations, and echoes the results of the previous study by Wilson et al. (2005; 2008) which identified factors of enhancement compared to the off-site reference soils in the order of ca. 4 – 50x in the hearth, house and byre. The findings seem to indicate that site-specific anthropogenic factors are largely responsible for these differences. However, it is possible that at older sites post-depositional soil forming processes and post-abandonment site use may be a more significant factor.

Conclusions

Multi-element soil analysis is now a well established technique for aiding archaeological understanding of space use and function. Interpretation of these geochemical signals, however, can be problematic because of the range of materials being deposited, their on-site mixing, natural variations in background soil chemistry and post-depositional processes. The traditional approach to aid interpretation has been the use of closely matched ethnographic or experimental sites. However, this study of two very similar sites (geologically, geographically, temporally, and functionally) has clearly illustrated the site specific nature of multi-element soil concentrations.

Differences in anthropogenic processes, particularly those of abandonment and post-abandonment use, such as the cleaning out of abandoned sites, have a significant effect on the scale of enhancement and the within site spatial patterning of element concentrations. As a result one to one comparative models (such as those traditionally used in ethnographic studies) may produce relatively poor results and in this case better prediction rates were achieved through the use of a model derived from data from a range of sites. It could be suggested that better results again would be gained if multiple sites from a geologically comparable region were used. However, it must be remembered that the model will always be limited by ‘unusual’ occurrences or practices. Although multi-element soil analysis is undoubtedly a valuable tool in archaeological investigation and ethnographic studies add greatly to our understanding of soil loadings, the results of this study highlight the great care that should be taken when trying to draw close comparisons between individual sites.

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Table 1: Summary of soil parameters from functional areas in Tombrek (TMB) and Balnreich (BLN)

	pH		**Loss on Ignition (%)**		**CEC (mmol C kg^{-1})**		**% Sand**		**% Clay**	
	TMB	**BLN**	**TMB**	**BLN**	**TMB**	**BLN**	**TMB**	**BLN**	**TMB**	**BLN**
Hearth	5.2	5.6	7.6	14.8	109.19	144.23	48.34	53.46	2.97	2.80
House	4.6	4.5	11.3	14.0	38.86	68.27	67.50	58.37	1.79	2.40
Byre	4.3	3.7	6.8	19.3	35.41	55.90	70.60	65.84	1.54	1.81
Garden	5.0	5.1	9.2	9.4	36.67	37.67	67.42	55.05	1.75	2.51
Arable fields	5.0	4.2	6.7	9.1	27.10	53.15	54.63	61.58	3.03	2.18
Reference (parent material)	5.7	5.6	2.7	2.5	n/d	12.48	n/d	57.85	n/d	3.09

Table 2: Patterns of elemental concentrations on Tombrek and all sites used in previous functional models (Wilson et al. 2005)

Site	**Tombrek**	**Balnreich**	**Auchindrain**	**Cwm Eunant**	**Far House**	**Grumby**	**Olligarth**
Al						•	•
Ba	••	••	•	••	•	••	••
Ca	••	••	•	••	••	••	••
Co		•			•	••	••
Cr			•			••	••
Cu	••	••	•	••		•	••
Fe						••	••
K	••	••					•
Li					•	•	••
Mg				•	••	•	•
Mn		•			••	••	••
Na	••				•		
Ni		•	•	•	•	•	•
P	••	••	••	•	•	•	••
Pb	••	••		••		••	••
Sr	••	••	•	••	••	••	••
Ti						•	
V						•	•
Y		•				••	••
Zn	••	••	••	••	••	••	••

• = general enhancement in element concentration in soils associated with buildings (houses, byres, middens and gardens) relative to surrounding arable and grazed fields
•• = as above but additional differences in element concentration between individual on-site functional areas (houses, hearths, byres, middens and gardens)

Table 3: One-way ANOVA results for functional areas at Tombrek based on natural log transformed mineral soil concentrations of P, Ca, K, Na, Pb, Sr and Zn

				Tukey's HSD subsets alpha = 0.05				
Element	**F-Value**	**Welch's statistic**	**Sig**	**1**	**2**	**3**	**4**	**5**
P	76.599	106.514	< .000	REF	RF	HR, HS, BY	GD	
Ca	40.653	97.806	< .000	REF, RF, GD	HR, HS, BY			
K	52.022	80.148	< .000	REF	RF, GD	HR, HS, BY		
Na	21.921	33.796	< .000	REF	HR, RF, GD	HR, GD, BY	HR, HS, BY	
Pb	130.017	153.165	< .000	REF	RF	BY, GD	HS	HR
Sr	38.617	111.183	< .000	REF, RF, GD	HR, HS, BY			
Zn	18.25	41.406	< .000	REF	RF	HR, HS, BY, GD		

REF, reference soil; RF, arable field; GD, garden; BY, byre; HS, house; HR, hearth.

Table 4: Standardized canonical discriminant function co-efficients for the regionally specific model based on data from Balnreich.

	Function				
	1	2	3	4	5
ln P	.536	-.084	-.960	-.730	.923
ln Na	.114	-.400	.933	.008	-.419
ln Mg	2.080	-1.322	.787	.733	.596
ln Fe	.285	-.328	.568	.575	-1.725
ln Ba	.480	.228	.817	.910	.270
ln Co	-0.77	1.063	-.227	-.643	-1.127
ln Pb	.021	.790	-.122	.545	-0.006
ln Ti	-1.129	.161	-1.734	.137	-.124
ln V	-.195	.111	.433	-.275	2.128
Ln Zn	-1.433	.907	.107	-1.115	.120
Eigenvalue	11.702	10.590	5.177	1.370	.972
% of variance	39.3	35.5	17.4	4.6	3.3

Table 5: Predicted context membership (%) for Tombrek data entered into regionally specific discriminant model.

	Predicted context membership					
Assigned context	**HR**	**HS**	**BY**	**GD**	**RF**	**REF**
HR		92.3		7.7		
HS	7.4	69.1	1.5	22.1		
BY	3.7	29.6		66.7		
GD		9.1		90.9		
RF		4		96		
REF				83.3	16.7	

REF, reference soil; RF, arable field; GD, garden; BY, byre; HS, house; HR, hearth.

Table 6: Predicted site membership (%) for unselected cases from Balnreich and Tombrek.

	Predicted site membership	
Assigned site	Balnreich	Tombrek
Balnreich	98.8	1.2
Tombrek	6	94

Table 7: Standardized canonical discriminant function co-efficients for the generic model based on data from Balnreich, Olligarth, Cwm Eunant, Far House, Grumby and Auchindrain.

	Function				
	1	2	3	4	5
ln Al	-.292	-.499	-1.374	1.866	1.056
ln Fe	.537	.081	-.663	-.047	-1.283
ln Mg	-.925	-.780	-.336	-.595	-1.526
ln Ca	.388	.379	.322	.592	1.90
ln Na	-.187	.663	.623	-.739	.730
ln K	.284	-.197	.400	.163	-.009
ln Ti	.373	.551	.455	.109	.828
ln P	.399	-.670	.576	.420	.140
ln Mn	-1.055	.248	-.076	.771	1.222
ln Ba	.026	-.545	-.353	-.418	.024
ln Co	1.632	-.489	.282	-1.144	.860
ln Cu	.017	.414	-.276	-.427	.308
ln Li	-.377	.809	1.962	-.347	.436
ln Ni	.692	.160	-.051	-.211	.254
ln Sr	.481	.417	-.654	.261	-.545
ln V	-.437	.684	.191	.433	-.631
ln Zn	-.001	-.684	-.171	-.095	-.841
ln Pb	.164	.492	-.343	-.058	.111
Eigenvalue	3.119	1.394	.709	.463	.391
% of variance	49.6	22.2	11.3	7.3	6.2

Table 8: Predicted context membership (%) for Tombrek data entered into generic discrimanant model

	Predicted context membership							
Assigned context	**HR**	**HS**	**BY**	**GD**	**RF**	**OF**	**REF**	**MD**
HR		92.3	7.7					
HS		85.3	14.7					
BY		14.8	70.4	11.1		3.7		
GD				100				
RF				48	4	48		
REF		16.7		33.3	33.3	16.7		

REF, reference soil; RF, arable field; GD, garden; BY, byre; HS, house; HR, hearth; MD, midden; OF, grazed field

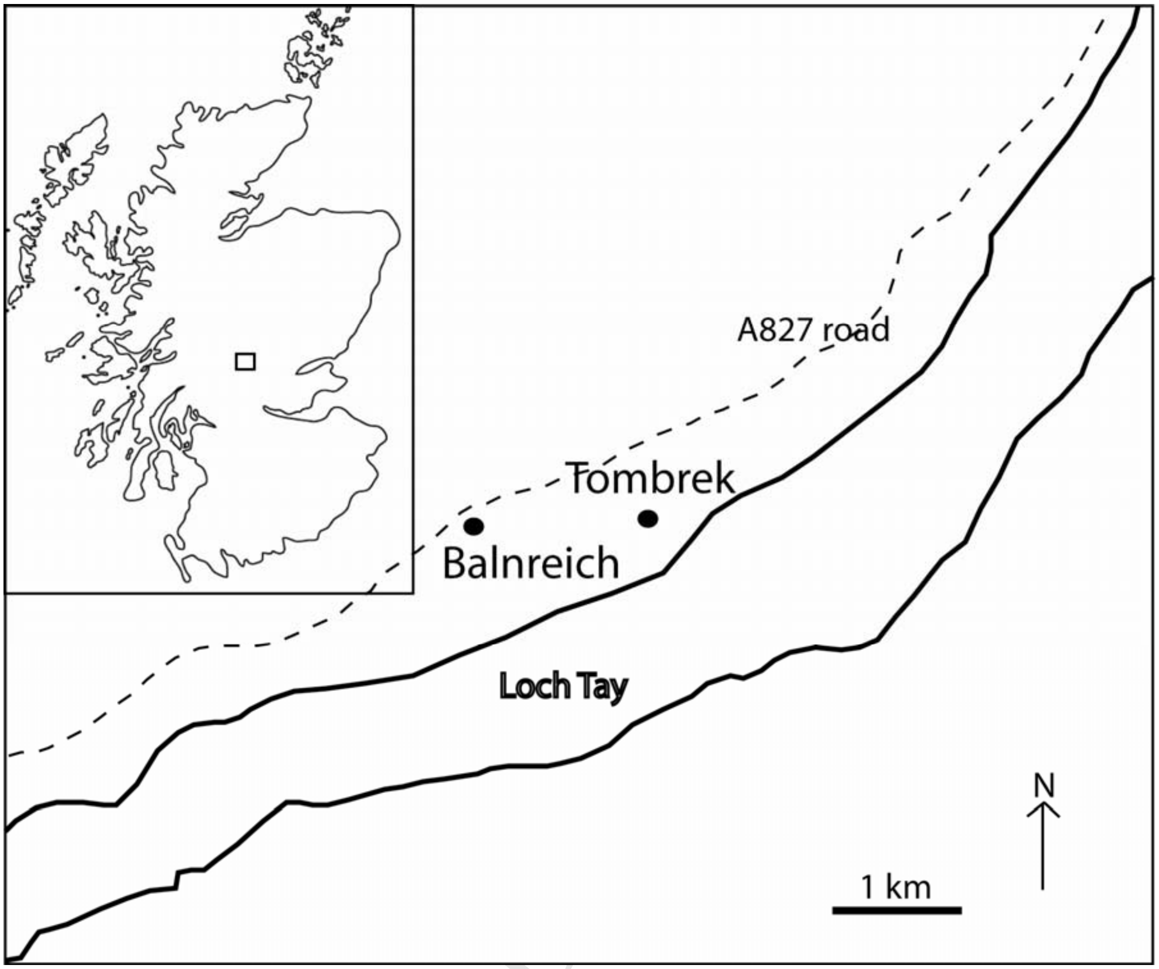
Figure Titles

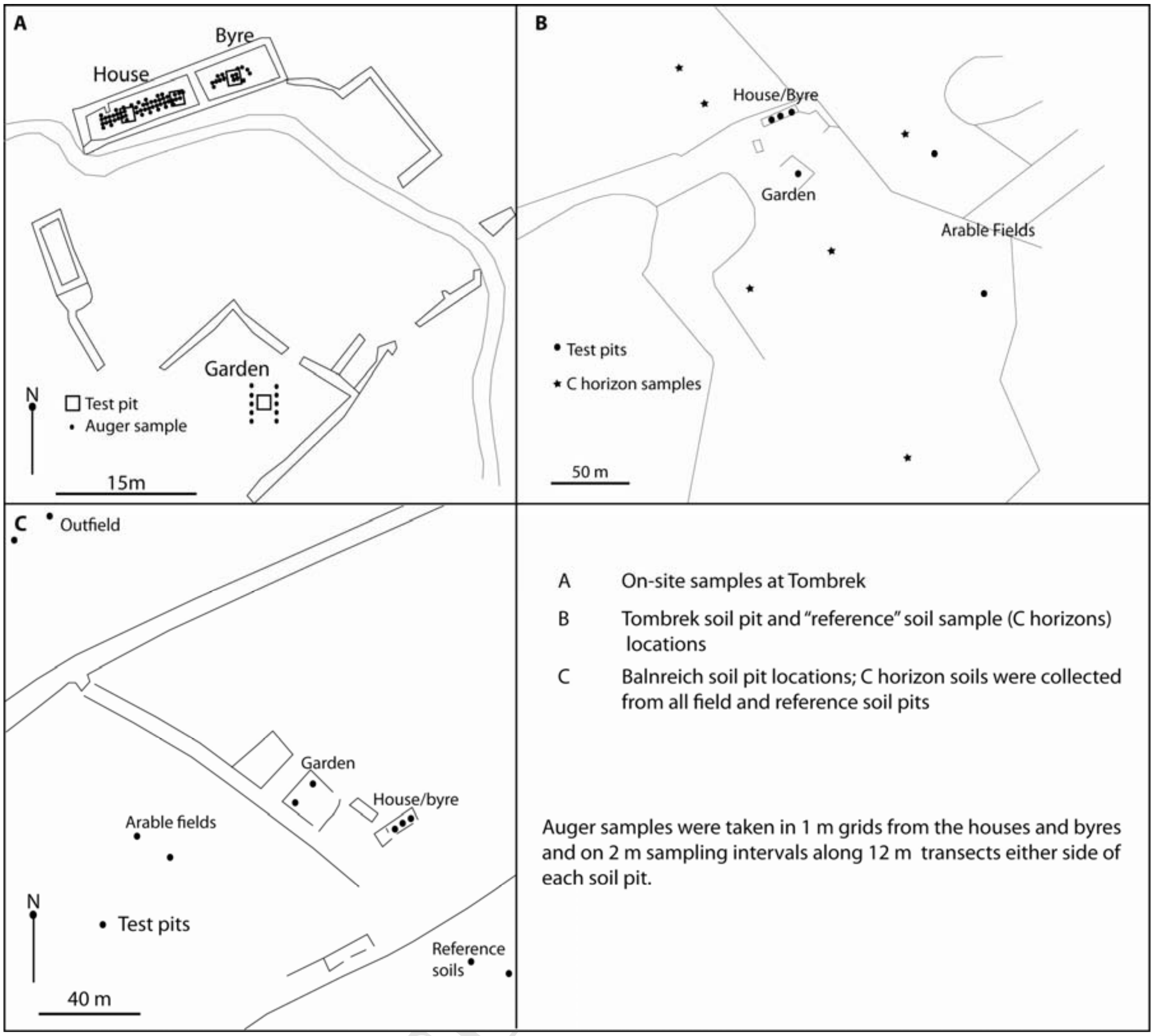
Figure 1: Location of study sites Balnreich and Tombrek.

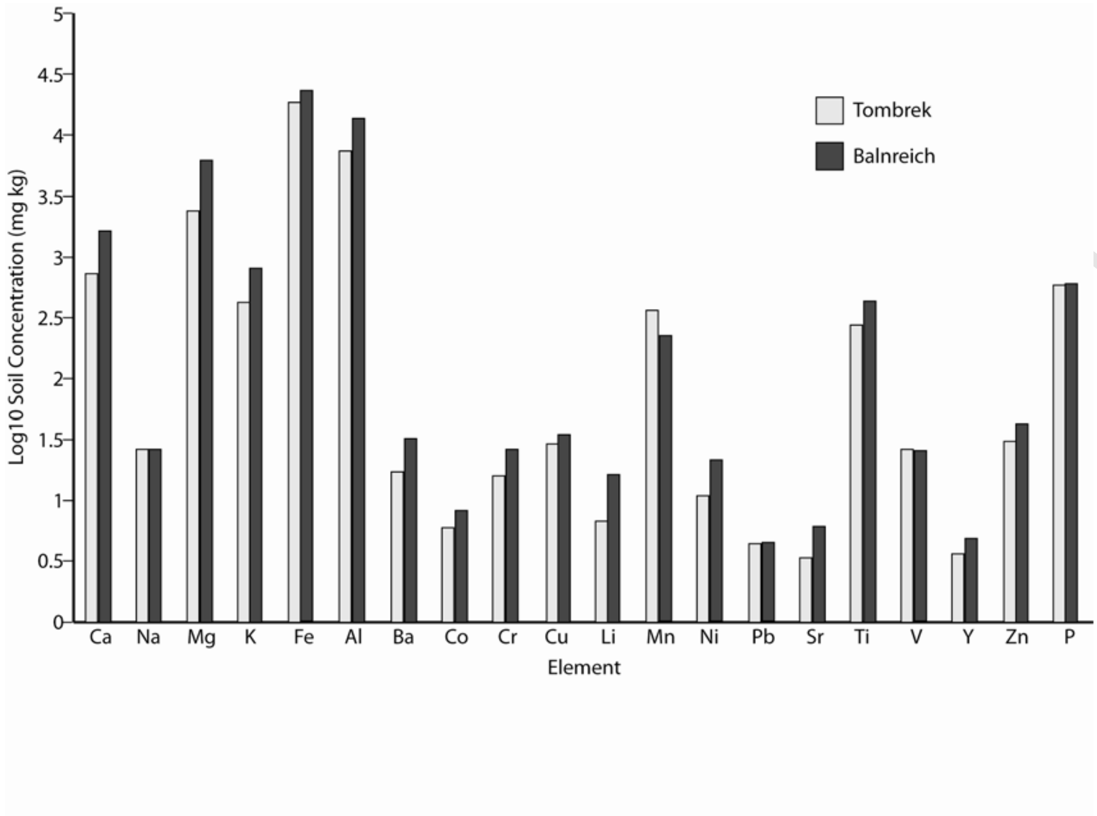
Figure 2: Site maps and sampling locations for Balnreich and Tombrek

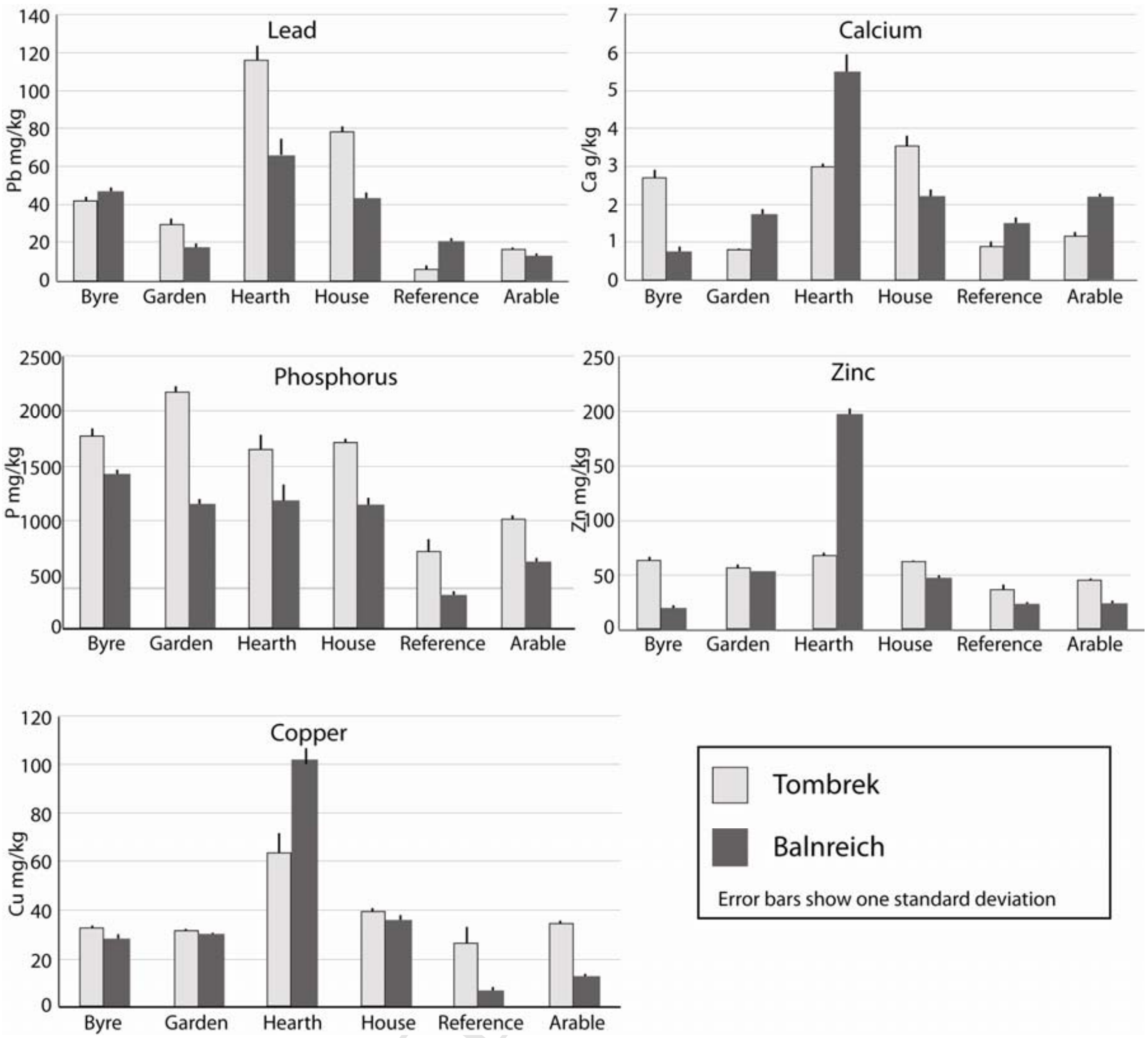
Figure 3: Comparison of element concentration in C horizons (sub-soils) of Easter Tombrek and Balnreich (Note: Concentration is plotted in $\log_{10}$ scale)

Figure 4: Mean element concentrations in top soils (A horizons of garden, field and reference contexts) and floor layers (hearth, house, byre) at Tombrek and Balnreich


A827 road
Tombrek
Balnreich
Loch Tay
N
1 km


A
Byre
House
Garden
N
Test pit
Auger sample
15m
B
House/Byre
Garden
Arable Fields
Test pits
C horizon samples
50 m
C
Outfield
Garden
House/byre
Arable fields
N
Test pits
40 m
Reference soils
A On-site samples at Tombrek
B Tombrek soil pit and "reference" soil sample (C horizons) locations
C Balnreich soil pit locations; C horizon soils were collected from all field and reference soil pits
Auger samples were taken in 1 m grids from the houses and byres and on 2 m sampling intervals along 12 m transects either side of each soil pit.


Tombrek
Balnreich
Log10 Soil Concentration (mg kg)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Ca
Na
Mg
K
Fe
Al
Ba
Co
Cr
Cu
Li
Mn
Ni
Pb
Sr
Ti
V
Y
Zn
P
Element


Lead
Pb mg/kg
0
20
40
60
80
100
120
140
Byre
Garden
Hearth
House
Reference
Arable
Calcium
Ca g/kg
0
1
2
3
4
5
6
7
Byre
Garden
Hearth
House
Reference
Arable
Phosphorus
P mg/kg
0
500
1000
1500
2000
2500
Byre
Garden
Hearth
House
Reference
Arable
Zinc
Zn mg/kg
0
50
100
150
200
250
Byre
Garden
Hearth
House
Reference
Arable
Copper
Cu mg/kg
0
20
40
60
80
100
120
Byre
Garden
Hearth
House
Reference
Arable
Tombrek
Balnreich
Error bars show one standard deviation