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The Geoarchaeological Significance and Spatial Variability of a Range of Physical and Chemical Soil Properties from a Former Habitation Site, Isle of Skye

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Of the 34 major and trace elements investigated in this study, enrichments of K, Th, Rb and, to a lesser extent, Cs, were associated with former habitation of the area, whilst high levels of Sr and, to a lesser extent, Ca were associated with the adjacent field area. This latter enrichment is thought to represent additions of shell sand and/or bone and fish refuse. Phosphorus is a less reliable indicator of human habitation than K, Rb and Th, possibly because P enrichment may be caused by additions of animal manure as well as by human habitation of an area. Vanadium, Co, Zn, Pb, Ni, Ga, Sc, Mg, Cu and U all indicated negligible on-site enrichment, whilst Cr and organic matter content were found to be depleted in the on-site soils relative to the control samples. Consideration of the degree of variability in the soil parameters investigated has implications for the bulk or composite sampling of soils over sites of former habitation.

Keywords: GEOANALYSIS, ICP-MS, ISLE OF SKYE, SPATIAL VARIABILITY, HABITATION SITES.

Introduction

The physical, biological and chemical properties of soils may be significantly altered as a direct result of human activities such as habitation and farming. Provided recent land-use has not obscured pre-historic and historic land-use activity, and given favourable soil conditions, variations in the concentration of certain chemical elements across a site have been shown to be of value in a range of archaeological prospection and interpretative studies. Thus, soil analysis has been used to distinguish different functions or land-use activity over a site and to aid identification and interpretation of settlement features such as hearths, mounds and livestock enclosures (Provan, 1973; Conway, 1983; Konrad *et al.*, 1983; Craddock *et al.*, 1985; Davidson *et al.*, 1986; Bethell & Carver, 1987).

Occupation and settlement of an area will tend to enrich the soil in certain elements, such as K and P, through the accumulation of general site occupation debris and excreta, whilst other soil parameters, such as organic matter content, may be depleted through associated anthropogenic activity such as cultivation. Investigation of the spatial variation of a range of elements and soil properties, when examined in conjunction with each other, should therefore enable differentiation between different types of land-use activity. In our study, a random stratified sampling system was undertaken over the entire site at Greaulin (Isle of Skye), and 60 topsoil samples were collected using the W traverse method. This is a common technique used to obtain a representative composite sample from an area (Rowell, 1994). The broad geochemical patterns produced from this study are presented in Entwistle, Abrahams & Dodgshon (1998). Obviously, this technique of bulking samples does not provide detailed information regarding the small scale (<10 m) spatial variability of the soil parameters under investigation. In comparison with the analysis of the township's overall land-use, this paper presents the findings of a detailed appraisal of part of the site. It focuses on the spatial variability of the soil parameters under investigation and comments on the extent to which multi-elemental analysis can provide information on individual occupation or habitation sites and their associated buildings and kailyards (small enclosures attached to the farmsteads or located nearby, where vegetables were grown and compost was stored). Consideration of the degree of variability in the soil

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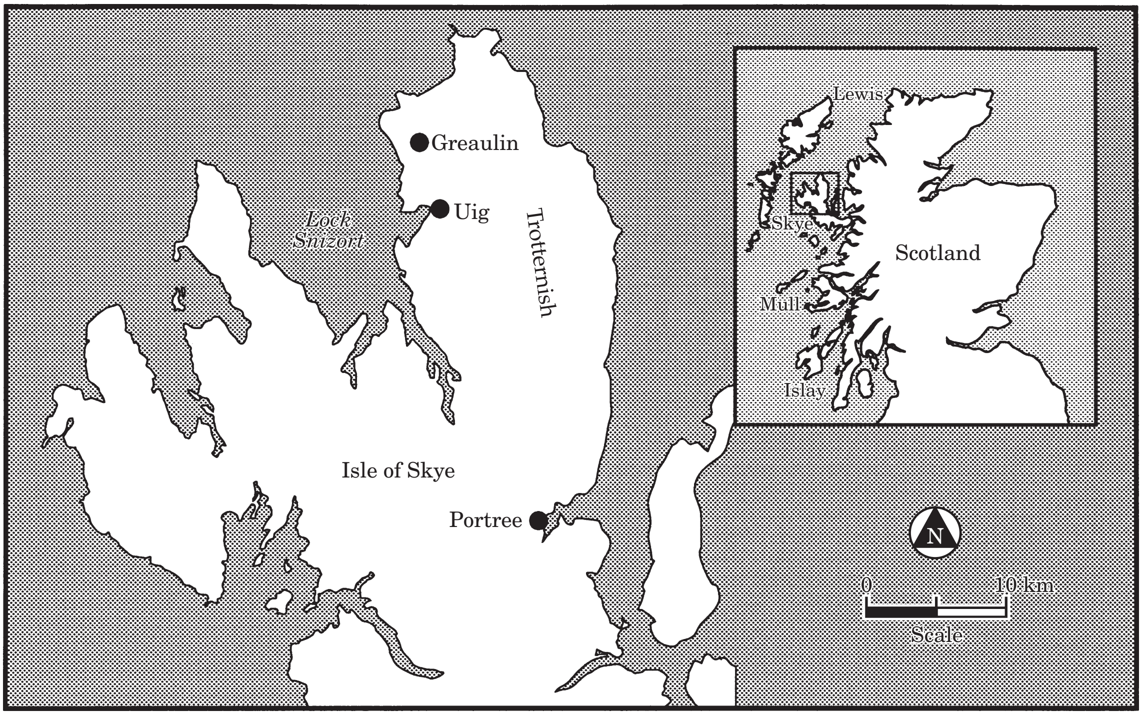

Figure 1. Location of Greaulin on the western side of the Trotternish Peninsula, Isle of Skye.

parameters investigated has obvious implications for the sampling strategy of soil collected at such sites.

Traditional Highland and Hebridean settlements

Traditional west Highland and Hebridean settlements pose two kinds of problem to the historian: the actual settlement form and the character of its dwellings. As regards the former, the conventional view is that prior to the 18th century, the typical unit of settlement was the farming township occupied by tenant farmers, sub-tenants, cottagers and labourers. The township or clachan (baile in Gaelic) formed a small nucleated cluster of dwellings, typically on the edge of the arable. Though attempts to excavate the clachan have produced inconclusive data on its origins (Fairhurst, 1969; Crawford, 1983), there is still a widespread assumption that it is an archaic, possibly prehistoric, settlement form. Recent work has questioned these assumptions, arguing that many townships had layouts in which settlement was often broken down into small clusters and even scattered farmsteads rather than a single nucleation (Dodgshon, 1993).

Except at the Udal on north Uist (Crawford & Switsur, 1977), the excavation of Highland or Hebridean townships has not produced a sufficient depth of occupation to enable us to discuss how domestic dwellings have developed in the long-term. In part, this lack of temporal depth may simply reflect the fact that earlier or pre-1700 settlement may have been more loosely dispersed across townships or, equally possible, greater use might have been made of perishable raw materials like turf for house walls, either exclusively or on top of stone footings (Dodgshon, 1993). By the late 17th century, when field evidence starts to become more forthcoming, the standard dwelling appears small, rectangular to oval-shaped and barely 3 or 4 m across its long axis, usually with small outbuildings and a small Kailyard. By the mid–late 18th century, dwellings become noticeably larger, now with squared-off corners. Beginning in the mid 18th century, townships were either entirely cleared for sheep farming or re-organized into crofting townships. The latter produced a regular layout of settlement along a single street, with crofts forming a ladder pattern stretching back on either side, laid out either directly over earlier settlement or on an adjacent site. Once we reach the main period of croft creation, dwellings become larger, with any outbuildings, byres and kailyards physically attached to it. In many cases, the construction of these larger crofts must have involved extensive stone robbing from earlier, abandoned dwellings, a recycling that adds to the problems of establishing the nature of earlier forms. Clearly, there are a range of basic questions about the temporal nature and form of Highland and Hebridean settlements that still need answers. Analyses of soil chemistry can help provide some of these answers. Through the elemental characterization of the human impact on soil, including associated sites (i.e. separate byres, kailyards), we can better understand the structure of settlement sites, and also begin to probe

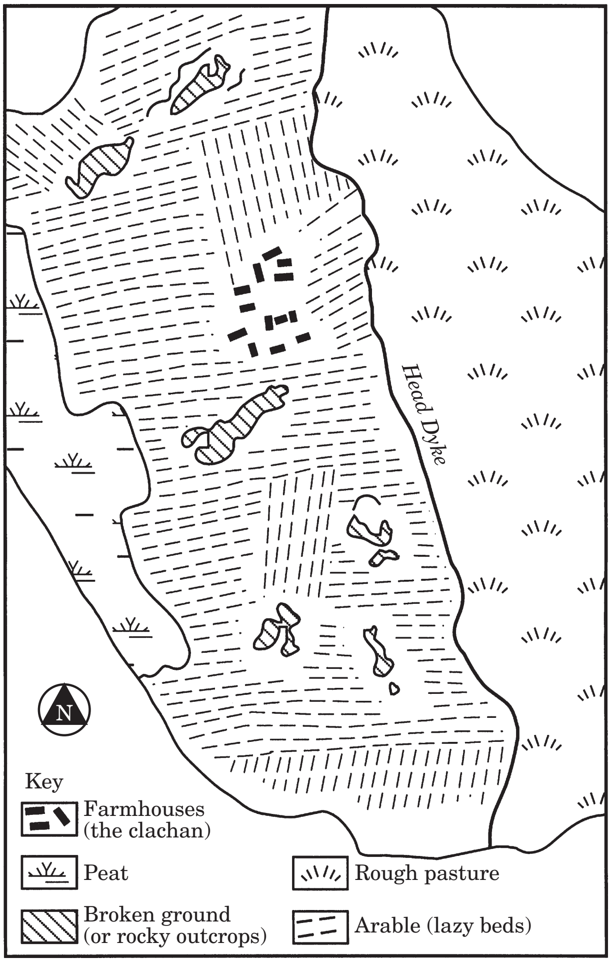

Figure 2. Plan of Greaulin taken from a map by Mathew Stobie (1764).

some of the long-term shifts that may underpin them for which no upstanding surface evidence now remains.

Study Site

Greaulin (grid reference NG 390674–397684) is located about 3·5 km north of Uig on the Trotternish peninsula, Isle of Skye (Figure 1). Greaulin is a Gaelic place name that occurs on a number of Hebridean islands (e.g. Eigg, Mull) and can be translated as "sunny stream or valley". Former settlement and farming activity at Greaulin has resulted in a complicated pattern of walls, trenches and lazy-beds (cultivation rigs where soil is heaped into narrow ridges) derived from various phases of occupation.

The earliest detailed reference to the site occurs in a 1733 rental for the Macdonald Estate. This rental describes Greaulin as a three penny land held by a John Macdonald. Pennylands were a unit of land measure used throughout the central and northern Hebrides. It derives from a Norse assessment of the area and its use at Greaulin might mean that, despite its Gaelic place-name, the site has Norse connections. As with other townships in the area, the fact that it was recorded in the 1733 rental for the Macdonald estate as held by a single tenant may be deceptive. The occupier, John Macdonald, may simply have been the tacksman, a person who held the tack (i.e. the lease on the land) but who sublet all or parts of the township to subtenants. In fact, a large scale map of the area compiled by Mathew Stobie in 1764 shows that the settlement at Greaulin consisted of a sizeable cluster of houses and outbuildings (Figure 2) and suggests that a small community, and not just a tacksman, farmed the site. A survey of the Macdonald estate drawn up in 1799 described the townships of Kilmuir parish (the parish in which Greaulin was located) as all farmed in runrig, with groups of tenants having their holdings sub-divided and intermixed in the form of strips.

Plans to divide the various townships out of lazy-bed cultivation into crofts were first discussed in 1802 but no action was taken until 1811. Land re-organization led to the formation of six crofts out of what had been the township's arable land. By the 1820s, these six crofts were each sub-divided or split in two to give a pattern of 12 crofts. The site's existence as a crofting township, however, was relatively short-lived. Evidence presented to the Crofter's Commission in the early 1880s reported that it had been cleared and the land added as extra pasture to the nearby township of Monkstadt (grid reference NG 378675). The evidence suggested that it had been cleared 30–40 years earlier, the tenants being moved to the nearby township of Kilmuir (grid reference NG 383705). However, as estate rentals show Greaulin to be still organized and held as 12 crofts to 1852/3, its clearance is likely to have been at some point during the mid-1850s.

The detailed site plan of Greaulin (Figure 3) indicates the main field boundaries visible at the site today which include the head dyke (a large earth and stone bank which delimits the township's arable land and part of the better pasture from the rough grazing or common pasture), and the 1811 croft boundaries. In order to show how multi-elemental analysis can shed light on the nature of occupation or habitation sites, a sample area was laid out embracing two of the crofts, together with their byres and kailyards. The sampling area lies close to the focus of the pre-1811 clachan as shown by Stobie's map. Figure 3 (inset) shows the two adjacent croft farmsteads and the surrounding field area subjected to sampling in this study. The solid lines on this figure represent stone walls, the buildings they delimit are labelled A–I, and the kailyards J and K. The location of former hearths within buildings A and F were suspected on the basis of their visual appearance, as the soils were a reddish colour (Munsell colour notation 2·5 YR 4/6), in marked contrast to the other

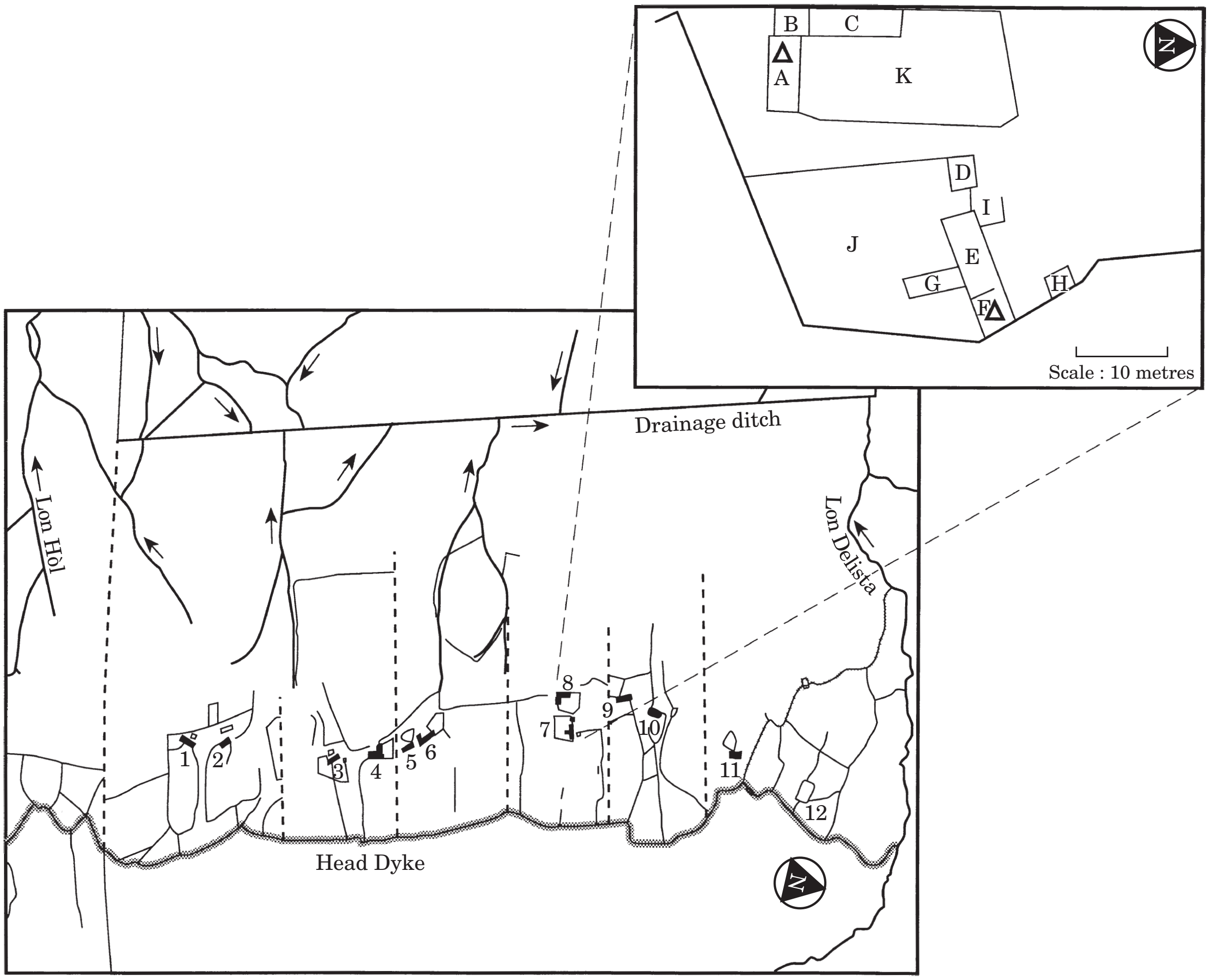

Figure 3. Field layout of the study site at Greaulin indicating the main field boundaries and lines of drainage. The numbers refer to the twelve croft farmsteads at the site. Inset: layout of the habitation site at Greaulin. Letters A–I label former buildings, whilst J and K mark the kailyards.

soils sampled over the site which were dark or very dark brown (7·5 YR 3/3 and 10 YR 2/2, respectively). The larger units (A–C and E–G) are almost certainly 19th-century croft dwellings, of a kind found elsewhere on Skye. The buildings are typical of Skye in that all four walls are the same height, are generally low and consist of double drystone walls (Sinclair, 1953). Despite their archaic nature, many such dwellings were still inhabited in the 1950s, although, as previously mentioned, at Greaulin documentary sources suggest that these croft farmhouses were abandoned in the mid-1850s. The former function of buildings D and H is unclear but the similarity of these buildings to the *cleitean* of St Kilda (small buildings used to store peat, manure or turf; Stell & Harman, 1988) suggests that these buildings may have been used to store manure, peat or turf. Traces of only two walls remain for building I and the former function of this building is unclear.

Methodology

Soil sampling

A systematic sampling grid, with an interval of 5 m, was superimposed over the habitation area described above. A regular grid layout was followed where possible, but in some instances fallen stones prevented sampling. Samples were also collected from within former buildings and this too led to some distortion of the regular grid. In total, 148 topsoil samples (field observation and subsequent analysis indicated that they were mineralized (A horizon) and humose (Ah horizon) material) were collected using a hand operated screw-type auger and stored in Kraft paper bags prior to analysis. Topsoil depth was recorded at each sampling point.

These samples collected from the former habitation area are referred to as on-site soils. In order to assess the extent to which such on-site soils have been affected

Table 1. The Kolmogorov–Smirnov Z value and associated probability (P) for the off-site (control) data. The Kolmogorov–Smirnov procedure was used to test for goodness of fit of the off-site geochemical data to a normal distribution (at a significance level of 0·05)

Element	Kolmogorov–Smirnov Z Value	2-tailed *P*	Element	Kolmogorov–Smirnov Z Value	2-tailed *P*
Magnesium (Mg)	0·8853	0·4133 ns	Lanthanum (La)	0·4954	0·9668 ns
Potassium (K)	0·5125	0·9554 ns	Cerium (Ce)	1·0274	0·2418 ns
Calcium (Ca)	0·8297	0·4967 ns	Praseodymium (Pr)	0·7917	0·5579 ns
Phosphorus (P)	0·9815	0·2903 ns	Neodymium (Nd)	0·6828	0·7397 ns
Scandium (Sc)	1·0362	0·2332 ns	Samarium (Sm)	0·5965	0·8689 ns
Vanadium (V)	1·1555	0·1384 ns	Europium (Eu)	0·6827	0·7398 ns
Chromium (Cr)	1·1315	0·1545 ns	Gadolinium (Gd)	0·7535	0·6212 ns
Cobalt (Co)	0·8860	0·4123 ns	Terbium (Tb)	0·5880	0·8797 ns
Nickel (Ni)	0·8042	0·5374 ns	Dysprosium (Dy)	0·8575	0·4540 ns
Copper (Cu)	0·5280	0·9432 ns	Holmium (Ho)	0·7471	0·6320 ns
Zinc (Zn)	0·7137	0·6883 ns	Erbium (Er)	0·6582	0·7792 ns
Gallium (Ga)	1·0644	0·2073 ns	Thulium (Tm)	0·8765	0·4260 ns
Rubidium (Rb)	0·9088	0·3808 ns	Ytterbium (Yb)	0·5222	0·9480 ns
Strontium (Sr)	1·2660	0·0811 ns	Lutecium (Lu)	0·5086	0·9582 ns
Yttrium (Y)	0·5585	0·9141 ns	Lead (Pb)	0·6658	0·7671 ns
Barium (Ba)	0·9896	0·2813 ns	Thorium (Th)	0·8005	0·5433 ns
Cesium (Cs)	0·5095	0·9576 ns	Uranium (U)	0·6920	0·7245 ns

ns: not significant at the 0·05 level, therefore accept the H_0; H_0, the data are drawn from a normally distributed population; H_1, the population from which the data are drawn is not normally distributed

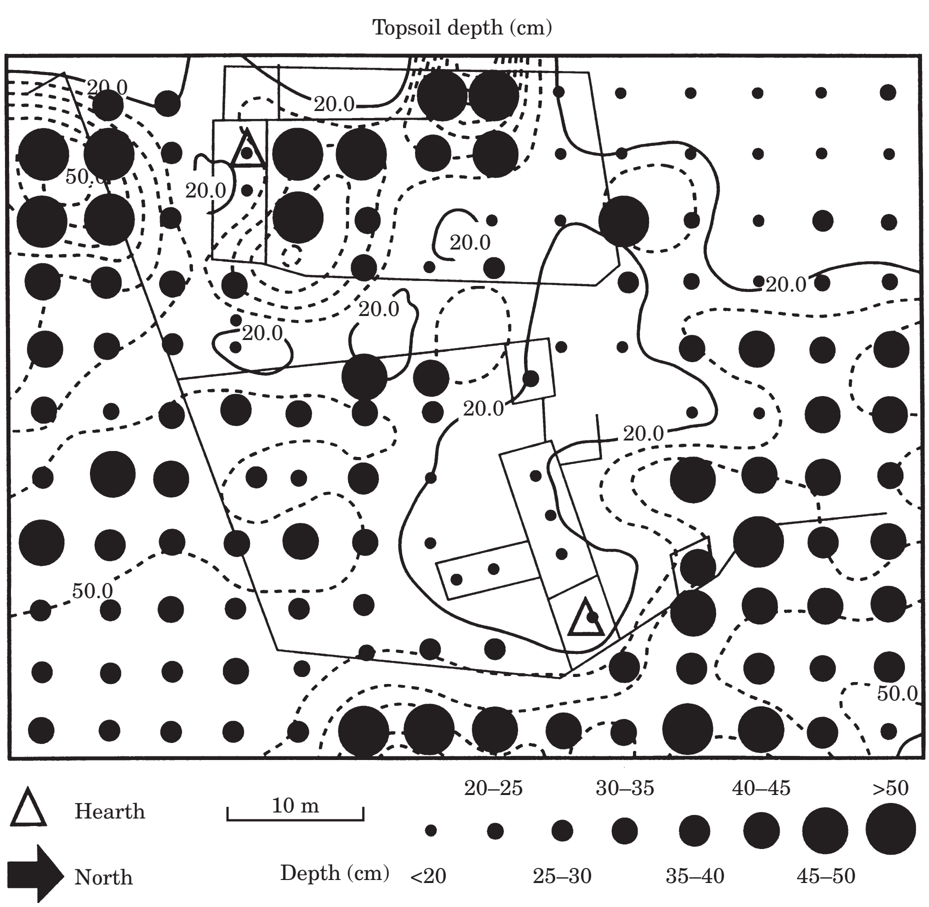

Figure 4. Spatial variation in topsoil depth (cm) over the habitation site at Greaulin.

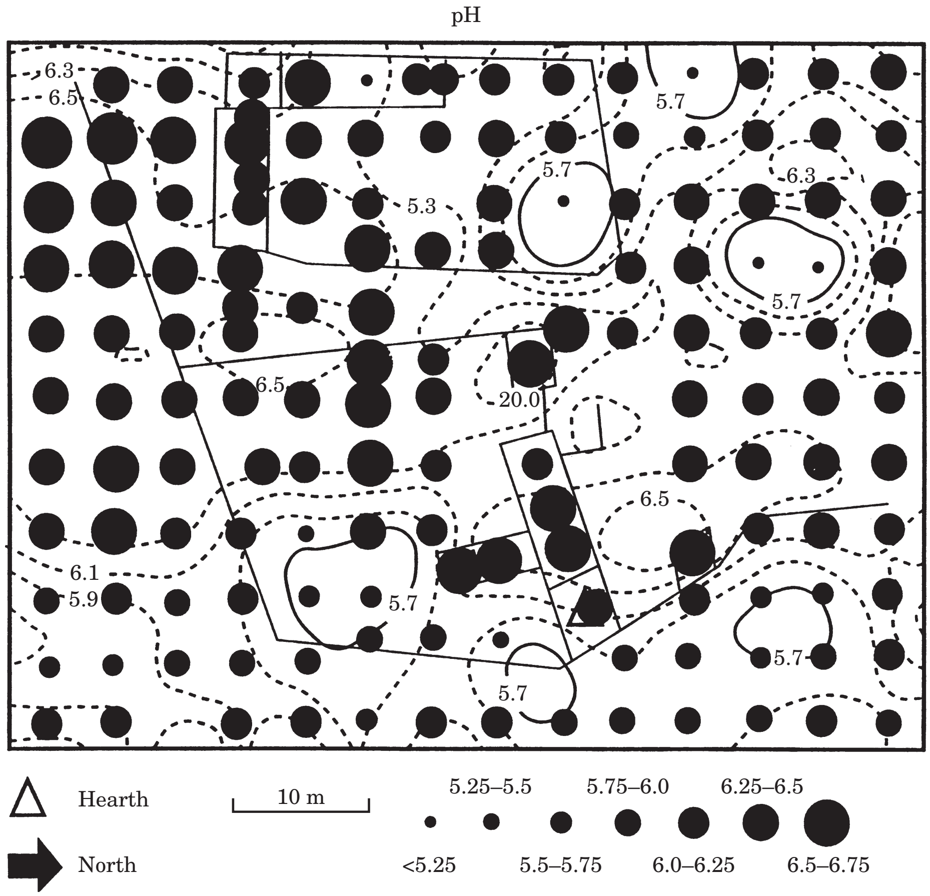

Figure 5. Spatial variation in pH over the habitation site at Greaulin.

by human activity, it was necessary to sample control soil for comparative purposes. Thirty control topsoil samples (i.e. A and Ah horizon material) were collected at regular intervals, about 15 m east of the head dyke. The location may not provide a wholly acceptable control site, but bearing in mind the difficulty of finding such a site (i.e. one which reflects the settlement area studied without human impact), then the location was considered the best available.

Soil analysis

Determination of soil pH was undertaken shortly after sample collection (within 24 h), using a portable pH meter (Whatman International Ltd), with built in pH probe and automatic temperature compensation. Measurements were made on a 1:2·5 (w/v) suspension of fresh soil and distilled water (Bascomb, 1987).

On return to the laboratory, the soil samples were air dried and disaggregated with subsequent analyses undertaken on the <2 mm "fine earth fraction" of the soil. Soil organic matter content was estimated gravimetrically (by loss-on-ignition at 375°C; Ball, 1964) and a "bulk" nitric-perchloric (HNO_3-$HClO_4$, 4:1 v/v) acid digestion procedure was selected for sample decomposition (after Thompson & Wood, 1982). Although chemical fractionation of the variously bound forms of each element may potentially provide more detailed information (e.g. Edwards *et al*., 1983; Ottaway, 1984), as we were interested in rapid site reconnaissance a standard bulk acid digestion technique was selected.

Following acid digestion, 30 elements were determined semi-quantitatively using the simultaneous multi-elemental analysis capability of ICP-MS. Phosphorus was determined separately by ICP-MS in fully-quantitative mode, K by flame emission and Mg and Ca by atomic absorption spectrometry. For our assessment of measurement precision (reproducibility), those elements where repeated sample digestion and analysis produced an arbitrarily chosen coefficient of variation of $\leqslant 15\%$ were deemed to have acceptable precision, and hence considered worthy of further study. The laboratory procedures (including quality control) employed for the determination of these elements are described in detail in Entwistle & Abrahams (1997).

Data analysis

The on-site geochemical data are expressed as "enrichment factors" relative to the mean value of the control (off-site) samples. Thus, the enrichment factor of each

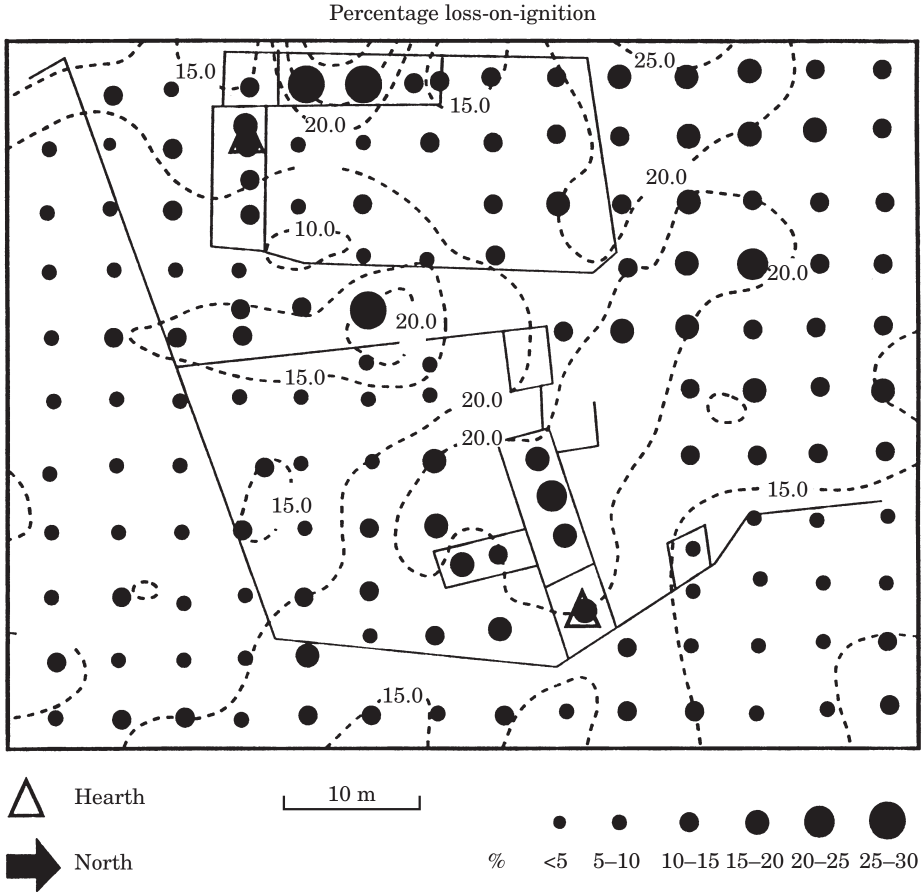

Figure 6. Spatial variation in % loss-on-ignition over the habitation site at Greaulin.

element for each on-site sample was calculated by dividing the concentration of the on-site sample by the mean off-site value. An estimation of what level of enrichment constitutes a minimum significant enrichment was arbitrarily set at two S.D. above the control mean. This value (off-site control mean +2S.D.) was divided by the mean off-site value to give an estimation of the minimum significant enrichment value for each element. As frequency distributions of geochemical data are often skewed (and estimations of the mean and the S.D. of a data set are only valid when the data are normally distributed) the Kolmogorov–Smirnov test was initially undertaken on the control data to check for normality of each of the 34 elements considered in our study. All of the 34 elements from the control data had an observed distribution which was not significantly different from the normal distribution at the 95% confidence level (Table 1). Following this consideration of the control data, any on-site enrichment factors which exceed the minimum significant enrichment value (i.e. control mean+2S.D./control mean) are considered to be significantly enriched. The calculation of minimum significant enrichment factors enables the identification of areas which are enriched in one or more element, and allows comparisons to be made between the various elements, which typically occur over a wide range of concentrations.

In an attempt to provide a clear picture of the overall trends in the soil properties investigated, the data are presented in the form of contour plots. As the on-site soils were collected following a near regular grid system the soil data lent themselves to contouring. As contours result mostly from a process of interpolation between data points any deviation from a regular grid (such as that enforced by the nature of the sampling site at certain locations at Greaulin) may result in contour inaccuracy and a distortion of the underlying trend in the data. Plotting the data as proportional symbols aids interpretation of the contour plots and reduces the chance of incorrect inferences due to contour inaccuracy.

The calculated level of minimum significant on-site enrichment is indicated by a solid, rather than a dashed, contour line on each of the diagrams. On-site samples with elemental enrichments below this level are indicated as "not significant" (Not Sig.) and are represented on the data plots by a cross (x).

Cluster analysis was undertaken on the on-site soil geochemical data in order to simplify the data set and group together those elements with similar spatial enrichment patterns. There is a great proliferation of clustering techniques and consideration must be given not only to the choice of method but also to the choice of which similarity or distance measure to use (Everrit, 1980). In this study, the analysis was carried out using the multivariate statistical package MVSP (Kovach, 1990), and Ward's minimum variance method was undertaken on a squared Euclidean distance dissimilarity matrix, following conversion of the data to enrichment factors to standardize the data set. This agglomerative clustering technique was selected as it exaggerates differences in the data and produces a dendrogram with large changes in level and clearly identifiable clusters.

Results

Spatial patterns: topsoil depth, pH and % loss-on-ignition

The mean topsoil depth of the off-site control soils at Greaulin is 20 cm and is represented by the solid 20 cm contour on Figure 4. For the on-site soils, a topsoil depth of less than 20 cm is observed within all buildings, with the exception of building H where a topsoil depth of 40–45 cm was recorded. Immediately adjacent to the former building A–C, and within kailyard K, the topsoil depth increases to greater than 50 cm. The abundance of fallen stone from the walls of farmstead E–G prevented an estimation of topsoil depth around this former dwelling. Topsoil depths in the field areas along the southern and eastern margins of the site are generally deeper than 30 cm. In contrast, topsoil depths in the field area to the north-western part of the site are less than 20 cm, similar to the values observed within the buildings.

The soil pH over the site ranges from 5·1 to 6·6 (i.e. strongly acidic to slightly acidic). The mean pH of the off-site control soils is 5·7, represented on Figure 5 by a solid contour line. In general the on-site soils are less acidic than the control soils, with the majority of samples (88%) having a pH value greater than 5·7. No trends are apparent in the variation of pH over the site, though a clustering of less acidic values (pH 6·5–6·75) occurs in the south-west region of the site.

The mean loss-on-ignition of the off-site control soils is 25% (indicative of a humose topsoil, Ah) and the on-site topsoils indicate a depletion in the level of % loss-on-ignition relative to this value (Figure 6). The highest levels of on-site loss-on-ignition (greater than 15%) are found over the north-west region of the site and in the interior of the buildings, with the exception of buildings D and H. The lowest levels (below 10%) are found in the field area to the south of the croft farmsteads.

Spatial patterns: major and trace elements

Four main groups of elements were identified by cluster analysis of the geochemical data and represent

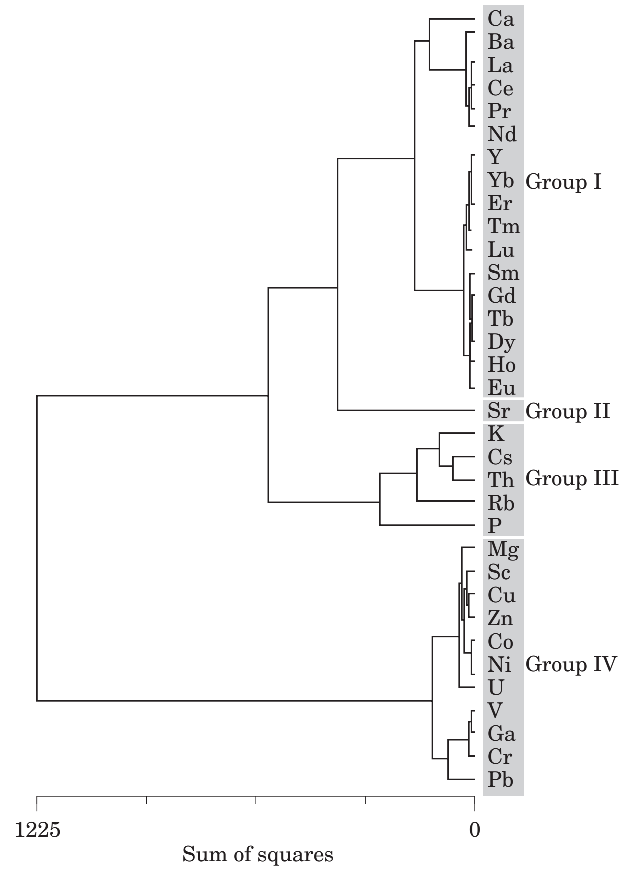

Figure 7. Dendrogram to show results of the cluster analysis of the geochemical data obtained from the analysis of the habitation site soils at Greaulin.

the four main patterns of spatial enrichment observed at Greaulin (groups I, II, III and IV on Figure 7). These four groups form the basis of the following discussion.

Cluster group I contains the elements Ca, Ba, Y and the rare earth elements (REEs; La–Lu). The members of this group can be further divided into three subgroups on the basis of the results shown in the dendrogram (Figure 7):

Subgroup A: this subgroup is represented by Ca. Virtually the whole site is significantly enriched in Ca (Figure 8), with concentrations up to 4·5 times the mean level found in the control soils.

Subgroup B: this group contains the elements Ce (Figure 9), Ba, La, Pr and Nd. The majority of samples indicate significant enrichment relative to the control soils. However, enrichment values are generally less than 3·5, with only a few samples having enrichment values of up to 4·0.

Subgroup C: this group contains Y and the REE's Tm (Figure 10), Yb, Er, Lu, Sm, Gd, Tb, Dy, Ho and Eu. Virtually the whole site shows significant enrichment, but enrichment is typically less than 2·5 times the control mean.

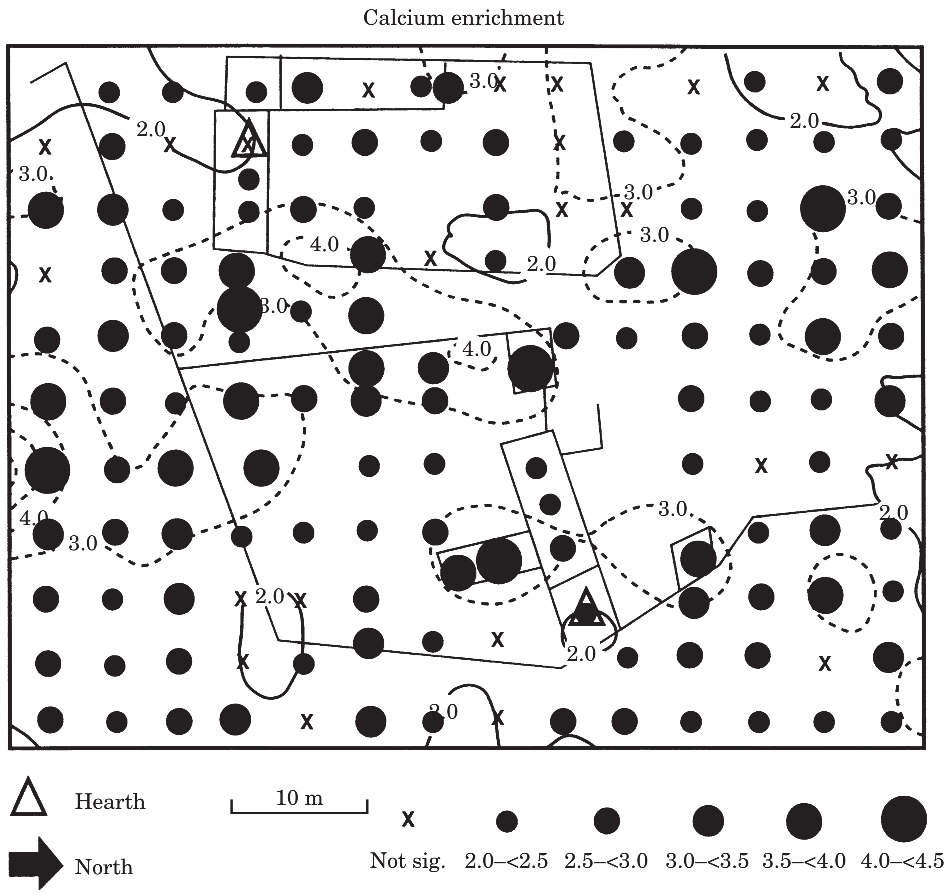

Figure 8. Calcium (Ca) enrichment over the habitation site at Greaulin relative to the off-site control soils. The calculated level of minimum significant enrichment for Ca (group IA) is 2·0.

Cluster group II contains the element Sr (Figure 11). The field area surrounding the croft farmsteads indicates significant Sr enrichment, with the exception of two areas to the north of the farmsteads A–C and E–G where enrichment values are generally less than 2·0. The level of Sr enrichment in the field areas is typically 3·0 times the control mean, with values up to and exceeding 5·0. Less enrichment is associated with the kailyards J and K, whilst negligible enrichment is observed within the buildings.

The elements of cluster group III have enrichment values up to and in excess of 6·5 times the control mean. Cluster analysis separates P from the other group III elements and hence group III is divided into two subgroups:

Subgroup A: this subgroup contains the elements K (Figure 12), Cs, Th and Rb. All these elements show enrichment values of greater than 5·0 in the north-western part of the site. Enrichment of K, Rb and Th is also observed within buildings A to H, and to a lesser extent the kailyards J and K. The remainder of the site generally shows enrichment levels below 2·5.

Subgroup B: this subgroup contains the element P (Figure 13). The pattern of P enrichment observed in the north-west corner of the surveyed site is relatively subdued compared to that found for the group III A elements. Although this region shows P enrichment values of 2·5–3·0, higher levels, in excess of 5·0, are found slightly to the east of this location. Elevated P levels are also observed in the buildings A–H and parts of kailyards J and K. Only minor P enrichment is found in the field areas to the east and south of the site, where enrichment values are typically less than 2·0.

Cluster group IV contains the elements Mg (Figure 14), Sc, Cu, Zn, Co, Ni, U, V, Ga, Cr and Pb. Very few samples indicate significant elemental enrichment relative to the control soils and, with the possible exception of Mg which is enriched in both of the suspected hearth soils in buildings A and F, samples indicating significant enrichment appear to be randomly distributed over the site, with no readily interpretable significance.

Small scale spatial variability

The relative variability of each of the soil parameters under investigation has been expressed through the coefficient of variation (CV, i.e. S.D./mean × 100). CV is a statistic that is independent of the unit of measurement and allows variability to be compared for sets of

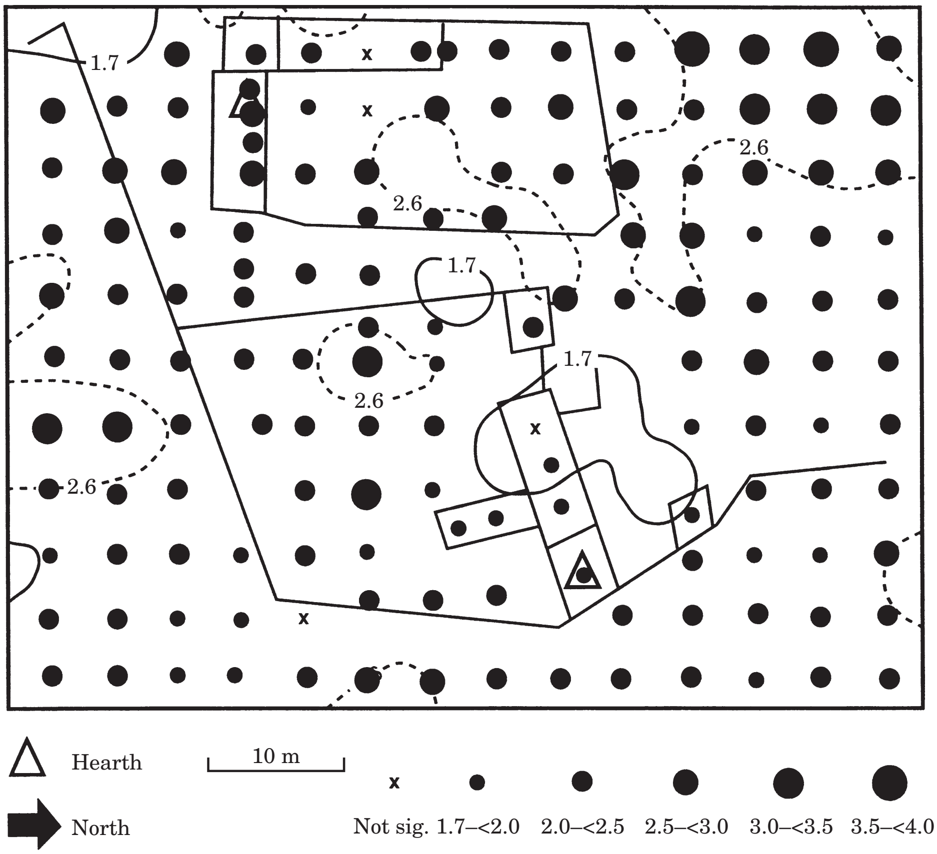

Figure 9. Cerium (Ce) enrichment over the habitation site at Greaulin relative to the off-site control soils. The calculated level of minimum significant enrichment for Ce (group IB) is 1·7.

data which typically occur over a range of units and concentrations. For data sets with high variability, CV approaches (or even exceeds) 100, whilst a CV near zero indicates low variability in the data set (Earickson & Harlin, 1994). As indicated in Table 2 (with the exception of pH), the on-site and off-site soils generally exhibit a moderate degree of spatial variability with values for CV ranging from 14·9% to 49·5% for the on-site soils and from 20·7% to 70·2% for the off-site soils. Those properties/elements which indicate on-site variability greater than twice that observed in the off-site soils are indicated in Table 2 by italics (i.e. depth, K, P, Rb and Cs).

Discussion

Soil properties indicative of human habitation

Elevated concentrations of K and Rb, and to a lesser extent Th, are observed in the soils collected from within the buildings A–H, while negligible enrichment is observed in the field areas along the southern and eastern margins of the study site. These results, and the results of the W traverse sampling strategy (Entwistle *et al.*, 1998), appear to suggest a link between the enrichment of these elements and sites of former dwellings and associated buildings at Greaulin. Previous studies have found a similar link between elevated levels of soil K and intense human activity (e.g. Woods, 1983) with cultural sources of K including excreta, seaweed and wood-ash (Woods, 1983; Davidson & Simpson, 1984).

Higher enrichment values (up to and exceeding 6·0) of these same elements as well as Cs are found in the north-western part of the intensive sampling site, suggesting that this area too has been influenced by human habitation, although no visible remains of buildings exist at this location today. This area is perhaps associated with the nucleated habitation site of the former clachan. Indeed, according to Stobie's map (1764), the clachan site occupied this part of the township prior to the laying out of the crofts. Furthermore, the high levels of enrichment suggest that the soils of the former clachan area have been influenced by settlement activity for a longer period of time than those of the croft farmsteads. It may equally reflect differences between the two types of settlement in the rates of annual input of these elements. As the clachan was a nucleated settlement inhabited by a number of families it is likely that the overall impact on the soil

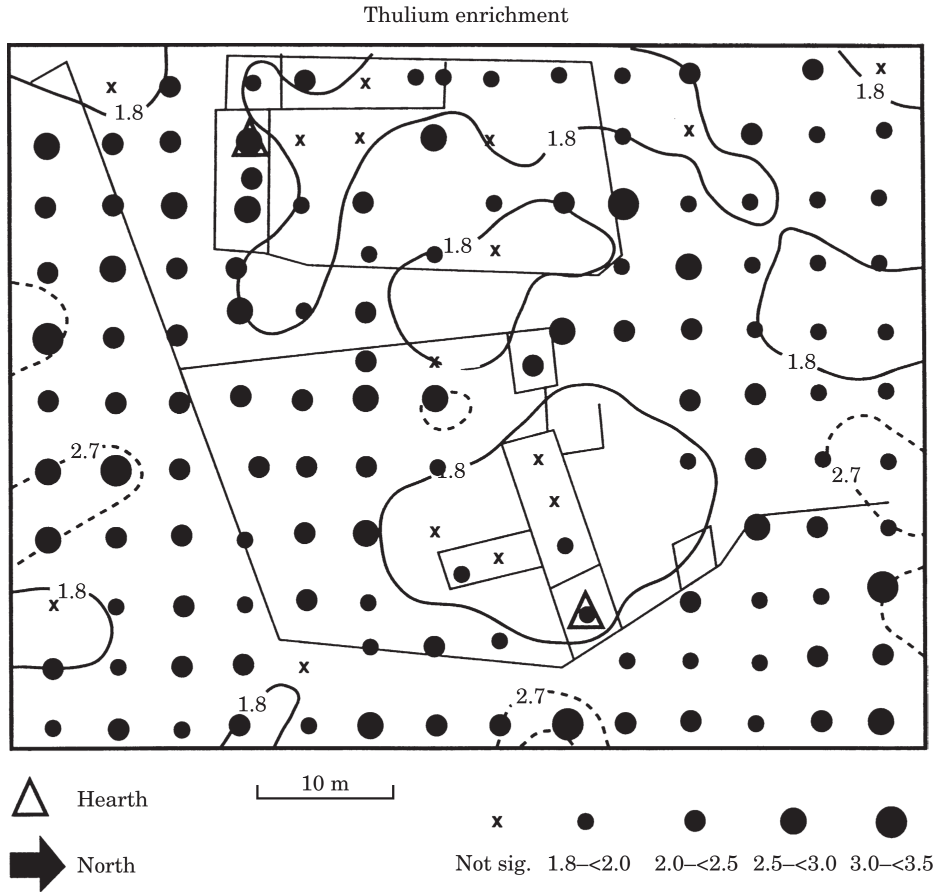

Figure 10. Thulium (Tm) enrichment over the habitation site at Greaulin relative to the off-site control soils. The calculated level of minimum significant enrichment for Tm (group IC) is 1·8.

could have been greater than that of a dispersed settlement, such as the croft farmsteads, where each site would have been occupied by only one family.

In contrast to soil K, no work has been published regarding the behaviour of Cs, Rb and Th in relation to human settlement activity, however a link is suggested by the results from Greaulin. It is not too surprising to find similarities in the spatial patterns of K, Rb and Cs since these three elements have similar geochemical characteristics (Wedephol, 1969; Kabata-Pendias & Pendias, 1984). Specific geoarchaeological sources of Rb and Cs are not known, but Wedephol (1969) suggests that plants may concentrate Cs in their tissues. Thus, additions of food scraps, animal fodder and bedding may result in Cs enrichment. Once incorporated into the soil Cs may be rapidly and strongly sorbed by solid soil material rendering it relatively immobile (Kabata-Pendias & Pendias, 1984). As such, Cs may be a reliable record of settlement activity and its correspondence with areas of K enrichment and the location of the former clachan seems to substantiate this. Thorium may be similarly sorbed in soils through the formation of only slightly soluble precipitates and by adsorption onto clays and organic matter (Wedephol, 1969; Kabata-Pendias & Pendias, 1984). As Th is not known to be an essential element in any organic process and is not known to accumulate to any significant degree in animal or vegetable matter, the reasons for the correspondence between elevated levels of Th and the former clachan site are unclear.

Measurements of topsoil depth are also very effective at picking out former habitation sites (Figure 3), with shallow topsoils (<20 cm) observed in the two croft farmsteads and over the north-western region of the site. Topsoil depths are typically in excess of 30 cm in the field area surrounding the two farmsteads and are thought to reflect the incorporation of fertilizers, such as seaweed and manure, and other additives, such as turf and peat, to the cultivated fields.

Many of the additives and manures which formed an important part of arable cultivation in the Hebrides would have supplied organic matter to the soils (Dodgshon & Olsson, 1988). This is especially true of manurial inputs from livestock. An initial consideration of this information may lead to a conclusion that inputs of manure lead to an accumulation of organic matter in the affected soils. However, the analytical evidence indicates that the soils of the areas adjacent to

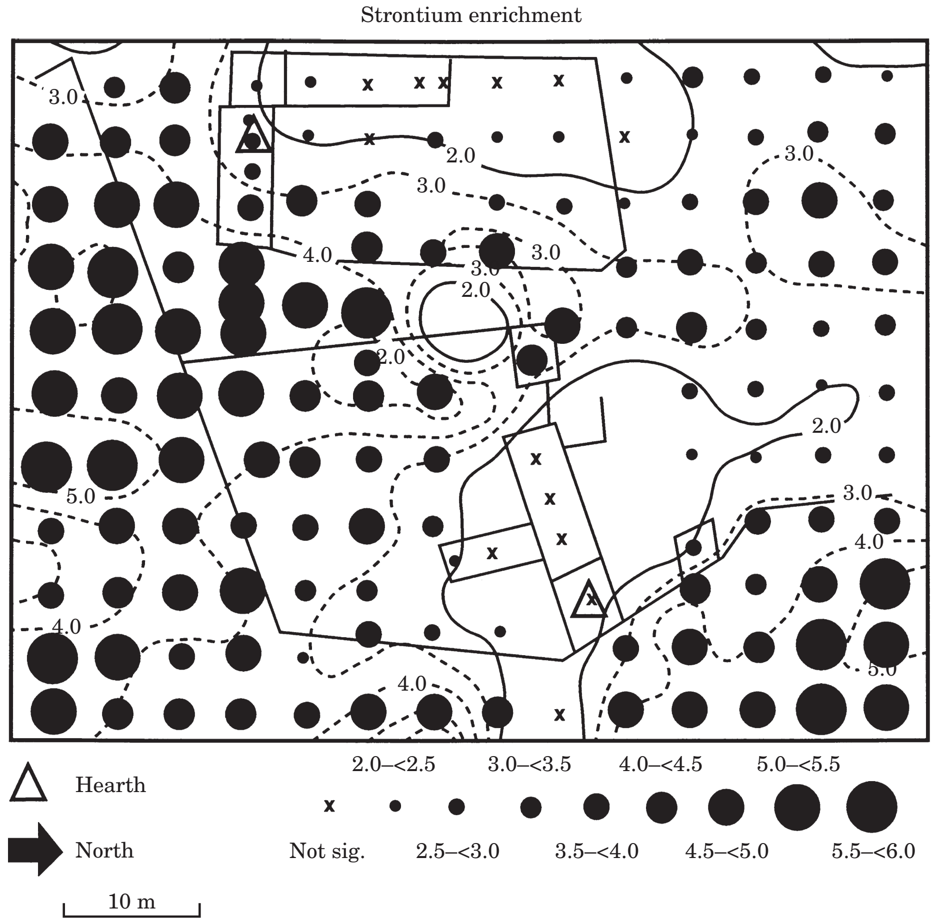

Figure 11. Strontium (Sr) enrichment over the habitation site at Greaulin relative to the off-site control soils. The calculated level of minimum significant enrichment for Sr (group II) is 2·0.

the croft houses are depleted in organic matter (and the loss-on-ignition values of these "field" soils are less than the off-site control soils). Possible reasons for this observed organic matter "depletion" relate to the former use of these soils for arable cultivation. Cultivation and regular cropping typically enhances the rate of organic matter decomposition by altering soil conditions in various ways, such as increasing soil aeration and breaking up soil aggregates exposing previously protected organic matter to microbial attack (Woods, 1983; Sandor, 1992). This may explain the apparent depletion of organic matter in these former arable soils.

As previously mentioned, the location of two suspected hearths within buildings A and F were identified on the basis of their reddish colour. The oxidation of Fe during the cooling down of fires, when air enters the system, gives hearth soils a characteristic red colour (Longworth & Tite, 1977). Heidenreich and Konard (1973), Griffith (1981) and Konrad *et al.* (1983) have suggested that peaks of Mg enrichment may also be used to identify the location of former hearths, possibly because Mg is concentrated in deposits of wood ash. As the components of ash are largely alkaline in reaction, one might also expect hearth samples to be more alkaline than adjacent soil samples. However, the pH values of the two hearth samples at Greaulin are similar to the other on-site soils (Figure 5). The two suspected hearth samples do show Mg enrichment (Figure 14), but the magnitude is low, and four other samples, not thought to be associated with hearths, have similar values. The suspected hearth samples also contain elevated concentrations of K, Rb and P compared with the other topsoils sampled within the buildings of the croft farmsteads (Figures 12 & 13). The elevated levels of these elements in the hearth samples may be associated with the large throughput of organic materials in areas associated with food preparation and cooking activity (Provan, 1973; Griffith, 1981; Conway, 1983). The enhanced P levels associated with the hearths may also be due to the fixation of P onto iron oxides, formed at elevated temperatures (Conway, 1983). Although geochemical enrichments of Mg, K, Rb and P are observed in the hearth samples, the geochemical data alone are insufficient to identify these samples as hearths since similar levels of enrichment are observed elsewhere over the site in samples which do not show the characteristic red colour.

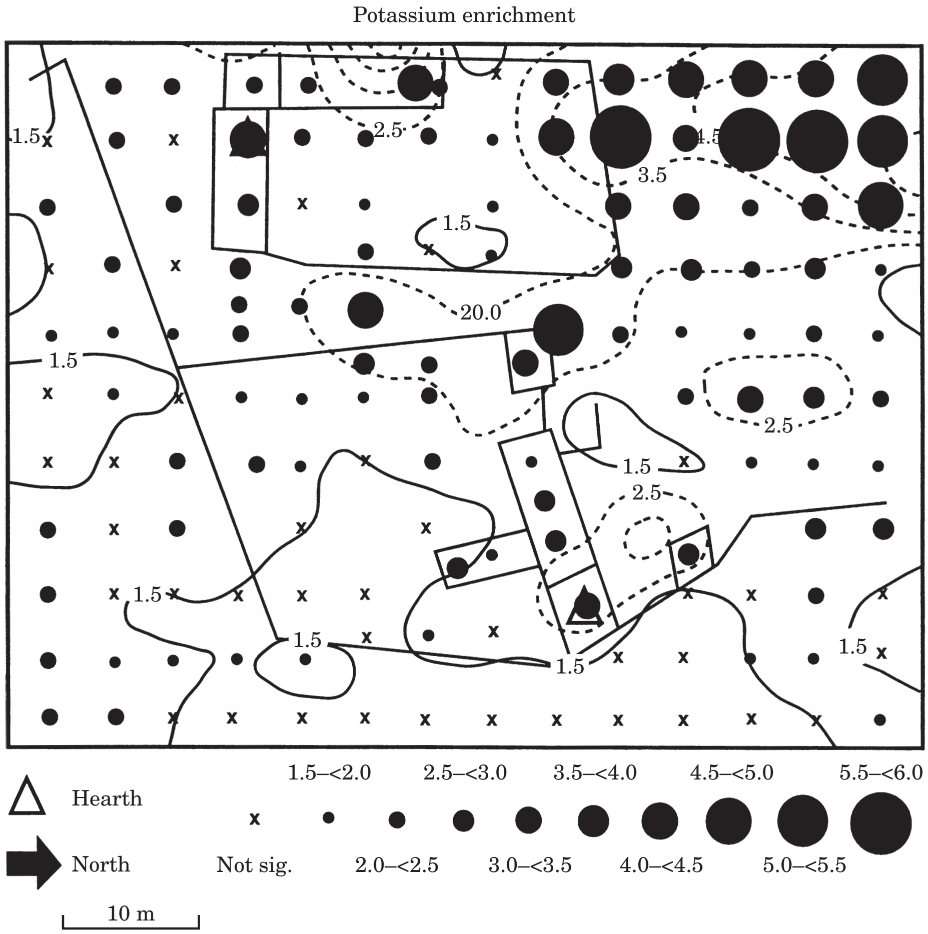

Figure 12. Potassium (K) enrichment over the habitation site at Greaulin relative to the off-site control soils. The calculated level of minimum significant enrichment for K (group IIIA) is 1·5.

Elemental enrichment associated with farming activity

Low levels of Ca and Sr enrichment are observed in the majority of the soils collected from within the croft buildings and from the north-western part of the site. In contrast, higher enrichments are found in the southern and eastern parts of the site associated with those areas which are thought to have been cultivated and which may have been given such enrichment may reflect additions of shell-sand, bone and fish refuse as manure (see Entwistle *et al*., 1998). The Sr enrichment to the north of the buildings E–G is low, implying that no such additions have been applied to this field area. This is an area discussed in more detail below.

Over this habitation site no distinct spatial patterns in the pH data are found, though the majority of the soils are less acidic than the off-site control samples. Soil acidity may have been decreased over the entire site by the addition of hearth ash, fish and bone debris in and around the buildings, and calcareous shell sand, fish and bone refuse to the fields. Indeed, this may account for the lack of any pH anomaly associated with the hearth samples.

Spatial distribution of soil phosphorus

In many previous studies, the value of P in archaeological diagnostic work has been more evident than for any other element (Bethell & Mate, 1989), and, interestingly in this study, the cluster analysis separates this element from the other group III elements (Figure 7). As such, P will be discussed separately in this section.

The pattern of P enrichment at Greaulin has many similarities with those for K, Cs, Th and Rb, which have been linked with areas of human habitation in this study. Over the habitation site at Greaulin the buildings A–H and parts of kailyards J and K contain up to 6·0 times the average amount of P found in the control soils. The north-western part of the site, believed to have been the location of the former clachan settlement, also shows elevated concentrations of P, with levels of enrichment between 2·5 and 3·5. The highest concentrations of P, with enrichment levels generally in excess of 5·0, are observed to the east of this former clachan area. However, the moderately deep topsoils (greater than 20 cm) and the lack of any

Figure 13. Phosphorus (P) enrichment over the habitation site at Greaulin relative to the off-site control soils. The calculated level of minimum significant enrichment for P (group IIIB) is 1·5.

corresponding enrichment of other elements indicative of human habitation (K, Rb, Th and Cs) suggest that this latter area has not been a site of human habitation. The low levels of Sr enrichment (and to a lesser extent Ca) imply that shell sand and other similar fertilizers have not been applied to this area which in turn suggests that this area does not indicate former use for cultivation. One possible interpretation of these data is that this area was the site of a byre, where manure accumulated during the overnight housing and penning of stock. Manure is rich in P, and high soil P values associated with the accumulation of livestock manure are consistent with the results of Balaam *et al.* (1982) and Craddock *et al.* (1985).

Elements of limited use in the differentiation of land-use activity

Previous studies have shown Cu and Zn to be enriched over sites influenced by human activity through the accumulation of refuse and excreta (Bintliff *et al.* 1990). At Greaulin the majority of samples indicate no significant enrichment of these elements, however, and although three samples from buildings A and B show Zn enrichment of between 2 and 2·5 relative to the control soils, neither Zn or Cu are consistent indicators of human habitation areas at this site.

The REE's (La–Lu), Y and Ba all indicate general on-site enrichment compared to the off-site control soils, though the peaks are scattered over the site and show no clear association with either those areas formerly influenced by human habitation or those affected by agricultural activity. Lead, Ni, Co, Sc, U, V and Ga show little or no significant on-site enrichment over the habitation site at Greaulin, while Cr, as for the overall site survey (Entwistle *et al.*, 1998), is the only element to indicate a noticeable depletion in concentration relative to the off-site soils.

Soil spatial variability

The data in Table 2 suggest that for the vast majority of elements, even those which show a significant on-site enrichment relative to the off-site control soils, when one compares the on-site with the off-site soils the degree of spatial variability (as expressed by the CV) is remarkably similar for the majority of elements. At first sight this might appear surprising given that the off-site data are believed to reflect solely natural background variability whilst the on-site soils have the

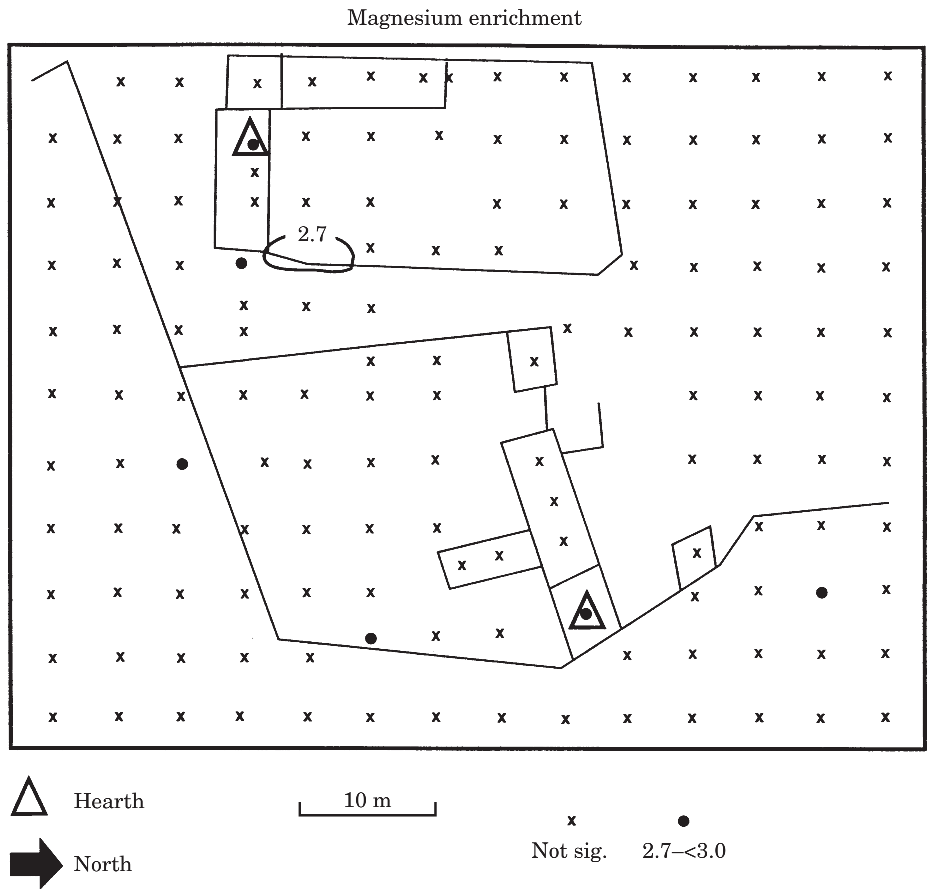

Figure 14. Magnesium (Mg) enrichment over the habitation site at Greaulin relative to the off-site control soils. The calculated level of minimum significant enrichment for Mg (group IV) is 2·7.

additional variability imposed by human activity, however, as the off-site soils were collected along an 800 m transect which runs the length of the study site, increased variability might result as a product of integrating results over a larger area. Whatever the reason for this similarity, it is interesting to note that those elements hypothesized to be directly related to human habitation, and extremely good indicators of former dwellings at this site, generally exhibit a much greater degree of on-site spatial variation than observed off-site (e.g. K CV—on-site 48·3, off-site 23·9; Rb CV—on-site 45·7, off-site 27·2; Cs CV—on-site 49·5, off-site 23·8).

It is clear that the degree of variability in the soil parameters investigated over this site has implications for the sampling strategy of soils collected from former habitation sites. The data sets presented above in Figures 4–6 and 8–14 indicate the complex patterns of variability found over the Greaulin site and highlight potential problems with the use of standard sampling procedures, such as the W traverse method, which produce bulked or composite samples. The problem is somewhat analogous to sampling contaminated land when one is trying to pin-point "hot spots" of contamination in an area where the majority of the site exhibits fairly low levels of contamination. If ancient farmstead boundaries are clearly defined, or if more recent habitation overlies a previous settlement site, then the problem of obtaining a representative soil sample following bulk sampling may not be so acute (e.g. see Entwistle *et al*., 1998). In such instances there is a greater likelihood of bulking soil samples which have all been influenced by the same type of activity. The vast literature dealing with the assessment of potentially contaminated land clearly recommends that spot samples, rather than bulk or composite ones, are the preferred method of sample collection (e.g. ICRCL, 1987; Ferguson, 1992). Such a recommendation would also seem appropriate when one is investigating a former occupation site.

Conclusions

One of the main aims of the soil analyses undertaken at Greaulin was to identify those soil properties that had been modified by human activity and to differentiate between those areas directly affected by human habitation and those influenced by arable cultivation of the adjacent field area. Five elements (K, Rb, Th, Cs and

Table 2. Mean and Coefficient of Variation (CV, S.D./mean × 100) for each of the soil properties and elements determined on the 148 on-site and 30 off-site soil samples. Elemental concentrations are in μg/g air-dried soil

Soil Property	On-site Soils Mean	On-site Soils CV	Off-site Soils Mean	Off-site Soils CV
Topsoil depth	31 cm	51·7	20 cm	33·2
pH	6·2	6·0	5·7	4·5
% loss-on-ignition	16·7%	26·1	25%	18·1
Ca	4,880	26·8	1,840	49·8
Mg	25,100	26·1	16,300	66·0
K	939	48·3	430	23·9
P	2,691	45·4	1,010	21·5
Sc	11·9	23·2	7·56	35·3
V	131	20·8	140	27·7
Cr	196	18·9	283	34·9
Co	46·6	18·3	35·1	53·5
Ni	187	22·5	157	50·7
Cu	102	21·1	70·3	39·7
Zn	155	21·2	107	38·8
Ga	15·2	14·9	16·5	23·8
Rb	9·70	45·7	3·13	27·2
Sr	142	38·8	43·2	70·2
Y	8·69	21·5	4·30	24·2
Cs	1·31	49·5	0·65	23·8
Ba	121	17·8	50·2	40·9
La	11·0	19·1	4·61	20·7
Ce	22·6	19·1	9·80	26·2
Pr	2·57	19·0	1·08	23·3
Nd	10·7	19·4	4·85	23·5
Sm	2·17	21·0	1·10	24·4
Eu	0·637	21·0	0·36	25·8
Gd	2·46	19·9	1·29	27·3
Tb	0·36	19·6	0·19	26·5
Dy	1·82	19·5	0·96	27·9
Ho	0·317	22·7	0·16	26·0
Er	0·917	20·1	0·44	29·8
Tm	0·112	21·8	0·05	34·9
Yb	0·686	21·2	0·34	25·0
Lu	0·09	24·4	0·05	33·5
Pb	11·05	48·4	10·2	40·2
Th	1·25	34·1	0·48	25·2
U	0·567	33·5	0·45	38·5

Sr) were found to be useful in differentiating between those areas that had been influenced by human habitation and those that had not. Enrichments of K, Th, Rb and, to a lesser extent Cs, were observed in areas of former habitation. The interpretation of P was more complex, with enrichment not only associated with former habitation areas, but also with the croft kailyards and an area which, we speculate, may be indicative of a former byre. The results suggest that P is a less reliable indicator of human habitation than K, Rb and Th, possibly because P enrichment may be caused by additions of animal manure as well as by habitation of an area.

Topsoil depth and % loss-on-ignition were both found to be useful in differentiating between those areas affected by human habitation and those influenced by arable cultivation. Topsoils were found to be shallower and to have higher levels of % loss-on-ignition in former habitation areas than in the former arable field areas.

Enrichments of Ba (and to a lesser extent La, Ce and Pr) occur both within the formerly inhabited areas and the former arable fields. As such, these elements are less reliable indicators of actual sites of human habitation than K, Rb, Th and Cs.

Hot spots of enrichment in areas of human occupation, which are not duplicated or matched by comparable enrichment of former arable or cultivated areas, can be used to prospectively locate possible sites of former settlement where no upstanding remains survive. Such chemical finger-printing of former settlement sites may have a valuable diagnostic role to play in researching the history of Highland settlement.

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