The Effect of Waste Disposal on Soils in and Around Historic Small Towns

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Submitted to University of Stirling, March 2008

For the degree of Doctor of Philosophy

This research was undertaken at the School of Biological and Environmental Sciences, University of Stirling, Stirling, UK

Statement of Originality

I hereby confirm that this research was carried out by the undersigned alone and that all research material has been duly referenced and cited.

Kirsty Ann Golding (28/03/08)

Acknowledgements

This study was primarily funded by the Natural Environment Research Council (NERC) with supplementary assistance from Scottish Natural Heritage (SNH).

I would like to thank Prof. Donald Davidson for having the chutzpah to take me on in the first place and for his continued support throughout the course of this research. I would also like to thank his ‘second in command’ Dr Clare Wilson who proved an invaluable source of knowledge on all things anthropogenic in thin section. She also bought me countless cocktails at conference dinners, for that I am appreciative. In addition retrospective gratitude goes to Dr David Shimwell, formerly of Geography at Manchester University, who paved the way for a future career in the realm of Geoarchaeology.

I would like to thank all past and present residents of Lauder, Pittenweem and Wigtown, for depositing rubbish in the first place and allowing me to investigate it several hundred years later. I am indebted to Dr Catherine Wearing and Andrew Collinge for help given during field work especially in digging test pits, driving, dodging cattle and avoiding the local crazies.

I would like to acknowledge the following people based within the School of Biological and Environmental Sciences, University of Stirling; Prof Ian Simpson for advice during early stages of research, Helen Ewen for assistance in the laboratories, George McLeod for making thin sections, Scott Jackson and Bill Jamison for all things computer related, and Kate Howie for guidance with statistical analyses.

Finally, thanks to the original proprietors of room 3a124a, you know who you are.

Abstract

Soils in the urban environment are distinctive in that they are modified through waste amendments. Consideration has been given to how urban soil properties reflect current human influence; however, recent studies highlight their potential as historical archives. The impact of waste disposal on the nature, properties and formation of urban soils is significant, especially in historic small towns where the extent and complexity of refuse management practices is only just emerging. This study uses a multi-method approach to characterise and understand modes of urban anthrosol formation in three Scottish burghs; Lauder, Pittenweem and Wigtown. The objectives of this study are threefold; to establish the nature and diversity of urban anthrosols in and near to historic small towns, to characterise and account for the multiplicity of urban anthrosols in and near to historic small towns, and to elucidate the processes associated with waste management and disposal in historic small towns.

Physical, chemical and micromorphological analysis of topsoil deposits indicate sustained addition of past waste materials to soils within and near to historic small towns. Soil characteristics were heterogeneous across burghs; however, distinct patterns according to past functional zones were identified. The burgh core and burgh acres are important areas of interest at all three burghs. Soil modification was most pronounced within burgh cores resulting in the formation of hortic horizons. Soils within burgh cores are characterised by neutral pH, increased organic matter content, enhanced magnetic susceptibility and elevated elemental concentrations such as calcium, phosphorus and potassium. In comparison the nature and extent of soil modification within burgh acres is more varied. At Lauder hortic soils were identified in the burgh acres suggesting pronounced soil modification through cultivation. Deepened topsoil in the burgh acres at Pittenweem provided evidence for application of mineral rich waste materials in the past. Moreover, magnetic and elemental enhancement (barium, phosphorus, lead, zinc) within the burgh acres south of Wigtown revealed historic soils based anthropogenic signal.

It is argued that changes in soil characteristics at Lauder, Pittenweem and Wigtown can be explained through processes of waste management and disposal in the past. Evidence from micromorphological analyses suggests that waste in burgh cores typically comprised domestic waste, animal waste, building materials and fuel residues. These materials were also identified within burgh acres, although it is noted that their abundances were significantly lower. Variation in urban anthrosol characteristics between burghs is attributed to differing industries and patterns of resource exploitation, for example marine waste associated with fishing was only identified in coastal burghs.

The sustained addition of waste materials to soils within and near to historic small towns was an effective waste management strategy. Waste disposal in burgh cores was likely to be a combination of direct application and midden spreading in back gardens. This led to enhanced soil fertility which was important in the development of urban horticulture; particularly for poorer inhabitants who did not have access to arable farm land adjacent to the burgh. Dunghills acted as temporary stores of waste in the main thoroughfares of Lauder, Pittenweem and Wigtown. These dunghills were systematically transported to the burgh acres for further use as a fertiliser; hence, an early form of urban composting. Processes of waste disposal could not be deduced from soil characteristics alone; however, likely methods include direct waste deposition, storage and redistribution of midden waste, and storage and redistribution of dunghills.

The limitations of soil classification systems and mapping are highlighted, for example urban soils are either omitted from soil maps or are misclassified. It is recommended that urban soils in historic towns should be incorporated into future regional soil maps. Urban soils represent a complex archive of past human behaviour not necessarily reflected in archaeological excavation or documentary analysis. It is argued that soil and artefacts are equally important, hence soil should be a consideration in urban heritage and conservation strategies.

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1 The Importance of Heritage and Conservation in Historic Small Towns

This chapter presents a brief introduction to previous and current trends in urban heritage conservation. Specific attention is paid to the importance of soils within historic small towns.

1.1 Trends in Urban Conservation

Historic small towns are complex urban archaeological sites characterised by the legacy of successive inhabitants. Moreover, they are diverse in form, scale and location, and have unique identities deep-rooted in local tradition, industries and agriculture (Evans 1999). Until recently little consideration has been given to conserving urban archaeology. Appreciation of the cultural value of urban heritage was especially lacking during the immediate post-war period in Britain when demands for new housing stock and infrastructural development led to the irreplaceable loss of countless historic buildings and urban deposits (Eydmann 1999).

The emergence of urban archaeology as an established sub-discipline in the 1970s signified an increasing awareness of the need to investigate and preserve the cultural and visual roots of historic urban environments (Owen 1999). Conservation in Britain focussed largely on protecting surviving architecture and structural remains, for example the 1972 Town and Country Planning Act gave statutory protection for listed buildings (Lynch 1999). Moreover, in Scotland emphasis was placed on preserving ecclesiastical and municipal buildings and monuments. However, there was increasing recognition that such structures do not necessarily represent everyday life in past urban societies (Lynch 1999).

1.1.1 <u>Historic Small Towns</u>

In 1976 the Scottish Burgh Survey was established by Historic Scotland as a response to concerns about increasing threats to the heritage of Scotland's burghs (Dennison 1999a). These surveys were progressive in that they evaluated the potential of urban archaeology both above and below ground (Coleman 1999). This approach viewed the urban environment as a collective rather than a series of independent structures, hence was useful for identifying sensitive zones and areas susceptible to future development.

Despite initial and ongoing work of the Scottish Burgh Survey, the legacy of past urban life within Scotland's historic burghs is threatened, for example re-development within burgh cores and processes of peripheral expansion are leading to the loss of characteristic medieval street layouts. This is especially resonant considering that urban archaeological deposits located within these areas are vulnerable to damage and loss. Moreover, deposits within smaller burghs are identified as particularly susceptible given that they are often thinner and overlooked in favour of artefact rich sequences from larger burghs (Owen 1999).

It is argued that soil deposits within historic burghs represent a heritage of everyday urban life not readily documented or represented by surviving structures and monuments. Moreover, it is expected that soils are heavily impacted by processes of waste disposal and management given it is estimated that up to 182,000 litres of urine, 182,500 Kg of solid waste, 8100 Kg of ash from cooking and heating, and 36,500 Kg of human faeces were produced annually per 100 households in pre-industrial societies (Brothwell 1982). Investigation into the legacy of urban soils will enable characterisation of a unique and until recently, largely ignored archaeological archive.

1.2 Thesis Structure

The following study investigates the effect of waste in and around soils in small historic towns. A summary of the historical legacy of urban soils with specific reference to Scottish royal burghs is provided in Chapter 2, followed by presentation of the research framework including aims, objectives and hypotheses in Chapter 3. Chapter 4 outlines materials and methods used in this study with specific reference to site selection, field work, laboratory analyses, soil micromorphology and data analyses. Results soil micromorphology, physical and chemical properties, and elemental concentrations in Chapter 5, 6 and 7 respectively. Chapter 8 discusses the impact of waste disposal in and around Lauder, Pittenweem and Wigtown. To conclude some reflections on the wider significance of waste disposal in and around historic small towns are offered in Chapter 9.

2 The Historical Legacy of Urban Anthrosols with Specific Reference to Scottish Royal Burghs

2.1 Urban Anthrosols

Soil classification systems no longer use soil formation processes to discriminate between soil types, thus, the term ‘anthropogenic soils’ is technically redundant. However here it is argued that there is a case for re-examination of anthropogenic soil classification with specific reference to soils studied within this research (Dudal 2004).

2.1.1 Anthropogenic Soil Classification

Anthropogenic soils are accounted for at the highest order within the Soil Classification for England and Wales as Man-made soils (Avery 1980). Similarly anthropogenic soils are separated at the highest level within the World Reference Base for Soil Resources (WRB) as the Anthrosol group (FAO 2006). Conversely, the North American based Soil Taxonomy (Soil Survey Staff 1999) does not have a separate category. Consequently, anthropogenic soils are separated at the sub-order level Anthrepts within Inceptisols using Anthropic and Plaggen epipedon diagnostic surface horizons. Nevertheless these systems are in agreement that anthropogenic soils occur as a result of human modification over time and secondly, such changes are attributable to permanent settlement and agricultural practises. Regarding the Soil Survey of Scotland (1984), provision for anthropogenic soils is absent from soil classification categories although discrete phases of deepened topsoil are mapped for Orkney.

Dudal (2004:3) offers an alternative proposal suggesting 6 main types of anthropogenic soils namely; human induced changes of soil class, human made diagnostic horizons, human induced new parent material, human induced deep soil disturbance, human induced change of landform and human induced topsoil changes. The latter category, human induced topsoil changes, is particularly resonant to this study given that it is the impact of waste disposal on topsoil in historic Scottish Royal burghs which is of principal interest. However the importance of topsoil characteristics in soil classification systems has traditionally been marginalised with preference given to more stable subsurface horizons (Dudal 2004). Within the scope of this study, it therefore seems particularly important in the first instance to establish the range of physical and chemical characteristics of these modified topsoils.

2.1.2 Urban Soil Classification

The soils studied in this research is located within the urban environment, specifically in Scottish Royal burghs, known to be urban for over 600 years. Soils in the urban environment are distinct from natural soils on account of their formation and location, in particular the scale and intensity of human impacts on them (Bullock and Gregory 1991, De Kimpe and Morel 2000). Despite the unique qualities of soils in the urban environment knowledge regarding the nature, diversity and extent is currently lacking (De Kimpe and Morel 2000, Hollis 1991. This is further reflected in the absence of sufficient provision for urban soils in both the Soil Classification for England and Wales and Soil Taxonomy. Regarding the WRB Soil Classification, an attempt at classifying urban soils has recently been made through the inclusion in 2006 of a new Reference Soil Group (RSG), Technosols. Technosols are defined as soils

"whose properties and pedogenesis are dominated by their technical origin. They contain a significant amount of artefacts, or are sealed by technic hard rock. They include soils from wastes (landfills, sludge, cinders, mine spoils and ashes), pavements with their underlying unconsolidated materials, soils with geomembranes and constructed soils in human–made materials".

(FAO 2006:95)

Technosols appear to be based on contemporaneous urban environments. Consequently it seems urban soils subject to human impacts over many centuries are largely ignored. Potentially, soils which do not meet Technosol requirements should be classed as Anthrosols. However the Anthrosol group primarily includes soils resulting from long standing practises of agriculture for example, organic material addition, irrigation and cultivation. Additionally, it seems that the Technosol RSG is not exclusive from the Anthrosol RSG given that in principle Technosols fulfil the remit of Anthrosols as "soils that have been modified profoundly through human activities" (FAO 2006:71).

As previously mentioned, soil studied in this research has formed an intrinsic part of the urban landscape for many centuries and accordingly it is suggested that changes in physical and chemical soil properties may reflect past processes specific to the urban environment. It is therefore argued that these soils do not readily fit into the established models of soil classification presented here. Consequently soils investigated within this project are generically referred to as Urban Anthrosols.

2.1.3 Current Research into Urban Anthrosols

Urban soils act as a sink for a variety of anthropogenic activities such as burning, vehicle emissions and industrial wastes resulting in soil contamination. These soils are often contaminated with carcinogenic, mutagenic and toxic elements and compounds which can be directly ingested, inhaled or consumed through home grown food (Alloway 2004, Hursthouse *et al*., 2004, Mielke et *al*., 2001). Hence the main concern regarding polluted urban soil is risk to human health (Chung Wong and Li 2004, Hough 2007, Liu *et al.,* 2005, Moller *et al.,* 2006, Senesi *et al.,* 1999, Yongming *et al*., 2006) . This problem has globally attracted the attention of governments and regulatory bodies (Li *et al.,* 2004, Tijhuis *et al.,* 2002) and is especially resonant in industrialising countries where urbanisation is accelerating (Lu *et al.,* 2003). The need to develop regulations and standards to minimise subsequent risk is imperative (Ona *et al.,* 2006). Consequently it is not surprising that current Urban Anthrosol research is focussed on aspects of soil contamination within modern towns and cities. These contaminants have largely been considered in two distinct groups, namely heavy metals and organic pollutants.

2.1.3.1 Heavy Metals

Urban soils exhibit elevated levels of certain elements for example Moller *et al*., (2005) comment that soils in Damascus city have significantly increased concentrations of Pb, Cu and Zn compared the surrounding rural areas. Similarly Chirenje *et al.,* (2003) found that As is significantly greater in urban soils of Florida compared to non-urban areas. Accordingly attempts have been made to distinguish discrete associations of elements indicative of anthropogenic origin for example, Manta *et al*., (2002) discriminate between anthropogenic contributions of Pb, Zn, Cu, Sn and Hg and lithogenic inputs of Co, Ni, Cr and Mn in Palermo, Sicily. Likewise both Li *et al*., (2004) and Yongming *et al*., (2006) separate anthropogenic elemental signals from natural associations in Hong Kong and Xi'an, Central China, respectively. These anthropogenic groups routinely contain Pb, Zn, Cu and Hg (Moller *et al.,* 2005, Tijhuis *et al.,* 2001). Additionally, it is recognised that certain elements such as Cu, Zn and Pb are more mobile and bio-available in urban soils, thus increasing the potential of groundwater contamination (Lu *et al.,* 2003, Manta *et al.,* 2002).

Elemental concentrations typically vary across urban soils (Li *et al.,* 2004, Ona *et al.,* 2006), however certain distribution patterns have been identified such as contamination near industrial areas (Kelly *et al.,* 1996, Moller *et al.,* 2005, Tijhuis *et al.,* 2001) and pollution pathways associated with vehicular emissions (Chung Wong and Li 2004, Kelly *et al.,* 1996, Li *et al.,* 2004, Manta *et al.,* 2002).

2.1.3.2 Organic Pollutants

Similar to certain elements, organic pollutants such as Polycyclic Aromatic Hydrocarbons (PAHs) and Polychlorinated Biphenyls (PCBs) have been found in elevated levels in urban soils (Garcia-Alonso *et al.,* 2003). Moreover, Mielke *et al.,* (2001) identify a strong association between PAHs and heavy metals in urban soils of New Orleans. Consequently when assessing environmental quality it appears that urban soil contaminants should not be examined in isolation. Additionally, attempts should be made to integrate physical and biological properties when investigating urban soils, for instance Scharenbroch *et al.,* (2005) suggest time since initial disturbance is inversely related to stability of physical, chemical and biological soil properties. This suggestion is supported by Nora *et al.,* (2005) who advocate investigating soil chemical and physical properties collectively and linking those properties to the function of urban soils as plant, faunal and microbial habitats.

2.1.4 The Historical Legacy of Urban Anthrosols

Since the advent of urbanisation humans have inadvertently altered physical and chemical soil properties (Griffith 1980) the nature of which is determined by management and accumulation of anthropogenic waste materials (Alexandrovskaya and Alexandrovskiy 2000, Rathje and Murphy 2001). Urban soils therefore provide a unique opportunity to reconstruct past activities, which traditionally may have been overlooked owing to lack of material evidence (Terry *et al.,* 2004). Research on the historical legacy of urban Anthrosols is limited in comparison to the overwhelming focus on contamination of contemporary urban soils. However studies demonstrate the utility of urban soils in reconstructing human activities in space (Bull *et al.,* 2001, Wells 2004) and time (Shahack-Gross *et al.,* 2005, Alexandrovskaya and Panova 2003). Current knowledge regarding past urban soil amendments is reviewed hereafter.

2.1.4.1 Occupational Sequences

Permanent human settlement modifies urban soil properties resulting in elemental enhancement (Griffith 1980) and changes in certain physical properties such as colour, depth and organic matter content (Aston 1998). Investigation of these changes has enabled the identification of distinct phases of site activity such as population decline and urban abandonment between the Roman and Medieval periods as inferred by 'Dark Earth' (Macphail *et al.,* 2003, Ottaway 1992). Similarly Alexandrovskaya and Panova (2003) and Alexandrovskaya and Alexandrovskiy (2000) reconstruct soil formation history through characterisation of successive deposits in Moscow, for example the medieval habitation layer is enriched in construction debris and waste materials such as charcoal, lime and timber, and has maximum concentrations of Pb, Cu and As attributable to industrial processes. Analysis of soil and sedimentary sequences has also been used to explore how individual space within a site is used over time. Shahack-Gross *et al.,* (2005) identify successive 'fill' and 'floor' depositional units from Late Iron Age I to Early Iron Age II in a public space at Tel Dor, Israel. The fill layers comprise domestic debris such as bone, charcoal, plaster and shells and the floor layers reflect a change from fish processing to livestock penning. These studies demonstrate the value of using anthropogenic waste inputs in soil characterisation and for reconstructing past activities.

2.1.4.2 Elemental Enhancement

Aston (1998) proposes five ways elemental composition influenced by past activities; human habitation, stalled animals, use of fires/hearths, metal working and other processing activities. It is therefore recognised that multi-element analysis of urban soils can provide information regarding the nature of past activities and the spatial distribution of their associated deposits. This is especially resonant when preservation of archaeological remains is limited, for example Cook *et al.,* (2005) identify three elemental hotspots in a Roman house complex, Silchester providing evidence for previously unidentified working of copper alloys, gold and silver, and potentially lead. Where artefacts have been recovered examination of elemental distributions serves to substantiate space use patterning. Terry *et al.,* (2004) associate midden refuse with elevated levels of P indicating areas of food preparation, consumption and storage at Aguateca, Guatemala. Moreover artefacts associated with crystal processing are linked to enhanced Fe concentrations indicative of specific workshops.

2.1.4.3 Elemental Signatures

Elemental signatures can be used to distinguish between anthropogenic deposits. Wells *et al.,* (2000) differentiate between kitchen, workshop, craft and ceremonial middens using specific elemental signatures of ancient Anthrosols in residential areas of Piedras Negras, Guatemala. Wells (2004) also delineates manufacturing, ritual and domestic functional areas using elemental signatures and links these areas to their associated middens at El Coyote, Honduras. Analysis of elemental distributions in the urban environment, therefore, provides a valuable tool for characterising and discriminating between deposits and for hypothesising which activities led to the formation of certain Urban Anthrosols. Spatial analysis of anthropogenic elements is identified as a necessary technique for more detailed investigation of waste disposal and management in Scottish Royal burghs. This recognition also follows Terry *et al's.,* (2004) recommendation that studies are needed in regional contexts to evaluate the effect of different climatic conditions and local soil properties on elemental concentrations.

2.1.4.4 Soil Improvement

The impact of past human activity is not confined to urban centres in isolation. Bull *et al.,* (2001) present evidence to suggest that during the Minoan period domestic waste was transported from the main site of occupation on Pseira Island, Crete and applied to nearby agricultural terraces (Figure 1). Similarly the occurrence of Terra Mulata, an Amazonian Black Earth, is attributable to intentional application of anthropogenic wastes to agricultural fields surrounding high density pre-Columbian Amerindian settlements (Sombroek *et al.,* 2002). Analyses of urban environments and associated waste disposal should therefore extend to surrounding areas likely to have been affected by central urban activities.

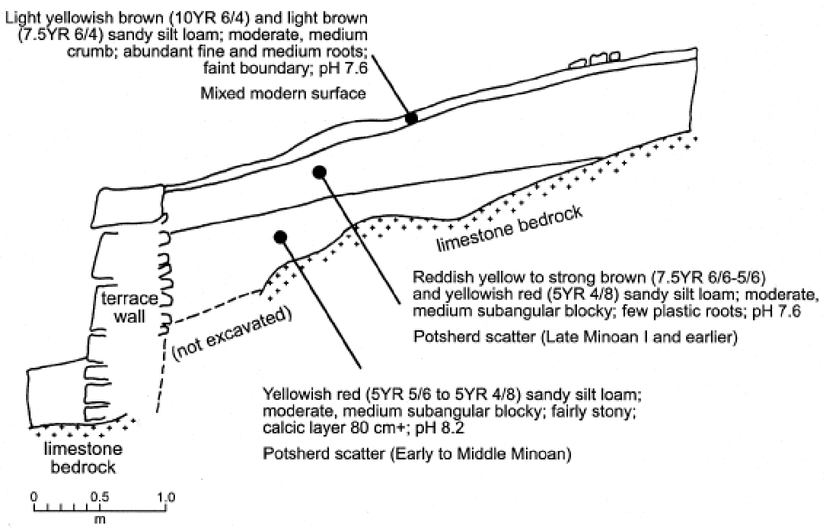


Figure 1: Cross section of terrace P1 Pseira Island, Crete showing Minoan potsherd scatters indicative of systematic spreading of household wastes across the cultivated landscape as a fertiliser (Bullock *et al*., 2001: 227)

2.1.5 <u>Summary</u>

Urban Anthrosols are distinctive owing to their location and that their properties are modified through waste amendments. Much consideration has been given to how these properties reflect current human influence. However, recent studies indicate the potential of investigating Urban Anthrosols to reconstruct past human activities in space and time. It is therefore assumed that urban soils in and near to Scottish Royal burghs will exhibit a historical legacy. Accordingly the following sections provide an overview of Royal burghs, environmental conditions and existing evidence for soil modification.

2.2 Waste Sources and Management in Royal Burghs

2.2.1 Medieval Origins of Urbanism

Despite absence of evidence, it is likely that pre-urban nuclei existed in Scotland before the 12th century AD (Dicks 1983). However, it was not until David I (1124-1153AD) whose Anglo-Norman policies resulted in the founding of a series of Royal burghs in the central belt and lowlands, that urbanism in Scotland was clearly identifiable (Adams 1978). Royal burghs engaged in a reciprocal relationship with the crown, for example, property was granted under permanent feudal tenure to burgesses in return for rents and personal services for the security of public peace. Similarly charters detailing privileges such as the right to engage in overseas trade and hold markets were granted in return for payment of customs duties (Adams 1978). Other burghs founded increasingly during the Medieval period include Baronial (burghs erected after royal petition from local barons) and Ecclesiastical burghs (burghs created by the church). These burghs shared many similarities with Royal burghs such as having planned towns and structured societies but differed in that overseas and regional domestic trade was prohibited. Unsurprisingly therefore, Royal burghs endured as the dominant economic force throughout the medieval period (Whyte 1997).

2.2.1.1 Morphology

Burghs with medieval origins are morphologically distinct. The fundamental component of urban planning was the burgage plot. Burgage plots were units ownership manifested in a predetermined strip of land usually fronting onto the main street (Adams 1978, Hall 2002) (Figure 2, Figure 3). The dense nature of these long and narrow plots meant access for a maximum number of plots holders to the central main street. This ‘High Street’ often acted as the market place whereby traders operated from stalls and booths attached to the front of houses and workshops (Coleman and Smith 2004). Consequently most burgh plans exhibit the single street system, although some, mostly east coast burghs, comprise two parallel streets (Figure 4). Medieval planning is still clearly identifiable in many burghs today, especially those subject to minimal commercial development and infilling.

Figure 2: 16^{th} century AD map of the Royal Burgh of Dumfries, Dumfries and Galloway shown as a single street of dwellings with burgage plots, taken from the Pont Manuscripts (Image © National Library of Scotland, Licensor www.scran.ac.uk)

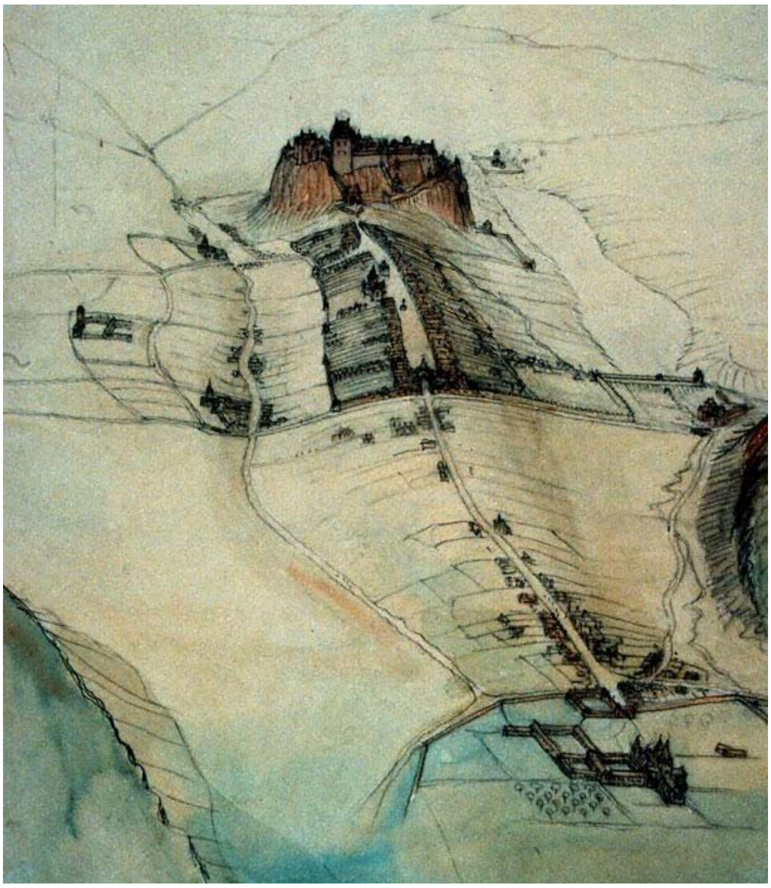


Figure 3: Edinburgh $_{c}$1460AD comprising Town (Royal Burgh, Burgh of Canongait), School (Castle), and Cloister (Holyrood Abbey, St. Giles Cathedral) (Image © Patrick Geddes Centre for Planning Studies, University of Edinburgh, Licensor www.scran.ac.uk)

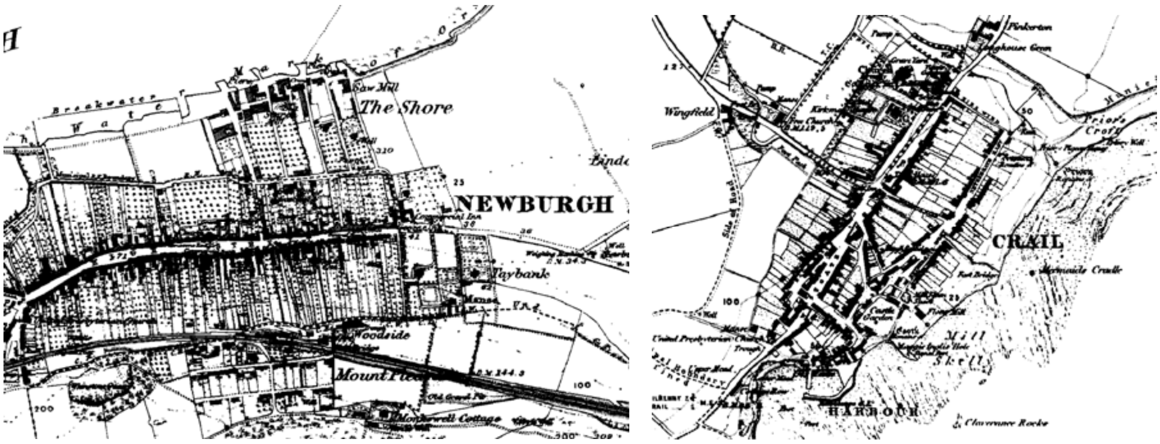


Figure 4: Medieval Street Patterns: Newburgh, Fifeshire 1855-56AD example of single street system and burgage plots and Crail, Fifeshire 1855AD example of parallel street system and burgage plots (Image produced from the www.old-maps.co.uk service with permission of Landmark Information Group Ltd. and Ordnance Survey)

2.2.2 Post-Medieval Urban Growth

The post-medieval period, spanning 1500 to $_{c}$1800AD (Darvill 2002, Starn 2002) is characterised by unprecedented urban growth emergent from a stagnant population at the turn of the 16th century AD (De Vries 1984, Whyte 1999) (see Table 1, Table 2). Consequently existing towns expanded, which often meant site intensification as opposed to outward growth (Whyte 1997, 1999) and increasing numbers of new Royal and Baronial burghs were created (Devine 2000). The resultant urban hierarchy was dominated by an abundance of small towns with comparatively few large centres and even less middle size settlements (Whyte and Whyte 1991).

Table 1: Urban Percentage of total population of Scotland, 1500-1800AD and percentage increase in urban population from previous date (from De Vries 1984:39)

Date AD	1500	1550	1600	1650	1700	1750	1800
% Urban Population	1.6	1.4	3.0	3.5	5.3	9.2	17.3
% Increase	*	0	130	17	51	124	132

Table 2: Percentage of total population in Scottish towns, mid 17th century to late 18th century AD (from Whyte 1989:28)

Date AD	1639	1690s	1755	1790s
Capital	2.7	4.5	4.5	5.6
Other towns >10,000	3.5	2.7	4.4	10.8
5000-9999	3.3	1.6	3.2	3.2
2000-4999	2.2	3.1	4.2	6.4
1000-1999	?	3.5	?	6.3
500-999	?	?	?	3.4
Total in towns >2,000	11.7	11.9	16.3	26.0

Sewerage and municipal rubbish collection was absent in most towns until the 19th century AD, hence alternative systems of waste management must have been in place to accommodate waste and any subsequent rises in volume. Given that changes in urban soil properties are determined by accumulation of anthropogenic wastes, it is proposed that investigation of soils in and near to Royal burghs will provide evidence for past processes associated with waste management.

2.2.3 <u>Waste Sources</u>

Royal burghs would have undoubtedly produced considerable volumes of rubbish from a variety of potential sources (Figure 5). The following section summarises the principal contributors.

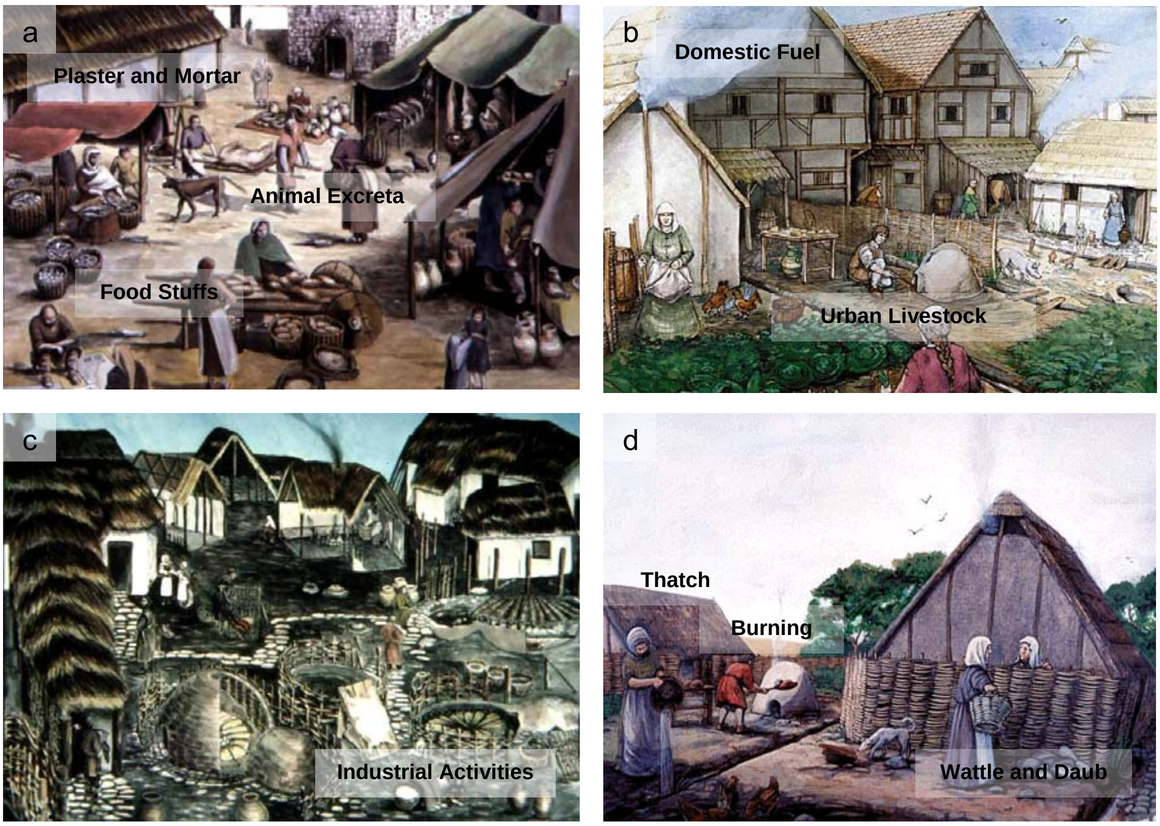


Figure 5: Graphical Summaries of Potential Waste Sources in the Medieval/Post-medieval Urban Environment (a) Reconstruction of market scene at St. Johns Kirk, Perth (b) Reconstruction of Upperkirkgate, Aberdeen backlands (c) Reconstruction of backland manufacturing in Meal Vennel, Perth (d) Reconstruction of Upperkirkgate, Aberdeen backlands (Images © Aberdeen City Council, Licensor www.scran.ac.uk)

2.2.3.1 Human and Animal Excreta

Absence of sanitation coupled with widespread holding of urban livestock meant that human and animal excrement was a significant source of organic urban waste (Croly 2003, Ewan 1990). Comparable accounts from 16^{th} century Prescott, England suggest that filth was a pervasive feature of historic small towns, where human excrement is documented on pavements, in the church and piled property windows (King 1992). Likewise in Scottish burghs excreta accumulated on the burghs' front streets forming so called dunghills (Croly 2003, Mair 1988). Annoyances pertaining to excreta were confined to issues of smell and access given that links between disease and health had not yet been established. Archaeological evidence for excreta and its management is limited hence analysis of certain soil properties should reveal the legacy of this material in Royal burghs.

2.2.3.2 Building Materials

Buildings typically comprised combinations of disposable materials such as wattle and daub, timber, clay, stone, turf, heather, straw and rushes (Reid 1909, Stones 1987) Accounts of early 18th century AD domestic dwellings at Monymusk, Aberdeenshire indicate the nature of materials used in domestic dwellings; reference is made to walls comprising "wooden supports packed with rough stones and clay topped with 1 to 2 feet of turf and the roof consisting of branches overlain with thinly pared turf which was in turn overlain with heather or thatch" (Hamilton 1945). Buildings were repaired and rebuilt on a regular basis, for example earth built houses in Kiltearn in the late 18th century AD are cited as "being razed to the ground once in every 5 or 7 years, when they are added to the dunghill" (Robertson 1791-99:289) likewise, the earthy parts of houses in Criech are referred to as being added to the dunghill and being rebuilt again (Rainy 1791-99:375-376).

2.2.3.3 Fuel

Fuel was fundamental to daily life given that most domestic activity such as heating, lighting and cooking, and many industrial processes were dependant on fire. Peat, wood, moss and coal were principal sources however, the precise nature and abundance used varied in accordance with proximity to local resources, access rights, resource pressure and, with reference to coal, market forces (Bruce 1791-99, Molleson 1791-99, Ogilvy 1791-99, Oram 2006). Constant burning ultimately produced considerable quantities of waste products including ash, charcoal and charred material, collectively referred to as fuel residues.

2.2.3.4 Industrial Wastes

Royal burghs supported a variety of industrial activities; some were common to all burghs especially those related to agriculture and processing animals (Spearman 1988) however, by the 16th century AD economic diversification resulted in burghs taking on distinct occupational structures (Whyte 1997). Accordingly both similarities and differences in types of industrial waste are expected between towns. It is likely that processing and disposal of primary and secondary materials affected soil properties, however the nature and location of impacts remains largely unknown (Spearman 1988). It is proposed that basic distinctions between burghs with differing principal economies can be made, for example it is expected that coastal burghs generated higher levels of marine waste such as fine fish bones and shell compared to inland burghs.

2.2.4 Waste Management

Historical evidence for waste management is largely focussed on the occurrence of dunghills. Dunghills comprising human, animal, domestic and industrial waste were ubiquitous along the streets of historic small towns acting as storage points of urban rubbish (Croly 2003, Dillon 1953). These waste heaps were important sources of fertiliser and intrinsically held monetary value. Accordingly they were bought, sold and auctioned to farmers, exchanged for food by the poor and even confiscated by burgh councils to generate revenue or for application to burgh lands without payment (Cook 1867, Mair 1988, Smout 2000). Application of dunghills to burgh acres, agricultural land belonging directly to the burgh, was therefore a common practice (McAlpine and Rolland 1791-99, Smout 2000, Stones 1987, Whyte 1997, Yeoman 1995).

Burgage plots to the rear of burgesses' houses flanking the central main street were a key area in terms of managing urban waste (Adams 1978, Coleman and Smith 2004, Ottaway 1992) (Figure 6). This 'Backlands' zone was distinctive in Royal burghs in that it was used for a variety of activities including domestic and industrial accommodation, holding livestock, small scale cultivation and waste disposal (Ewan 1990). The precise nature and intensity of backland use differed within and between burghs, responding in space and time to economic and demographic factors (Coleman and Smith 2004, Hall 2002, Stones 1987, Whyte 1997). Nevertheless garden cultivation was an enduring backland activity; hence it is likely that dunghills were applied to open burgage plots. Moreover, mixtures of straw and dung from adjacent yards and byres also provided an immediate and convenient source of fertiliser (Coleman and Smith 2004, Hall 2002, Oram 2006).

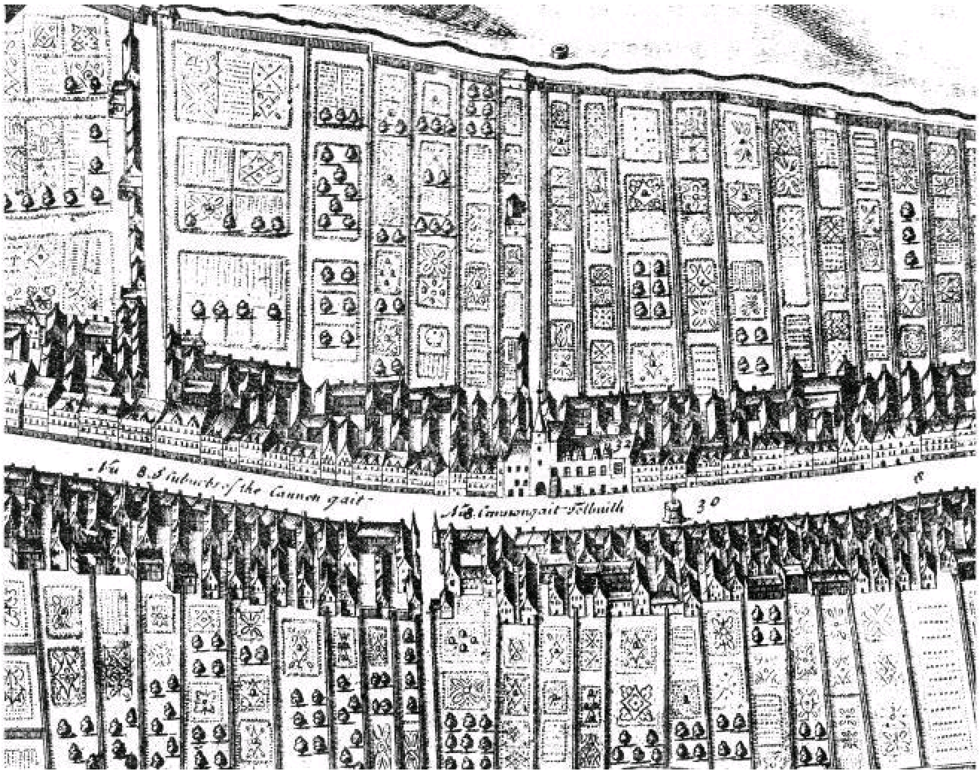


Figure 6: Mid 17th century AD view of Canongate, City of Edinburgh. Note differences in land use within and between burgage plots (Image © Royal Commission on the Ancient and Historical Monuments of Scotland, Licensor www.scran.ac.uk)

2.2.5 Summary

The generation of waste was an integral part of urban life during the medieval and post-medieval periods. Limited aspects of the nature and management of waste sources can be extrapolated from documentary evidence and archaeological survey. However, considering that soil within and near Royal burghs presents a record of past waste disposal practises, it is proposed that investigation of soil properties will enable systematic insight into the legacy of waste both within and between historic small towns. The following section introduces existing evidence for urban soil modification in Scottish burghs.

2.3 Evidence for Past Soil Modification in Royal Burghs

Understanding soil modification in Royal burghs is limited to subsidiary information gained from urban excavation and a small number of recent studies integrating archaeology and soil science (Carter 2004, 2001, Davidson *et al.,* 2006, Golding and Davidson 2005). Nevertheless, collaborative evidence indicates the existence of distinct changes in certain soil properties attributable to past waste amendments.

2.3.1 Deepened Soil Deposits

Deepened soil deposits are a distinctive feature of Royal burghs occurring in both large (Bowler 2004, Carter 2004, 2001, Cachart 2000, Coleman and Smith 2004, Rains, Hall 1997) and small (Dercon *et al.,* 2005, Davidson *et al.,* 2006, Golding and Davidson 2005, Hall and Bowler 1997, Hall *et al.,* 1998, Lowe 2001, Spearman 1982) towns. Phases of deepened topsoil are characteristically varied resulting in pronounced spatial heterogeneity, for example accumulated deposits are identified across Holyrood, Edinburgh ranging from 0.8 to 2.2m (Carter 2004). Similarly, Lowe (2001) notes anthropogenic soils ranging in depth from 0.5 to 1.5m at Crail, Fife (Figure 7). The extent of topsoil depth spatial variability is further demonstrated at Nairn, Nairnshire (Davidson *et al.,* 2006) and Pittenweem, Fife and Lauder, Borders (Golding and Davidson 2005) where topsoil depth survey results indicate stark differences both within and between burgage plots.

It is proposed that deepened soil deposits result from sustained past waste material addition. Carter (2004) attributes deepened topsoil at Holyrood, Edinburgh to continual application of mineral material derived from ash and turf as indicated by the presence of burnt coal, burnt sedimentary fragments and fine burnt residues. Furthermore, considering the occurrence of pottery, bone, mortar and shell, it is argued that periodic spreading of midden material onto cultivated burgage plots was the dominant mechanism of accumulation. Aside from Carter (2001, 2004) there have been limited attempts to systematically understand how and why these deposits formed. Accordingly, this study will investigate the nature of deepened soil deposits spatially and through physical and chemical characterisation.

Figure 7: Crail from the air (a) Deepened anthropogenic sediments, west end of Nethergate, (b) Shallower sediments, east end of Nethergate, (c) Deep soils with medieval and mixed medieval and post-medieval assemblages, attributed to medieval cultivation of the burghs infield and/or off loading ballast by Dutch herring traders (Lowe CE, 2001, Image © Colin J M Martin, Licensor www.scran.ac.uk)

2.3.2 Backland Garden Soils

The term 'garden soil' refers to deep, homogenous, highly mixed soil resulting from intensive cultivation (Carter 2001, Wordsworth and Clark 1997). Although garden soils are recognised in many burghs, for example, Forfar, Angus (Spearman 1982), Elgin, Moray (Hall *et al.,* 1998) and North Berwick, East Lothian (Hall and Bowler 1997), they have received most attention in St Andrews, Fife. It is accepted that garden soils represent deliberate and sustained improvement in the backlands of St Andrews (Cachart 2000) however, significant conjecture exists regarding processes leading to their accumulation.

Clark (1997) proposes that these deposits imply a major change in post-medieval land use whereby backland activity ceased, land was turned over to cultivation and accordingly material was imported for horticulture, hence giving rise to the widely accepted 'Imported Garden Soil Model'. Carter (2001) suggests an alternative 'Occupation Deposit Model' attributing accumulation of mineral sediments to continual replacement of building materials associated with intensive occupation of the backlands. Considering that differentiation between topsoil introduced for cultivation and turf used in building construction is problematical, resolution of this issue seems unlikely. Moreover, given that both scenarios could have produced similar deposits, a potential third hybrid model of the two theories is plausible.

2.3.3 Stratigraphy and Dating

Garden soils comprising two distinct layers, a lower brown layer attributable to the medieval period and an upper darker layer to the post-medieval period, have been noted in several burghs (Cachart 2000, Carter 2001, Hall *et al.,* 1998, Spearman 1982). Aside from differences in colour, differentiation of soil properties between these layers has not been elucidated. Accordingly this project will investigate differences in layer composition. Despite this elementary distinction within some garden soils, urban soils associated with Royal burghs do not exhibit definite stratification rendering relative and absolute dating ineffective.

2.3.3.1 Relative Dating

Analysis of artefacts from garden soils indicates that deposit accumulation occurred throughout the medieval and post-medieval periods, for instance, pottery dating to 14th-15th centuries AD and clay pipe fragments typical of 17th-18th centuries AD have been identified at the Market Street excavation, St. Andrews (Hall 1997). Similarly, at the Rumford and Westgate sites in Crail, mixed assemblages of medieval and 17th century AD pottery sherds have been recovered in association with deep soil, bone and glass (Lowe 2001). Nonetheless, reliable determination of deposit stratification is problematical, for example although Ross and Clark (1997) propose successive phases of cultivation from 14-15th and 16-17th centuries AD at the Cinema House site, St. Andrews, a lack of dateable material from primary contexts impedes interpretation. In addition to residual finds, modern activities also hinder chronological establishment. Excavation at Castle Street, St. Andrews revealed intrusions resulting from modern services coupled with small quantities of modern pottery reworked into phase II soil deposits (Cox 1997). Moreover, it is recognised that dates of artefact manufacture and deposition are separate entities. Hall (1997) suggests that although phase V homogenous garden soil deposits at Market Street, St. Andrews are dominated by 14-15th AD century pottery sherds, it is possible that such artefacts may not relate to earlier occupation of the site if soil was imported and dumped.

2.3.3.2 Absolute Dating

Utilisation of techniques such as radiocarbon (^{14}C) and optically stimulated luminescence (OSL) is problematic for chronological dating of soils formed over the medieval and post-medieval periods. This is especially true for urban soils in Royal burghs where it is argued that fundamental assumptions associated with these methods cannot be met. Primarily radiocarbon dating relies on intact stratigraphy with minimal reworking and bioturbation (Rapp and Hill 1998), yet presence of artefacts in residual contexts, modern intrusions and evidence for past cultivation in garden soils (Hall 1997, Ross and Clark 1997) infer high uncertainty as to whether this prerequisite can be met. Age contamination within these soils is also a possible problem especially from fossil carbon sources such as limestone associated with building mortar, paints and washes (Renfrew and Bahn 1997). Moreover, turf material associated with building construction and fuel has an existing radiocarbon age, hence soil would appear too old (Bokhorst *et al.,* 2005). Radiocarbon dating is further dismissed as a viable technique for dating post-medieval deposits given its upper dating edge of 300 years BP (Taylor 2001).

Dating post-medieval deposits is possible using OSL dating which spans 100 to 100-200 000 years BP (Grün 2001). This method relies on the OSL signal of mineral grains being reset to zero upon exposure to daylight prior to deposition. However incorporation of material such as paired turf from building construction whose signal is not necessarily reset at deposition may affect sample age, though Bokhorst *et al.,* (2005) suggest this effect is minor. The main concern using OSL to date post-medieval soils is low precision (Cluett 2007, Feathers 2003, Sommerville *et al.,* 2001). This is not necessarily an issue when constructing age models over millennia however, dates with errors of ± 100-300 years would result in considerable overlap over this shorter time period. Aside from problems associated with absolute dating techniques, it is argued that dating urban soils associated with Royal burghs is ultimately meaningless considering the mixed and re-worked nature of deposits. Furthermore, given that Royal burghs originated and developed throughout the medieval and post-medieval periods, it seems logical that impacts on soil also date to those periods.

2.3.4 Hinterland

Deepened soil deposits are not exclusive to the backlands as demonstrated at Nairn, Nairnshire (Davidson *et al.,* 2006, Dercon *et al.,* 2005), Pittenweem, Fife and Lauder, Borders (Golding and Davidson 2005). Evidence from deepened phases at Nairn indicates that these deposits are testament to sustained urban waste material addition. Dercon *et al.,* (2005) attribute finer material in the A horizon to mineral accumulation through the addition of turves used in buildings, sand added to burgh dunghills and sand in association with seaweed application. Deepened topsoil in Nairn's hinterland is in agreement with the location of burgh acres cultivated throughout the post-medieval period, indicating that urban waste was intentionally used to enhance soil quality (Davidson *et al.,* 2006) (Figure 8) . Moreover, analysis of total phosphorus concentrations revealed a peak in the AP3 horizon corresponding to the lowest old cultivated layer. Despite these initial findings little is known about the occurrence, location and physical and chemical legacy of deepened hinterland soil.

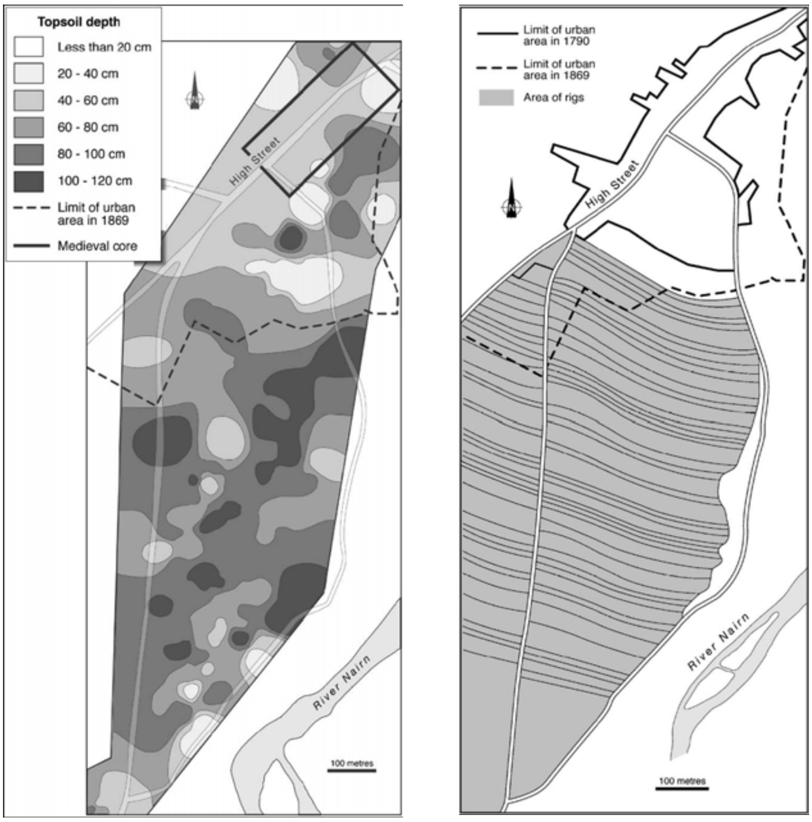


Figure 8: Depth of topsoil in and near the Burgh of Nairn (left), distribution of rigs in burgh acres 1790AD (right) (Davidson *et al*., 2006: 780)

2.3.5 Summary

Results from archaeological excavation and geoarchaeological studies suggest that management of urban waste has had long lasting impacts on soil both within and near to Royal burghs. However, no attempt has been made to systematically identify, characterise and compare deposits arising from waste material addition. Consequently the following chapter provides a research framework detailing the project aims and objectives addressing these knowledge gaps.

3 Investigating Urban Anthrosols in Historic Small Towns: A Research Framework

This chapter presents the adopted research framework for investigating urban anthrosols in small historic towns and outlines the project's aims, objectives and hypotheses. The research framework is centred on a refuse flow model developed through a review of archaeological concepts of rubbish, contemporary and historical perceptions of rural-urban interaction and previously identified factors affecting material procurement, management and disposal in Royal burghs.

3.1 Archaeological Concepts of Rubbish

3.1.1 Defining Rubbish

Rubbish can be defined socially as opposed to physically (Thompson 1979, 2003). This idea is manifested in Rubbish Theory (Figure 9) where it is proposed that everything we deal with can be divided into three categories, transient (things with an estimated lifetime within which they continually lose value to the point where they have none), durable (things that have an unlimited lifetime) and rubbish (all items that are neither transient nor durable). To accommodate constantly shifting social definitions of rubbish, transfers between categories are possible, for example from transient to rubbish and rubbish to durable. Rubbish Theory incorporates social and economic fluidity hence is a useful tool for conceptualising the status of material culture within past societies. Essentially understanding what constituted waste in particular cultures and periods is dependant on the ability to deduce past social perceptions however caution should be taken to avoid superimposing contemporary values.

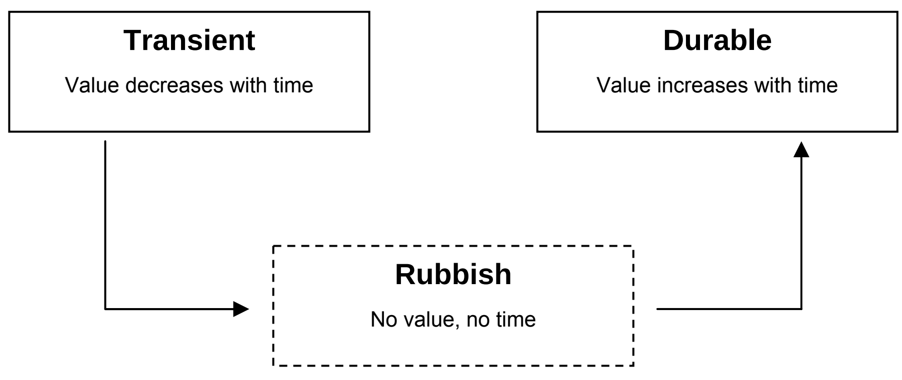


Figure 9: 'Rubbish Theory' model showing cultural categories of objects and possible transfers between them (Thompson 2003: 322, 1979: 10)

3.1.2 Garbology

The study of rubbish is a recognised archaeological sub-discipline. More specifically it can be argued that garbology "the study of a community or culture analysing its refuse" (Soanes and Stevenson 2006) is a fundamental approach in understanding the nature and formation of archaeological records. Garbology was first pioneered in the 1970s by William Rathje (1974) who argued that present societies should be systematically investigated using archaeological enquiry to advance current understanding of past cultures. This was in contradiction to traditional archaeological theory where antiquity is understood using evidence from the past or correlates to the present. The University of Arizona Garbage Project (Rathje 1974) was the first systematic attempt to study contemporary discard behaviour. One of the key trends identified was that high income households are associated with low rubbish generation. This finding challenges established theories which assume conspicuous consumption in ancient societies is related to social elites. Moreover, it was found that different racial and economic groups exhibited different discard behaviour in terms of what and how much they threw away.

This novel approach to understanding waste has been largely adopted by social anthropologists (for example, Edwards 2004, Harpet 2003, Pessel 2006, Rathje and Murphy 2001b). Within archaeology the impact of garbology has been less pronounced. Nevertheless, at a generic level its principal theories provoke enquiry into notions of race, place and status and their role in waste management and discard behaviour in past societies.

3.1.3 Classification of Rubbish Deposits

Concentrations of rubbish discovered on archaeological sites are usually referred to as midden deposits regardless of their spatial characteristics and content. However, it is argued that a basic distinction between middens and 'refuse rich' deposits exists. Middens are spatially discrete features and have identifiable modes of construction, constituents, resource roles and spatial associations (Needham and Spence 1997). In contrast, indistinct areas of general waste accumulation can be described as "deposits rich in refuse". This basic distinction alludes to differences in discard behaviour.

A systematic attempt to classify rubbish disposal according to artefact use and disposal histories is proposed by Schiffer (1972:156) in response to the consensus in traditional archaeology that "spatial patterning of archaeological remains reflects the spatial patterning of past activities". Three categories of rubbish classification are proposed, primary refuse (rubbish discarded at its location of use), secondary refuse (rubbish discarded away from its location of use) and de facto refuse (material abandoned at the use location but still having a perceived re-use value, for example large household items left upon site abandonment) (Figure 10). In addition, Haydon and Cannon (1983) propose a fourth addition to this system, provisional refuse (stored refuse having a perceived re-use value) which differs from de facto refuse in that it infers intentional storage rather than intentional abandonment. These categories are useful for understanding the social perception, use and discard behaviour associated with material culture. Moreover, this model provides a framework for investigating life cycle histories of material omitted from the archaeological record.

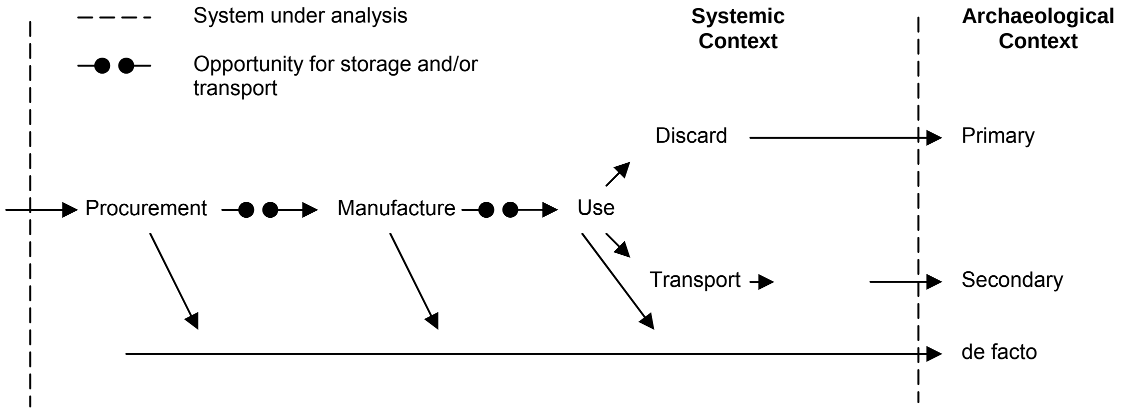


Figure 10: Flow model showing artefact histories and proposed rubbish categories (Schiffer 1972:162)

3.1.4 <u>Refuse Cycle Flow Models</u>

It is argued that the key to understanding past societies is through the ability to relate archaeological finds to systemic structures (Schiffer 1976). This has been realised in refuse cycle flow models, where ‘refuse cycle’ is defined as a “conceptualisation of refuse movement and management” (Needham and Spence 1997:77). These models make a basic distinction between the systemic context (life cycles) and archaeological context (incorporation and burial) (Figure 11 and Figure 12). Material flow moves generally left to right from system processes to the archaeological record. However re-routing is possible, for example recycling which refers to routing of an element at the completion of use to the manufacture process of a different element (Schiffer 1972).

Alternatively, Rathje and Murphy (2001a) propose that rubbish management in antiquity can be accounted for by four universal methods; dumping, burning, turning a material into something that can be useful and source reduction (minimising the volume of material goods that comes into existence in the first place). It is argued that all civilisations have used these methods simultaneously to some extent. These proposals do not discount refuse cycle models, conversely they reiterate fundamental concepts such as ‘dumping’ which is akin to discard processes and ‘turning material into something useful’ which is analogous to re-use flows.

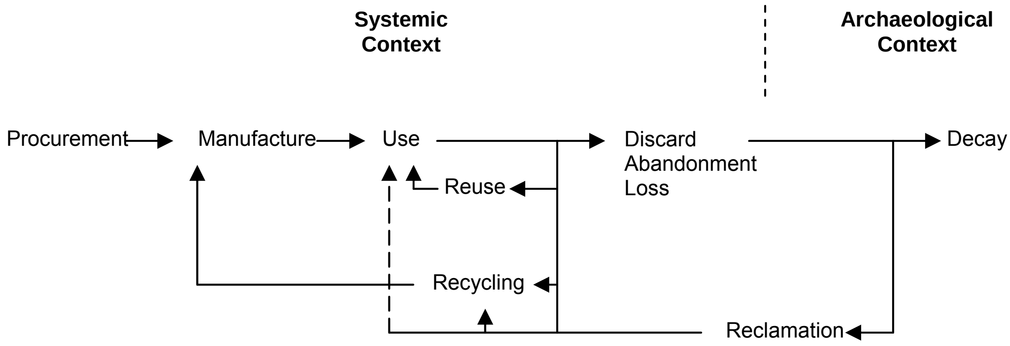


Figure 11: Flow model of adapted artefact life histories (LaMotta and Schiffer 2001:20)

3.1.5 Summary

Insight into the social and economic environment of historic towns is essential for understanding the nature and management of waste materials. Schematic models are identified as a useful tool for conceptualising and visualising material flow in small historic towns, although it is noted that such models are not prescriptive representations of reality.

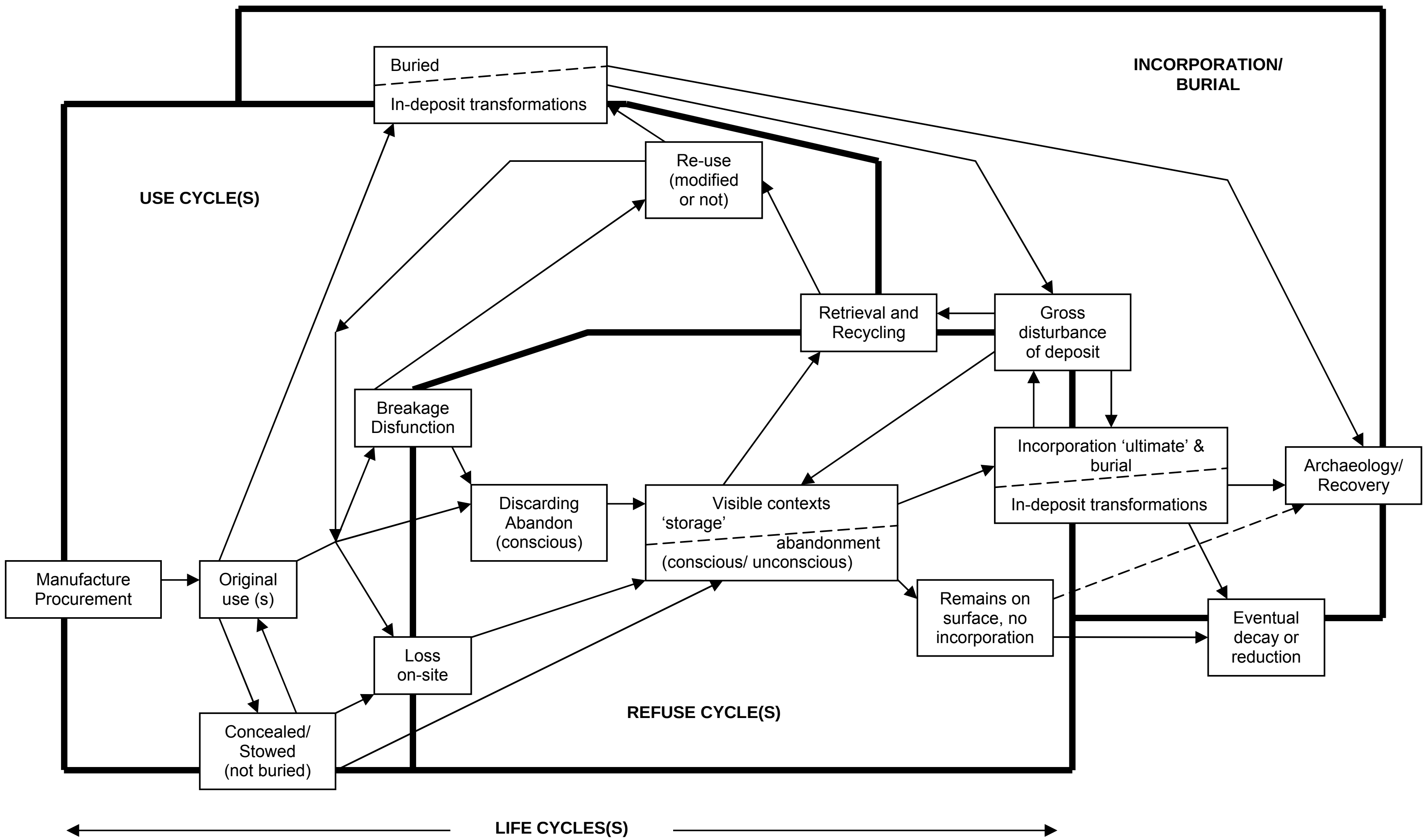


Figure 12: Refuse cycle flow model for possible stages in artefact histories (Needham and Spence 1997:78)

3.2 The Nature and Significance of Rural-Urban Interaction

In developing a research framework for investigating urban anthrosols in small historic towns it is important to consider what is meant by the terms rural and urban with specific reference to their relationship with each other. Determining the nature and significance of urban-rural interaction is vital in understanding resource flows, particularly for waste materials in historic towns. The following section looks at key concepts associated with rural-urban interaction derived from a brief review of contemporary and historical studies.

3.2.1 Contemporary Research of Rural-Urban interaction

Whilst the terms ‘rural’ and ‘urban’ serve as meaningful concepts for descriptive purposes, their value in understanding complex spatial, sectoral and economic trends is subject to debate (Lin 2001, Nivalainen and Schimdt-Thome 2003). Their comparability on an international level is also questioned given that nations discriminate between rural and urban according to varying population thresholds and densities (Tacoli 1998). It is proposed that investigating the nature of rural-urban interaction is a more objective approach than analysis of the spatial categories themselves (Gould 1987). Implicit within rural-urban interaction is the notion of a spatial rural-urban continuum (Aguilar and Ward 2003). It is therefore argued that the idea of a rural-urban dichotomy in contemporary and historic towns is a false divide.

3.2.1.1 Rural-Urban Fluxes

Fluxes of people, commodities, knowledge, assets and social transactions form the basis of rural-urban interaction (Kaida and Maharjan 1990, Lin 2001). Determining the nature and significance of these linkages is vital in evaluating society and economy in towns both past and present. Current research focuses largely on population fluxes in developing countries with specific reference to migration scale, migration direction, gender, diaspora and age selectivity (Fekade 1995, Gould 1987, Lin 2002, Tacoli 1998, Tanner 2003). It is argued that understanding people as agents of change in rural-urban interaction is important considering their decisions economically, politically, socially and culturally define the urban environment (Coppack 1998). Reconstruction of population fluxes is problematic for historic towns considering the limited nature of past documentation in terms of the number of records which diminishes with time and the recognition that surviving sources do not necessarily record information relevant to certain study questions.

3.2.1.2 Rural-Urban Interaction Zones

Physical manifestations of rural-urban interaction are noted in contemporary cities. Some examples are discussed hereafter for a variety of urban scales ranging from mega cities to local urban centres, whilst scale differs it should be noted that similarities exist in the nature and extent of rural-urban interactions. Lin (2001) delineates a zone of rural-urban interaction adjacent to and in between metropolitan centres in the Pearl River delta, China. This area is characterised by functional duality comprising a mixture of agriculture and industrial activities. Moreover Aguilar and Ward (2003) note two distinct rural-urban interaction zones in Mexico City, Mexico collectively termed the peri-urban hinterland. The inner peri-urban zone is functionally integrated with the city core and is typified by a mixture of urban and rural land uses. In comparison the outer peri-urban zone consists of more remote settlements outwith the metropolitan area but crucially they remain contiguous to it. Urban-rural interaction zones are not specific to developing or industrialising cities. Nivalainen and Schmidt-Thome (2003) estimate that up to one quarter of Finland's population live in distinct rural-urban interaction zones which are defined as neighbourhoods of urban centres consisting of a high proportion of commuters. Multi-agent system models of land-use/cover change (MAS/LUCC) are identified as important tools for investigating complex spatial relationships associated with rural-urban interaction. MAS/LUCC models are unique in that they integrate aspects of the physical landscape with political, economic and cultural decision making processes. Accordingly they can be applied to a variety of scenarios ranging from natural resource management and agriculture to modern and historical settlements (for a comprehensive review of MAS/LUCC models refer to Parker *et al.,* 2003).

3.2.1.3 Sectoral Interaction

Principles of rural-urban interaction are also manifested in sectoral interactions. Sectoral interactions are classed as rural activities taking place in urban zones and urban activities occurring in rural zones (Tacoli 1998). One of the most prevalent cases of urban-rural sectoral interaction is the recent increase of urban agriculture in developing cities as a response to escalating poverty and food prices (Tacoli 1998). Likewise some rural areas are becoming more urban in nature, for example Tanner (2003) notes how competition among municipalities to present a more 'modern' and urban way of life has resulted in infrastructural developments such as water and electricity in the north-western province of Jujuy, Argentina.

3.2.2 Rural-Urban Interaction in Historic Towns

3.2.2.1 Hinterland Resource Flows

Investigation of rural-urban fluxes in historic towns is limited to analysis of surviving physical remains. Accordingly most studies focus on flows of natural resources, foodstuffs and manufactured commodities between hinterland and town, for example bone evidence from medieval and post medieval Oslo, Norway suggests that cod was transported as cargo stock from the north whereas fish like haddock, ling, eel and flatfish were caught locally and brought in fresh (Schia 1994). Similarly archaeological and documentary evidence from medieval and post medieval Oxford indicates that although dairy herds were reared on the town's common land, some cattle came from as far away as Berkshire as a result of cattle droving from Wales and the west of England (Wilson 1994).

The case study of Oslo also presents evidence for changes in hinterland resource supply and demand. Chemical analysis of 11-16th century AD iron suggests that hinterland production sites fell from 4 to 1 during this period. This can be explained through a decline in local bog iron sites coupled with increased dependence on Swedish mountain iron (Schia 1994). Moreover, it is recognised that reconstructing patterns of hinterland exploitation is useful for investigating society and economy of historic towns. This is demonstrated at Medieval Lübeck, Germany where shifts from local resource exploitation and agriculture to reliance on imported grain is explained by increased pressure on available space caused by accelerating urbanisation (van Haaster 1994).

3.2.2.2 Evidence for Rural-Urban Zones and Sectoral Interactions

Given the importance of rural-urban resource fluxes the existence of historic rural-urban interaction zones is not surprising, for example Wilson (1994) notes the importance of animal rearing and marketing at sub-urban and sub-rural zones within Medieval and Post-medieval Oxford. Moreover, Ciezar *et al.,* (1994) identify a *suburbanus* on the periphery of Roman and Medieval Paris. It is suggested that this zone represents an urban food-belt which emerged as a response to declining or unstable rural food networks. This theory is supported by archaeological excavation which revealed habitation deposits, animal penning, animal bones and high soil phosphates.

Regarding sectoral interactions, organic soil rich in phytoliths at the Roman Deansway Site, Worcester provide evidence for open air penning of herbivores and associated burning of animal manure and trampled soil from animal pens (Macphail 1994).

Moreover, high concentrations of faecal material and coprolites indicative of systematic dung spreading at 1st century AD Whittington Avenue Site, London infer that urban horticulture was an important practise in Romano-British towns (Macphail 1994). Soil management associated with urban horticulture is similarly recognised in late Medieval Lübeck, Germany where urban gardens were being intensively fertilised through dung application from as early as the 14th century AD (van Haaster 1994).

3.2.3 Summary

Evidence for resource fluxes, hinterland exploitation, suburbs and urban horticulture supports the notion of a rural-urban continuum in historic towns. Moreover considering that modern parallels are identified in contemporary towns and cities, it is argued that such rural-urban interactions are inherent in the development and continued existence of urban environments. The importance of appropriate nomenclature and provision for rural-urban interactions in developing a waste flow model for small historic towns is therefore recognised.

3.3 Research Framework

3.3.1 <u>Modelling Waste in Small Historic Towns</u>

The following section presents a flow model of waste movement in small historic towns (Figure 13) and discusses its component features. The purpose of this model is to act as a research framework for understanding management of different types of waste and to identify variables affecting waste procurement, movement and disposal, within and between historic small towns.

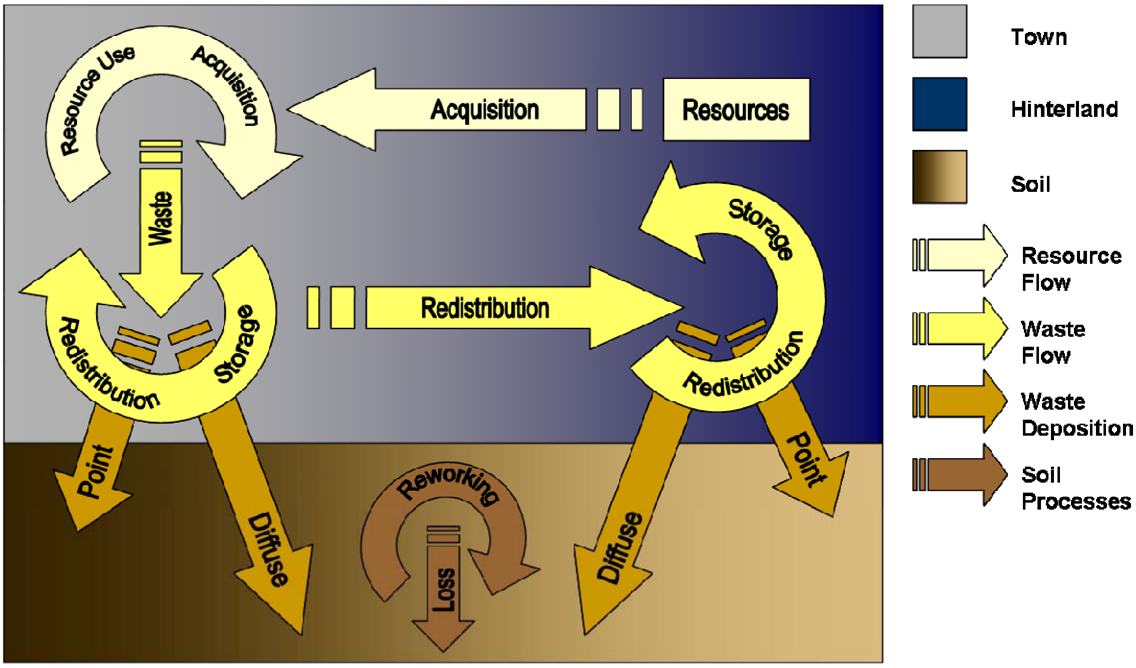


Figure 13: Flow model of waste movement in small historic towns

3.3.1.1 Town and Hinterland

In the first instance a distinction is made between town and hinterland. The town zone corresponds to the built environment of historic towns hence is typically urban. In addition this zone encompasses areas characterised by rural-urban interactions and sectoral interactions accounting for activities traditionally classed as rural such as cultivation and animal rearing. The hinterland is a theoretical area of resource exploitation characterised by both rural-urban linkages and urban-urban linkages. The hinterland can therefore be defined at different scales ranging from national and regional to land immediately adjacent to the town. The town and hinterland are linked by rural-urban fluxes of resources, goods and waste materials, hence are not mutually exclusive zones. The interdependence of town and hinterland is represented in the model by colour gradation as opposed to a definite boundary. Provision is therefore made for shifting definitions of urban and rural, allowing reassessment of the nature and extent of town-hinterland interactions.

3.3.1.2 Resource Flow

Acquisition represents movement of materials from the hinterland to town. These materials range from locally available natural resources to manufactured trade goods. The precise nature and abundance of incoming materials is largely dependant on geographical location, proximity to local natural resources and industrial demand. These variables are often inextricably linked, for example fishing and trade being the dominant industries of coastal burghs. To a lesser extent materials can also be acquired from the town itself including animal meat, vegetables and dairy products. Acquired resources are incorporated into a cycle of use and re-use, for instance animal carcasses supply primary material for fleshers, tanners, leather workers, horners and candle makers. This is akin to LaMotta and Schiffer's (2001) systemic context which features material reuse and recycling as key flows.

3.3.1.3 Waste Flow and Deposition

Materials with no remaining economic or cultural value are classed as waste (Thompson 1979, 2003). Accordingly such materials transition to a cycle of waste management which is characterised by processes of storage and redistribution. Storage refers to temporarily holding waste at a given location, such as the use of dunghills. In contrast redistribution is concerned with material movement. Redistribution of waste can occur within the town itself, for instance to the backlands, and also in the hinterland.

Deposition of waste falls into two categories, point and diffuse. This distinction discriminates between spatially discrete features such as middens and, deposits rich in refuse. Potentially these practises can occur in both the town and hinterland, for example town waste can be spread in town gardens and the burgh acres. Upon deposition, waste is incorporated in the soil matrix. It is suggested that the impact and magnitude of waste disposal diminishes with distance from the town core. The hypothesised distance decay effect of the impact of waste disposal on soil properties is reflected in graduation of colour from dark brown (town) to light brown (hinterland). After deposition, continual reworking of waste is expected in association with system loss of more mobile elements.

3.3.1.4 Model Limitations

It is acknowledged that some scenarios do not readily follow the model, for example cattle have multiple roles such as producing milk, meat and as industrial raw materials. However it can be debated whether cattle dung is a resource or waste material given that it follows processes of storage, movement and deposition associated with waste material flows. Conversely dung is known to have held an economic value hence its place arguably belongs in the cycle of resource use and acquisition. Accordingly, it is expected that model modifications will be proposed upon discussion of the project findings.

3.3.2 Aim and Objectives

The project aim, objectives and hypotheses are stated below and are further presented in a hierarchical flow model (Figure 14). The proposed hypotheses are broad and relate to expected study outcomes.

3.3.2.1 Aim

Urban Anthrosols are distinctive owing to their location and that their properties are modified through waste material amendments. Much consideration has been given to how changes in soil physical and chemical properties reflect current human influence (Chapter 2) however, their role as a historical archive is only just being recognised. Recent studies indicate that urban soils reflect differences in past soil inputs over space, time and location. There has been no systematic attempt to account for the diversity and distribution of urban anthrosols either within or between historic towns. The aim of the study therefore is to characterise and understand the modes of urban anthrosol formation in historic small towns.

3.3.2.2 Objective 1

Discrete patterns in soil physical and chemical properties are identified both within and adjacent to historic towns. This is especially true for Scottish royal burghs where deepened phases of topsoil are identified in the medieval core and town hinterland. It is proposed that such trends are the legacy of past waste material inputs. The first study objective therefore is to establish the nature and diversity of urban anthrosols in and near to historic small towns. Accordingly it is hypothesised that differences in soil characteristics exist across burghs and their hinterland and that soil properties of urban anthrosols in and near to burghs are determined by past waste material amendments.

3.3.2.3 Objective 2

Although trends in certain soil properties are replicated across historic towns, for example dark earth deposits and garden soils, differences both within and between historic towns are expected on account of past geographical, functional and economic diversity. Consequently, the second study objective is to characterise and account for the multiplicity of urban anthrosols in and near to historic small towns. It is expected that different types of urban anthrosol exist, that distributions of different urban anthrosols are related to functional zones and distributions of urban anthrosols are related to past burgh functions and economies.

3.3.2.4 Objective 3

Urban anthrosols present a historical archive of human activities in towns. It is argued that deposits formed through sustained application of waste materials reflect past waste management practises. The nature and location of such practises are influenced by burgh function and economy, and type, quantity and perceived utility of waste materials. Consequently the third study objective is to elucidate the processes associated with waste management and disposal in historic small towns. Additionally it is proposed that processes of waste disposal can be deduced from urban anthrosol properties and that processes of waste disposal were associated with economic and cultural functions of the royal burgh.

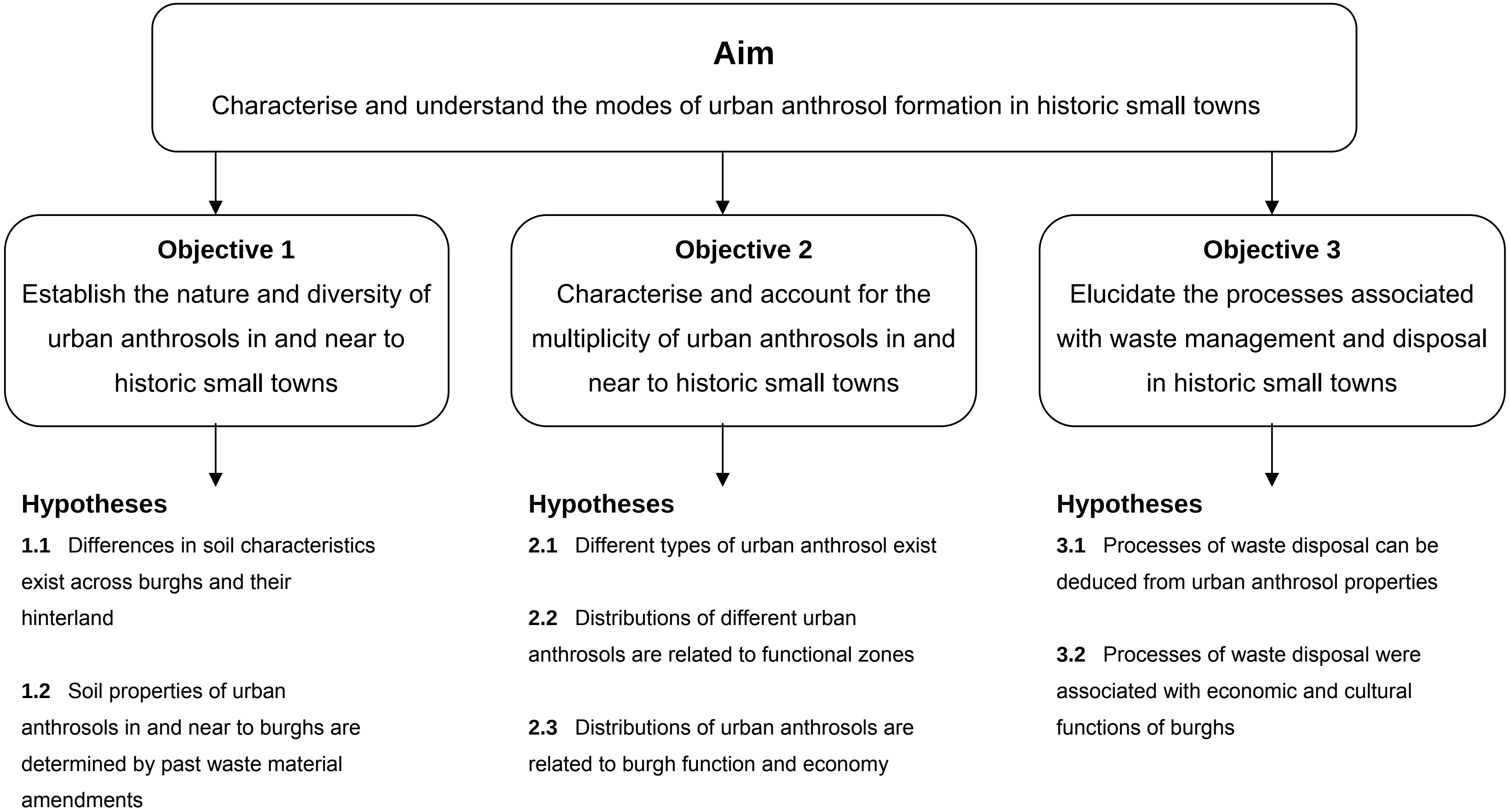


Figure 14: Project aim, objectives and hypotheses

4 Materials and Methods

This chapter outlines the materials and methods used in this study with specific reference to site selection, field work, laboratory analyses, soil micromorphology and data analyses.

4.1 Site Selection

To facilitate selection of suitable study sites a series of practical and theoretical criteria was developed. It was deemed important that potential burghs had limited modern urban development infill and peripheral expansion given the need for abundant and relatively unrestricted sampling opportunities both within and adjacent to medieval town cores. Moreover, to enable comparison of past functional zones preference was given to sites with characteristic medieval street layouts such as single street and parallel street systems. Geographical and functional diversity were also identified as important factors, for example it was desirable that towns had differing trading patterns, local resources and principal economies. Twelve potential study sites were identified through desk-based studies and a series of preliminary field visits (Figure 15).

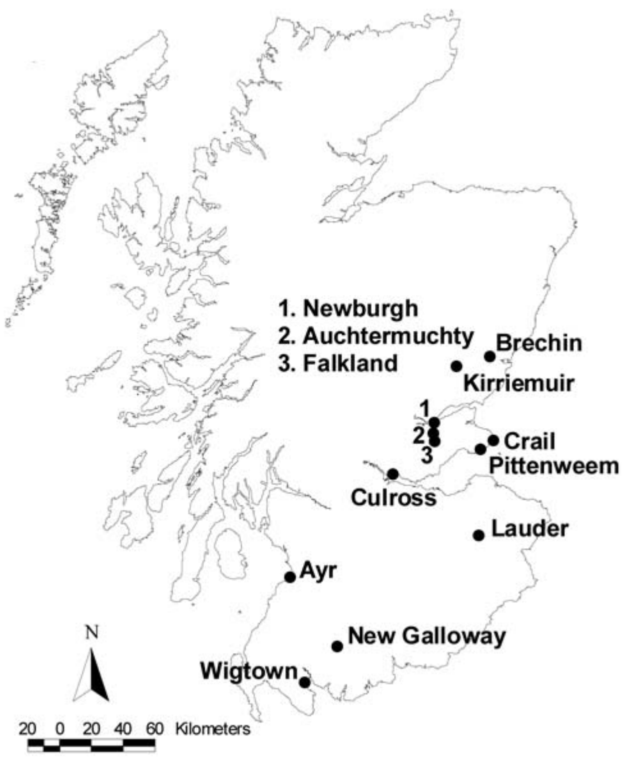


Figure 15: Location of preliminary field visits undertaken between 12/11/04 and 04/01/05

Burghs with low sampling potential were discounted (Auchtermuchty, Ayr, Brechin, Crail, Kirriemuir and Newburgh). Burghs without characteristic medieval street morphologies were also excluded (Culross and Falkland). Of the remaining four burghs, Lauder, Pittenweem and Wigtown were identified as the most geographically and functionally diverse, hence New Galloway was eliminated from subsequent selection.

4.1.1 <u>Study Sites</u>

4.1.1.1 Lauder

The royal burgh of Lauder, Scottish Borders, lies immediately east of the A68 which runs between Edinburgh and the English border. The town is located in a valley overlooked by the Lammermuir hills and is situated on the right bank of the River Leader (Figure 16). The soil mapped at Lauder is a freely drained brown forest soil with low base status belonging to the Lauder (LA) soil series. This series is part of the Lauder (LA) association derived from conglomerates and sandstones of Upper Old Red Sandstone (O.R.S) age (Soil Survey of Scotland 1959). In the 2001 census the population of Lauder was recorded as 1087. The largest two employment sectors identified were retail and wholesale, and health and social work accounting for 26% of employed persons, followed by business services (12%), education (11%) and public administration (11%) (General Register Office for Scotland 2007).

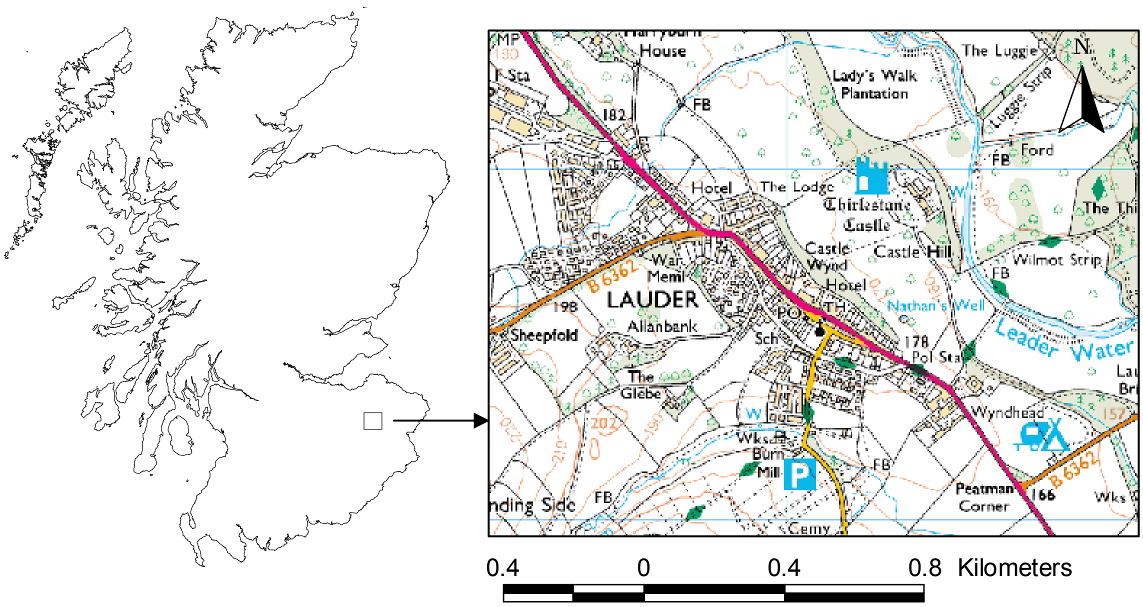


Figure 16: Location and situation of Lauder, Scottish Borders

The origins of Lauder are unclear although it is suggested that its foundation lay in the 12th century AD when Hugh de Moreville built a castle, church and mill complex for his followers in the barony of Lauderdale (Simpson and Stevenson 1980). The first documented existence of Lauder was in the late 13th century AD when Bishop William Lamberton of St. Andrews noted '*duo burgagia in villa de Lawder*'. This recognition indicates the presence of a settlement however; it does not necessarily confirm burghal status at that time (Pryde 1965). Lauder was officially elevated to burgh status with baronial privileges in the 14th century (1324x1325AD) and was subsequently granted royal status in 1455AD after being forfeited by the Douglas family to the crown.

Throughout the medieval period the principal economy of Lauder was merchandising and trade. Prosperity associated with these activities was largely dependant on external factors, for example a 16th century AD burgh charter indicates the absence of foreign trade on account of war, assaults and fire (Turner-Simpson and Stevenson 1980). By the late 18th century AD Lauder held six yearly fairs and two weekly markets. Moreover, growing political stability resulted in an increase in the town's population, foreign trade and traffic. In addition to trade, milling was a significant economic component in the development of Lauder. This is confirmed in various 16th century AD references which cite the existence of a corn mill, a waulk mill, a common Burn Mill belonging to town and a Mill belonging to a Lauder family.

4.1.1.2 Pittenweem

The royal burgh of Pittenweem, Fife, lies on the A917 coastal road which runs between Elie and St. Andrews on the East Neuk of Fife. The town is located 2 km south west of Anstruther and is situated on a raised beach overlooking the northern North Sea (Figure 17). The soil mapped at Pittenweem is an imperfectly drained brown forest soil belonging to the Quivox (QX) soil series. This series is part of the Dreghorn association characterised by raised beach deposits derived mainly from Carboniferous sediments (Soil Survey of Scotland 1975). In the 2001 census the population of Pittenweem was recorded as 1747. The principal employment sectors identified were retail and wholesale and health and social work accounting for 16% and 12% of employed persons respectively. Other significant sectors included hotels and restaurants (10%), real estate (10%) and education (10%) (General Register Office for Scotland 2007).

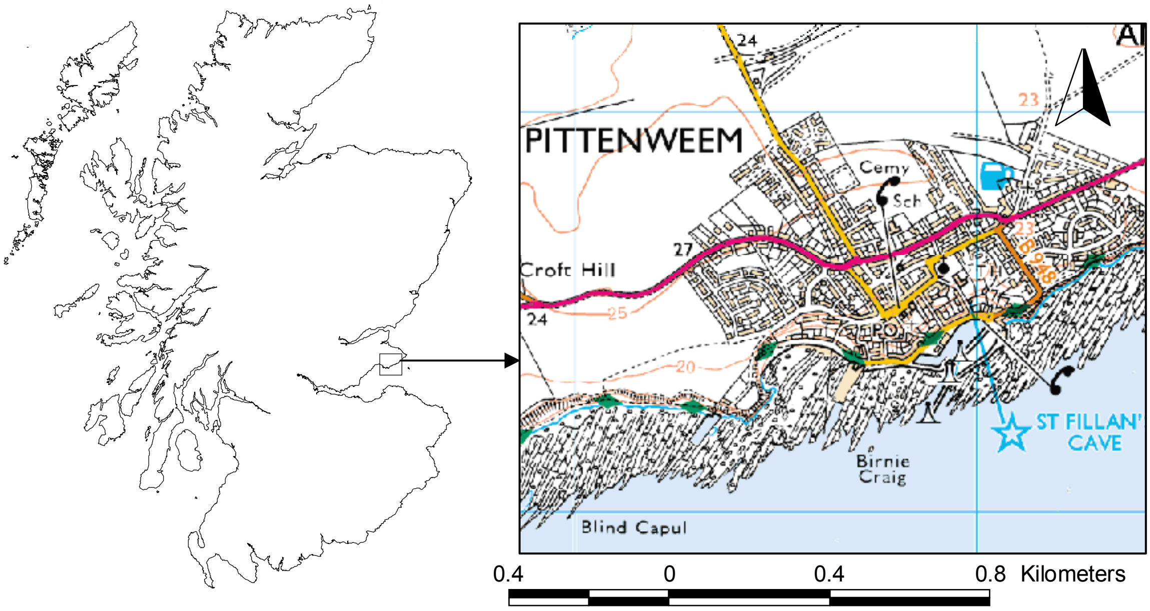


Figure 17: Location and situation of Pittenweem, Fife

The origins of Pittenweem can be traced to the 12th century AD when its lands were bestowed to monks resident on the Isle of May. This resulted in the transfer of the Augustinian priory from the Isle of May to the site of the current parish church (Simpson AT and Stevenson S 1981a). The development of the site over the following centuries is uncertain, however, a charter dating to 1526 AD indicates that by the late 15th century Pittenweem was a legitimate baronial burgh. In 1541 AD Pittenweem was subsequently changed 'in *liberum burgum regalen*' to royal burgh status (Pryde 1965).

The principal economies of Pittenweem were fishing and trade, for example in 1537 AD Pittenweem paid £205 16s duty on hides, cod, herring, malt and English goods in contrast to nearby Kinghorn which paid £6 7s 4d (Simpson and Stevenson 1981a). The financial dominance of Pittenweem in the 16th century AD was further demonstrated in 1542 AD when Pittenweem exported £432 19s in hides, salmon, cod, coal and herring compared to £139 5s 4d by Perth. Civil war and plague during the 17th century AD had a negative impact on Pittenweem's population which in turn led to a decline in seafaring and export revenues. Consequently a ruined pier and harbour, empty houses and an absence of foreign trade were noted (Simpson and Stevenson 1981a). Nevertheless, by the mid 18th century AD the town had started to recover. This was reflected in renewed export of salt fish, herrings and malt to the Baltic, Mediterranean and Low Countries (Horsburgh 1865).

4.1.1.3 Wigtown

The royal burgh of Wigtown, Dumfries and Galloway, lies on the A714 which connects Girvan in west Scotland to the Machars peninsula in south west Scotland. The town is located 11km south of Newton Stewart and is situated overlooking Wigtown Bay on the Solway Firth (Figure 18). The soil mapped at Wigtown is a freely drained brown forest soil belonging to the Linhope (LP1) soil series. This series is part of the Ettrick association derived from Ordovician and Silurian greywackes and shales and their associated drifts (Soil Survey of Scotland 1971). In the 2001 census the population of Wigtown was recorded as 987. The principal employment sectors identified were retail and wholesale (21%), construction (14%) and manufacturing (14%). Other important sectors included health and social work, and agriculture, hunting and forestry accounting for 17% of employed persons collectively (General Register Office for Scotland 2007).

Although it is thought that Wigtown existed as a burgh during the 12th century AD, it was not until 1292AD that its status as a royal burgh was recognised by charter. However, Wigtown's position as a royal burgh was short lived. In 1341AD it was granted to Sir Malcolm Fleming due to unpaid revenues (Pryde 1965). Ultimately Wigtown was restored to its former royal status in 1455AD after it was forfeited by the Douglas family to the crown.

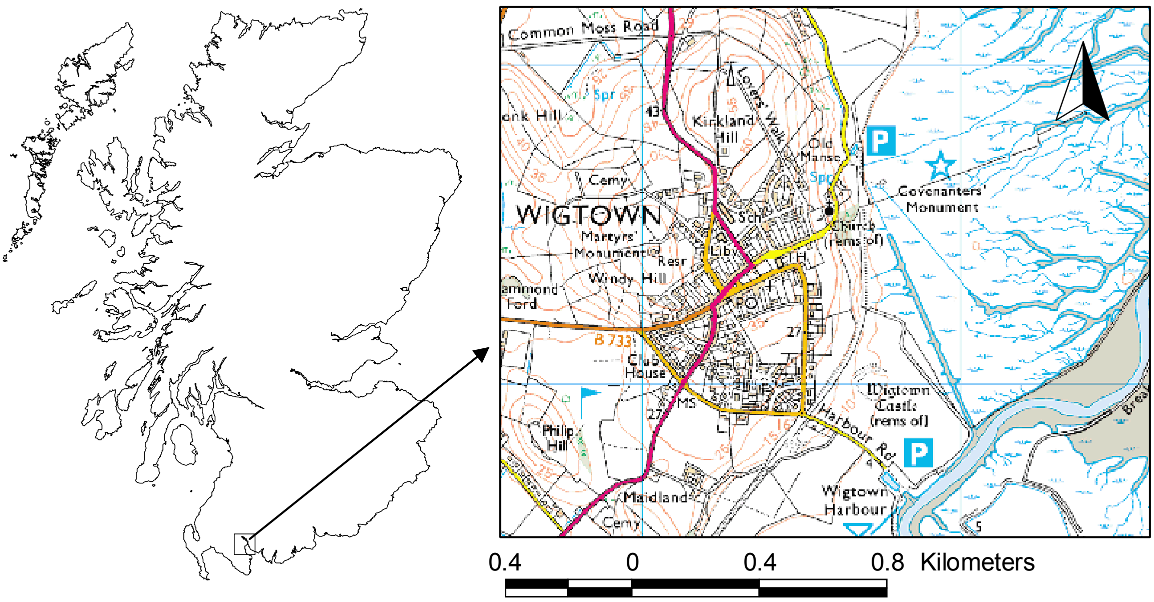


Figure 18: Location and situation of Wigtown, Dumfries and Galloway

The principal economies of Wigtown were trade and agriculture. During the 15th century AD Wigtown was one of the five principal west coast ports of Scotland including Ayr, Irvine, Dumbarton and Kirkcudbright. Throughout the 16th and 17th centuries AD trade steadily declined to the extent that in 1692AD foreign trade was absent and inland trade was limited. The main reason for this demise was that Wigtown did not participate in the herring trade which became a major export of rival west coat ports (Simpson and Stevenson 1981b). Nevertheless, Wigtown remained a dominant agricultural centre. This is attested to in the Old Statistical Account for Scotland where considerable documentation is devoted to land, farming practises and agricultural revolution at Wigtown (Duncan 1791-99). Towards the latter 18th century AD an increase in population associated with the onset of industrialisation and Irish immigration is noted along with the reinstatement of Wigtown's markets (Simpson and Stevenson 1981b).

4.2 Soil Survey

Special-purpose soil survey was identified as a useful tool for systematically investigating changes in soil properties across small historic towns (Bui 2004, Dent and Young 1981, McRae 1988). The survey objective was to determine variation in soil physical and chemical properties in historic urban landscapes. Furthermore, the intent of soil mapping was to reveal differences in specific soil properties indicative of past anthropogenic activities. The following section provides an overview of survey design and subsequent field methods.

4.2.1 Survey Design

In the first instance the location and extent of the survey area was determined for Lauder, Pittenweem and Wigtown (Figure 19, Figure 20 and Figure 21). The siting of each survey area represents the most effective compromise between three factors; historical land use, modern urban encroachment and abundance of potential sampling opportunities. Each survey area included the medieval burgh core and its adjacent land, whilst avoiding recent urban development. The survey area consisted of a 200 x 800 m rectangle covering 160,000 m^2 (0.16 km^2). This was deemed large enough to reveal identifiable changes in soil properties associated with different past functional zones. Survey area dimensions were consistent for all burghs to maintain comparable sampling densities. It is suggested that 100 observations per km^2 should be made for very detailed surveys (Bridges 1982, McRae 1988). This recommendation largely refers to natural soil variation which is more homogenous than urban anthrosols. Therefore, the adopted sampling density was 1 observation per 1600 m^2, totalling 100 observations for each 0.16 km^2 survey area.

4.2.1.1 Stratified Grid

The use of a grid system is an effective mechanism for structuring observations in areas with complex soil patterns (Dent and Young 1981). Moreover it is advantageous over free sampling in that regular spaced sampling results in equal statistical representation of soil variance (Bridges 1982). Grid surveys consist of four types, random survey, square grid survey, stratified random survey and stratified grid survey. Random survey is problematic for heterogeneous soil because observations are pre-determined through random number generation which can result in large areas remaining un-sampled (Tan 1996).

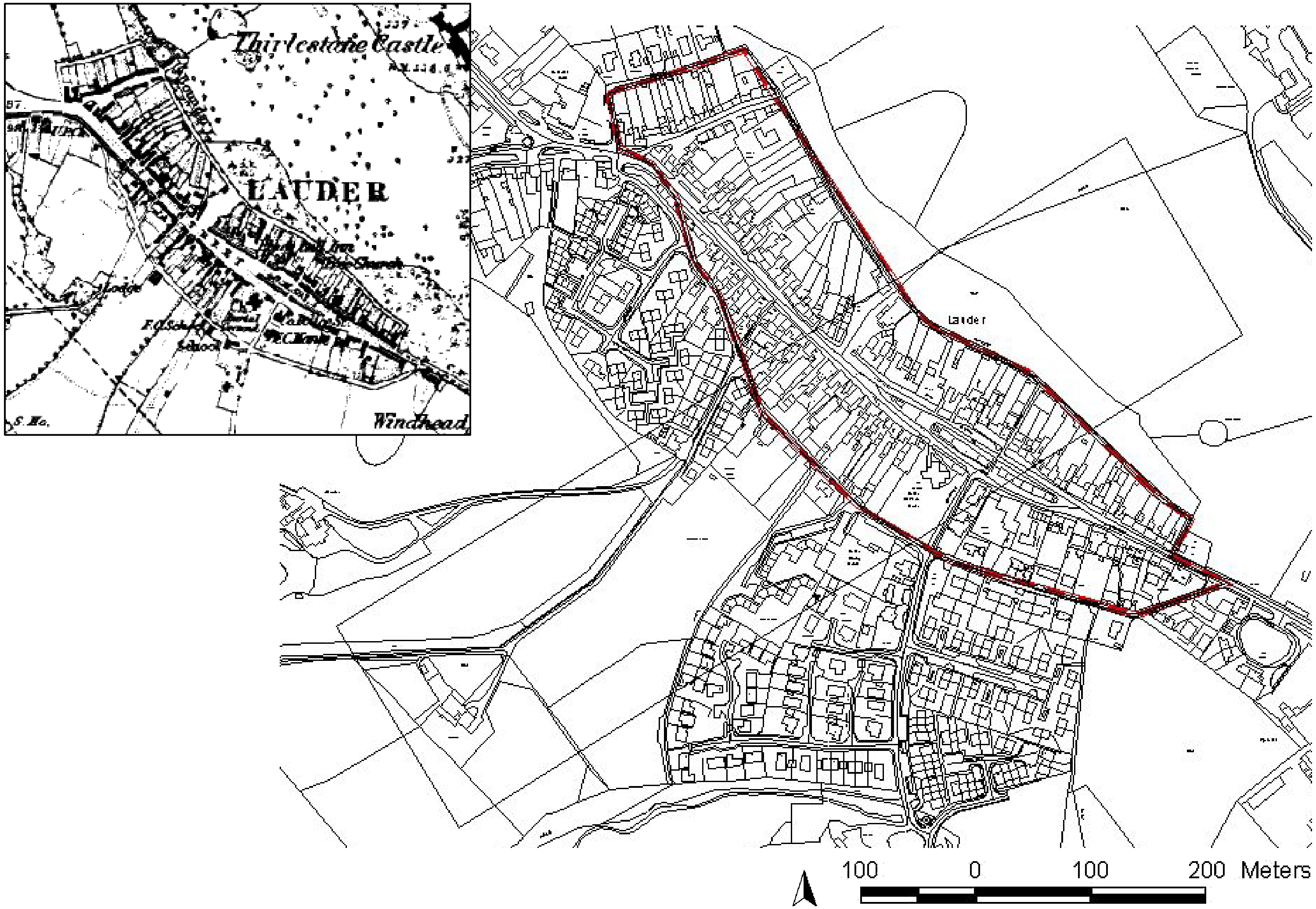


Figure 19: Location of survey area at Lauder (black rectangle). Red boundary delimits 1862AD urban extent taken from 1:10,560 scale Ordnance Survey map inset © Landmark information group, www.old-maps.co.uk

Figure 20: Location of survey area at Pittenweem (orange rectangle). Red boundary delimits 1855AD urban extent taken from 1:10,560 scale Ordnance Survey map inset © Landmark information group, www.old-maps.co.uk

Figure 21: Location of survey area at Wigtown (orange rectangle). Red boundary delimits 1850AD urban extent taken from 1:10,560 scale Ordnance Survey map inset © Landmark information group, www.old-maps.co.uk

Square grid survey is also inappropriate for this study due to inflexibility of observation points and the potential that trends may go unnoticed if variations in soil properties coincide with orientation and spacing of the grid (Rudeforth 1982). Stratified random survey and stratified grid survey present a compromise between the latter approaches. Stratified random and stratified grid survey use pre-defined grid squares to structure observations. Observations are chosen at random in the former method and systematically in the latter. Stratified grid survey was identified as the most appropriate choice for this study given that provision is made for sampling obstacles associated with urban environments, for example car parks, grave yards, roads and recreational ground.

4.2.2 Field Methods

4.2.2.1 Auger Sampling

Soil sample acquisition through auguring was chosen as the primary method of soil survey because it is a relatively quick and easy technique for surveying both laterally and vertically (Bridges 1982). In addition it enabled field assessment of soil variation aiding subsequent location of representative soil pits. Auger sampling was structured through stratified grid survey. The grid consisted of 40 x 40 m grid units totalling 100 potential observation locations per survey area. In some circumstances grid units were not sampled, for instance when covered by an impermeable surface or modern housing. Consequently, additional observations were made in emerging areas of interest. These areas corresponded to past functional areas and exhibited pronounced variability in certain field characteristics such as topsoil depth. The resulting sample distributions comprised 117 observations at Lauder (Figure 22), 102 at Pittenweem and 102 at Wigtown (Figure 23).

To compare soil properties over space and depth, soil samples were taken at 0-20 cm, 20-40 cm, 40-60 cm and 60-80 cm depth at each observation location or until the auger could go no further. Samples were taken at depth increments rather than from discrete horizons given that prior determination of horizon boundaries is impractical using a Dutch auger and mixing between boundaries is an unavoidable consequence of the barrelled auger tip. Soil samples were taken from the centre of the auger head at the lowest depth of each increment range. Sample volume was dictated by the auger headspace which equated to between 100-150 g of moist soil. In total 270, 377 and 158 loose bag samples were obtained from Lauder, Pittenweem and Wigtown respectively.

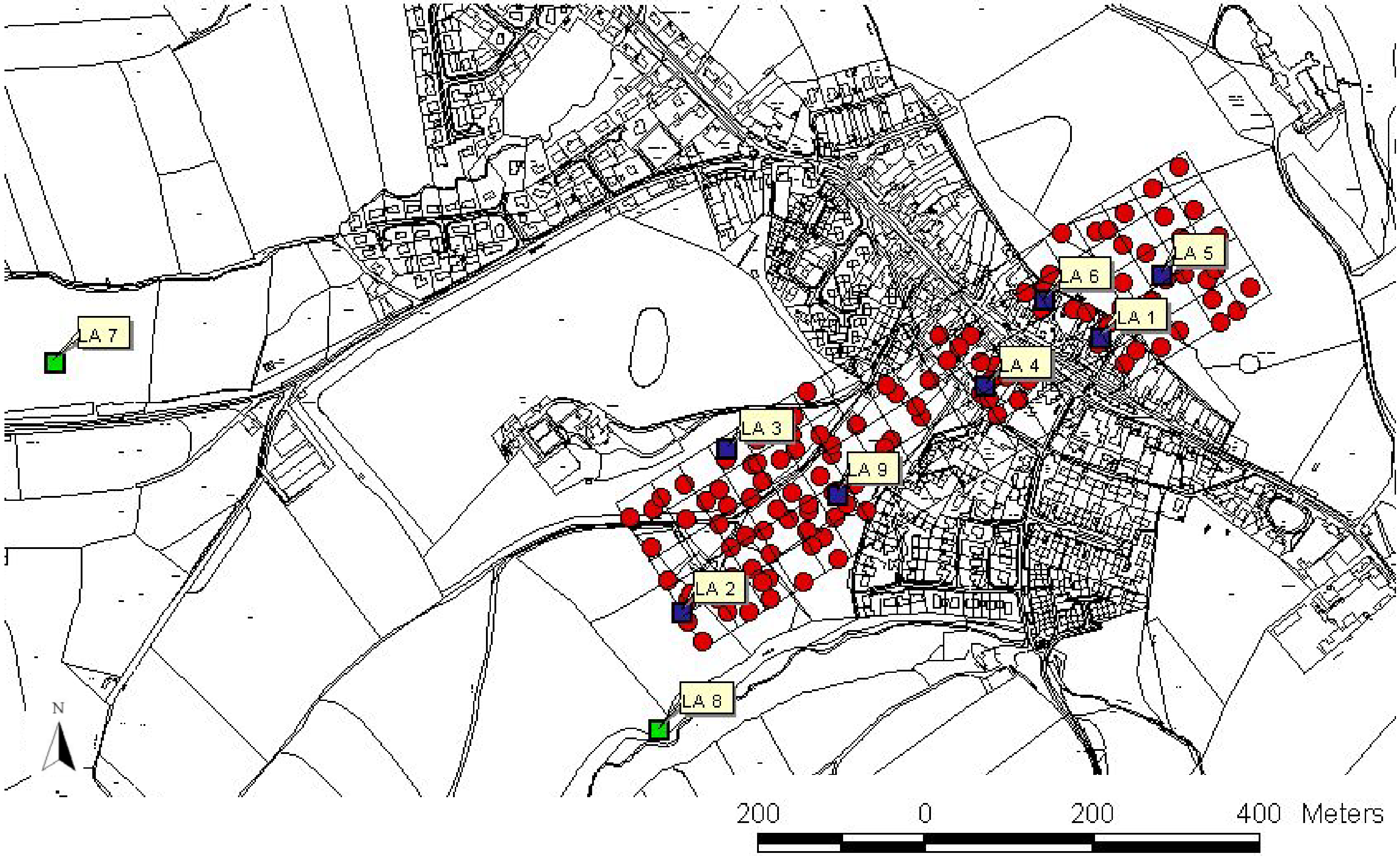


Figure 22: Stratified grid survey at Lauder showing auger sample locations (red circles), soil pit locations (blue squares) and 'reference' soil pit locations (green squares)

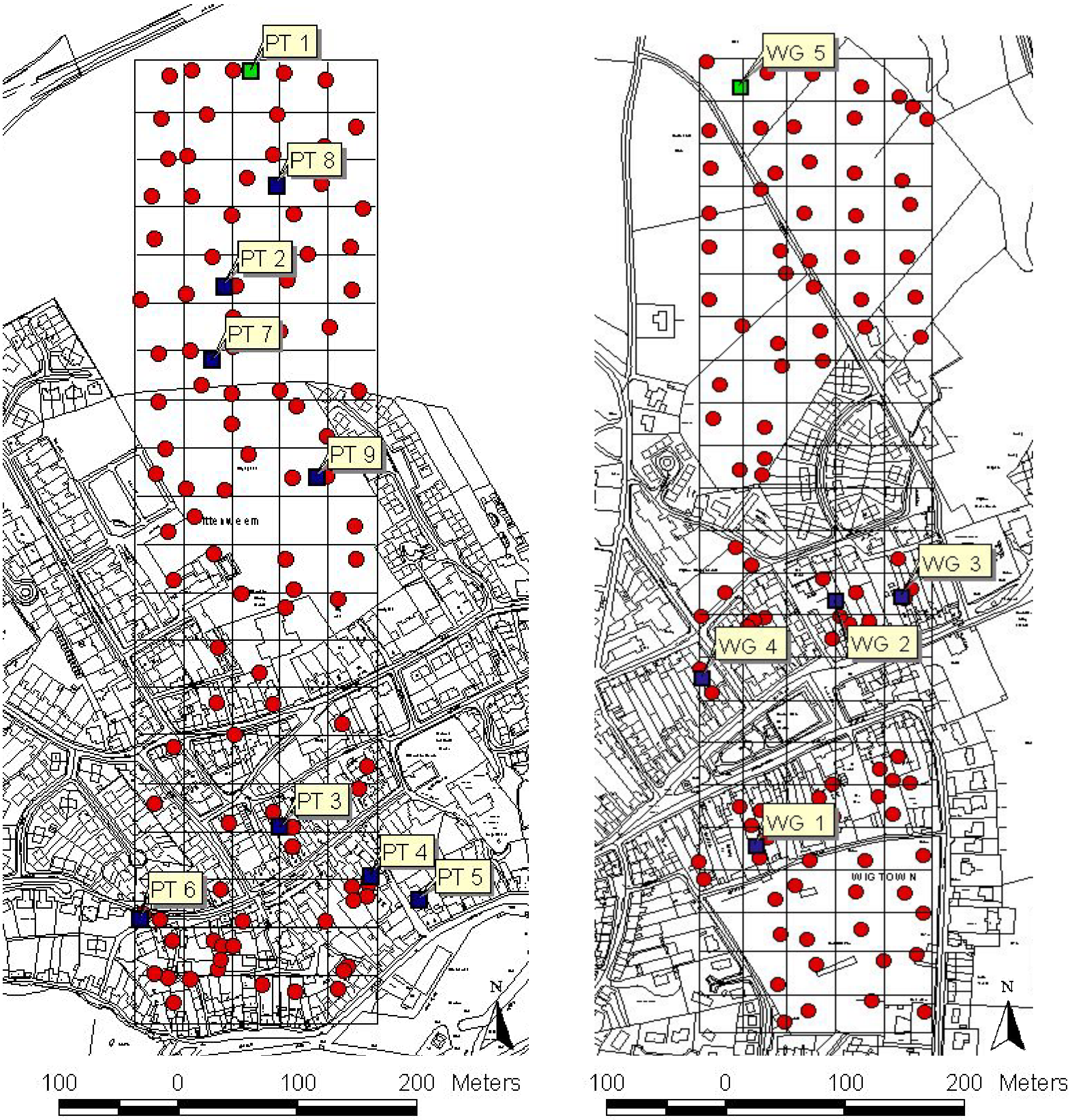


Figure 23: Stratified grid survey at Pittenweem (left) and Wigtown (right) showing auger sample locations (red circles), soil pit locations (blue squares) and 'reference' soil pit locations (green squares)

Horizon depth(s), soil colour and presence of anthropogenic inclusions were also noted at each observation location to provide context to subsequent results and supplement field observations of soil characteristics.

4.2.2.2 Soil Pit Sampling

To enable further investigation of areas with distinct soil characteristics, samples were taken from soil pits. The location and number of soil pits was determined by identification of emergent patterns in soil variability in association with the need to investigate comparable functional zones. Samples were also taken from so-called ‘reference’ soil pits to provide a comparison of soil with lesser anthropogenic modification. It was assumed that the impact and magnitude of waste disposal diminished with distance from the town core (as discussed in section 3.3). Consequently, reference pits were located at the far northern edge of each survey area with the exception of Lauder (Figure 22, Figure 23). In the latter case there is evidence to suggest that burgess acres extended to the rear of the survey area. Accordingly, topsoil samples were taken from a pit 1km northwest of the survey area and C horizon samples extracted from an exposed profile 200m south of the survey area.

Prior to sampling a brief site description was made at each soil pit location. The following information was recorded; profile identification number, grid reference, date, preceding weather conditions, elevation (m), locality and vegetation/land use. Soil pits were dug to a maximum of 1m or until the topsoil could be clearly distinguished from underlying horizons. Field sketches were made at each location in association with a soil profile description recording depth (cm), Munsell soil colour, macropores, mottling, stoniness, roots and exotic inclusions (Hodgson 1974, Munsell Color ® 1994) (Figure 24).

To enable subsequent determination of physical and chemical soil properties, loose bag samples were taken from each horizon. Bulk samples were extracted from a depth range of 20cm allowing collection of sufficient material. To avoid incorporation of material from adjacent horizons a 2cm buffer zone was imposed at each horizon boundary. In some cases horizons were deeper than 44cm, hence, 20cm samples were taken in vertical succession. Moreover if horizons were less than 24cm the utility of sampling was decided on an individual basis. In total 18, 32 and 14 bulk samples were taken at Lauder, Pittenweem and Wigtown respectively. In addition Kubiena tin samples were taken for the purpose of micromorphological characterisation. Kubiena samples were extracted in accordance with recommendations outlined in Goldberg and MacPhail (1996: 328-333). Care was taken to ensure all Kubiena samples were contiguous with bulk samples.

As reference soil pits, three profile faces were described and sampled instead of one (Figure 25). This was done to increase confidence when characterising areas representative of lesser anthropogenic influence. Alternatively, additional reference soil pits could have been sampled; however, locations were limited in terms of space and suitability.

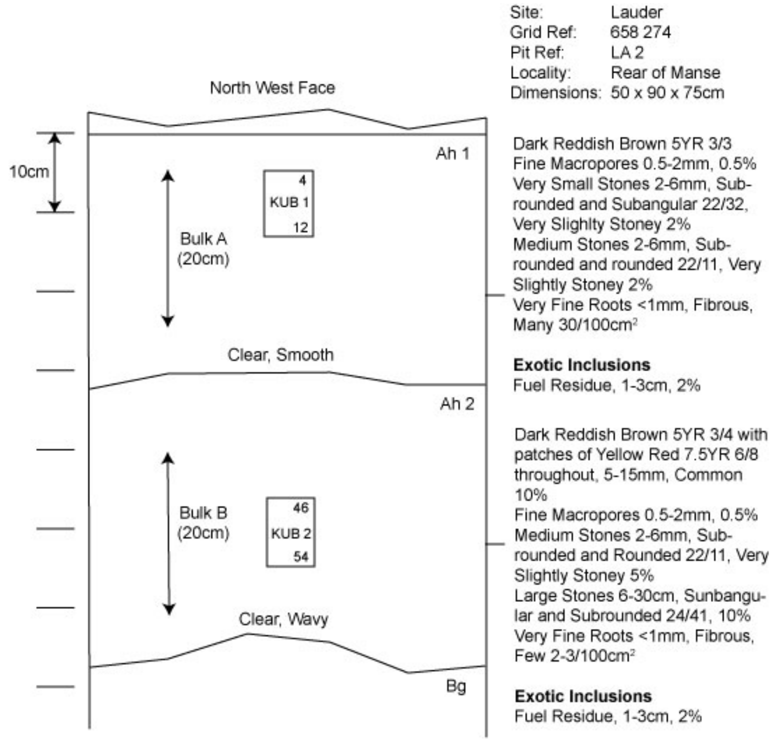


Figure 24: Example of field sketch, profile description and soil sampling undertaken for LA 2 (Lauder soil pit number 2)

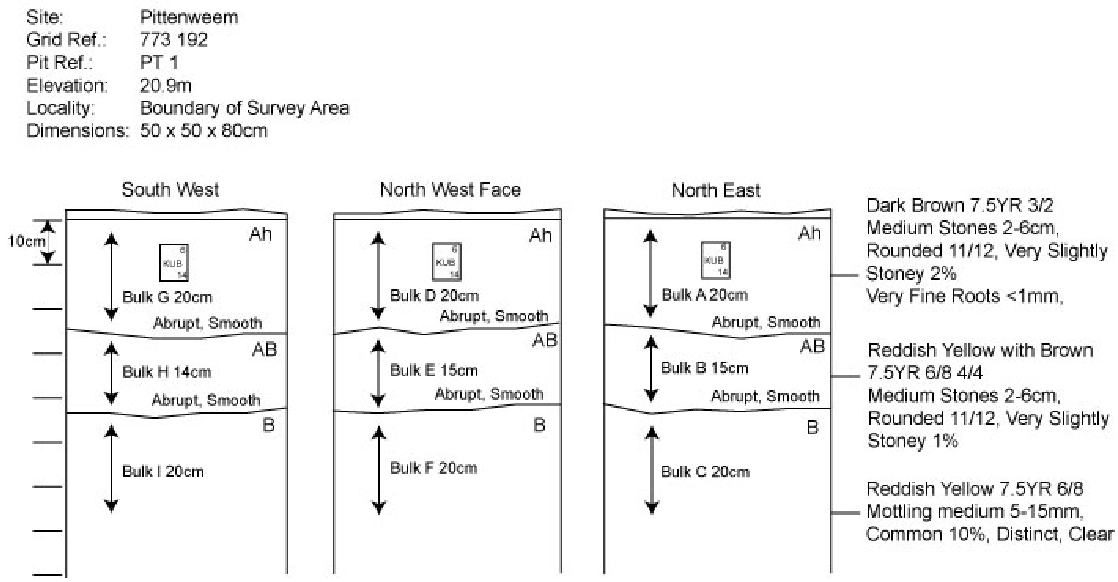


Figure 25: Example of field sketch, profile description and soil sampling undertaken for 'reference' soil pit PT 1

4.3 Laboratory Analyses

The following section presents a summary of laboratory analyses undertaken on bulk soil samples obtained through auger and soil pit extraction. Prior to analysis all samples were air dried for a minimum of two weeks until steady state mass was achieved. Samples were then sieved to separate the fine fraction (<2mm) from the coarse fraction (>2mm) to remove larger roots and stones. Exotic inclusions such as pottery sherds and charcoal fragments were retained before discarding the coarse fraction. Considering time constraints it was not possible to take replicate measurements of all soil samples, therefore samples obtained through auger survey were analysed only once. Soil pit samples were analysed three times to assess data variability. In all cases anomalous values were systematically identified and re-checked.

4.3.1 <u>pH</u>

Soil pH is a measure of the concentration of hydrogen ions in a solution which is defined as '-log (H^+) where (H^+) is the activity of hydrogen ions in solution' (Rowell 1994:159). Measurement of soil pH, therefore, allows determination of the degree of soil acidity or alkalinity. In the natural environment soil pH is controlled by climate where rainfall and temperature influence processes of nutrient leaching and weathering. Moreover additional variables such as parent material, hydrology and vegetation further act to influence pH at regional and local scales (Brady and Weil 1999).

Although soil pH is largely controlled by environmental factors, anthropogenic activities can impact soil acidity, for example the use of ammonium based chemical fertilisers are known to react with organic wastes resulting in nitric and sulphuric acid accumulation (Brady and Weil 1999). Likewise, fossil fuel combustion and vehicular traffic are identified as causes of increased acidity in urban soils (Bridges 1991). Certain agricultural practices can result in an intentional reduction in soil acidity such as application of lime, marl, shells and ground limestone. Similarly, decreased soil acidity through addition of domestic refuse and fuel residues such as ash and soot is noted in domestic urban gardens (Bridges 1991). Nonetheless increased soil alkalinity can be problematic, for instance when salts drain insufficiently from soils irrigated with salty water (Brady and Weil 1999, Rowell 1994).

Studies of soil pH in geoarchaeology are usually limited to issues of artefact preservation (Berna *et al*., 2004, Matthiesen 2004). However, it seems logical that variations in soil pH may reflect the historical legacy of past soil amendments such as shell, bone, fuel residue and midden waste (Carter 2001, Cachart 2000, Davidson *et al*., 2006). Soil pH is also an important supplementary measure when interpreting spatial patterns in elemental concentrations, for example Entwistle *et al*., (1998) note a narrow pH range in soils both on and off site at Greaulin, Isle of Skye suggesting that on site variation in elemental concentrations is anthropogenic in origin.

Soil pH can be described as a ‘master variable’ affecting a multitude of chemical, biological and physical soil properties (Brady and Weil 1999:252). Analysis of soil pH, therefore, presents a relatively quick and easy method for obtaining information about a multitude of soil properties including changes associated with past anthropogenic activities. Accordingly, soil pH was measured using a MK11 Series Analogue meter in accordance with procedures outlined by Rowell (1994:159-161). The meter was calibrated using pH 4 and pH 7 buffer solutions and subsequently recalibrated after every 40 readings to prevent instrumental drift.

4.3.2 Loss on Ignition (% LOI)

Loss on ignition (LOI) is a measure of the percentage mass of ‘soil organic matter (SOM) lost from oven dry soil when heated to between 105^{o}C and 500^{o}C (Rowell 1994:48). However, overestimation of SOM loss using the LOI method is possible, for example through loss of structural water from clay minerals and loss of CO_2 from carbonates in calcareous soils. Ball (1964) proposes that error associated with CO_2 loss can be minimised through ignition in the lower temperature region (375^{o}C as opposed to 850^{o}C) and suggests that variation in LOI is only 4-6% between soils with 5% clay and 50% clay content. This level of accuracy is considered acceptable for most archaeological and pedological studies (Ball 1964). LOI is therefore identified as a reliable and rapid technique for approximation of SOM. LOI was determined in accordance with procedures outlined in Rowell (1994:48) using the formula below. All results are expressed as g per 100g of oven dry soil i.e. % LOI.

$$\%\ LOI = 100 * \frac{(mass\ oven\ dry\ soil\ (g) - mass\ ignited\ soil\ (g))}{mass\ oven\ dry\ soil\ (g)}$$

In geoarchaeological studies LOI has been used in association with elemental analysis to identify areas cultivated in the past, for example it is suggested that a moderate positive correlation between LOI and phosphorus (P) at Knockaird, Isle of Lewis reflects sustained application of manure rich in organic matter and P (Entwistle *et al.,* 2000). Areas with lower LOI levels compared to offsite control samples at Greaulin, Isle of Skye are thought to reflect the practice of applying manure rich in nitrogen (N) to cultivated land resulting in rapid microbial decomposition of SOM (Entwistle *et al.,* 1998). Cultivation and regular cropping also enhance SOM decomposition through changes in soil conditions such as increased soil aeration and disaggregation. Elevated levels of SOM in cultivated soil are likely to quickly disappear. It is therefore recognised that past soil enrichment may not necessarily be reflected in higher LOI values.

4.3.3 Environmental Magnetism

Environmental magnetism refers to the study of rock-magnetic properties of natural environmental materials such as soils, sediments, peat cores and ice cores, and anthropogenic wastes arising from agricultural and industrial processes (Oldfield 1999, Robinson 2002). All these materials exhibit magnetic behaviour which can be measured and quantified allowing identification of processes associated with their formation and recognition of component minerals (Dearing 1999). In pedological and archaeological studies the most widely used measurements are low frequency magnetic susceptibility (X_{LF}) and frequency dependant magnetic susceptibility (X_{FD}). These techniques differ from most other mineral magnetic measurements in that they are determined in the presence of an induced magnetic field. In comparison parameters such as isothermal remanent magnetisation (IRM) and saturation isothermal remanence (SIRM) are a measure of magnetisation retained after removal from an external magnetic field (Smith 1999).

Magnetic susceptibility can be defined as a measure of 'the ability of a substance to be magnetised' (Rapp and Hill 1998:184). In the natural environment magnetic susceptibility is dependant on concentrations of ferrimagnetic minerals such as magnetite (Fe_3O_4) and maghaemite (Fe_2O_3) (Dearing 1999). Hence, magnetic susceptibility of soils and sediments is largely controlled by the nature and abundance of iron oxides originating from underlying parent material. Anthropogenic activities are known to enhance magnetic susceptibility of soils, for example burning can result in formation of ferrimagnetic minerals such as maghaemite and non-stoichiometric magnetite (Crowther 2003).

Frequency dependant magnetic susceptibility reflects the percentage of viscous-superparamagnetic (VSPM) grains present in a mineral magnetic assemblage (Dearing 1999). This is based on the observation that relaxation times of superparamagnetic grains differ at high and low magnetisation frequencies (Jordanova *et al.,* 2001). Low frequency (X_{LF}) measures the combined response of stable single domain grains (SSD), pseudo-single domain grains (PSD), multidomain grains (MD) and superparamagnetic (SP) grains present within a sample. Conversely high frequency (X_{HF}) measurements exclude the contribution made by SP grains (for a full explanation see Dearing 1999:60-62).

In geoarchaeological studies magnetic measurements have been used to discriminate artefact origins, for example Jordanova *et al.,* (2001) identify differences in magnetic behaviour of burnt clay materials such as plaster and brick, and burnt soils between archaeological sites in northern and southern Bulgaria. Recognition that anthropogenic activity can lead to magnetic enhancement of soils has resulted in the use of magnetic susceptibility in archaeological site prospectation, for instance spatial patterns derived from underlying occupation and industrial sites are identified at Serra di Vaglio, Southern Italy (Chianese *et al.,* 2004). Moreover magnetic measurements can be used to investigate use of individual dwellings, for instance Peters *et al*., (2000) associate hearth residues with selected internal floor deposits and external midden material from Late Iron Age houses at Galson site, Isle of Lewis.

Magnetic measurements have also been extensively used to identify past evidence of burning including fuel residues. Dewar *et al.,* (2002) use modern analogues to identify fuel sources contributing to deposits from Old Scatness Broch, Shetland. Although deposits comprised a mixture of minerals with differing magnetic properties, it was possible to identify inputs from ash derived from turf and furnace residues. Similarly Peters *et al.,* (2001) demonstrate the utility of experimental data in investigating archaeological deposits at Calanais Farm, Isle of Lewis where techniques such as high temperature magnetic susceptibility were used to distinguish well humified peat and wood from fibrous upper peat and peat turf.

Magnetic susceptibility and frequency dependant magnetic susceptibility are simple, non-destructive and rapid techniques for investigating anthropogenic impact on soils with particular reference to burning, fire histories and fuel residues.

4.3.3.1 Mass Dependant Magnetic Susceptibility

To determine mass dependant magnetic susceptibility soil samples were dried at 105^{o}C overnight to remove excess moisture prior to analysis. Measurements were undertaken on a Bartington MS2 Magnetic Susceptibility Meter according to procedures outlined in Bartington Instruments Ltd (1996). The chosen measurement interval was x0.1 which provides an average reading every 10 seconds. This measurement interval is more robust than taking individual readings and provides additional noise filtering. Corrections for any thermally induced drift were made using the formula below.

$$corrected\ measurement\ (R_k) = sample\ measurement\ (10^{-5}) - air\ measurement\ (10^{-5})/2$$

Measurements for mass dependant magnetic susceptibility (Χ) were taken under low frequency (0.4465 kHz) which measures the response of all magnetisable material in a sample. Mass dependant magnetic susceptibility was calculated using the following formula according to Dearing (1999:46).

$$\chi\ (10^{-6} m^3 Kg^{-1}) = R_k (10^{-5}) \ /\ sample\ weight\ (g) / 10$$

4.3.3.2 Frequency Dependant Magnetic Susceptibility

The procedure outlined in section 3.3.3.1 was repeated under high frequency (4.65 kHz) conditions to enable calculation of frequency dependant magnetic susceptibility ($Χ_{FD}$). Frequency dependant magnetic susceptibility was calculated using the following formula according to Dearing (1999:47) where K_{LF} is the corrected measurement under low frequency and K_{HF} under high frequency.

$$\chi_{FD}\ (10^{-6} m^3 Kg^{-1}) = ((K_{LF} - K_{HF}) \ /\ sample\ weight\ (g) / 10)$$

4.3.4 Elemental Concentrations

Anthropogenic activities such as habitation, agriculture and industrial processing modify soil chemical properties (Aston 1998, Wilson *et al.,* 2006a). Accordingly, identification of changes in elemental concentrations enable differentiation of former land use patterns in space (Bull *et al*., 2001, Wells 2004) and time (Shahack-Gross *et al*., 2005, Alexandrovskaya and Panova 2003). However, it should be noted that human induced elemental changes are affected by elemental retention rates, elemental fixation, climatic conditions and soil properties (Holliday and Gartner 2007).

Phosphorus (P) is routinely used in geoarchaeological studies as an indicator of human activity considering its high soil retention rate and relative stability (Leonardi *et al.,* 1999). Increased phosphorus concentrations occur through deposition of anthropogenic materials rich in organic matter including human and animal excreta, domestic refuse and fuel residue (Holliday and Gartner 2007). Accordingly, spatial analysis of enhanced phosphorus concentrations can be used to identify and delineate areas associated with human habitation in the past (Schlezinger and Howes 2000). However, it must be noted that although phosphorus can be used to identify areas of past human activity it cannot differentiate between specific land use practises, for example accumulation of debris from settlements and manuring practises both lead to elevated phosphorus concentrations (Entwistle *et al.,* 2000a, Entwistle *et al.,* 2000b).

Conversely multi-element analysis enables investigation into a range of anthropogenic activities using elemental signatures to identify patterns of enhancement, for example Entwistle *et al.,* (1998) identify four groups of elements representing differences in land use at a Greaulin, Isle of Skye. Similarly Wilson *et al.,* (2006a) discriminate a suite of elements including barium (Ba), calcium (Ca), phosphorus (P), lead (Pb), strontium (Sr) and zinc (Zn) which are consistently indicative of former activity areas across a range of abandoned farms in Britain. Further it is suggested that emphasis should be placed on interpreting relative enhancement patterns rather than absolute elemental concentrations when comparing sites (Wilson *et al.,* 2006a). This approach discounts the influence of differing geology and soil properties between sites.

Multi-element analysis is identified as a relatively quick tool for investigating differences in past land use at historic sites. Accordingly samples were prepared by nitric acid digestion as described in Wilson *et al*., (2005:1095). Pseudo-total acid extraction was preferred over weak acid or exchangeable fraction extraction considering Wilson *et al's.,* (2006b) finding that the latter methods impede the recovery of anthropogenic elements associated with historic land use. Accordingly elemental concentrations were measured with a Perkin Elmer Optima 3300RL Inductively Coupled Plasma-Atomic Emission Spectrometer (ICP-AES) using the in-house traces programme at the NERC ICP-AES Facility, Royal Holloway. Corrections for instrumental drift were subsequently made using procedural blanks. Elemental concentrations (mg/Kg) for Ba, Co, Cr, Cu, Li, Ni, Pb, Sc, Sr, V, Y and Zn were obtained using the following formula where the BCV is the blank corrected values and the sample mass is 5±.01g.

$$elemental\ concentration\ (mg / Kg) = BCV (mg / Kg)\ /\ sample\ mass\ \left(5 \pm 0.01g\right)$$

The following formula was used to determine elemental concentrations (mg/Kg) for oxides (Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, MnO, K_2O, TiO_2 and P_2O_5). The abbreviation BCV represents the raw blank corrected value. AM_X stands for the total atomic mass of the element in question and AM_Y the total atomic mass of oxygen.

$$elemental\ concentration\ (mg / Kg) = (BCV\ / 5 \pm 0.01) * (AM_X\ / AM_X + AM_Y) * 10{,}000$$

4.4 Micromorphological Analysis

Soil micromorphology is the 'study of the structure of spatial patterns in natural and non-natural layers, deposits and soils using microscopic techniques' (Kooistra and Kooistra 2003:605). Micromorphology has been used since the 1950s as a routine analytical method in archaeological science for investigation of palaeosols (Kemp 1998, Macphail and Goldberg 1995), however, its use in geoarchaeological studies is still relatively recent (Courty *et al.,* 1989, Davidson *et al.,* 1992, French 2003). Micromorphological investigation into impacts of past human activities on soils and sediments is noted for a range of applications including, soil formation processes (Simpson *et al.,* 2006, Simpson *et al.,* 1998a), agriculture (Bryant and Davidson 1996, Davidson and Carter 1998, French and Whitelaw 1999, Simpson 1997, Simpson *et al.,* 1998b), occupation deposits (Homsey and Capo 2006, Matthews 1995, Matthews *et al.,* 1997) and cultural landscape studies (Simpson *et al.,* 2003, Simpson *et al.,* 2005).

Micromorphological studies of urban contexts are limited although 'dark earth' deposits (Macphail 1994, Macphail 2003, MacPhail *et al*., 2003, Ottaway 1992), garden soils (Clark 1997, Carter 2001) and occupation sequences (Shahack-Gross *et al*., 2005) have received some attention. It is recognised that soils are often neglected in urban archaeology in favour of artefact recovery (Macphail and Goldberg 1995), however they provide an important resource for investigating anthropogenic processes of deposition, emplacement and modification (Courty *et al.,* 1989). Anthropogenic features in thin section largely consist of waste materials associated with human occupation, for example fuel residues, domestic refuse and construction materials. Accordingly micromorphology is a useful tool for characterising urban anthrosols and investigating processes associated with waste management and disposal in historic small towns.

4.4.1 Sample Preparation

Thin sections were prepared from undisturbed soil samples at the Thin Section and Micromorphology Laboratory, University of Stirling according to standard procedures (http://www.thin.stir.ac.uk/methods.html, 2007). Samples were dried through solvent exchange (acetone) in the vapour phase and impregnated under vacuum using an epoxy resin (Araldite MY750 with hardener HY951). Subsequently impregnated blocks were cut and precision lapped to 30μm thickness prior to mounting.

4.4.2 Semi-Quantification of Anthropogenic Features

There is a lack of an established protocol for analysing anthropogenic features in thin section. It should therefore be noted that the methodology presented hereafter was self evolutionary and guided by the study research objectives as recommended by Courty *et al.,* (1989).

In the first instance coarse mineral anthropogenic features were identified using a series of reference images and descriptions (Courty *et al.,* 1989, Stoops 2003). The ascribed categories were verified by Dr Clare Wilson, University of Stirling. Key characteristics of each mineral anthropogenic feature are listed in Table 3 and example images are presented in Figure 26. Coarse organic anthropogenic features were categorised according to differences in morphology and optical properties between black carbon exotic inclusions termed 'fuel residue' (Table 4, Figure 27). In addition each category was divided into two size classes, for example FR Type 1 10-255 µm and FR Type 1 255-500+ µm. Distinctions were based solely on descriptive differences in accordance with recommendations made by Kemp (1998); it should therefore be noted that classifications of fuel residue categories (FR) do not necessarily represent different fuel sources.

Table 3: Mineral Anthropogenic Features (PPL: Plane polarised light, XPL: Cross polarised light, OIL: Oblique incident light)

Feature	Key Characteristics
Shell (Mollusc)	Fibrous internal fabric (striations), very fine crystal size, high interference colours (XPL)
Clinker/Slag	Grey/brown/dirty yellow (PPL), bubbles in matrix, growth of some minerals (crystalline, skeletal, dendritic)
Bone	Fibrous internal fabric, presence of abundant Haversian Canals
Heated Mineral	Red in (OIL), high interference (XPL), mineral matrix
Pottery/Brick	Deep red/brown (PPL), diffuse strong/red (OIL), well sorted fabric, high density
Mortar/Plaster	Grey/green-grey (PPL), grey (OIL), inclusions of straw, brick, bone, areas of cryptocrystalline calcite/calcitic fabric, well sorted matrix

Table 4: Organic Anthropogenic Features (PPL: Plane polarised light, XPL: Cross polarised light, OIL: Oblique incident light), FR: Fuel Residue

Feature	Key Characteristics
Charcoal	Complete cellular structure with little/limited decay, black (PPL), black (XPL), morphology ranges from rounded to semi-angular.
FR Type 1	Morphology is angular/sub-angular, well defined perimeter, black (PPL), black (XPL), limited-moderate evidence of internal cracking/fracturing.
FR Type 2	Morphology is rounded/sub-rounded, defined perimeter, internal degradation characterised by holes, black (PPL), black (XPL), internal mineral content high interference (XPL).
FR Type 3	Morphology is angular/sub-angular, well defined perimeter, black (PPL), black (XPL), limited- moderate evidence of internal cracking/fracturing, strong red bands present (PPL).
FR Type 4	Morphology can be angular, sub-angular, sub-rounded or rounded, black (PPL), black (XPL), pronounced internal degradation characterised by large rounded/elongated holes in close proximity, appearance almost 'skeletal' like, intermixture of groundmass, organic material/excrements adjacent to perimeter.
FR Type 5	Morphology is angular/sub-angular, well defined perimeter, black with areas of brown/red-brown (PPL), black (XPL), pronounced internal degradation.
FR Type 6	Morphology can be angular, sub-angular, sub-rounded or rounded, black (PPL), black (XPL), internal degradation characterised by rounded/sub-rounded holes, organic material/excrements adjacent to perimeter.
FR Type 7	Morphology is angular/sub-angular, well defined perimeter, black (PPL), Black (XPL), pronounced internal degradation.
FR Type 8	Morphology sub-angular/sub-rounded, 'ragged' perimeter edge, black (PPL), black (XPL), limited/moderate evidence of internal cracking/fracturing.
FR Type 9	Morphology sub-angular/sub-rounded, 'ragged' perimeter edge, black with areas of brown/red-brown (PPL), black (XPL), limited/moderate evidence of internal cracking/fracturing.
FR Type 10	Morphology sub-angular, black (PPL), black with high interference colours near perimeter (XPL), calcitic fabric near perimeter, limited-moderate internal degradation.

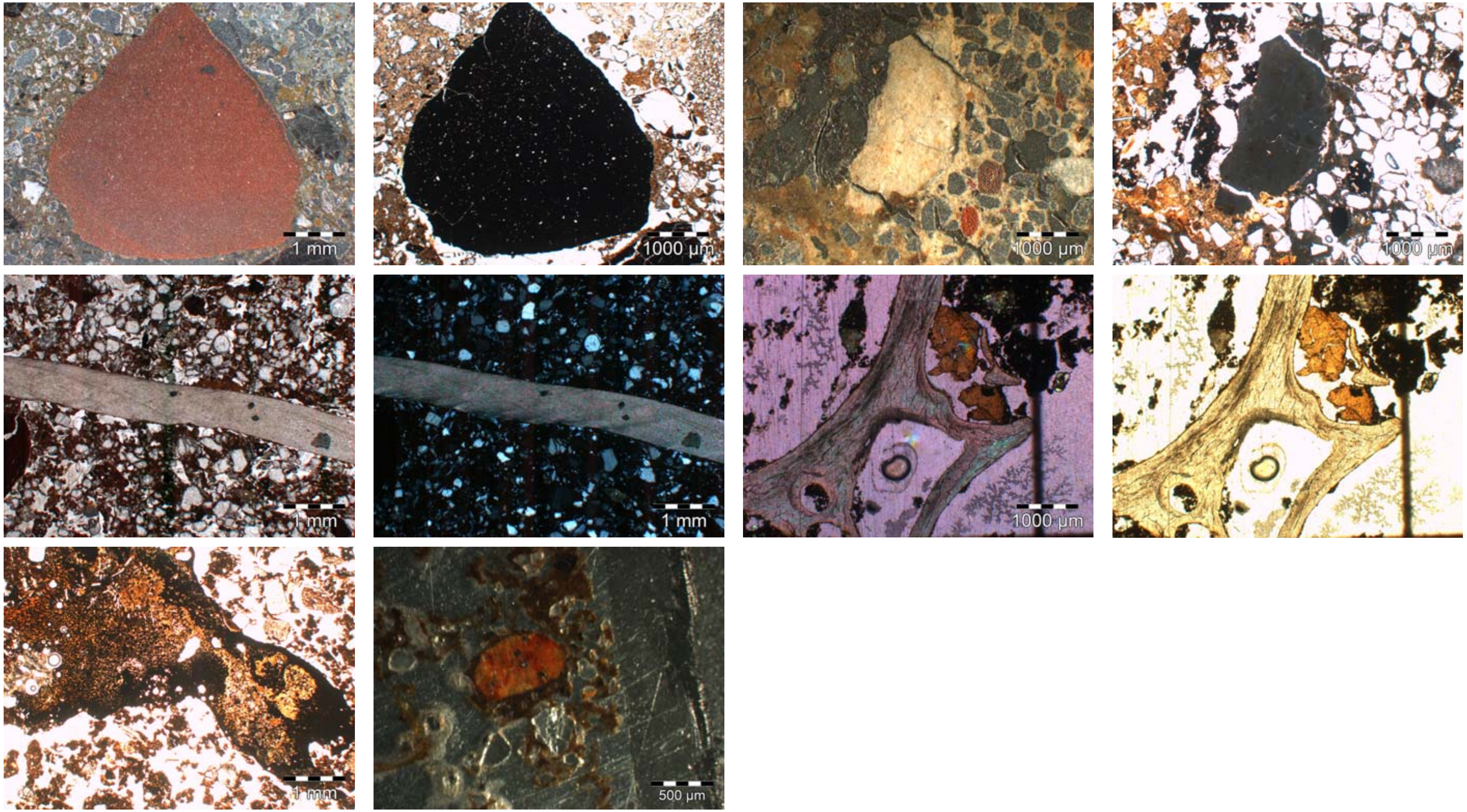


Figure 26: Example images of coarse mineral anthropogenic features in thin section from Lauder, Pittenweem and Wigtown. First row (left to right): pottery (OIL), pottery (PPL), mortar (OIL), mortar (PPL). Second row (left to right): shell (PPL), shell (XPL), bone (XPL), bone (PPL). Third row (left to right): clinker/slag (PPL), heated mineral (OIL)

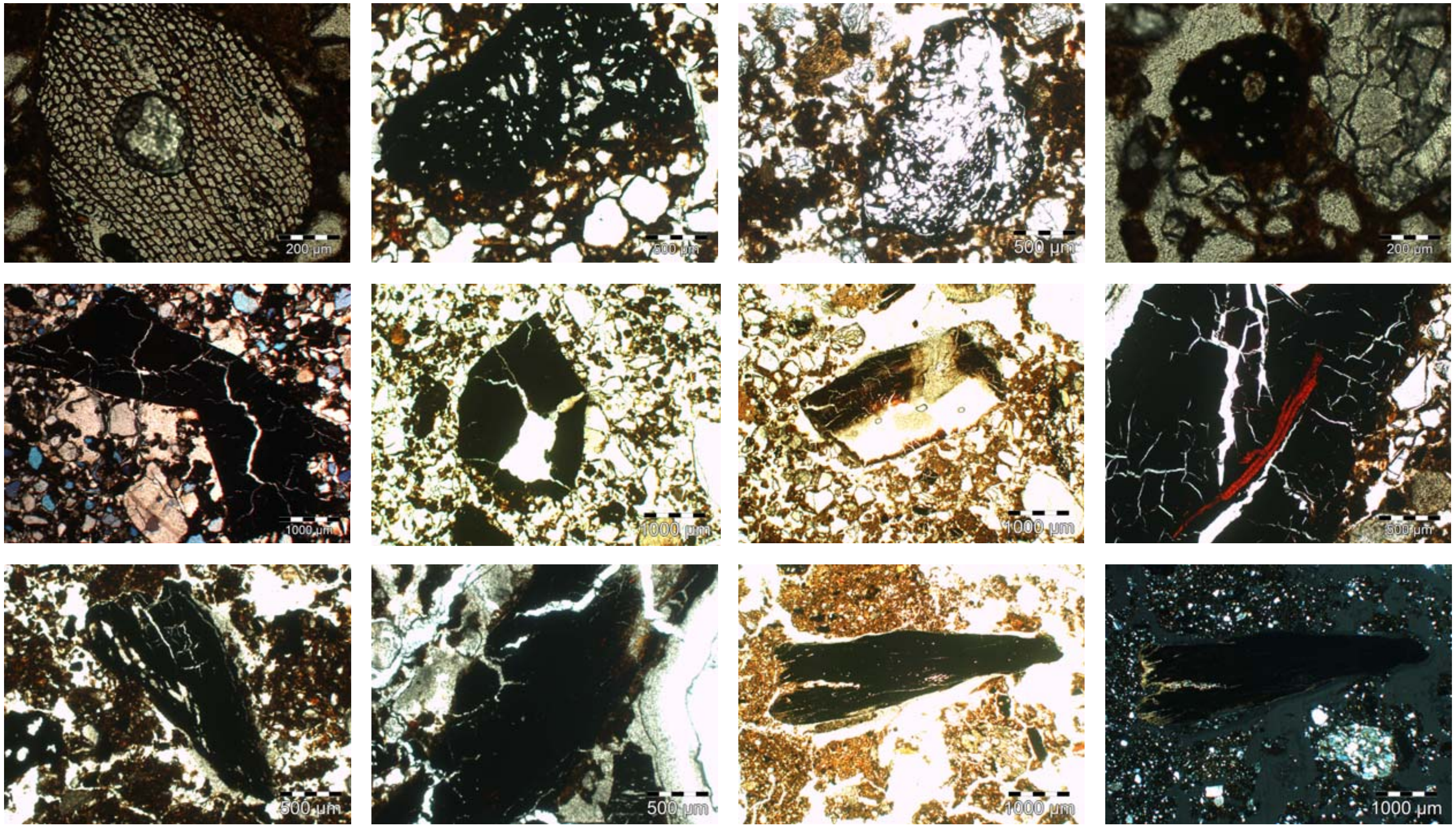


Figure 27: Example images of coarse organic, anthropogenic features in thin section from Lauder, Pittenweem and Wigtown. First row (PPL) (left to right): Charcoal, FR4, FR 6, and FR 2. Second row (PPL) (left to right): FR1 (XPL), FR7, FR5 and FR3. Third row (PPL) (left to right): FR 8, FR9, FR10 and FR 10 (XPL)

It is recommended that analysis of anthropogenic contexts should be holistic in approach and undertaken by experienced well trained analysts (Macphail 1998, Macphail and Goldberg 1995). However such interpretations often lack validation (Davidson and Simpson 2001). Moreover, it is argued increasing priority in micromorphological studies should be placed on experimental control, verification and quantification (Davidson and Carter 2000). Accordingly, a semi-quantitative approach to slide description was adopted using the methodology outlined hereafter.

An acetate grid consisting of 165 5x5mm squares was placed over the surface of each slide covering 4125 mm^2. A total of 66 numbers between 1 and 165 were independently generated for each slide using a random number generator (Daniels 2001-2003). Corresponding grid squares were subsequently highlighted with a blue transparent mark (Figure 28). Percentage abundance estimates of coarse mineral (>10μm), coarse organic (>10μm), pedofeatures, C:F ratio (coarse) and void space were made for each individual square using absolute numbers, for example 2=<2%, 5=2-5%, 10=5-10%, 15=10-15%. This enabled calculation of a representative mean for each feature per slide. Abundance estimates were made using an Olympus BX 51 petrological microscope following procedures in Bullock *et al,* (1985) and Stoops (2003). Furthermore a range of magnifications (x10-x400) and light sources (plane polarised light, cross polarised light and oblique incident light) were utilised enabling feature description and identification.

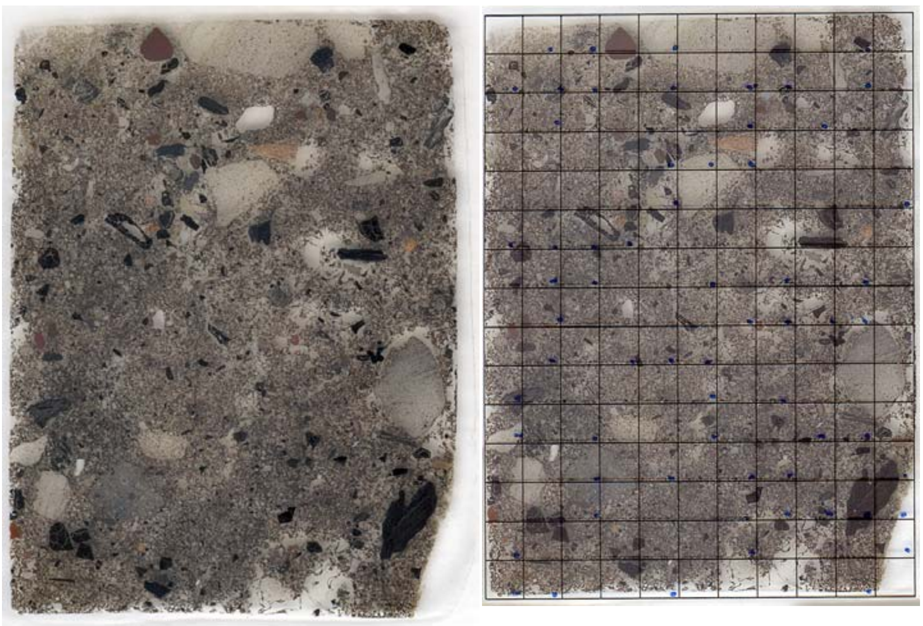


Figure 28: Left: slide prior to grid overlay, Right: slide with grid overlay, grid squares selected through random number generation are highlighted with a blue mark

Abundance estimates were made for 1650mm^2 of the total slide surface (4125mm^2) equating to 40% randomly distributed coverage. To verify whether 40% constitutes a representative sub-sample of the total slide area, % mean void space was calculated incrementally (1%) for Wigtown thin sections (Figure 29). Initially (1-15%) the data are noisy and characterised by pronounced variation in estimated % mean void space. However as % slide area increases the estimated % mean void space becomes progressively steady resulting in nearly constant values between 30-40%. Similarly continuous measurement of the C:F ratio for Lauder thin sections indicates distinct variation in % coarse material between 0-20% slide area which becomes more uniform as slide area increases (Figure 30).

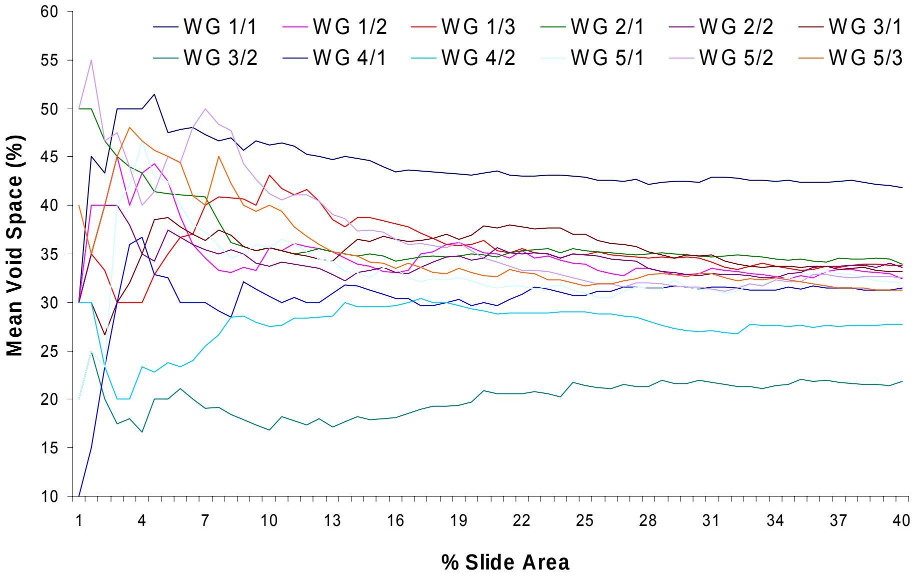


Figure 29: Mean void space of Wigtown thin sections calculated incrementally (every 1%). Legend denotes town code (WG) and slide reference and context number (1/1)

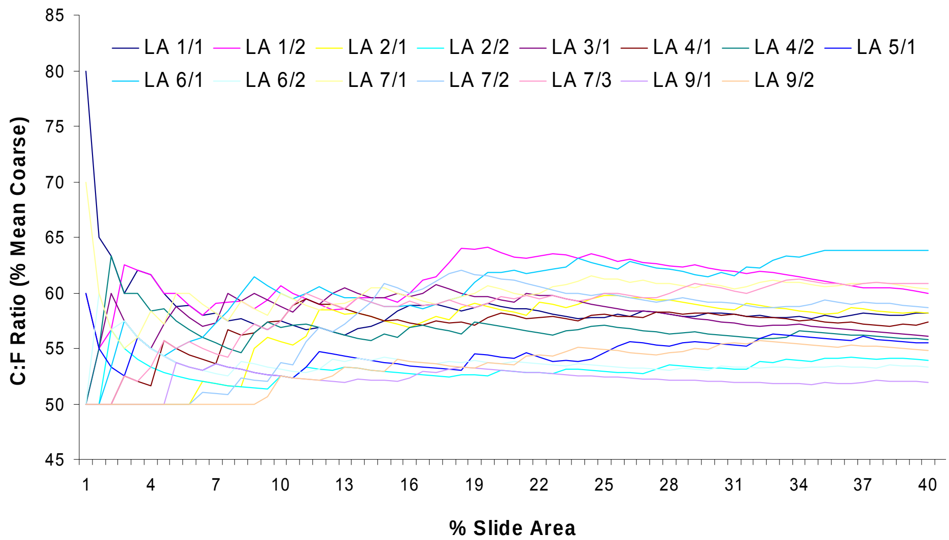


Figure 30: Mean % coarse material of Lauder thin sections calculated incrementally (every 1%). Legend denotes town code (LA) and slide reference and context number (1/1)

Analysis of changes in mean % relative abundance of anthropogenic features for slide PT 4/1 (Figure 31) and WG 4/1 (Figure 32) also indicate relative stability in estimations exceeding 30% of the slide surface area. Accordingly it is proposed that 40% is an acceptable minimum representative area for anthropogenic features and soil characteristics. Conversely, VandenBygaart and Protz (1999) suggest an alternative method for determining the minimum representative area for quantitative analysis of pedofeatures using image analysis systems. This approach is useful for determining features readily identifiable when digitised, for example void space and soil pores. However, it is argued that insufficient provision currently exists for accurate and consistent identification of anthropogenic features using image separation techniques.

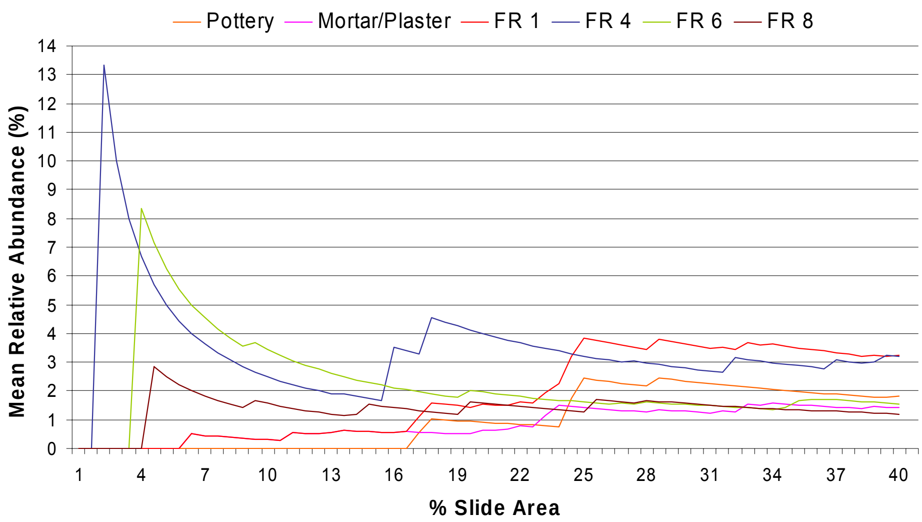


Figure 31: Mean % relative abundance of selected anthropogenic features for soil pit 4, context 1 (4/1), Pittenweem

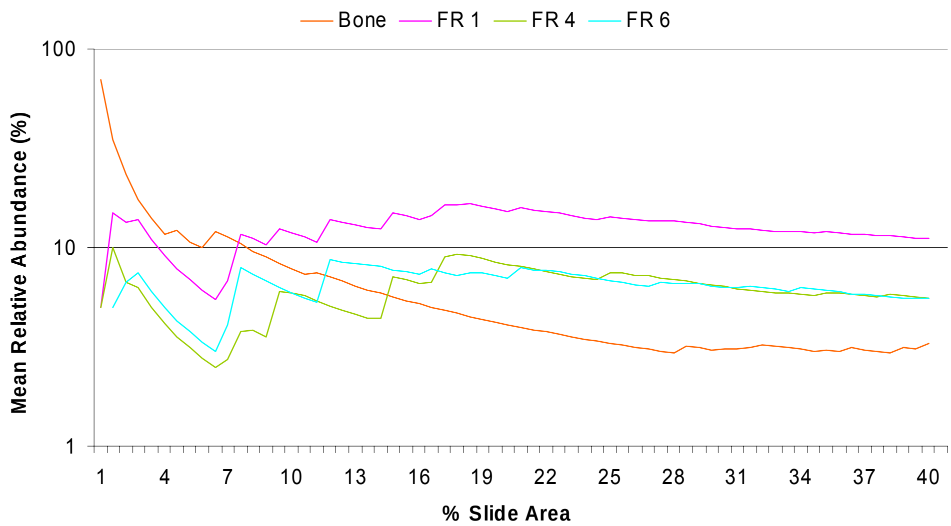


Figure 32: Mean % relative abundance of selected anthropogenic features for soil pit 4, context 1, Wigtown

4.4.2.1 Revision of Coarse Organic Material Classification

Size classes (10-255μm and 255-500μm) of coarse organic material were amalgamated due to a lack of discernable trends within the lower size classification. To investigate size differences in fuel residue more broadly the percentage of total fuel residue sized 10-255μm was calculated for each thin section (% FR 10-255μm). In addition, certain coarse organic material categories were merged to enable better detection of differences in the abundance of fuel residue classes between zones and burghs. Categories FR 4 and FR 6 (FE 4 & 6) were merged owing to their similar morphological characteristics. It is suggested that these two classes represent the same material albeit in different states of degradation. Categories FR 5 and FR7 (FR 5 & 7) were also combined due to similarities in their composition. The only difference between FR 5 and FR 7 is that FR 5 has areas which are brown/red-brown (PPL); however, it is suggested that this may reflect variation caused through slide production rather than difference in the nature of material. Variation in colour may occur due to variations slide thickness over the surface area of the slide. Similarly, FR 8 and 9 (FR 8 & 9) were merged given the only difference between these two categories was limited to colour. These revised categories produced clearly identifiable patterns both within and between burghs. Results were summarised in the form of ‘blobby table’ diagrams to enable comparison of data between zones.

4.5 Spatial Interpolation

Spatial distributions of topsoil depth, pH, LOI, mass dependant magnetic susceptibility and frequency dependant magnetic susceptibility were plotted using the Inverse Distance Weighted (IDW) spatial interpolation function available within ArcView 3.2. IDW was identified as the most appropriate spatial interpolation method given that it is suitable data with pronounced variation over very short distances (ArcView 3.2 GIS 2002). Consideration was given to the use of Spline interpolation; however, this technique is more suitable for data with limited variation (ArcView 3.2 GIS 2002). Spatial distributions of logged (LOG_{10}) elemental concentrations (Ba, Ca, K, Sr, P, Pb and Zn) were also plotted using the IDW spatial interpolation function. Logged elemental concentrations were used to minimise the effect of geochemical 'hotspots' present in natural data (Figure 33).

a) b)

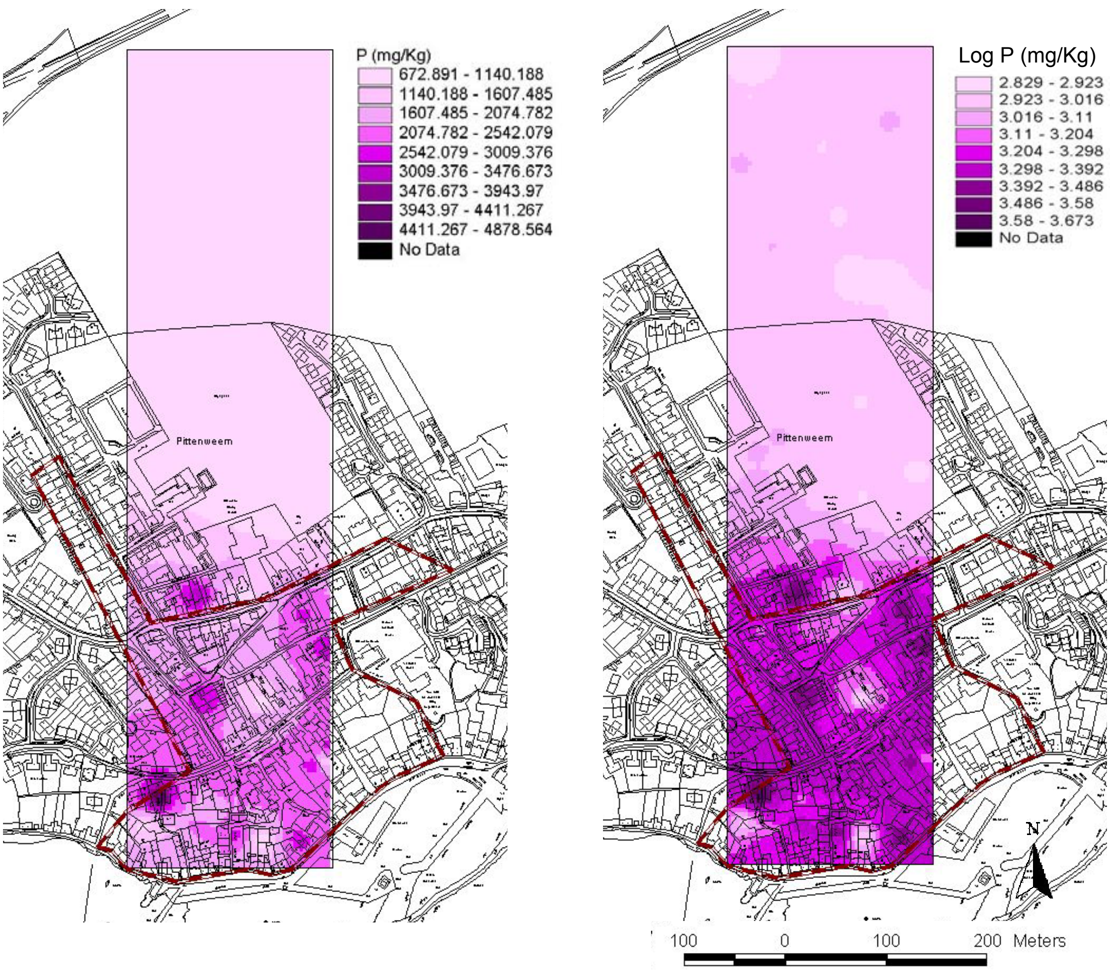


Figure 33: Spatial distributions of P (mg/Kg) (a) and Log P (mg/Kg) (b) at Pittenweem. Red boundary delimits 1855AD urban extent

4.6 Statistical Analyses

4.6.1 Zonal Delimitation

To enable statistical comparison of data both within and between burghs, each town was divided into functional zones. Zones were delineated through a combination of historical review (section 2.2, section 2.3), field experience and spatial analysis of selected soil properties.

Zones at Lauder consist of; High Street, Hinterland Near, Hinterland Far and Hinterland Thirlstane. The High Street zone is constrained by Lauder’s 1862 AD urban extent, hence represents the location of the old burgh core. The Hinterland Near zone corresponds to the immediate hinterland south of Lauder. Similarly the Hinterland Thirlstane zone corresponds to the immediate hinterland north of Lauder. The Hinterland Far zone represents the distant hinterland immediately south of Lauder.

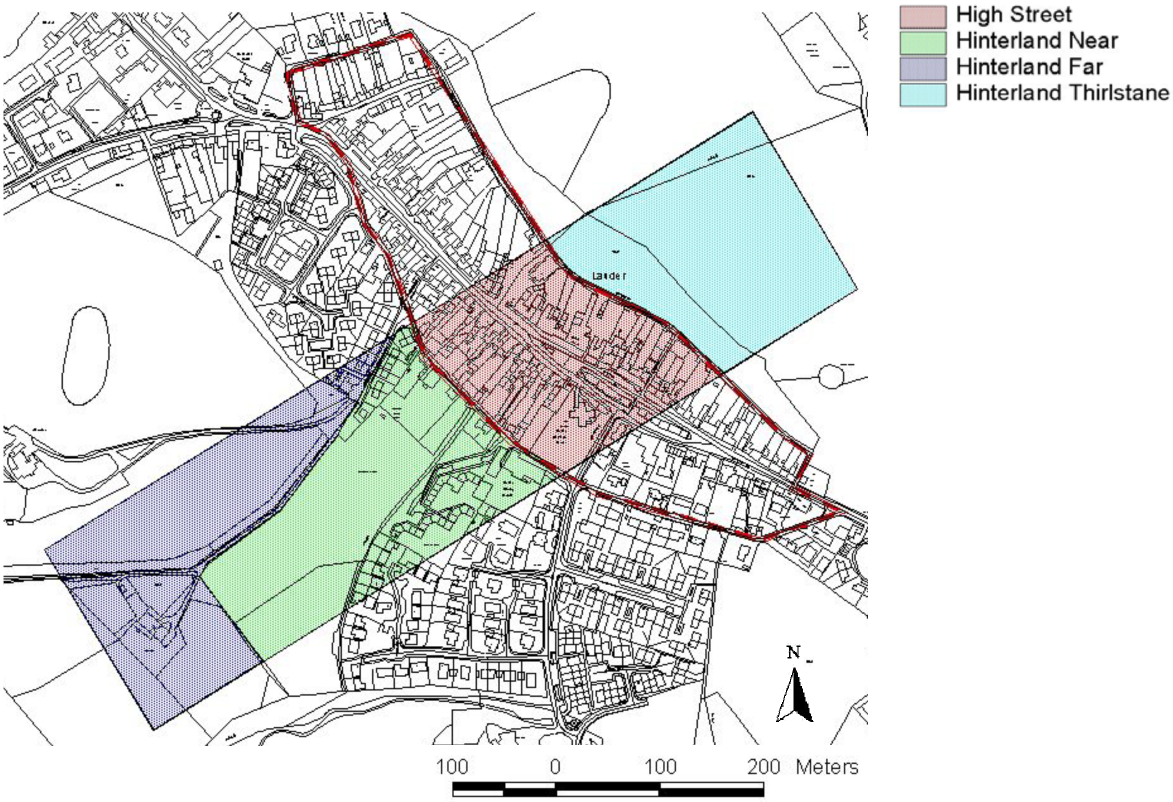


Figure 34: Delineation of zones at Lauder. Red boundary delimits 1862AD urban extent

Figure 35: Delineation of zones at Pittenweem (a) and Wigtown (b). Red boundary delimits 1855AD and 1850AD urban extent respectively

Zones at Pittenweem comprise; Harbour, High Street, Hinterland Near and Hinterland Far. The Harbour and High Street zones are constrained by Pittenweem's 1855AD urban extent, hence represent the location of the old burgh core. The Hinterland Near and Hinterland Far zones correspond to the immediate and distant hinterland north of Pittenweem.

Zones at Wigtown include; High Street, Hinterland Near and Hinterland Showfield. The High Street zone is constrained by Wigtown's 1850AD urban extent, hence represents the location of the old burgh core. The Hinterland Near zone corresponds to the immediate hinterland north of Wigtown and the Hinterland Showfield corresponds to the immediate hinterland south of Wigtown.

4.6.2 Determination of Significant Differences between Zones

Minitab (15) statistical software was used for all statistical analyses described hereafter. Statistical analyses of physical and chemical and elemental data were conducted on 0-20cm depth soil data to enable direct comparison between burghs. Consideration was given to comparing zones to 'reference' soil pits in addition to each other. However, inclusion of 'reference' soil data was problematic given that it frequently overlapped with zone data which is more variable in nature. This resulted in very few significant differences between zones and 'reference' soil pits despite particular zones having considerably larger average values. Statistical analysis of soil micromorphology data was conducted on percentage abundance estimates of coarse organic material within zones and 'reference' soil pits.

4.6.2.1 Physical and Chemical Data

Topsoil depth, pH, LOI, mass dependant magnetic susceptibility and frequency dependant magnetic susceptibility data were tested for normality using the Anderson-Darling normality test. In most cases data were non-normal and could not be transformed using logarithmic or square root transformations.

Kruskal-Wallis analysis was identified as the most appropriate non-parametric method to test for significant differences between zones. One of the limitations of Kruskal-Wallis analysis is that it does not indicate which specific zones are different and in what way. Consequently Kruskal-Wallis analysis was performed in collaboration with Dunn's test. Dunn's test enables multiple comparisons to be made using non-parametric data with unequal sample populations (Wheater and Cook 2000). Results of Kruskal-Wallis analysis with Dunn's test were presented in Pairwise Comparison diagrams. The test statistic (z score) of each comparison was plotted and z scores exceeding –z or z were classed as significant at $p<0.05$ (95%) confidence level. In cases where data were normal a One Way Analysis of Variance (One-Way ANOVA) with Tukey-Kramer (95% confidence) multiple comparisons was used to determine significant differences in sample means between zones.

4.6.2.2 Elemental Data

All elemental concentrations were tested for normality using the Anderson Darling normality test. Elemental data were predominantly non-normal and could not be transformed using logarithmic or square root transformations. Kruskal-Wallis analysis in association with Dunn's test was therefore used to identify significant differences in median elemental concentrations between zones. Results of Kruskal-Wallis analysis with Dunn's test were presented in Pairwise Comparison diagrams. The test statistic (z score) of each comparison was plotted and z scores exceeding –z or z were classed as significant at $p<0.05$ (95%) confidence level. In cases where data were normal a One Way Analysis of Variance (One-Way ANOVA) with Tukey-Kramer (95% confidence) multiple comparisons was used to determine significant differences in sample means between zones.

4.6.2.3 Soil Micromorphology

Statistical investigation of significant differences between zones was limited to comparison of coarse organic material given the limited abundance of coarse mineral anthropogenic inclusions. Percentage abundance estimates of coarse organic anthropogenic inclusions (Charcoal, FR 1, FR 2, FR 3, FR 4 & 6, FR 5 & 7, FR 8 & 9, FR 10 and % FR 10-255µm) were tested for normality using the Anderson-Darling normality test. In most cases data were non-normal and could not be transformed using logarithmic or square root transformations.

Kruskal-Wallis analysis was identified as the most appropriate non-parametric method to test for significant differences between zones. One of the limitations of Kruskal-Wallis analysis is that it does not indicate which specific zones are different and in what way. Consequently Kruskal-Wallis analysis was performed in collaboration with Dunn's test. Dunn's test enables multiple comparisons to be made using non-parametric data with unequal sample populations (Wheater and Cook 2000). Results of Kruskal-Wallis analysis with Dunn's test were presented in Pairwise Comparison diagrams. The test statistic (z score) of each comparison was plotted and z scores exceeding –z or z were classed as significant at $p<0.05$ (95%) confidence level. In cases where data were normal a One Way Analysis of Variance (One-Way ANOVA) with Tukey-Kramer (95% confidence) multiple comparisons was used to determine significant differences in sample means between zones.

4.6.3 Determination of Significant Differences between Depths

Soil pH and % LOI data for 0-20 and 20-40cm depth at Lauder, and 0-20, 20-40, 40-60 and 60-80cm depth at Pittenweem were tested for normality using the Anderson Darling normality test. All data were non-normal and could not be collectively transformed using logarithmic or square root transformations. Hence, Kruskal-Wallis analysis in association with Dunn's test was used to identify significant differences between depths. It should be noted that Wigtown was omitted from this analysis due limited sample numbers at lower depths.

Furthermore, to investigate the relationship between depth and zone a Two Way Analysis of Variance with Tukey-Kramer multiple comparisons (Two Way ANOVA) was undertaken using a General Linear Model (GLM). A GLM was used in favour of a Balanced ANOVA because it does not assume equal sample populations. It is recognised that a Two Way ANOVA is a parametric test, hence not necessarily appropriate for non-normal data. However, there are no non-parametric analyses which test for interaction between variables. Accordingly, results from this analysis are discussed cautiously.

4.6.4 Determination of Significant Differences between Burghs

4.6.4.1 Physical and Chemical Data

To investigate differences in topsoil depth, pH, LOI, mass dependant magnetic susceptibility and frequency dependant magnetic susceptibility between burghs a Two Way Analysis of Variance with Tukey-Kramer multiple comparisons (Two Way ANOVA) was undertaken using a General Linear Model (GLM). This analysis allows comparison of sample means between burghs and sample means between zones in addition to testing for interaction between burghs and zones. It should be noted that only the High Street and Hinterland Near zones were used in the model given that these are the only two zones which are present in all three burghs.

As stated in section 4.6.2.1, soil physical and chemical data were predominantly non-normal. It could therefore be argued that a non-parametric test should have been used to investigate data variation between burghs. However, there are no alternative non-parametric methods which test for interaction between variables. The robustness of Two Way ANOVA was confirmed though comparison of data with and without outliers. Removal of outliers had minimal effect on the significance of data trends; hence outliers were kept within datasets.

4.6.4.2 Elemental Data

To investigate differences in elemental concentrations between burghs consideration was given to the use of Two Way Analysis of Variance with Tukey-Kramer multiple comparisons (Two Way ANOVA). This technique allows investigation into differences between burghs and zones, in addition to testing for interaction. However initial analyses proved unreliable, for example the direction of relationships between multiple comparisons was incorrect. This problem was attributed to the presence of outliers which adversely skewed mean values. Consideration was given to excluding extreme data points; however, it is argued that these values are an integral component of elemental datasets. Therefore investigation into variation of elemental concentrations between burghs focussed on comparing spatial trends identified using non-parametric tests (section 4.6.2.2).

4.6.4.3 Soil Micromorphology

Statistical investigation of significant differences between burghs was limited to comparison of coarse organic material between High Street zones given that the High Street zone was the only area systematically sampled within each burgh. Percentage abundance estimates of coarse organic anthropogenic inclusions were tested for normality using the Anderson-Darling normality test. In all cases data were not normal and could not be transformed using logarithmic or square root transformations.

Kruskal-Wallis analysis was identified as the most appropriate non-parametric method to test for significant differences between High Street zones. One of the limitations of Kruskal-Wallis analysis is that it does not indicate which specific zones are different and in what way. Consequently Kruskal-Wallis analysis was performed in collaboration with Dunn's test. Dunn's test enables multiple comparisons to be made using non-parametric data with unequal sample populations (Wheater and Cook 2000). Results of Kruskal-Wallis analysis with Dunn's test were presented in Pairwise Comparison diagrams. The test statistic (z score) of each comparison was plotted and z scores exceeding –z or z were classed as significant at $p<0.05$ (95%) confidence level.

4.6.5 Multivariate Analyses

4.6.5.1 Cluster Analysis

Cluster analysis is as an appropriate method for simplifying elemental datasets and grouping together elements with similar spatial distributions. Cluster analysis was undertaken on elemental data for Lauder, Pittenweem and Wigtown using the Cluster Variables function. This is an agglomerative hierarchical method which means that all variables begin as independent clusters which are subsequently amalgamated in a series of steps until there is only one remaining group.

Correlation was the preferred distance measure over absolute correlation because it maximises the distance between positively correlated elements and negatively correlated elements. The linkage method used was median linkage which calculates the distance between clusters using the median distance between a variable in one cluster and a variable in the other cluster, hence reducing the effect of outliers. The final number of clusters for each burgh was determined through a combination of prior knowledge relating to patterns in elemental concentrations and identification of an abrupt drop between amalgamation steps. Results were displayed in the form of a dendrogram to visualise similarities between clusters. It should be noted that the median linkage method does not always produce a hierarchical dendrogram. In cases where amalgamation distances do not increase with each step cluster joins that are both upward and downward are produced.

4.6.5.2 Discriminant Analysis

Discriminant analysis is a useful tool for investigating whether predicted classifications are similar to those observed, hence is an appropriate method to determine the classification accuracy of zones delineated in section 4.6.1. Discriminant analysis was undertaken on elemental data for Lauder, Pittenweem and Wigtown using cross validation. The use of cross validation is important because it compensates for overly optimistic classification given that the data being classified is the same as that used to build the classification function. The summarised results were displayed in a classification matrix table.

5 Field Observations and Soil Micromorphology

This chapter presents results obtained from micromorphological analysis of topsoil deposits including; semi-quantification of coarse mineral material, coarse organic material and pedofeatures, and characterisation of fine mineral material and soil structure.

5.1 Soil Profile Characteristics

Profile descriptions, field sketches and photographs of soil pits are presented in Appendix 1 for Lauder, Pittenweem and Wigtown. Soil profiles are typically varied in all three burghs; however, distinct horizons relating to certain zones are identified within and between towns.

5.1.1 Variation within Burghs

The High Street and Hinterland Near zones within Lauder are characterised by two deep dark horizons which comprise the topsoil. These layers are classed as hortic horizons, hence are ascribed the notation Aht 1 (upper topsoil) and Aht 2 (lower topsoil). The Aht 1 horizon is characteristically black/dark brown in colour and ranges in depth from 30 to 50cm. The Aht 2 horizon is dark brown/brown in colour and varies in depth from 20cm to 50cm (Figure 36). The combined depth of horizons Aht 1 and Aht 2 result in topsoil deposits which are consistently over 60cm. Moreover, both of these horizons contain cultural debris such as fuel residue and pottery sherds. Topsoil within the Hinterland Far and Thirlstane zones consists largely of a singular horizon which ranges from dark reddish brown to brown in colour. This layer is ascribed the notation Ah on account of its dark colour indicating high organic matter content. Similarly, ‘reference’ soil pit LA 7 is characterised by an Ah horizon which is reddish brown in colour. In contrast to Aht horizons, Ah horizons contain limited cultural debris.

Topsoil within the Harbour and High Street zones at Pittenweem comprises an upper (Aht 1) and lower (Aht 2) hortic horizon (Figure 37). The Aht 1 horizon is black and ranges in depth from 50-≥100cm in the Harbour zone and 30-40cm in the High Street zone. The Aht 2 horizon is very dark brown/dark brown in colour and varies in depth from 20-40cm. The combined depth of horizons Aht 1 and Aht 2 result in topsoil depths which are consistently ≥80cm within the Harbour zone and over 60cm in the High Street zone. Moreover, both of these horizons contain cultural debris such as fuel residue, pottery sherds and shell. Topsoil within the Hinterland Near and Hinterland Far comprises an Ah horizon which is consistently very dark brown in colour. Typically this horizon ranges from 20 to 30cm in depth. The ‘reference’ soil pit PT 1 contains an Ah horizon which is dark brown and 25cm deep. In contrast to Aht horizons, Ah horizons contain limited cultural debris.

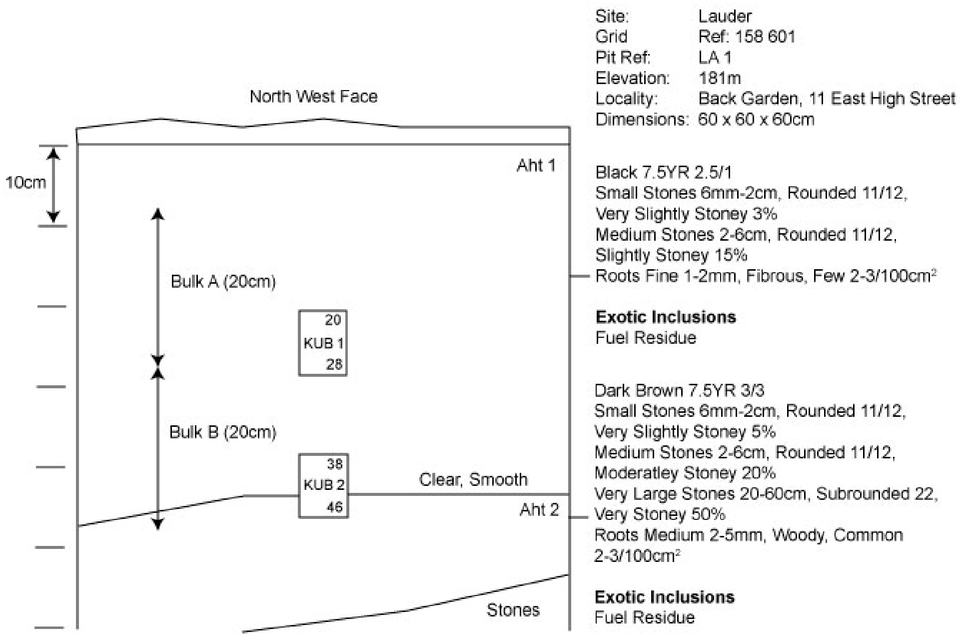


Figure 36: Soil profile description of soil pit LA1 (see Appendix 1 for photographs)

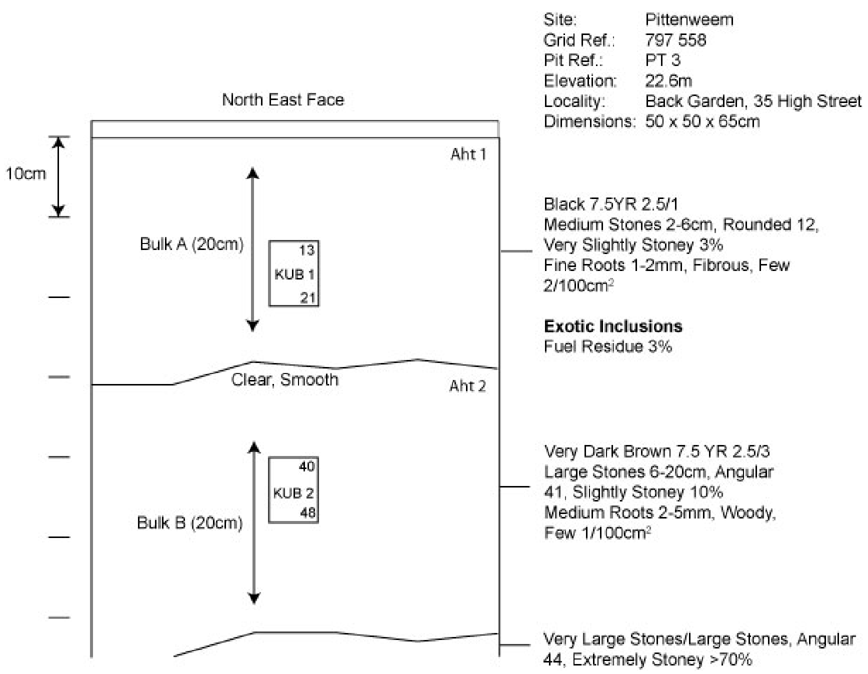


Figure 37: Soil profile description of soil pit PT3 (see Appendix 1 for photographs)

The High Street zone within Wigtown is characterised by topsoil consisting of an upper (Aht 1) and lower (Aht 2) hortic horizon (Figure 38). The Aht 1 horizon is characteristically black in colour and ranges in depth from 30 to 50cm. The Aht 2 horizon is very dark brown/dark brown and is 30-50cm deep. The combined depth of Aht 1 and Aht 2 horizons result in topsoils of over 70cm. Both of these horizons contain cultural debris such as fuel residue, pottery sherds and shell remains. Topsoil within 'reference' soil pit WG 5 comprises an Ah horizon which is brown and 27cm deep. In contrast to the High Street zone no cultural debris was identified within the 'reference' soil pit. Soil was not described for the hinterland north of Wigtown given that the 'reference' soil pit is located within the Hinterland Near zone. Accordingly it is suggested that the 'reference' soil pit provides a good indication of soil characteristics within the Hinterland Near zone. Additionally, soil was not described for the Showfield zone due to problems of restricted access. Nevertheless, soil descriptions made during the auger survey indicate the presence of an Ah horizon within the Showfield zone which is typically dark brown in colour and 15-25cm in depth.

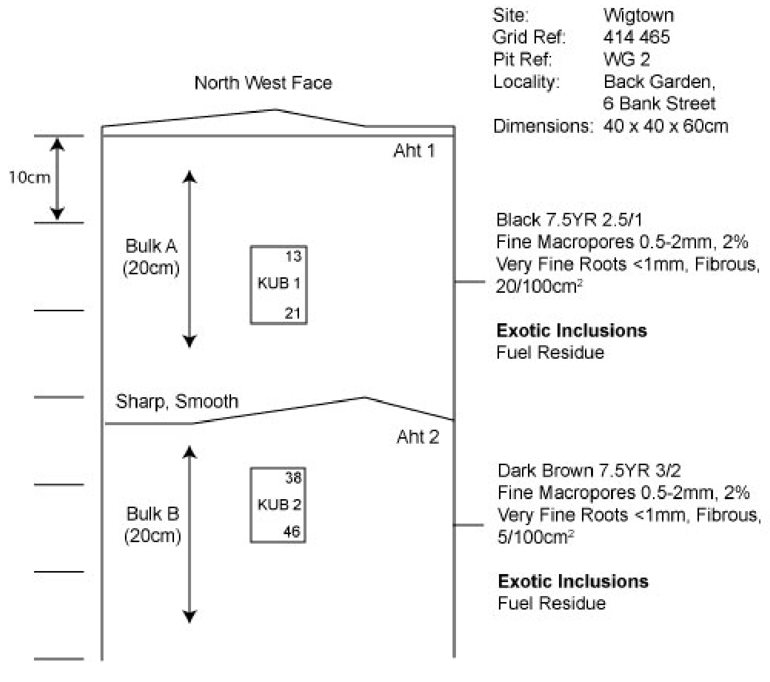


Figure 38: Soil profile description of soil pit WG2 (see appendix 1 for photographs)

5.1.2 Variation between Burghs

Topsoil within the burgh core at Lauder, Pittenweem and Wigtown is characterised by two hortic soil horizons. These horizons are typically dark (black/dark brown), deep and contain clearly identifiable cultural debris such as fuel residue and pottery. Hortic topsoils are limited to the burgh core at Pittenweem and Wigtown; however, they extend to the immediate hinterland south of Lauder (Hinterland Near).

5.2 Coarse Mineral Material

The abundance of coarse mineral material within topsoil deposits at Lauder, Pittenweem and Wigtown is summarised in tables presented in Appendix 2. Differences in the nature and abundance of inclusions are identified and comparisons between zones, horizons and burghs are made.

5.2.1 Variation within Burghs

5.2.1.1 Zones

Bone, pottery/brick, clinker/slag, mortar/plaster and heated mineral material are present within the High Street zone at Lauder (<2%). There is considerable variation in the occurrence of coarse mineral material between soil pits within this zone, for example mortar/plaster is present within all soil pits whereas bone, pottery/brick and clinker/slag are confined to soil pit LA 1. Heated mineral is present (<2%) within the Hinterland Near zone and clinker/slag is identified within the Hinterland Far zone (<2%). Contrastingly coarse mineral anthropogenic inclusions are absent within the Thirlstane zone and 'reference' soil pit LA 7. These results indicate addition of anthropogenic mineral material to soils within the burgh core and hinterland south of Lauder (Hinterland Near, Hinterland Far). This finding is significant considering there are no coarse mineral inclusions within the 'reference' soil pit. Moreover, it is recognised that coarse mineral material is greater in abundance and diversity within the burgh core.

Shell, bone, pottery/brick, clinker/slag, mortar/plaster and heated mineral are present within topsoils in the Harbour zone at Pittenweem. These materials are typically trace in abundance (<2%) although abundances of 2-5% are noted for shell and mortar within soil pit PT 5, and heated mineral within soil pit PT 4. Shell, bone, pottery/brick, clinker/slag, mortar/plaster and heated mineral are also present in topsoil deposits within the High Street zone. Shell, bone and clinker/slag are present in trace abundances (<2%) whereas pottery/brick and heated mineral inclusions vary in abundance from <2% to 2-5%, and mortar/plaster ranges from <2% to 5-10%. The Harbour and High Street zones contain the same classes of coarse mineral inclusions; however, shell is more abundant within the Harbour zone and pottery/brick and mortar/plaster inclusions are higher in number within the High Street zone.

There is a difference in the nature of coarse mineral material between the Hinterland Far zone and Hinterland Near zone at Pittenweem, for example only heated mineral material is present within the Hinterland Near zone (<2%) whereas pottery/brick, clinker/slag, mortar/plaster and heated mineral are identified within the Hinterland Far zone (<2%). Additionally, 'reference' soil pit PT 1 contains trace abundances (<2%) of pottery/brick, mortar/plaster and heated mineral. These results indicate addition of anthropogenic mineral material to soils within the burgh core and hinterland north of Pittenweem (Hinterland Near, Hinterland Far). Coarse mineral material is most abundant and diverse within the burgh core although subtle differences in shell, pottery/brick and mortar/plaster are identified between the Harbour and High Street zones. Moreover, it should be noted that inclusions of shell and bone are confined to zones within the burgh core.

Shell, bone, pottery/brick, clinker/slag, mortar/plaster and heated mineral are present within topsoils in the High Street zone at Wigtown. These materials are consistently present within all High Street zone soil pits with the exceptions of pottery/brick and heated mineral which are absent in soil pit WG 4, and mortar/plaster which is absent in soil pit WG 3. Coarse mineral inclusions are typically trace in abundance (<2%) although abundances of 2-5% are noted for mortar/plaster in soil pit WG 1 and bone in soil pit WG 4. In contrast coarse mineral inclusions are absent within 'reference' soil pit WG 5. These results indicate addition of mineral material to soils within the burgh core. This finding is significant given the lack of mineral inclusions within the 'reference' soil pit. Moreover, considering the 'reference' soil pit is located within the Hinterland Near zone, it is argued that coarse mineral inclusions are lacking in the hinterland north of Wigtown.

5.2.1.2 Hortic Horizons

Lauder

Differences in coarse mineral material classes are identified within Aht 1 horizons at Lauder, for example bone and heated mineral inclusions are identified at 20-28cm within soil pit LA 1 and pottery/brick and mortar/plaster inclusions are noted at 38-46cm (Figure 39). Likewise pottery/brick and mortar/plaster inclusions are limited to 25-33cm within soil pit LA 6. Where materials are present throughout Aht 1 horizons their abundances are shown to differ. Clinker/slag is <1% at 20-28cm within soil pit LA 1 and <2% at 38-46cm. Similarly, heated mineral inclusions are <1% at 10-18cm within soil pit LA 6 and <2% at 25-33cm. It is therefore argued that coarse mineral material varies in diversity and abundance within Aht 1 horizons. Furthermore it is recognised that coarse mineral material is limited to Aht 1 horizons at Lauder, for instance mineral inclusions are absent from the Aht 2 horizon within soil pits LA 4, LA 6 and LA 9.

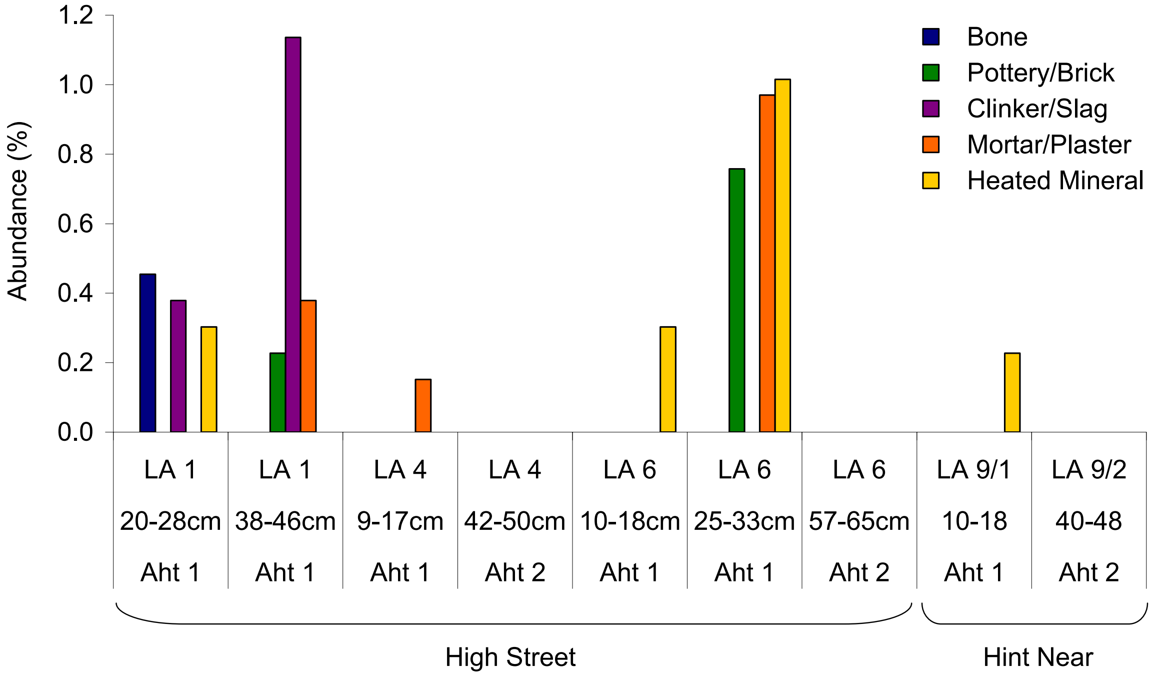


Figure 39: Percentage abundance estimates of coarse mineral material within upper (Aht 1) and lower (Aht 2) topsoil deposits in the High Street and Hinterland Near zones at Lauder. Depth indicates the location of Kubiena tin samples

Pittenweem

Differences in coarse mineral material classes are identified within Aht 1 horizons at Pittenweem, for example shell and bone inclusions are limited to 41-49cm within soil pit PT 4. Likewise clinker/slag inclusions are exclusive to 62-70cm within soil pit PT 4 (Figure 40). In cases where materials are present throughout Aht 1 horizons it is recognised that their abundances differ. Shell and mortar/plaster inclusions vary in abundance from 2-5% at 20-28cm within soil pit PT 5 yet are <2% at 40-48cm. Similarly, pottery/brick inclusions are <1% at 20-28cm within soil pit PT 5 but are <2% at 40-48cm. Accordingly, it is suggested that coarse mineral material varies in diversity and abundance within Aht 1 horizons at Pittenweem.

Differences in coarse mineral material classes are identified between Aht 1 and Aht 2 horizons, for instance bone inclusions are limited to the Aht 1 horizon within soil pit PT 3 and shell inclusions are exclusive to the Aht 2 horizon. In addition, differences in abundances of coarse mineral anthropogenic material classes are recognised between Aht 1 and Aht 2 horizons. Pottery/brick is 2-5% abundant within the Aht 1 horizon at soil pit PT 3 and <2% within the Aht 2 horizon. Conversely mortar/plaster inclusions are <2% abundant within the Aht 1 horizon at soil pit PT 3 in contrast to 5-10% within the Aht 2 horizon. Hence it is recognised that coarse mineral material varies in diversity and abundance between Aht 1 and Aht 2 horizons at Pittenweem.

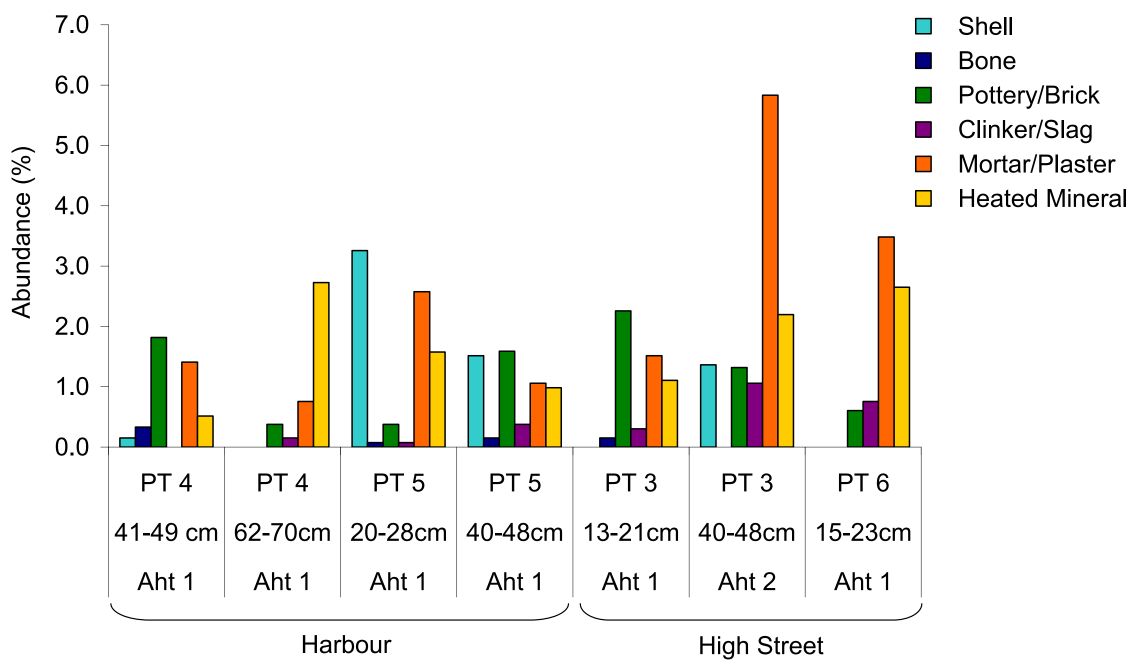


Figure 40: Percentage abundance estimates of coarse mineral material within upper (Aht 1) and lower (Aht 2) topsoil deposits in the Harbour and High Street zones at Pittenweem. Depth indicates the location of Kubiena tin samples

Wigtown

Differences in coarse mineral material classes are identified within Aht 1 horizons at Wigtown, for example shell and bone are limited to 32-40cm within soil pit WG 1. Likewise clinker/slag inclusions are exclusive to 12-20cm within soil pit WG 1 (Figure 41). In cases where materials are present throughout Aht 1 horizons it is recognised that their abundances differ. Mortar/plaster inclusions vary from 2-5% at 12-20cm within soil pit WG 1 and are <1% at 32-40cm. Similar to results obtained for Lauder and Pittenweem, it is recognised that coarse mineral material varies in diversity and abundance within Aht 1 horizons at Wigtown.

Differences in coarse mineral material classes are identified between Aht 1 and Aht 2 horizons, for instance shell, bone, pottery/brick, clinker/slag, mortar/plaster and heated mineral inclusions are limited to the Aht 1 horizon within soil pit WG 1. Similarly, pottery/brick and heated mineral are restricted to the Aht 1 horizon within soil pit WG 2. In addition, differences in abundances of coarse mineral anthropogenic material classes are recognised between Aht 1 and Aht 2 horizons. Bone is <1% within the Aht 1 horizon at soil pit WG 4 in contrast to abundances of 2-5% within the Aht 2 horizon. Coarse mineral material therefore varies in diversity and abundance between Aht 1 and Aht 2 horizons at Wigtown.

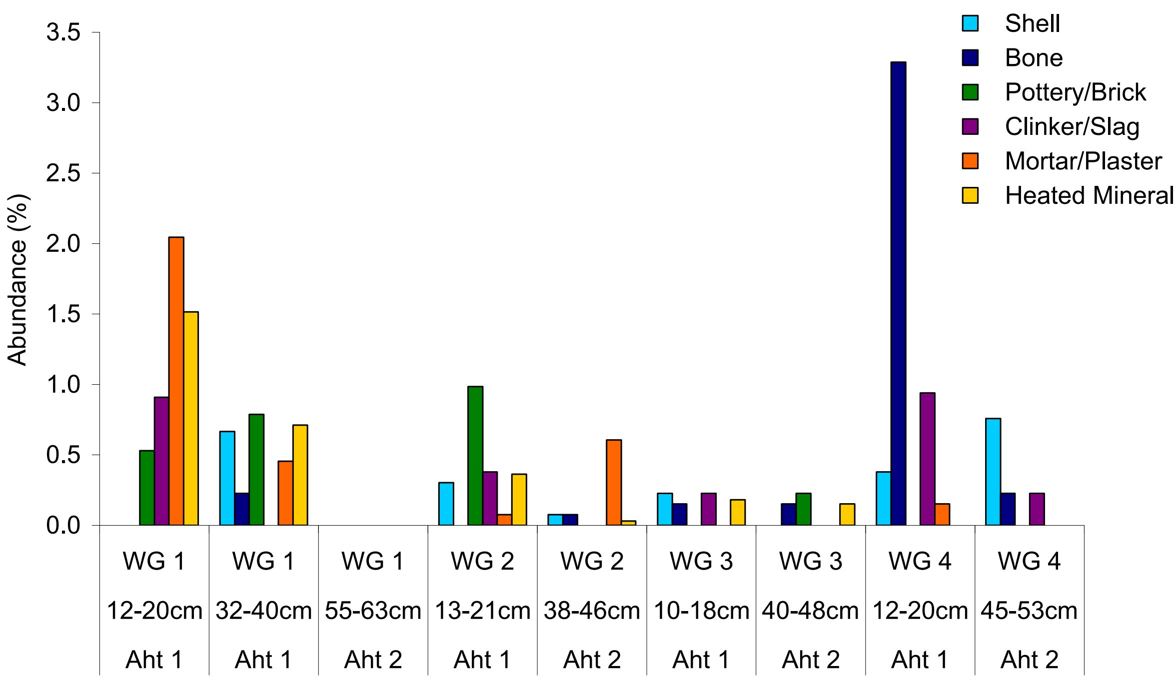


Figure 41: Percentage abundance estimates of coarse mineral material within upper (Aht 1) and lower (Aht 2) topsoil deposits in the High Street zone at Wigtown. Depth indicates the location of Kubiena tin samples

5.2.2 Variation between Burghs

Coarse mineral anthropogenic material is typically most diverse and abundant within the burgh core at Lauder, Pittenweem and Wigtown. All three burghs have bone, pottery/brick, clinker/slag, mortar/plaster and heated mineral inclusions in zones corresponding to the burgh core (Harbour, High Street). In addition shell inclusions are identified within the burgh core at Pittenweem and Wigtown.

Coarse mineral anthropogenic material is limited to the burgh core at Wigtown; however, selected inclusions are present within hinterland topsoils at Lauder and Pittenweem. Heated mineral and clinker/slag inclusions occur in the immediate hinterland south of Lauder (Hinterland Near) and far hinterland (Hinterland Far) respectively. Similar to results obtained for Lauder, topsoils within the immediate hinterland north of Pittenweem (Hinterland Near) contain trace abundances of heated mineral inclusions. Moreover the Hinterland Far zone and ‘reference’ soil pit at Pittenweem are characterised by pottery/brick, clinker/slag and mortar/plaster inclusions. It is suggested that the ‘reference’ soil is of limited utility considering is location within the Hinterland Far zone.

Considerable variation in coarse mineral anthropogenic material is also apparent within and between topsoil hortic horizons. Coarse mineral anthropogenic material classes vary in diversity and abundance within Aht 1 horizons and between Aht 1 and Aht 2 horizons at Lauder, Pittenweem and Wigtown. Differences within and between horizons appear random with the exception of Lauder where coarse mineral anthropogenic inclusions are absent from Aht 2 horizons.

5.3 Summary of Results: Coarse Mineral Material

The following section presents a brief summary of key trends in the nature and abundance of coarse mineral material both within and between burghs. The significance of these results is discussed in sections 8.1.3 and 8.2.3; in particular consideration is given to differences in the nature and distribution of waste materials both within and between burghs.

5.3.1 Variation within Burghs

5.3.1.1 Lauder

The main area of interest at Lauder is the High Street zone. This zone is characterised by trace abundances of bone, pottery/brick, clinker/slag, mortar/plaster and heated mineral inclusions. In addition, clinker/slag is present within the Hinterland Far zone and heated mineral is identified within the Hinterland Near zone (Table 5).

5.3.1.2 Pittenweem

The Harbour, High Street, Hinterland Near and Hinterland Far zones and 'reference' soil pit at Pittenweem contain coarse mineral inclusions. The burgh core is characterised by shell, bone, pottery/brick, clinker/slag, mortar/plaster and heated mineral inclusions. Abundances are typically <2% although it is noted that shell is most abundant within the Harbour zone (2-5%), and pottery/brick and mortar/plaster are most abundant within the High Street zone (2-5% to 5-10%) (Table 5). Coarse mineral material within the Hinterland Near zone is limited to trace abundances of heated mineral. However, inclusions within the Hinterland Far zone and 'reference' soil comprise trace abundances of pottery/brick, clinker/slag, mortar/plaster and heated mineral.

5.3.1.3 Wigtown

The High Street zone is characterised by trace abundances of shell, bone, pottery/brick, clinker/slag, mortar/plaster and heated mineral inclusions. Coarse mineral inclusions are absent from the hinterland north of Wigtown.

5.3.1.4 Hortic Horizons

Results presented in section 5.2.1.2 indicate that coarse mineral anthropogenic material classes vary in diversity and abundance within Aht 1 horizons and between Aht 1 and Aht 2 horizons at Lauder, Pittenweem and Wigtown. Differences within and between horizons appear random with the exception of Lauder where coarse mineral anthropogenic inclusions are absent from Aht 2 horizons.

Table 5: Summary of trends in coarse mineral material identified at Lauder, Pittenweem and Wigtown, summary abundances are given in brackets

Inclusion	Lauder	Pittenweem	Wigtown
Shell	Absent.	Shell is present within the burgh core (Harbour <2% to 2-5%, High Street <2%).	Shell present is within the burgh core (<2%).
Bone	Bone is present within the burgh core (<2%).	Bone is present within burgh core (<2%).	Bone is present within the burgh core (<2% to 2-5%).
Pottery /Brick	Pottery/Brick is present within the burgh core (<2%).	Pottery/brick is present within the burgh core (Harbour <2%, High Street <2% to 2-5%) and far hinterland (<2%).	Pottery/Brick is present within the burgh core (<2%).
Clinker/ Slag	Clinker/Slag is present within the burgh core and far hinterland (Hinterland Far) (<2%).	Clinker/Slag is present within the burgh core and far hinterland (<2%).	Clinker/Slag is present within the burgh core (<2%).
Mortar/ Plaster	Mortar/Plaster is present within the burgh core (<2%).	Mortar/Plaster is present within the burgh core (Harbour <2% to 2-5%, High Street <2% to 5-10%) and far hinterland (<2%).	Mortar/Plaster is present within the burgh core (<2% to 2-5%)..
Heated Mineral	Heated Mineral is present within the burgh core and immediate hinterland (Hinterland Near) (<2%).	Heated Mineral is present within the burgh core (2% to 2-5%) and hinterland (Hinterland Near, Hinterland Far <2%).	Heated Mineral is present within the burgh core (<2%).

5.3.2 Variation between Burghs

All three burghs have bone, pottery/brick, clinker/slag, mortar/plaster and heated mineral inclusions in zones corresponding to the burgh core (Harbour, High Street) (Table 6). In contrast shell inclusions are limited to the burgh core at Pittenweem and Wigtown. Coarse mineral material is most abundant within burgh cores. Moreover, coarse mineral inclusions are most abundant within the burgh core at Pittenweem in comparison to burgh cores at Lauder and Wigtown. Coarse mineral anthropogenic inclusions are present in topsoils within the hinterland at Lauder and Pittenweem. Mineral material within the hinterland at Lauder is limited to isolated traces of heated mineral and clinker/slag; however, pottery/brick, clinker/slag, mortar/plaster and heated mineral inclusions are consistent within the far hinterland at Pittenweem.

Table 6: Comparison of trends in the abundance of coarse mineral anthropogenic material at Lauder, Pittenweem and Wigtown, summary abundances are given in brackets

Inclusion	Comparison between Burghs
Shell	Shell is present within the burgh core at Pittenweem (<2% to 2-5%) and Wigtown (2%).
Bone	Bone is present within the burgh core at all three towns (Lauder and Pittenweem <2%, Wigtown <2% to 2-5%).
Pottery/Brick	Pottery/Brick is present within the burgh core at all three towns (Lauder and Wigtown <2%, Pittenweem <2% to 2-5%). Pottery/Brick is present within the Hinterland Far zone and ‘reference’ soil (<2%) at Pittenweem.
Clinker/Slag	Clinker/slag is present within the burgh core at all three towns (<2%). Clinker/slag is present in the Hinterland Far zone at Lauder and Pittenweem (<2%).
Mortar/Plaster	Mortar/plaster is present within the burgh core at all three towns (Lauder <2%, Pittenweem <2% to 5-10%, Wigtown <2% to 2-5%). Mortar/plaster is present within the Hinterland Far zone and ‘reference’ soil (<2%) at Pittenweem.
Heated Mineral	Heated mineral is present within the burgh core at all three towns (Lauder and Wigtown <2%, Pittenweem <2% to 2-5%). Heated mineral is present in trace abundance (<2%) within the immediate hinterland (Hinterland Near) at Lauder, and hinterland (Hinterland Near and Hinterland Far zones/’reference’ soil) at Pittenweem.

5.4 Fine Mineral Material

The colour and limpidity of fine mineral material within topsoil deposits at Lauder, Pittenweem and Wigtown is summarised in tables presented in Appendix 2. Differences in fine mineral material characteristics are identified and comparisons between zones and burghs are made.

5.4.1 Variation within Burghs

Fine mineral material within the High street, Hinterland Near and Thirlstane zones at Lauder is brown/dark brown and dotted. In contrast fine mineral material within the Hinterland Far zone and ‘reference’ soil pit LA 7 is red/red brown and speckled, with the exception of topsoil within soil pit LA 3 which is brown and dotted.

There is no difference in fine mineral material characteristics between zones at Pittenweem. Fine mineral material within the Harbour, High Street, Hinterland Near and Hinterland Far zones and ‘reference’ soil pit PT 1 is characteristically brown/dark brown and dotted.

Fine mineral material within the High Street zone and ‘reference’ soil WG 5 at Wigtown is brown/dark brown. Despite similarities in colour, it is recognised that limpidity of fine mineral material differs between these areas. Fine mineral material within the High Street zone is dotted in contrast to the ‘reference’ soil which is speckled.

5.4.2 Variation between Burghs

Fine mineral material within the burgh core at all three towns is characteristically brown/dark brown and dotted. Similarities in the nature of fine mineral material are identified within the burgh core and immediate hinterland north (Thirlstane) and south (Hinterland Near) of Lauder. Additionally it is noted that there is no distinction in the nature of fine mineral material between zones at Pittenweem. Fine mineral material within the burgh core and hinterland (Hinterland Near/’reference’ soil) at Wigtown is similar in colour; however, a marked difference in limpidity is apparent.

5.5 Coarse Organic Material

The abundance of coarse organic material within topsoil deposits at Lauder, Pittenweem and Wigtown is summarised in tables presented in Appendix 2. Differences in the nature and abundance of inclusions are identified and comparisons between zones, horizons and burghs are made.

5.5.1 Charcoal

5.5.1.1 Variation within Burghs

Charcoal is present in trace abundances (<2%) within the High Street and Hinterland Near zones at Lauder. In contrast charcoal is absent from the Hinterland Far and Thirlstane zones, and 'reference' soil pit LA 7. Charcoal is therefore limited to the burgh core and immediate hinterland south of the historical burgh limits (Hinterland Near).

Charcoal inclusions are <2% within the Harbour, High Street, Hinterland Near and Hinterland Far zones at Pittenweem. In comparison charcoal is absent from 'reference' soil pit PT 1. Nevertheless these results indicate that there is no difference in the abundance of charcoal between zones at Pittenweem.

Charcoal occurs as trace abundances (<2%) within the High Street zone at Wigtown. However charcoal is absent from 'reference' soil pit WG 5. Charcoal inclusions are thus limited to the burgh core at Wigtown.

5.5.1.2 Variation between Burghs

Charcoal is <2% within zones corresponding to the burgh core (Harbour and High Street) at all three towns. Results of Kruskal-Wallis analysis with Dunn's test multiple comparisons indicate no statistical difference in the abundance of charcoal between High Street zones at Lauder, Pittenweem and Wigtown. Charcoal inclusions are present within the immediate hinterland south (Hinterland Near) of the historical burgh limits at Lauder and across the hinterland (Hinterland Near, Hinterland Far) at Pittenweem. In contrast charcoal is limited to the burgh core at Wigtown.

5.5.2 <u>Fuel Residue 1 (FR 1)</u>

5.5.2.1 Variation within Burghs

FR 1 inclusions are identified within the High Street, Hinterland Near, Hinterland Far and Thirlstane zones, and ‘reference’ soil pit LA 7 at Lauder. Abundances of FR 1 within the High Street zone range from <2% to 5-10%. Similarly FR 1 varies between <2% to 2-5% within the Hinterland Near zone. FR 1 inclusions are <2% within the Hinterland Far and Thirlstane zones and ‘reference’ soil pit. FR 1 is significantly more abundant within the High Street zone than the Hinterland Near, Hinterland Far and Thirlstane zones, and ‘reference’ soil pit LA 7 ($p<0.001$) (Figure 42a). In addition FR 1 is significantly greater within the Hinterland Near zone than the Hinterland Far zone ($p<0.01$). There is no statistical difference in the abundance of FR 1 between the Hinterland Far and Thirlstane zones and ‘reference’ soil pit. FR 1 inclusions are therefore greatest within the burgh core followed in succession by the immediate hinterland south (Hinterland Near) of Lauder.

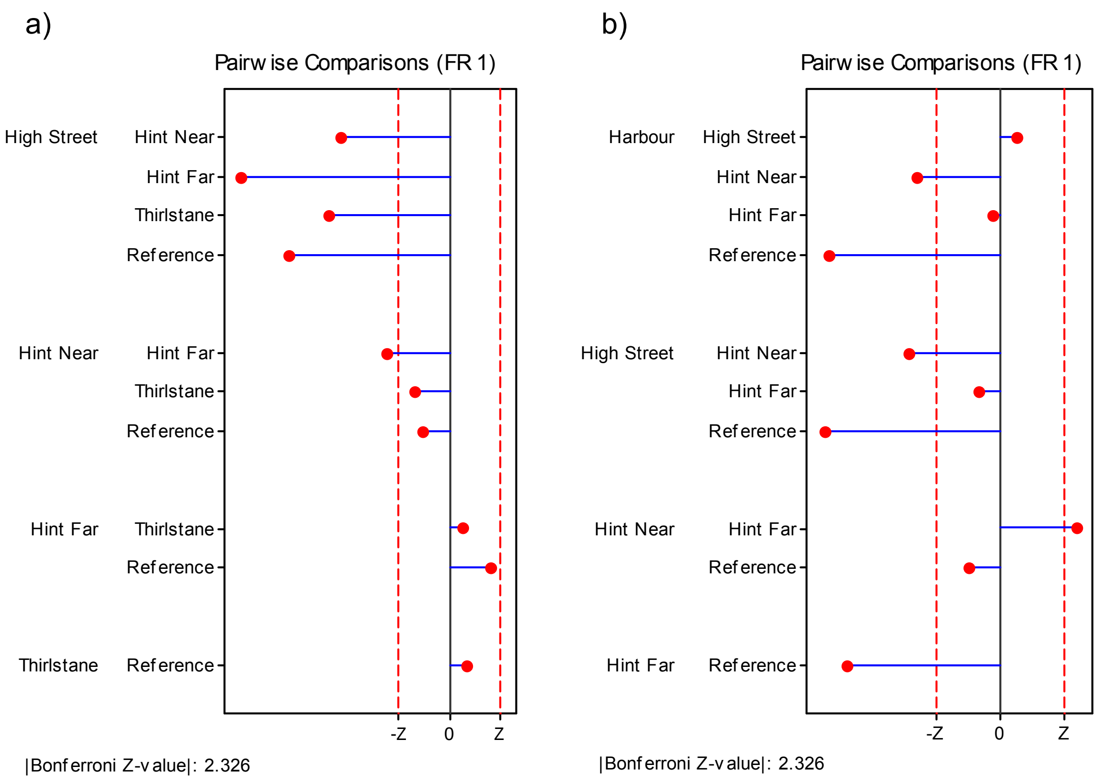


Figure 42: Kruskal-Wallis analysis with Dunn’s test multiple comparisons of FR 1 for individual zones at Lauder (a) and Pittenweem (b), z values exceeding –Z or Z are significant at p<0.05 confidence level

FR 1 inclusions are present within the Harbour, High Street, Hinterland Near and Hinterland Far zones, and 'reference' soil pit PT 1 at Pittenweem. Abundances of FR 1 within the Harbour and High Street zones range from 5-10% to 10-15%. FR 1 varies between 5 to 10% within the Hinterland Near and Hinterland Far zones, and between 2 to 5% within the 'reference' soil. FR 1 is significantly more abundant within the Harbour and High Street zones than the Hinterland Near zone and 'reference' soil pit ($p<0.001$) (Figure 42b). In addition FR 1 is significantly greater within the Hinterland Far zone than the Hinterland Near zone ($p<0.01$) and 'reference' soil pit ($p<0.001$). There is no statistical difference in the abundance of FR 1 between the Harbour, High Street and Hinterland Far zones. FR 1 inclusions are therefore greatest within the burgh core at far hinterland (Hinterland Far) at Pittenweem.

FR 1 inclusions occur within the High Street zone and 'reference' soil pit WG 5 at Wigtown. Abundances of FR 1 within the High Street zone range from <2% to 5-10%, although values of 2-5% to 5-10% are typical. FR 1 varies between <2% to 2-5% within the 'reference' soil pit. FR 1 is significantly greater within the High Street zone than the 'reference' soil pit ($p<0.001$). FR 1 inclusions are therefore greatest within the burgh core at Wigtown.

5.5.2.2 Variation between Burghs

FR 1 inclusions are present within zones corresponding to the burgh core (Harbour and High Street) and the hinterland at all three towns. FR 1 inclusions are greatest in abundance within the burgh core at Lauder and Wigtown and within the burgh core and far hinterland (Hinterland Far) at Pittenweem. Results of Kruskal-Wallis analysis with Dunn's test multiple comparisons indicate that FR 1 is significantly more abundant within the High Street zone at Pittenweem than High Street zones at Lauder and Wigtown ($p<0.001$). There is no statistical difference in the abundance of FR 1 between the High Street zone at Lauder and Wigtown.

5.5.3 <u>Fuel Reside 2 (FR 2)</u>

5.5.3.1 Variation within Burghs

FR 2 inclusions are <2% within the High Street zone at Lauder. In contrast FR 2 inclusions are absent from the Hinterland Near, Hinterland Far and Thirlstane zones, and ‘reference’ soil pit LA 7. FR 2 inclusions are therefore limited to the burgh core at Lauder.

FR 2 inclusions occur as trace abundances (<2%) within the Harbour, High Street and Hinterland Far zones, and ‘reference’ soil pit PT 1 at Pittenweem. FR 2 is absent from the Hinterland Near zone. There is no difference in the abundance of FR 2 inclusions between the burgh core and far hinterland (Hinterland Far/’reference’ soil) at Pittenweem.

FR 2 inclusions are present in trace abundances (<2%) within the High Street zone at Wigtown. In comparison FR 2 is absent from ‘reference’ soil pit WG 5. FR 2 inclusions are therefore limited to the burgh core at Wigtown.

5.5.3.2 Variation between Burghs

FR 2 inclusions occur within zones corresponding to the burgh core (Harbour and High Street) at all three towns and within the hinterland at Pittenweem. Results of Kruskal-Wallis analysis with Dunn’s test multiple comparisons indicate no statistical difference in the abundance of FR 2 between High Street zones at Lauder, Pittenweem and Wigtown. FR 2 inclusions are limited to the burgh core at Lauder and Wigtown; however, FR 2 is noted within both the burgh core and far hinterland (Hinterland Far/’reference’ soil) at Pittenweem.

5.5.4 Fuel Residue 3 (FR 3)

5.5.4.1 Variation within Burghs

Abundances of FR 3 within the High Street zone at Lauder range from <2% to 2-5%. FR 3 inclusions are <2% within the Hinterland Near and Hinterland Far zones and 'reference' soil pit. FR 3 is significantly more abundant within the High Street zone than the Hinterland Far ($p<0.01$) and Thirlstane ($p<0.001$) zones and 'reference' soil pit LA 7 ($p<0.01$) (Figure 43a). There is no statistical difference in the abundance of FR 3 between the High Street and Hinterland Near zones. In addition there is no significant difference in FR 3 between the Hinterland Far and Thirlstane zones, and 'reference' soil pit. FR 3 inclusions are therefore greatest within the burgh core followed in succession by the immediate hinterland south (Hinterland Near) of Lauder.

Abundances of FR 3 within the Harbour and High Street zones at Pittenweem vary between <2% and 2-5%. FR 3 inclusions are <2% within the Hinterland Near and Hinterland Far zones and 'reference' soil pit. FR 3 is significantly more abundant within the High Street zone than the Harbour ($p<0.05$), Hinterland Near ($p<0.01$) and Hinterland Far zones ($p<0.01$), and 'reference' soil pit ($p<0.001$) (Figure 43b). There is no statistical difference in the abundance of FR 3 between the Harbour, Hinterland Near and Hinterland Far zones and 'reference' soil pit. FR 3 inclusions are therefore greatest within the burgh core with specific reference to the High Street zone.

FR 3 inclusions occur as trace abundances (<2%) within the High Street zone at Wigtown. In contrast FR 3 is absent from 'reference' soil pit WG 5. FR 3 inclusions are therefore limited to the burgh core at Wigtown.

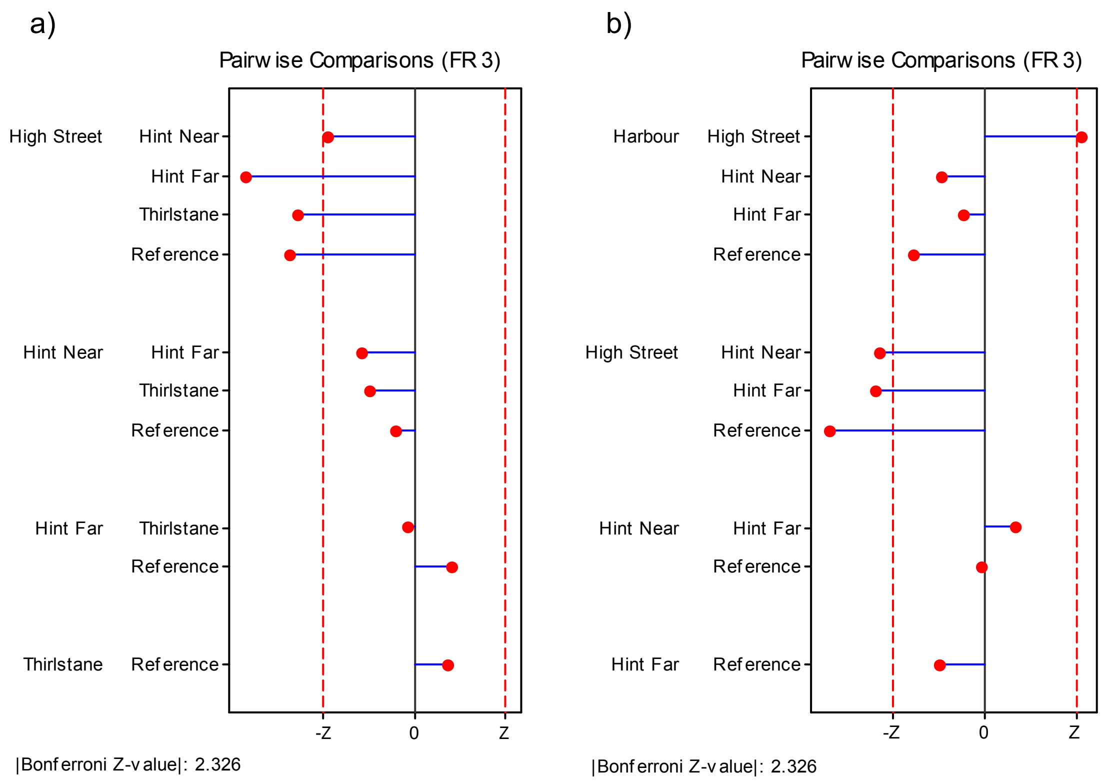


Figure 43: Kruskal-Wallis analysis with Dunn's test multiple comparisons of FR 3 for individual zones at Lauder (a) and Pittenweem (b), z values exceeding –Z or Z are significant at p<0.05 confidence level

5.5.4.2 Variation between Burghs

FR 3 inclusions are present within zones corresponding to the burgh core (Harbour and High Street) at all three towns and within the hinterland at Lauder and Pittenweem. FR 3 inclusions are greatest in abundance within the burgh core (High Street zone) at Lauder, Pittenweem and Wigtown. Results of Kruskal-Wallis analysis with Dunn's test multiple comparisons indicate that FR 3 is more abundant within the High Street zone at Pittenweem in comparison to High Street zones at Lauder ($p<0.05$) and Wigtown ($p<0.001$). FR 3 is also significantly greater within the High Street zone at Lauder than the High Street zone at Wigtown ($p<0.01$). It is therefore recognised that FR 3 is greatest in abundance within the High Street zone at Pittenweem and least abundant within the High Street zone at Wigtown.

5.5.5 <u>Fuel Residue 4 & 6 (FR 4 & 6)</u>

5.5.5.1 Variation within Burghs

Abundances of FR 4 & 6 within the High Street zone at Lauder range from <2% to 5-10%, although values between 2-5% and 5-10% are typical. FR 4 & 6 inclusions within the Hinterland Near and Hinterland Far zones vary from <2% to 2-5%. In contrast FR 4 & 6 is <2% within the Thirlstane zone and ‘reference’ soil. FR 4 & 6 is significantly more abundant within the High Street zone than the Hinterland Near, Hinterland Far and Thirlstane zones and ‘reference’ soil pit ($p<0.001$) (Figure 44a). There is no statistical difference in the abundance of FR 4 & 6 between the Hinterland Near, Hinterland Far, and Thirlstane zones and ‘reference’ soil pit. FR 4 & 6 inclusions are therefore greatest within the burgh core.

Abundances of FR 4 & 6 within the Harbour zone at Pittenweem range from 2-5% to 5-10%. FR 4 & 6 inclusions within the High Street and Hinterland Far zones vary between <2% to 2-5%. In contrast FR 4 & 6 is <2% within the Hinterland Near zone and ‘reference’ soil pit. FR 4 & 6 is significantly more abundant within the Harbour zone than the Hinterland Near ($p<0.01$) and Hinterland Far ($p<0.05$) zones and reference soil ($P<0.001$) (Figure 44b). In addition FR 4 & 6 is greater within the High Street and Hinterland Far zones than the ‘reference’ soil pit ($p<0.001$). There is no statistical difference in the abundance of FR 4 & 6 between the Harbour and High Street zones. Moreover there is no significant difference in the abundance of FR 4 & 6 between the High Street, Hinterland Near and Hinterland Far zones. FR 4 & 6 inclusions are therefore greatest within the burgh core with specific reference to the Harbour zone.

Abundances of FR 4 & 6 within the High Street zone at Wigtown range from 5-10% to 10-15%. FR 4 & 6 inclusions within the ‘reference’ soil pit vary between <2% and 2-5%. FR 4 & 6 is significantly more abundant within the High Street zone than the ‘reference’ soil pit ($p<0.001$). FR 4 & 6 inclusions are therefore greatest within the burgh core at Wigtown.

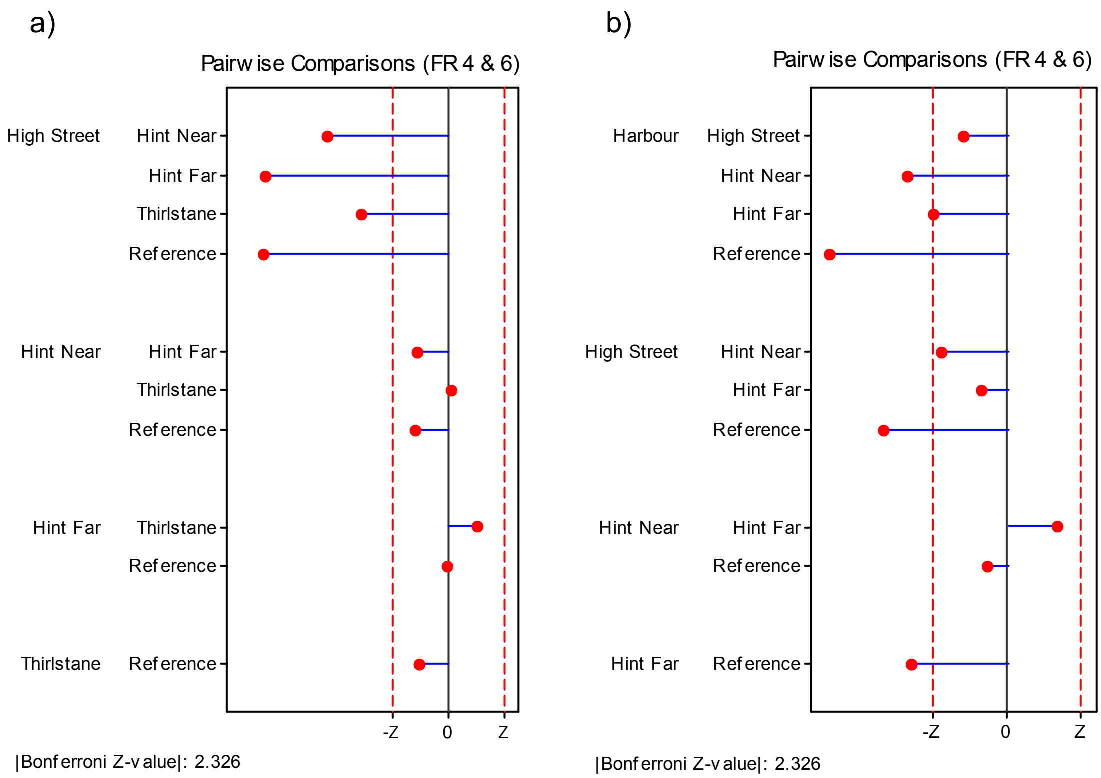


Figure 44: Kruskal-Wallis analysis with Dunn's test multiple comparisons of FR 4 & 6 for individual zones at Lauder (a) and Pittenweem (b), z values exceeding –Z or Z are significant at p<0.05 confidence level

5.5.5.2 Variation between Burghs

FR 4 & 6 inclusions are identified within zones corresponding to the burgh core (Harbour and High Street) and selected hinterland zones all three towns. It is noted that FR 4 & 6 inclusions are greatest in abundance within burgh cores at Lauder, Pittenweem and Wigtown. Results of Kruskal-Wallis analysis with Dunn's test multiple comparisons indicate FR 4 & 6 is significantly more abundant within the High Street zone at Wigtown in comparison to High Street zones at Lauder and Pittenweem ($p<0.001$). There is no statistical difference in the abundance of FR 4 & 6 between the High Street zone at Lauder and Pittenweem.

5.5.6 Fuel Residue 5 & 7 (FR 5 & 7)

5.5.6.1 Variation within Burghs

Abundances of FR 5 & 7 within the High Street, Hinterland Near, Hinterland Far and Thirlstane zones and 'reference' soil pit LA 7 at Lauder are <2%. Hence, there is no significant difference in the abundance of FR 5 & 7 between zones.

Abundances of FR 5 & 7 within the Harbour zone at Pittenweem range from 5-10% to 10-15%. In contrast FR 5 & 7 inclusions within the High Street, Hinterland Near and Hinterland Far zones and 'reference' soil pit are <2%. FR 5 & 7 is significantly more abundant within the Harbour zone than the High Street, Hinterland Near and Hinterland Far zones and 'reference' soil pit ($p<0.001$) (Figure 45). In addition FR 5 & 7 is significantly greater within the High Street zone compared to the 'reference' soil pit ($p<0.01$). It is therefore identified that FR 5 & 7 inclusions are greatest within the Harbour zone and to a lesser extent the High Street zone.

FR 5 & 7 occur as trace abundances (<2%) within the High Street zone and 'reference' soil pit WG 5 at Wigtown. There is no statistical difference in the abundance of FR 5 & 7 between the High Street zone and 'reference' soil pit.

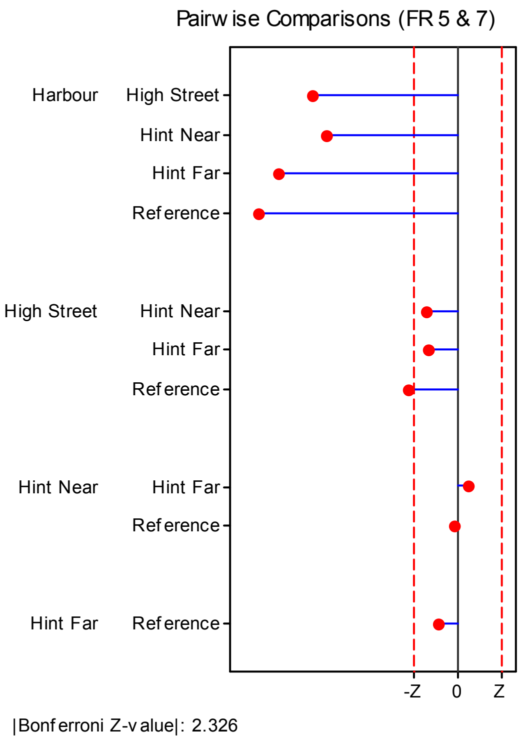


Figure 45: Kruskal-Wallis analysis with Dunn's test multiple comparisons of FR 5 & 7 for individual zones at Pittenweem, z values exceeding –Z or Z are significant at p<0.05 confidence level

5.5.6.2 Variation between Burghs

FR 5 & 7 inclusions are present within both the burgh core and hinterland at all three burghs. There is no difference in the abundance of FR 5 & 7 between zones at Lauder and Wigtown; however it is noted that FR 5 & 7 is greatest in abundance within the burgh core at Pittenweem. Results of Kruskal-Wallis analysis with Dunn's test multiple comparisons reveal that FR 5 & 7 is significantly more abundant within the High Street zone at Pittenweem than High Street zones at Lauder and Wigtown ($p<0.001$). There is no statistical difference in the abundance of FR 5 & 7 between High Street zones at Lauder and the High Street zone at Wigtown.

5.5.7 <u>Fuel Residue 8 & 9 (FR 8 & 9)</u>

5.5.7.1 Variation within Burghs

Abundances of FR 8 & 9 within the High Street and Hinterland Near zone at Lauder range from <2% to 2-5%. FR 8 & 9 inclusions within the Hinterland Far and Thirlstane zones and 'reference' soil pit are typically <2%. FR 8 & 9 is significantly more abundant within the High Street zone than the Hinterland Far and Thirlstane zones and 'reference' soil pit ($p<0.001$) (Figure 46a). In addition FR 8 & 9 is significantly greater within the Hinterland Near zone than the Hinterland Far and Thirlstane zones ($p<0.05$) and 'reference' soil pit ($p<0.001$). FR 8 & 9 is also significantly higher in the Hinterland Far and Thirlstane zones than 'reference' soil pit ($p<0.01$). There is no difference in the abundance of FR 8 & 9 between the High Street and Hinterland Near zones. FR 8 & 9 is greatest in abundance within the burgh core and immediate hinterland south (Hinterland Near) of Lauder.

Abundances of FR 8 & 9 within the Harbour and High Street zone at Pittenweem range from <2% to 2-5%, although abundances within the Harbour zone are typically 2-5%. FR 8 & 9 inclusions within the Hinterland Far zone and 'reference' soil pit range from <2% to 2-5%. In contrast FR 8 & 9 is <2% within the Hinterland Near zone. FR 8 & 9 is significantly more abundant within the Harbour than the High Street ($p<0.01$), Hinterland Near ($p<0.001$) and Hinterland Far zones ($p<0.001$) and 'reference' soil pit ($p<0.001$). FR 8 & 9 is significantly greater within the High Street zone than the 'reference' soil pit ($p<0.05$) (Figure 46b). It is therefore recognised that FR 8 & 9 inclusions are greatest within the Harbour zone and to a lesser extent the High Street zone.

Abundances of FR 8 & 9 within the High Street zone at Wigtown range from <2% to 5-10%. In contrast FR 8 & 9 within the 'reference' soil is typically <2%. FR 8 & 9 is significantly more abundant within the High Street zone than the 'reference' soil (p<0.001). FR 8 & 9 inclusions are, therefore, greatest within the burgh core.

5.5.7.2 Variation between Burghs

The burgh core and hinterland at all three burghs contain FR 8 & 9 inclusions. FR 8 & 9 is greatest in abundance within the burgh core at Pittenweem and Wigtown and within the burgh core and immediate hinterland south (Hinterland Near) of the historical burgh limits at Lauder. Results of Kruskal-Wallis analysis with Dunn's test multiple comparisons indicate that FR 8 & 9 is significantly more abundant within the High Street zone at Lauder in comparison to High Street zones at Pittenweem and Wigtown (p<0.001). In addition FR 8 & 9 is significantly greater within the High Street zone at Wigtown than the High Street zone at Pittenweem (p<0.001).

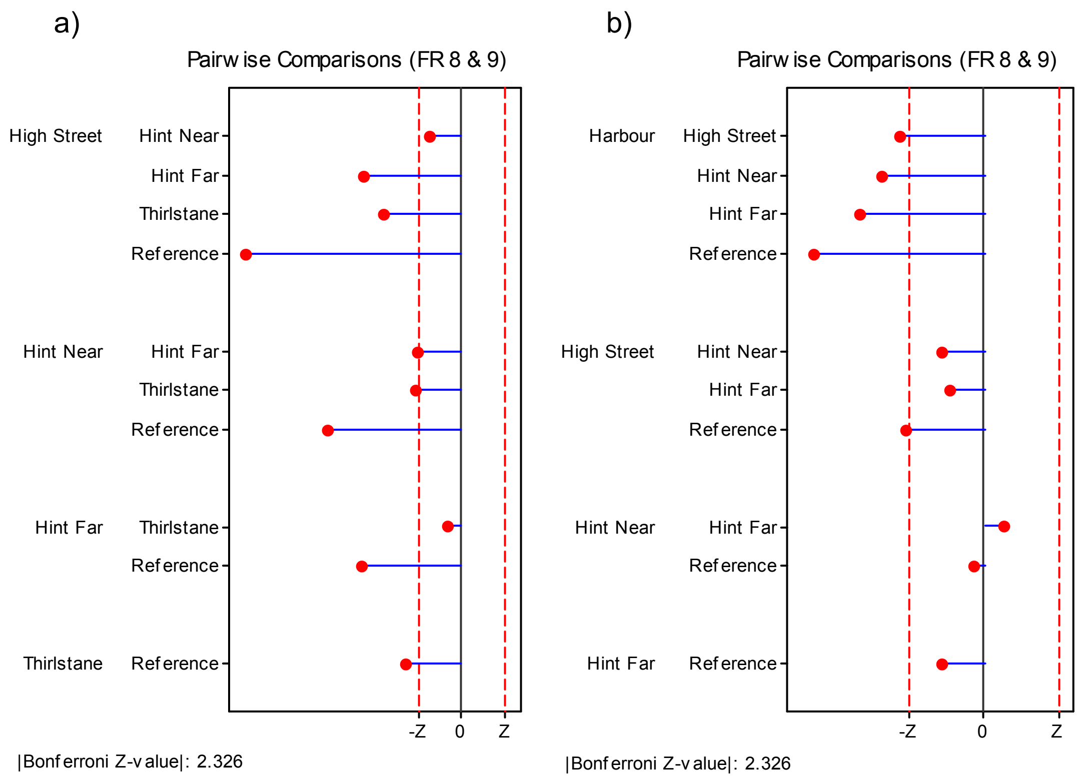


Figure 46: Kruskal-Wallis analysis with Dunn's test multiple comparisons of FR 8 & 9 for individual zones at Lauder (a) and Pittenweem (b), z values exceeding –Z or Z are significant at p<0.05 confidence level

5.5.8 Fuel Residue 10 (FR 10)

5.5.8.1 Variation within Burghs

Trace abundances (<2%) of FR 10 inclusions are present within the High Street zone at Lauder. In contrast FR 10 inclusions are absent from the Hinterland Near, Hinterland Far and Thirlstane zones, and 'reference' soil pit LA 7. FR 10 inclusions are therefore limited to the burgh core at Lauder.

FR 10 inclusions occur as trace abundances (<2%) within the Harbour, High Street and Hinterland Far zones, and 'reference' soil pit PT 1 at Pittenweem. FR 10 is absent from the Hinterland Near zone. There is no difference in the abundance of FR 10 inclusions between the burgh core and far hinterland (Hinterland Far/'reference' soil) at Pittenweem.

The High Street zone at Wigtown contains trace abundances (<2%) of FR 10 inclusions. However FR 10 inclusions are absent from 'reference' soil pit WG 5. FR 10 inclusions are therefore limited to the burgh core at Wigtown.

5.5.8.2 Variation between Burghs

FR 10 inclusions are present within zones corresponding to the burgh core (Harbour and High Street) at all three towns and within the hinterland at Pittenweem. Results of Kruskal-Wallis analysis with Dunn's test multiple comparisons indicate no statistical difference in the abundance of FR 10 between High Street zones at Lauder, Pittenweem and Wigtown. It is recognised that FR 10 inclusions are limited to the burgh core at Lauder and Wigtown; however, FR 10 is noted within both the burgh core and far hinterland (Hinterland Far/'reference' soil) at Pittenweem.

5.5.9 <u>Fuel Residue 10-255 µm (%)</u>

5.5.9.1 Variation within Burghs

The percentage of total fuel residue sized between 10 and 255µm within the High Street zone at Lauder ranges from 10 to 18% (Figure 47). In comparison the % of total fuel residue 10-255µm within Hinterland Near, Hinterland Far and Thirlstane zone varies between 27 to 59%. Similarly, the % of total fuel residue 10-255µm within the 'reference' soil pit LA 7 varies between 28 and 52%. Results of One Way Analysis of Variance (ANOVA) with Tukey-Kramer multiple comparisons indicate that the % of total fuel residue 10-255µm is significantly lower within the High Street zone in comparison to the Hinterland Near, Hinterland Far and Thirlstane zones and 'reference' soil pit LA 7 ($p<0.001$). The % of total fuel residue 10-255µm is therefore lowest within the burgh core at Lauder.

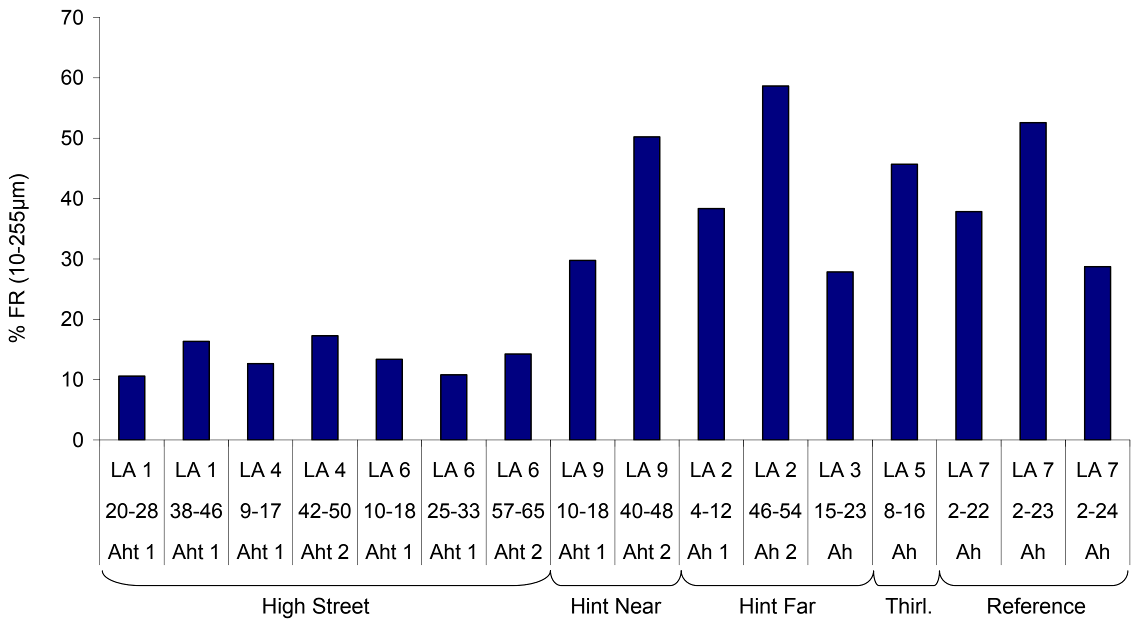


Figure 47: % FR (10-255µm) within topsoil deposits in the High Street, Hinterland Near, Hinterland Far and Thirlstane zones, and 'reference' soil at Lauder. Number range refers to depth of Kubiena sample (cm)

The percentage of total fuel residue sized between 10 and 255μm within the Harbour and High street zone at Pittenweem varies between 4 and 16% (Figure 48). In comparison the % of total fuel residue 10-255μm within the Hinterland Near and Hinterland Far zones ranges from 21 to 26% with the exception of soil pit PT 2 which has a very low value of 7.7%. The % of total fuel residue 10- 255μm within 'reference' soil pit PT 1 has a mean value of 19%. Results of One Way Analysis of Variance (ANOVA) reveal that there is no statistical difference in the % of total fuel 10-255μm between zones at Pittenweem.

The mean percentage of total fuel residue sized between 10 and 255μm within the High Street zone and 'reference' soil pit WG 5 at Wigtown is 12 and 18% respectively (Figure 49). These results indicate a lower % of total fuel residue 10-255μm within the burgh core. However, results of One Way ANOVA reveal that there is no significant difference in the % of total fuel residue 10-255μm between zones at Wigtown.

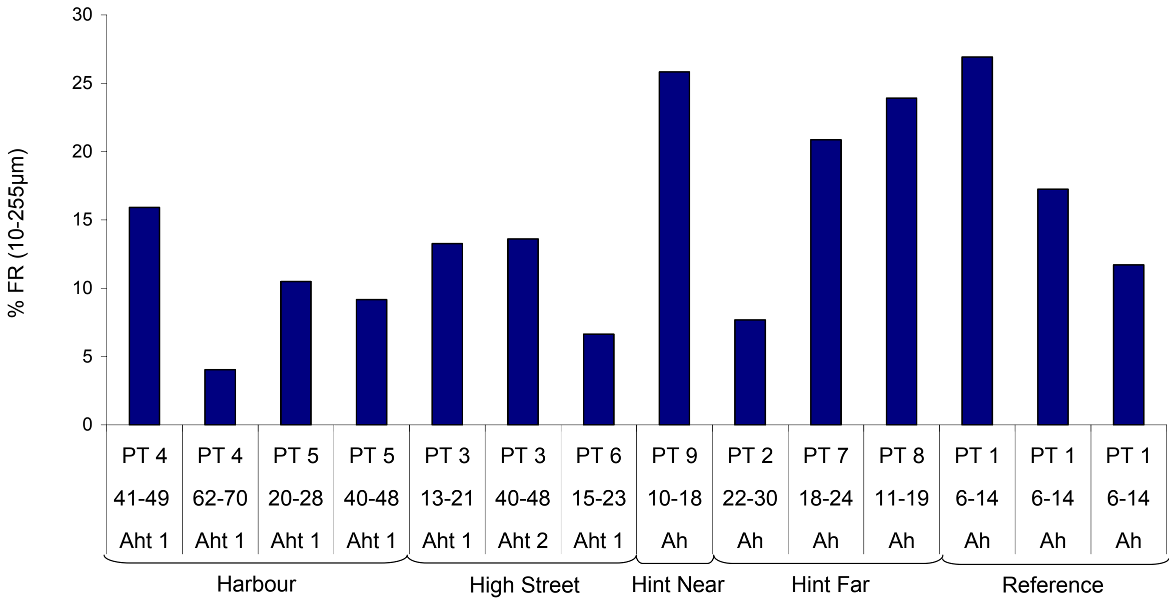


Figure 48: % FR (10-255μm) within topsoil deposits in the Harbour, High Street, Hinterland Near, and Hinterland Far zones, and 'reference' soil at Pittenweem. Number range refers to depth of Kubiena sample (cm)

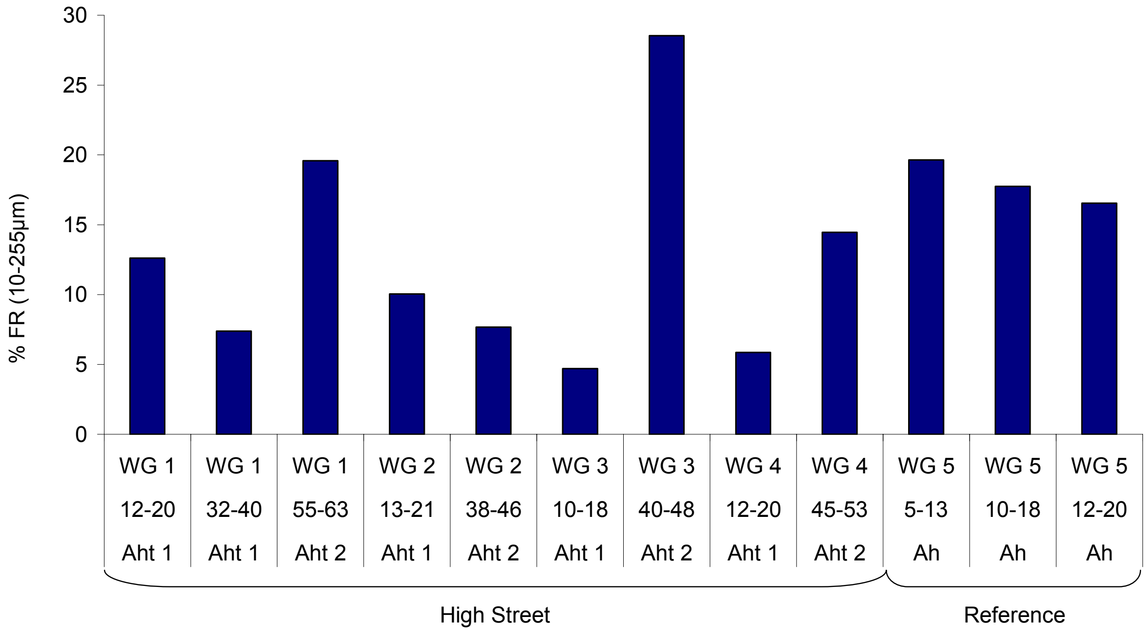


Figure 49: % FR (10-255µm) within topsoil deposits in the Harbour, High Street, Hinterland Near, and Hinterland Far zones, and 'reference' soil at Pittenweem. Number range refers to depth of Kubiena sample (cm)

5.5.9.2 Variation between Burghs

The percentage of total fuel residue sized between 10 and 255µm is variable within all three burghs ranging from 10.6 to 58.6% at Lauder, 4 to 26.5% at Pittenweem and 4.7 to 28.5% at Wigtown. The % of total fuel residue 10-255µm is significantly lower within the burgh core at Lauder; however, there is no difference in % FR 10-255µm between zones at Pittenweem and Wigtown. Additionally results of One Way ANOVA indicate that there is no statistical difference in the % of total fuel residue 10-255µm between High Street zone at Lauder, Pittenweem and Wigtown.

5.5.10 <u>Micromorphological Characteristics of Hortic Horizons</u>

5.5.10.1 Variation within Burghs

Lauder

Similarities in fuel residue classes exist within Aht 1 horizons at Lauder, for example FR 1, FR 3, FR 4 & 6 and FR 8 & 9 are present at 20-28cm and 38-46cm within soil pit LA 1 (Figure 50). Likewise, FR 1, FR 3, FR 4 & 6 and FR 8 & 9 are recognised at 10-18cm and 25-33cm within soil pit LA 6. It is noted that abundances of fuel residue classes are consistent throughout Aht 1 horizons. The total abundance of fuel residue at 20-28cm and 28-46cm within soil pit LA 1 is 15 and 15.5% respectively. Moreover, the total abundance of fuel residue within soil pit LA 6 is 14% at successive depths. Aside from trace abundances of infrequent fuel reside classes such as FR 2 and FR 10, it is argued variation in the diversity and abundance of fuel residue classes within upper topsoil hortic horizons is minimal.

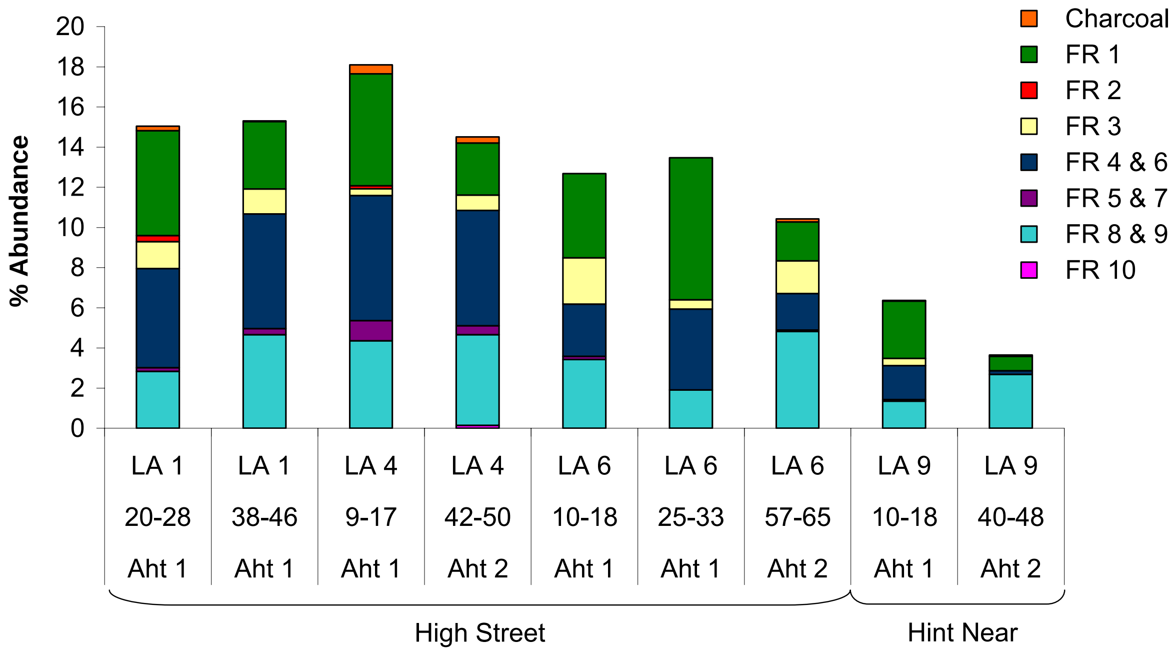


Figure 50: Percentage abundance estimates of coarse organic material (Fuel Residue categories) within upper (Aht 1) and lower (Aht 2) topsoil deposits in the High Street and Hinterland Near zones at Lauder. Number range indicates the depth (cm) of Kubiena tin samples

Similarities in fuel residue classes are noted between Aht 1 and Aht 2 horizons, for example charcoal, FR1, FR 3, FR 4 & 6, FR 5 & 7 and FR 8 & 9 are present within both the Aht 1 and Aht 2 horizon within soil pit LA 4. Likewise FR1, FR 3, FR 4 & 6 and FR 8 & 9 are present within the Aht 1 and Aht 2 horizon in soil pit LA 6. Fuel residue classes are less abundant within Aht 2 horizons than Aht 1 horizons. The total abundance of fuel residue within the Aht 1 and Aht 2 horizon in soil pit LA 6 is 13.1 and 10.4% respectively. Similarly, the total abundance of fuel residue within the Aht 1 horizon in soil pit LA 9 is 6.4% in contrast to 3.7% within the Aht 2 horizon. It is argued that variation in the diversity of fuel residue classes between upper and lower topsoil hortic horizons is minimal. Furthermore, is it suggested that fuel residue is less abundant within the lower topsoil hortic horizon.

Pittenweem

Similarities in fuel residue classes are identified within Aht 1 horizons at Pittenweem, for instance FR 1, FR 2, FR 4 & 6, FR 5 & 7 and FR 8 & 9 are present at 41-19 and 62-70cm within soil pit PT 4. Similarly charcoal, FR 1, FR 3, FR 4 & 6, FR 5 & 7 and FR 8 & 9 and FR 10 are recognised at 20-28 and 40-48cm within soil pit PT 5 (Figure 51). It is identified that abundances of fuel residue classes typically vary within Aht 1 horizons, for example at FR 5 & 7 (5-10%) is the most abundant class at 20-28cm within soil pit PT 5 yet FR 1 (10-15%) is the most abundant class at 40-48cm. Additionally it is noted that the total abundance of fuel residue within Aht 1 horizons is higher at lower depths.

The total abundance of fuel residue at 20-28cm and 40-48cm within soil pit PT 5 is 21.8 and 25.4% respectively. Similarly the total abundance of fuel residue at 41-49cm within soil pit PT 4 is 17% in contrast to 27% at 62-70cm. It is argued variation in the diversity of fuel residue classes within upper topsoil hortic horizons is minimal. Moreover, it is recognised that abundances of fuel residue classes are characteristically varied within upper topsoil hortic horizons; however, total fuel reside abundances are higher at lower depths.

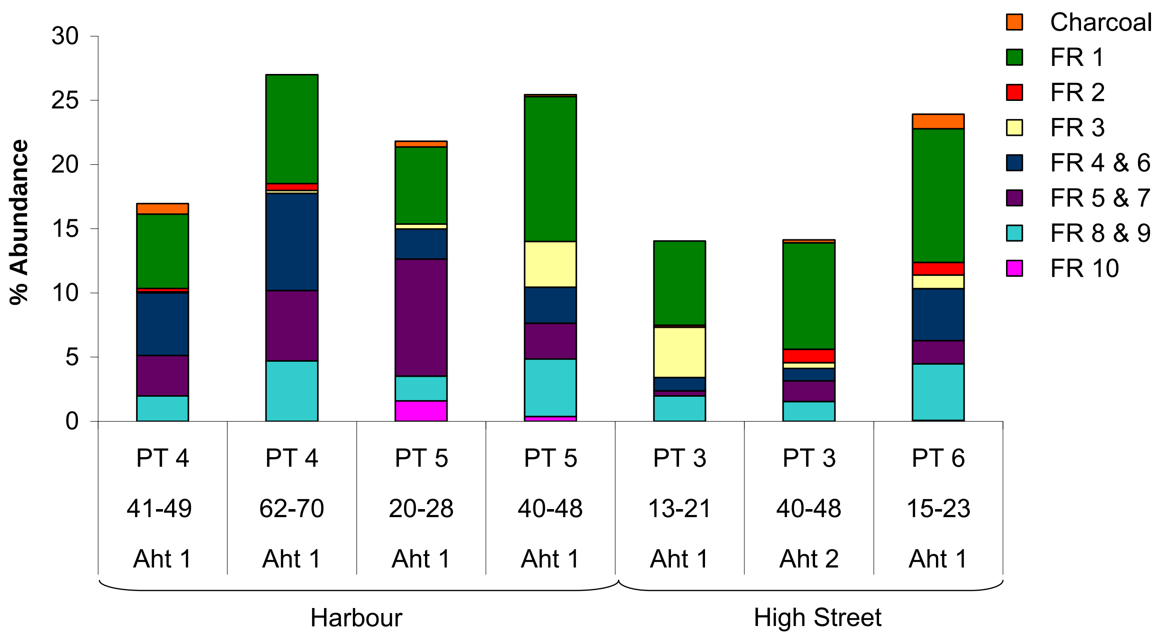


Figure 51: Percentage abundance estimates of coarse organic material (Fuel Residue categories) within upper (Aht 1) and lower (Aht 2) topsoil deposits in the Harbour and High Street zones at Pittenweem. Number range indicates the depth (cm) of Kubiena tin samples

Similarities in fuel residue classes are noted between Aht 1 and Aht 2 horizons, for example FR 1, FR 2, FR 4 & 6, FR 5 & 7 and FR 8 & 9 are present within both the Aht 1 and Aht 2 horizon in soil pit PT 3. It is identified that abundances of fuel residue classes typically vary between Aht 1 and Aht 2 horizons. However, it is recognised that the abundance of individual fuel residue classes varies between horizons, for example FR 3 ranges from 2-5% within the Aht 1 horizon at soil pit 3 to <1% within the Aht 2 horizon (Figure 51). Likewise FR 8 & 9 varies from 2-5% within the Aht 1 horizon to <2% within the Aht 2 horizon at soil pit PT 3. Despite differences in the abundance of individual fuel residue classes between the Aht 1 and Aht 2 horizons at soil pit PT 3, the total abundance of fuel residue of both horizons is consistent at 14%. It is argued that variation in the diversity of fuel reside classes between upper and lower topsoil horizons is minimal. Moreover, it is recognised that abundances of fuel residue classes are characteristically varied between upper and lower topsoil hortic horizons.

Wigtown

Similarities in fuel residue classes exist within Aht 1 horizons at Wigtown, for example FR 1, FR 2, FR 3, FR 4 & 6, FR 5 & 7 and FR 8 & 9 are present at both 12-20 and 32-40cm within soil pit WG 1. It is noted that abundances of fuel residue classes are consistent throughout Aht 1 horizons. Abundances of FR 1 (5-10%), FR 4 & 6 (10-15%) and FR 8 & 9 (2-5%) are the same at both sample depths within the Aht 1 horizon at soil pit WG 1 (Figure 52). In addition, the total abundance of fuel residue at 12-20cm and 32-40cm within soil pit WG 1 is 27 and 25.2% respectively. It is therefore concluded that variation in the diversity and abundance of fuel residue classes within upper topsoil hortic horizons is minimal.

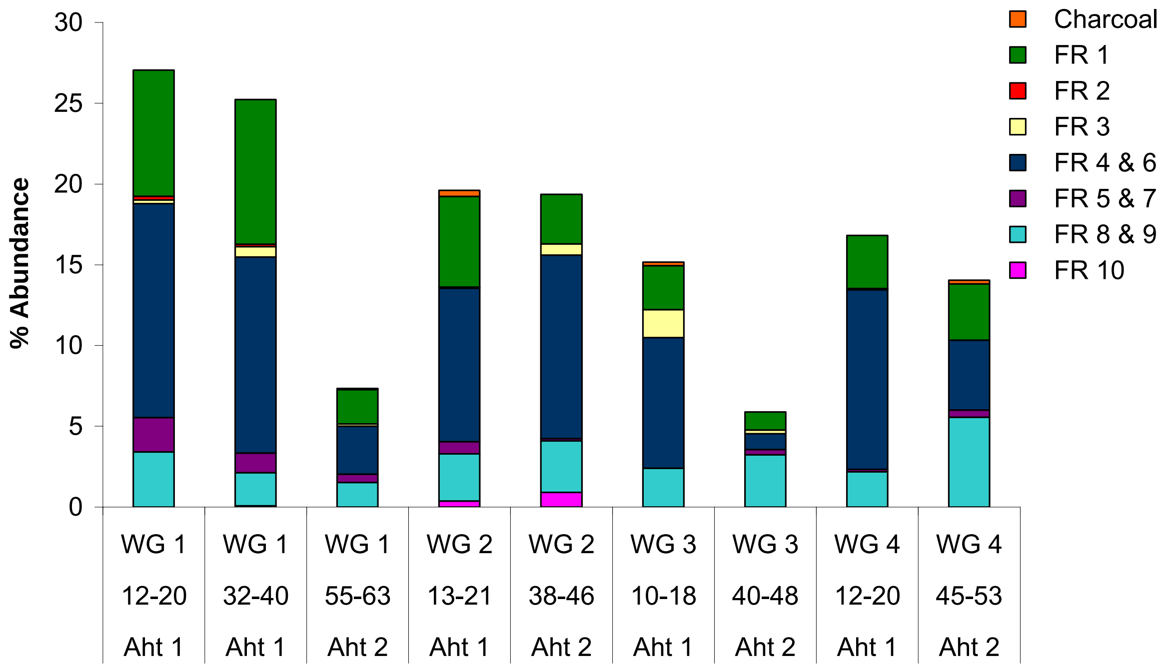


Figure 52: Percentage abundance estimates of coarse organic material (Fuel Residue categories) within upper (Aht 1) and lower (Aht 2) topsoil deposits in the High Street zone at Wigtown. Number range indicates the depth (cm) of Kubiena tin samples

Similarities in fuel residue classes are noted between Aht 1 and Aht 2 horizons, for example FR 1, FR 3, FR 4 & 6, and FR 8 & 9 are present within the Aht 1 and Aht 2 horizon at soil pit WG 3. Similarly FR 1, FR 4 & 6, FR 5 & 7 and FR 8 & 9 occur within Aht 1 and Aht 2 horizons at soil pit WG 4. Fuel residue classes are less abundant within Aht 2 horizons than Aht 1 horizons. The total abundance of fuel residue within the Aht 1 and Aht 2 horizon in soil pit WG 1 is 26.1 and 7.3% respectively. Similarly, the total abundance of fuel residue within the Aht 1 horizon in soil pit WG 3 is 15.2% in contrast to 5.9% within the Aht 2 horizon. However this trend is not observed at soil pit WG 2, for instance the total % abundance of fuel residue within the Aht 1 and Aht 2 horizon is 19.6% and 19.4%. Nevertheless variation in the diversity of fuel residue classes between upper and lower topsoil hortic horizons is minimal. Furthermore, is it suggested that fuel residue is less abundant within the lower topsoil hortic horizon with the exception of soil pit WG 2.

5.5.10.2 Variation between Burghs

There is minimal variation in the nature of coarse organic anthropogenic material classes throughout Aht 1 horizons at Lauder, Pittenweem and Wigtown. Abundances of coarse organic anthropogenic materials at Lauder and Wigtown are consistent throughout Aht 1 horizons. Conversely, the abundance of coarse organic anthropogenic materials within Aht 1 horizons at Pittenweem is characteristically varied. In addition total fuel residue abundances are higher at lower depths within Aht 1 horizons at Pittenweem. Similar classes of coarse organic anthropogenic material are identified in Aht 1 and Aht 2 horizons at Lauder, Pittenweem and Wigtown. Abundances of coarse organic anthropogenic material are characteristically less abundant within Aht 2 horizons at Lauder and Wigtown. In comparison, the abundance of coarse organic anthropogenic materials between Aht 1 and Aht 2 horizons at Pittenweem is typically varied. Moreover, there is no difference in the total abundance of fuel residue between the Aht 1 and Aht 2 horizons at Pittenweem.

5.6 Summary of Results: Coarse Organic Material

The following section presents a brief summary of key trends in the nature and abundance of coarse organic material both within and between burghs. The significance of these results is discussed in sections 8.1.4 and 8.2.4; in particular' consideration is given to differences in the nature and distribution of fuel residue both within and between burghs.

5.6.1 Variation within Burghs

5.6.1.1 Lauder

Coarse organic material is present within topsoils in the High Street, Hinterland Near, Hinterland Far and Thirlstane zones at Lauder in addition to 'reference' soil pit LA 7 (Table 29). FR 2 and FR 10 inclusions are limited to the burgh core. In addition charcoal is restricted to the burgh core and immediate hinterland south of Lauder (Hinterland Near). FR 1, FR 3, FR 4 & 6, FR 5 & 7 and FR 8 & 9 are present within all zones at Lauder; however, FR 4 & 6 is most abundant within the burgh core and FR 1, FR 3 and FR 8 & 9 are highest within the burgh core and immediate hinterland south of the historical burgh limits (Hinterland Near). In contrast there is no difference in the abundance of FR 5 & 7 between zones at Lauder.

Accordingly two areas of interest are identified at Lauder, the High Street zone and the Hinterland Near zone. The High Street zone is characterised by charcoal, FR 2 and FR 10 inclusions and significantly higher abundances of FR 4 & 6, FR 1, FR 3 and FR 8 & 9. The Hinterland Near zone is characterised by charcoal inclusions and significantly higher abundances of FR 1, FR 3 and FR 8 & 9.

5.6.1.2 Pittenweem

The Harbour, High Street, Hinterland Near and Hinterland Far zones at Pittenweem in addition to 'reference' soil pit PT 1 contain coarse organic material (Table 29). Charcoal, FR 1, FR 2, FR 3, FR 4 & 6, FR 5 & 7 and FR 8 & 9 are present within all zones at Pittenweem. There is no difference in the abundance of charcoal and FR 2 inclusions between zones. FR 3 is most abundant within the High Street zone and FR 4 & 6 inclusions are greatest within the Harbour zone. FR 5 & 7 and FR 8 & 9 are most abundant within the burgh core. More specifically FR 5 & 7 and FR 8 & 9 are greatest within the Harbour zone followed in succession by the High Street zone. In addition, FR 1 inclusions are significantly less abundant within the Hinterland Near zone. In contrast FR 10 is absent from the Hinterland Near zone.

Accordingly two areas of interest are identified at Pittenweem; the Harbour zone and the High Street zone. The Harbour zone is characterised by significantly higher abundances of FR 4 & 6, FR 5 & 7 and FR 8 & 9 in comparison to the High Street, Hinterland Near and Hinterland Far zones. The High Street zone is characterised by significantly higher abundances of FR 3 in comparison to the Harbour, Hinterland Near and Hinterland Far zones, and significantly more FR 5 & 7 and FR 8 & 9 inclusions than the Hinterland Near and Hinterland Far zones.

5.6.1.3 Wigtown

Coarse organic material is present within both the High Street zone and 'reference' soil pit WG 5 at Wigtown (Table 7). As previously stated in section 5.1.1, it is argued that the 'reference' soil provides a good indication of soil characteristics within the Hinterland Near zone. Charcoal, FR 2, FR 3 and FR 10 inclusions are limited to the burgh core at Wigtown. FR 1, FR 4 & 6, FR 5 & 7 and FR 8 & 9 are present with both the burgh core and hinterland north of the historical burgh limits; however FR 1, FR 4 & 6 and FR 8 & 9 are significantly more abundant within the burgh core. In contrast there is no difference in the abundance of FR 5 & 7 between the burgh core and hinterland.

The High Street zone is recognised as an important area of interest at Wigtown. The High Street zone is characterised by charcoal, FR 2, FR 3 and FR 10 inclusions and significantly greater abundances of FR 1, FR 4 & 6 and FR 8 & 9.

5.6.1.4 Hortic Horizons

Results presented in section 5.3.1.4 indicate that coarse organic material classes are consistent throughout Aht 1 horizons at Lauder, Pittenweem and Wigtown. Abundances of coarse organic material are relatively constant throughout Aht 1 horizons at Lauder and Wigtown; however, abundances of individual classes are more varied at Pittenweem. Similar classes of coarse organic material are also identified within Aht 1 and Aht 2 horizons at Lauder, Pittenweem and Wigtown. It should be noted that coarse organic material is lower in abundance within Aht 2 horizons at Lauder and Wigtown. In contrast, there is minimal difference in total abundances of coarse organic material between Aht 1 and Aht 2 horizons at Pittenweem.

Table 7: Summary of trends in coarse organic inclusions identified at Lauder, Pittenweem and Wigtown, summary abundances are given in brackets

Inclusion	Lauder	Pittenweem	Wigtown
Charcoal	Charcoal is present within the burgh core and immediate hinterland (Hinterland Near (<2%).	Charcoal is present within the burgh core and hinterland (Hinterland Near, Hinterland Far) (<2%).	Charcoal is present within the burgh core (<2%).
FR 1	FR 1 is present within the burgh core (<2% to 5-10%) and hinterland (<2% to 2-5%). FR 1 is most abundant within the burgh core and immediate hinterland (Hinterland Near).	FR 1 is present within the burgh core (5-15%) and hinterland (2-10%). FR 1 is most abundant within the burgh core (Harbour, High Street) and far hinterland (Hinterland Far).	FR 1 is present within the burgh core (<2% to 5-10%) and hinterland (Hinterland Near/'reference' soil) (<2% to 2-5%). FR 1 is most abundant in burgh core.
FR 2	FR 2 is present within the burgh core (<2%).	FR 2 is present within the burgh core and hinterland (Hinterland Near, Hinterland Far) (<2%).	FR 2 is present within the burgh core (<2%).
FR 3	FR 3 is present within the burgh core (<2% to 2-5%) and hinterland (<2%). FR 3 is most abundant within the burgh core and immediate hinterland (Hinterland Near).	FR 3 present within the burgh core (<2% to 2-5%) and hinterland (<2%). FR 3 is most abundant in burgh core (High Street).	FR 3 is present within the burgh core (<2%).
FR 4 & 6	FR 4 & 6 is present within the burgh core (<2 to 5-10%) and hinterland (<2% to 2-5%). FR 4 & 6 is most abundant within the burgh core.	FR 4 & 6 is present within the burgh core (2-5%, to 2-10%) and hinterland (<2% to 2-5%). FR 4 & 6 is most abundant within the burgh core (Harbour).	FR 4 & 6 is present within the burgh core (5-10% to 10-15%) and hinterland (Hinterland Near/'reference' soil) (<2% to 2-5%). FR 4 & 6 is most abundant within the burgh core.
FR 5 & 7	FR 5 & 7 is present within the burgh core and hinterland (<2%).	FR 5 & 7 is present within the burgh core (Harbour 5-10% to 10-15%, High Street <2%) and hinterland (<2%). FR 5 & 7 is most abundant in burgh core (Harbour followed by High Street).	FR 5 & 7 is present within the burgh core and hinterland (Hinterland Near/'reference' soil) (<2%).
FR 8 & 9	FR 8 & 9 is present within the burgh core (<2% to 2-5%) and	FR 8 & 9 is present within the burgh core and hinterland (<2% to	FR 8 & 9 is present within the burgh core (<2% to 5-10%) and

	hinterland (<2% to 2-5%). FR 8 & 9 is most abundant within the burgh core.	2-5%). FR 8 & 9 most abundant in burgh core (Harbour followed by High Street)	hinterland (Hinterland Near/'reference' soil) (<2%). FR 8 & 9 is most abundant within the burgh core
FR 10	FR is 10 present within the burgh core (<2%)	FR 10 is present within the burgh and far hinterland (Hinterland Far) (<2%).	FR 10 is present within the burgh core (<2%).

5.6.2 Variation between Burghs

All three burghs have charcoal, FR 1, FR 2, FR 3, FR 4 & 6, FR 5 & 7, FR 8 & 9 and FR 10 in zones corresponding to the burgh core (Harbour and High Street). Coarse organic inclusions are also identified in the hinterland at Lauder, Pittenweem and Wigtown, for example abundances of FR 1, FR 3 and FR 8 & 9 inclusions are comparable between the burgh core and the immediate hinterland south of the historical burgh limits at Lauder (Hinterland Near). Likewise, there is no difference in the abundance of FR 1 inclusions between the burgh core and Hinterland Far zone at Pittenweem. Abundances of coarse organic material are most abundant within burgh cores, although in the case of Pittenweem differences in the nature of fuel residue classes between the Harbour and High Street are noted.

It is proposed that differences in the abundance of selected coarse organic materials can be used to discriminate between High Street zones at Lauder, Pittenweem and Wigtown. FR 1, FR 3 and FR 5 & 7 inclusions are most abundant within the High Street zone at Pittenweem (Table 8). These inclusions share similar morphologies characterised by sharp, well defined angular/sub-angular perimeters (see Figure 27). FR 4 & 6 inclusions are most abundant within the High Street zone at Wigtown. These inclusions are typically sub-rounded with internally degraded holes. FR 8 & 9 inclusions are greatest within the High Street zone at Lauder. These inclusions range from sub-angular to sub-rounded but are distinct in that they have a 'ragged' perimeter edge. There is no difference in the abundance of charcoal, FR 2 and FR 10 inclusions between High Street zones.

Table 8: Summary of trends in the abundance of coarse organic anthropogenic material between High Street zones at Lauder, Pittenweem and Wigtown as indicated by Kruskal-Wallis analysis with Dunn's test

Inclusion	Comparison between High Street zones
Charcoal	There is no difference in charcoal between High Street zones
FR 1	FR 1 is most abundant within Pittenweem ($p<0.001$)
FR 2	There is no difference in FR 2 between High Street zones
FR 3	FR 3 is most abundant within Pittenweem, followed in succession by Lauder
FR 4 & 6	FR 4 & 6 is most abundant within Wigtown
FR 5 & 7	FR 5 & 7 is most abundant within Pittenweem
FR 8 & 9	FR 8 & 9 is most abundant within Lauder, followed in succession by Wigtown
FR 10	There is no difference in FR 10 between High Street zones

5.7 Fine Organic Material

The abundance of fine organic material within topsoil deposits at Lauder, Pittenweem and Wigtown is summarised in tables presented in Appendix 2. Differences in the nature and abundance of organic material are identified and comparisons between zones and burghs are made.

5.7.1 <u>Variation within Burghs</u>

Fine organic material at Lauder consists of cell residues and amorphous red organic material. Trace abundances (<2%) of cell residues are present within the High Street, Hinterland Near, Hinterland Far and Thirlstane zones and ‘reference’ soil pit LA 7. Hence, there is no difference in the abundance of cell residue between zones. Amorphous red organic material is <2% within the Hinterland Near and is absent from the High Street, Hinterland Far and Thirlstane zones and the ‘reference’ soil pit. Amorphous red organic material is therefore limited to the burgh core.

Fine organic material at Pittenweem comprises cell residues, amorphous red organic material and amorphous yellow organic material. Trace abundances (<2%) of cell residues are identified within the Harbour, High Street, Hinterland Near and Hinterland Far zones and ‘reference’ soil pit PT 1. Hence, there is no difference in the abundance of cell residue between zones. Amorphous red organic material is <2% within Harbour, High Street and Hinterland Far zones and ‘reference’ soil pit. In contrast amorphous red amorphous organic material is absent from the Hinterland Near zone. There is no difference in the abundance of amorphous red amorphous organic material between the burgh core and far hinterland (Hinterland Far). Amorphous yellow organic material is <2% within Harbour and High Street zones, yet is absent from the Hinterland Near and Hinterland Far zones and the ‘reference’ soil pit. Amorphous yellow organic material is therefore limited to the burgh core.

Fine organic material at Wigtown includes cell residues, amorphous red organic material and amorphous yellow organic material. Trace abundances (<2%) of cell residues occur within the High Street zone and ‘reference’ soil WG 5. There is no difference in the abundance of cell residue between zones. Trace abundances (<2%) of amorphous red and yellow organic material are confined to selected soil pits within the High Street zone. Amorphous red and yellow organic material is therefore limited to the burgh core at Wigtown.

5.7.2 Variation between Burghs

There is no difference in the abundance of cell residues between zones at all three burghs. It is suggested that spatial distributions of red and yellow amorphous organic material are more site specific. Amorphous red organic material is present within the burgh core at Lauder, Pittenweem and Wigtown and within the immediate hinterland south of Lauder (Hinterland Near) and within the hinterland at Pittenweem (Hinterland Near/Hinterland Far). In contrast amorphous yellow organic material is restricted to individual soil pits within the burgh core at Pittenweem and Wigtown.

5.8 Pedofeatures

The abundance of pedofeatures within topsoil deposits at Lauder, Pittenweem and Wigtown is summarised in tables presented in Appendix 2. Differences in the nature and abundance of pedofeatures are identified and comparisons between zones and burghs are made.

5.8.1 Variation within Burghs

Trace abundances (<2%) of spheroidal excremental pedofeatures and iron impregnated siltstone nodules are present within the High Street, Hinterland Near, Hinterland Far and Thirlstane zones and 'reference' soil pit LA 7 at Lauder. Hence there is no difference in the abundance of spheroidal excremental pedofeatures and iron impregnated siltstone nodules between zones at Lauder. Mammilate excremental pedofeatures are identified in trace abundances within the High Street and Hinterland Near zones (<2%) and are absent from the Hinterland Far and Thirlstane zones and 'reference' soil pit. Mammilate excremental pedofeatures are therefore limited to the burgh core and immediate hinterland south (Hinterland Near) of Lauder. In addition it is recognised that trace abundances (<2%) of iron impregnated amorphous organic material are restricted to the burgh core (High Street).

Trace abundances (<2%) of spheroidal excremental pedofeatures, iron nodules and iron impregnated siltstone nodules are present within the Harbour, High Street, Hinterland Near and Hinterland Far zones, and 'reference' soil pit PT 1 at Pittenweem. Therefore there is no difference in the abundance of spheroidal excremental pedofeatures, iron nodules and iron impregnated siltstone nodules between zones at Pittenweem. Mammilate excremental pedofeatures are identified in trace abundances within the High Street and Hinterland Near zones (<2%) and are absent from the Harbour and Hinterland Far zones at 'reference' soil. Mammilate excremental pedofeatures are therefore limited to the burgh core (High Street) and immediate hinterland north of Pittenweem (Hinterland Near). Iron impregnated amorphous organic material and organic heated coatings are present in trace abundance (<2%) within the High Street and Hinterland Far zones yet are absent from the Harbour and Hinterland Near zones and 'reference' soil pit. These materials are therefore limited to the burgh core (High Street) and far hinterland north of Pittenweem (Hinterland Far). In addition it is recognised that monomorphic organic coatings are present in trace abundances (<2%) within the Harbour and High Street zones and are absent from the Hinterland Near and Hinterland Far zones and 'reference' soil pit.

Trace abundances (<2%) of spheroidal and mammillate excremental pedofeatures and iron nodules are present within the High Street zone and 'reference' soil pit WG 5 at Wigtown. Therefore there is no difference in the abundance of spheroidal and mammillate excremental pedofeatures and iron nodules between the burgh core and hinterland north of Wigtown. In contrast it is identified that iron impregnated amorphous organic material (<2%) is limited to the 'reference' soil and heated organic coatings (<2%) are limited to the High Street zone.

5.8.2 Variation between Burghs

Spheroidal and mammilate excremental pedofeatures, iron impregnated amorphous organic material and organic coatings are identified within topsoils at all three burghs. There is no difference in the abundance of spheroidal excremental pedofeatures between zones at Lauder, Pittenweem and Wigtown. It is suggested that spatial distributions of mammilate excremental pedofeatures, iron nodules, iron impregnated siltstone nodules, iron impregnated amorphous organic material, monomorphic organic coatings and heated organic coatings are more site specific.

5.9 Structure

5.9.1 Variation within Burghs

The microstructure of topsoils within the High Street zone is channel and chamber with vughy elements. Similarly, topsoils within the Hinterland Near, Hinterland Far and Thirlstane zones and 'reference' soil pit LA 7 are characterised by channel and chamber microstructures. The coarse material arrangement of topsoils within all zones is random and the groundmass (b fabric) is stipple-speckled. The C:F related distribution of topsoil deposits at Lauder is close porphyric. The mean C:F ratio of the High Street, Hinterland Near, Hinterland Far and Thirlstane zones and 'reference' soil is 58:42, 53:47, 56:44, 55:45 and 59:41 respectively. Results of One Way Analysis of Variance (ANOVA) reveal that there is no statistical difference in the C:F ratio between zones. The mean % void space of High Street, Hinterland Near, Hinterland Far and Thirlstane zones and 'reference' soil pit is 29, 21, 22, 28 and 27%. There is no statistical difference in void space between the Harbour, High Street and Hinterland Near zones.

The microstructure of topsoils within the Harbour, High Street and Hinterland Far zones and 'reference' soil PT 1 is channel and chamber with vughy elements. In contrast topsoil within the Hinterland Near zone is predominantly vughy. The coarse material arrangement of topsoils within all zones is random and the groundmass (b fabric) is stipple-speckled. The C:F related distribution of topsoil deposits at Pittenweem is close porphyric. The mean C:F ratio of Harbour, High Street, Hinterland Near and Hinterland Far zones and 'reference' soil pit is 55:45, 57:43, 63:36, 54:46 and 55:45. Results of One Way Analysis of Variance (ANOVA) reveal that there is no statistical difference in the C:F ratio between zones. The mean % void space of Harbour, High Street, Hinterland Near and Hinterland Far zones and 'reference' soil pit is 32, 32, 62, 22 and 16 %. Mean % void space is significantly higher within the Harbour and High street zones than the 'reference' soil pit ($p<0.01$). In addition, mean % void space within the Hinterland Near zone is greater than the Hinterland Far zone and 'reference' soil pit ($p<0.01$). There is no statistical difference in void space between the Harbour, High Street and Hinterland Near zones.

The microstructure of topsoils within High Street zone is channel and chamber with vughy elements. In contrast the microstructure if topsoil within the ‘reference’ soil WG 5 (Hinterland Near) is channel and chamber. The coarse material arrangement of topsoils within all zones is random and the groundmass (b fabric) is stipple-speckled. The C:F related distribution of topsoil deposits at Wigtown is close porphyric. The mean C:F ratio of both the High Street zone and ‘reference’ soil pit is 58%, hence there is no significant difference. Similarly there is no significant difference in mean % void space between the High Street zone and ‘reference’ soil which is 32% for both zones.

5.9.2 Variation between Burghs

The microstructure of topsoils within the burgh core at all three burghs is characteristically channel and chamber with vughy elements. In contrast the microstructure within the hinterland at Lauder, Pittenweem and Wigtown is channel and chamber, with the exception of soil pit PT 9 at Pittenweem (Hinterland Near) which is vughy. There is no difference in the coarse material arrangement, groundmass (b fabric), C:F related distribution and C:F ratio of topsoils either within or between burghs. In addition there is no difference in void space within topsoils at Lauder and Wigtown; however, it is recognised that void space is significantly higher within topsoils in the burgh core and immediate hinterland north of Pittenweem (Hinterland Near).

5.10 Summary: Soil Micromorphology

A succinct overview of key findings resulting from micromorphological analyses presented in this chapter is provided in Table 9. The significance of these results is discussed throughout chapter 8 in association with soil physical and chemical properties and elemental concentrations.

Table 9: Summary of trends in key micromorphological analyses of topsoils within Lauder, Pittenweem and Wigtown

Analysis	Summary of Key Trends
Profile Characteristics	All three burgh cores and immediate hinterland at Lauder characterised by hortic topsoil horizons
Coarse Anthropogenic Mineral Material	Coarse mineral material is most abundant and diverse in burgh cores Coarse mineral material is present in selected hinterland zones at Lauder and Pittenweem Shell inclusions are limited to Pittenweem and Wigtown Coarse mineral material is absent from Aht 2 horizons at Lauder
Fine Mineral Material	All three burgh cores are characterised by brown/dark brown, dotted fine mineral material Similarities in fine mineral material between burgh cores and selected hinterland zones exist at all three burghs
Coarse Anthropogenic Organic Material	Coarse organic material is most abundant and diverse in burgh cores Coarse organic material is present within the hinterland at all three burghs There are differences in principal fuel residue types between burghs Coarse organic material is lower in abundance within Aht 2 horizons at Lauder and Wigtown
Fine Organic Material	All three burghs contain amorphous red and yellow organic material. Distributions of organic material are site specific
Pedofeatures	The nature and distribution of pedofeatures is site specific
Structure	All three burgh cores are characterised by channel and chamber microstructures with vughy elements There is no difference in coarse material arrangement, groundmass, C:F distribution or C:F ratio between burghs

6 Soil Physical and Chemical Properties

This chapter presents results obtained from selected soil physical and chemical analyses including topsoil depth, pH, % loss on ignition, magnetic susceptibility and frequency dependant magnetic susceptibility. Data are presented collectively for Lauder, Pittenweem and Wigtown to facilitate visual and statistical comparisons.

6.1 Topsoil Depth

Spatial distributions of topsoil depth are presented for Lauder (Figure 53), Pittenweem (Figure 54a) and Wigtown (Figure 54b). Pronounced spatial variability in topsoil depth is observed for all three burghs; however specific patterns relating to distinct zones are identified both within and between towns.

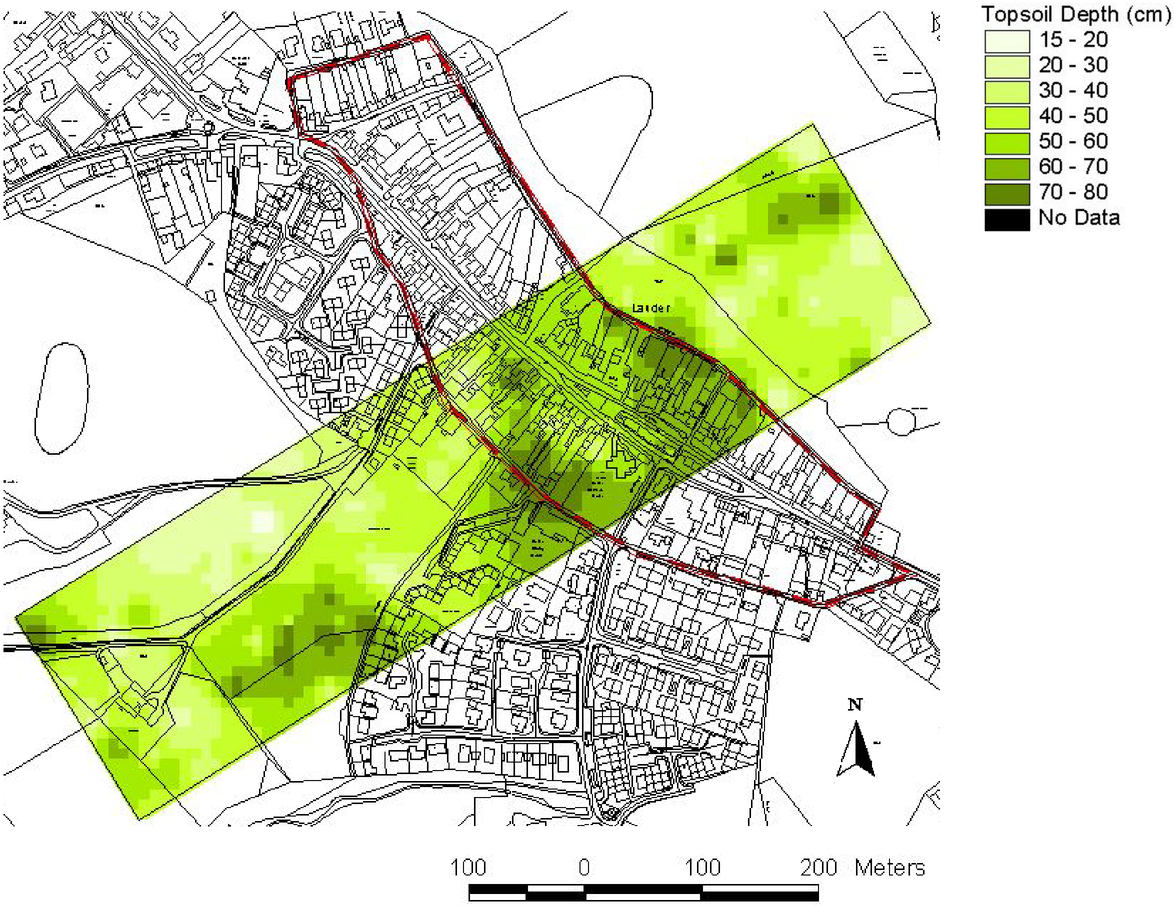


Figure 53: Distribution of topsoil depth at Lauder. Red boundary delimits 1862AD urban extent

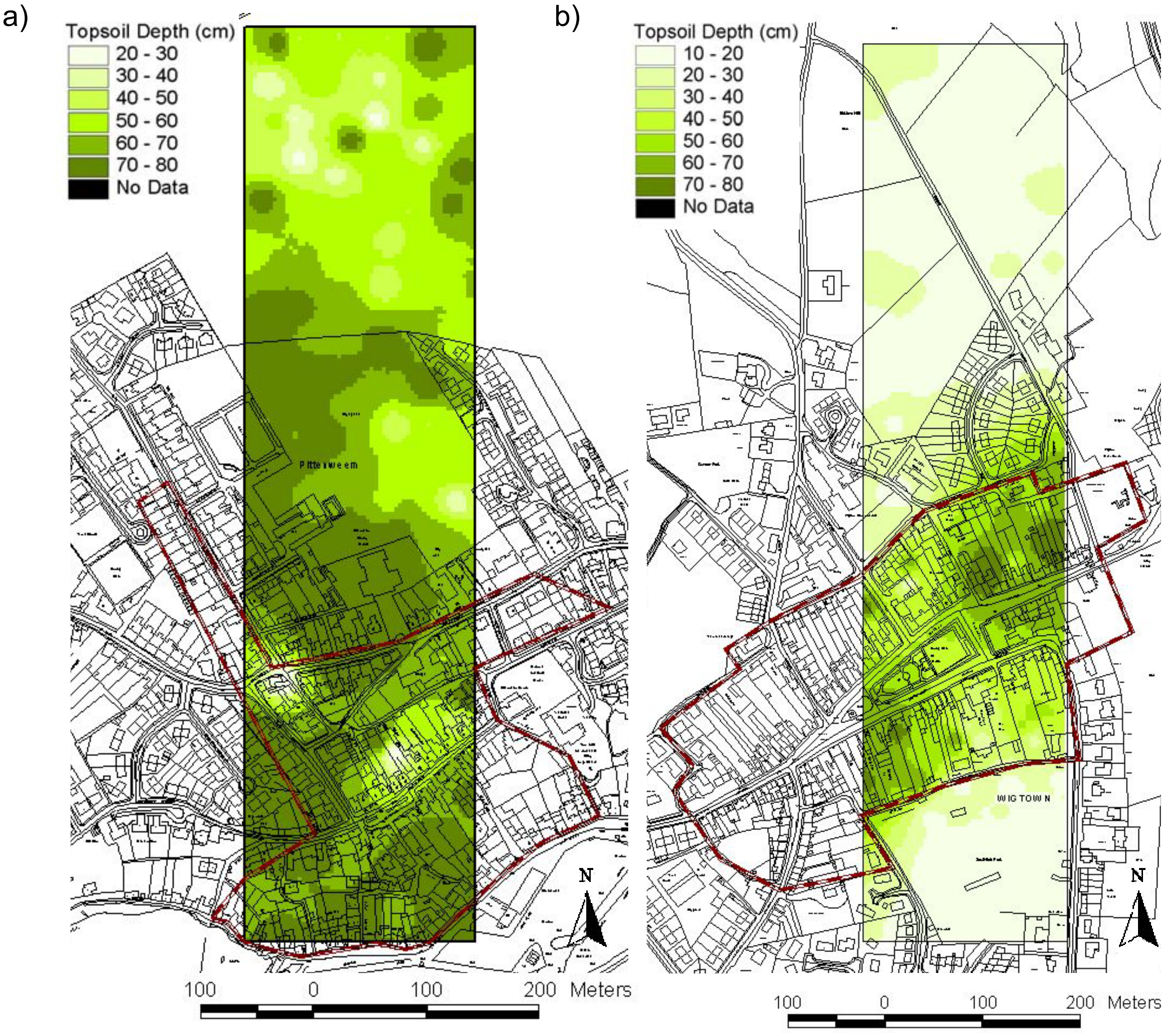


Figure 54: Spatial distribution of topsoil depth at Pittenweem (a) and Wigtown (b). Red boundary delimits 1855AD and 1850AD urban extent respectively

6.1.1 Variation within Burghs

There is clear evidence for topsoil deepening within the High Street and Hinterland Near zones at Lauder. The median topsoil depth of the High Street zone is 75cm and 53cm for the Hinterland Near zone. Statistically there is no significant difference between these two zones, however both the High Street and Hinterland Near zones are significantly deeper than the Hinterland Far and Thirlstane zones ($p<0.05$). The Hinterland Far and Thirlstane zones have median topsoil depths of 38cm and 36cm respectively (Figure 55). Deepened topsoil deposits are, therefore, identified in both the burgh core and land immediately adjacent to the historical burgh limits (Hinterland Near).

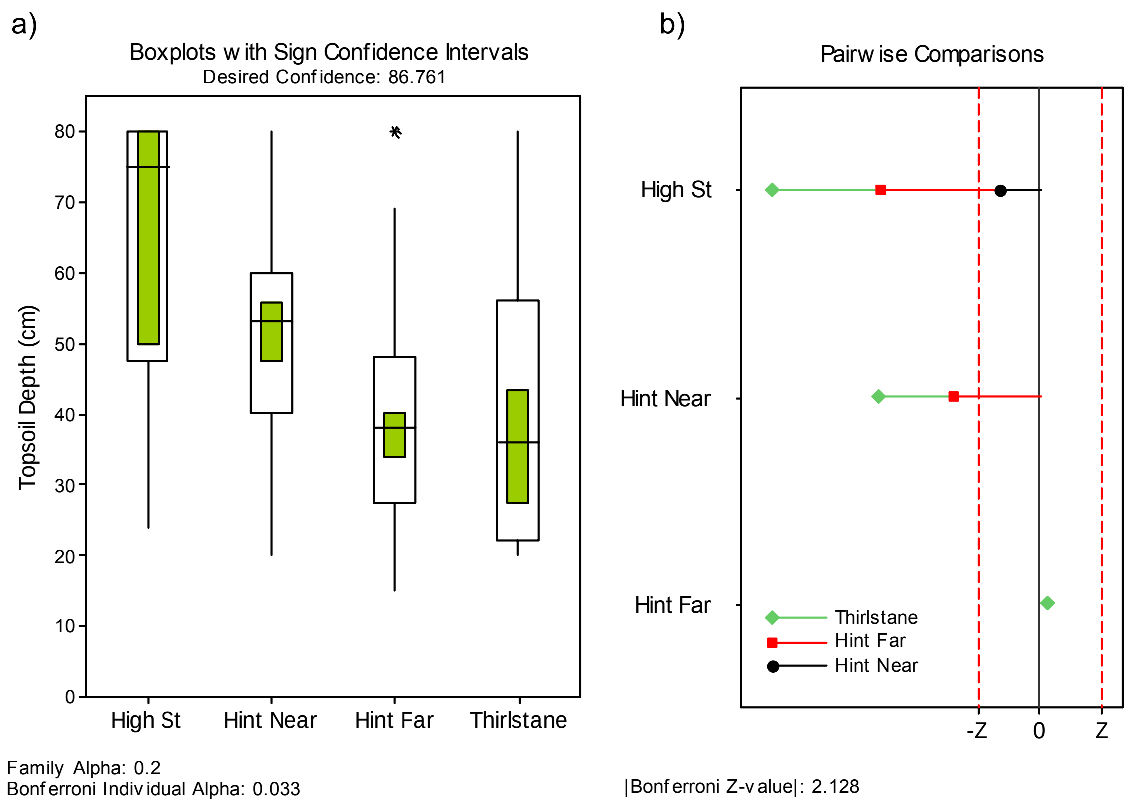


Figure 55: (a) Boxplot of median topsoil depth for individual zones at Lauder; boundaries of boxes represent interquartile range, green shading indicates 86.761% confidence interval for median, outliers identified as *, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Lauder, Z values exceeding –Z or Z are significant at p<0.05 confidence level

The median topsoil depth of the Harbour, High Street and Hinterland Near zones at Pittenweem is ≥80cm, ≥80cm and 72.5cm respectively. There is no significant difference in topsoil depth between these zones, however the Harbour, High Street and Hinterland Near zones are all significantly deeper than the Hinterland Far zone (p<0.05) (Figure 56b). Accordingly deepened topsoil deposits are identified within both the burgh core and land immediately adjacent to the historical burgh limits (Hinterland Near).

The median topsoil depth of the High Street, Hinterland Near and Showfield zones at Wigtown is 55cm, 18cm and 17cm respectively. The High Street zone is significantly deeper than the Hinterland Near and Showfield zones (p<0.05). In addition it is evident that the Hinterland Near and Showfield zones are spatially homogenous with minimal variation in topsoil depth values (Figure 57a). A clear contrast in topsoil depth between the burgh core and the hinterland is therefore noted.

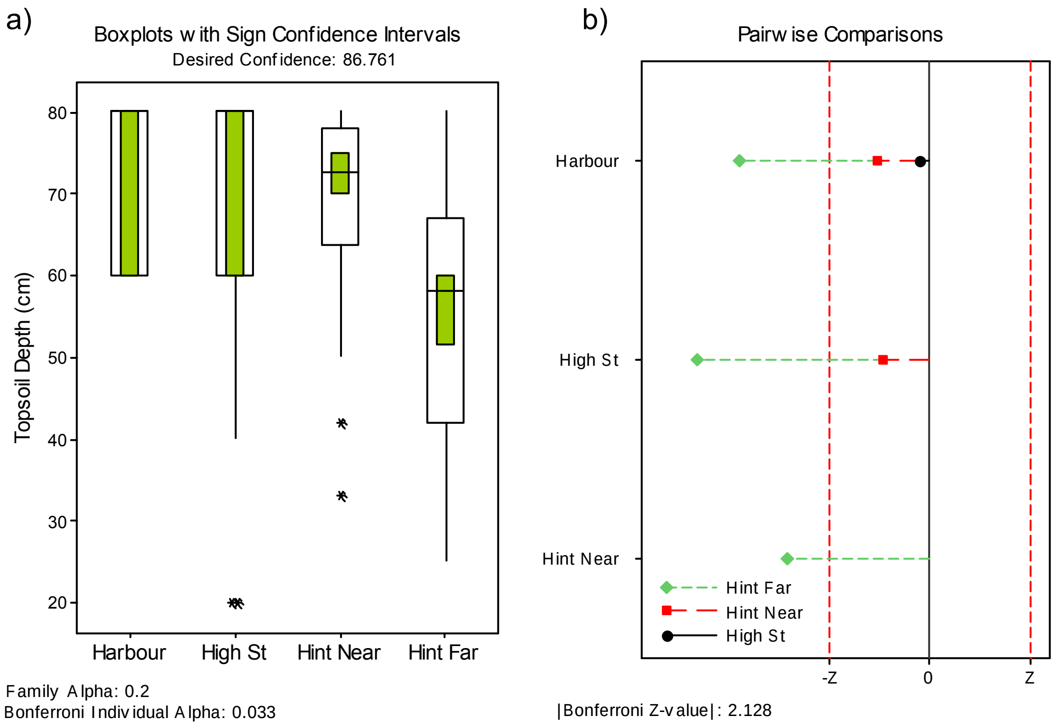


Figure 56: (a) Boxplot of median topsoil depth for individual zones at Pittenweem; boundaries of boxes represent interquartile range, green shading indicates 86.761% confidence interval for median, outliers identified as *, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Pittenweem, Z values exceeding –Z or Z are significant at p<0.05 confidence level

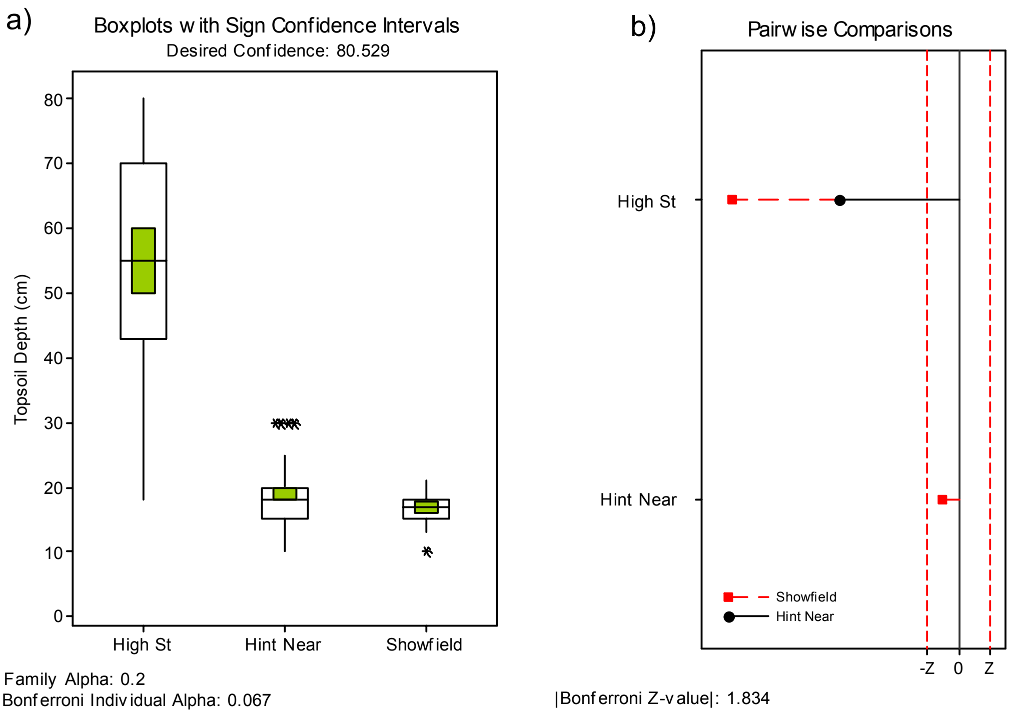


Figure 57: (a) Boxplot of median topsoil depth for individual zones at Wigtown; boundaries of boxes represent interquartile range, green shading indicates 80.529% confidence interval for median, outliers identified as *, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Pittenweem, Z values exceeding –Z or Z are significant at p<0.05 confidence level

6.1.2 Variation between Burghs

The results of a Two Way Analysis of Variance (ANOVA) undertaken using a General Linear Model (GLM) indicate that mean topsoil depth is significantly different between burghs ($p<0.001$). Tukey-Kramer (95% confidence intervals) multiple comparisons reveal that the mean topsoil depth at Pittenweem is significantly greater than Lauder ($p<0.005$) and Wigtown ($p<0.001$), and the mean topsoil depth at Lauder is significantly greater than Wigtown ($p<0.001$). It is therefore argued that mean topsoil depth varies between different burghs with Pittenweem having the deepest mean topsoil depth and Wigtown the shallowest.

Results presented in section 6.1.1 show differences in topsoil depth between certain zones within each burgh. These findings are supplemented by ANOVA which confirms a significant difference in mean topsoil depth between the High Street and Hinterland Near zones ($p<0.001$). Tukey-Kramer multiple comparisons indicate a greater mean topsoil depth for the High Street zone compared to the Hinterland Near zone ($p<0.001$). Conversely results from Kruskal Wallis pairwise comparisons suggest that there is no significant difference between the High Street and Hinterland Near zones at Lauder and Pittenweem. This discrepancy may reflect differences in measurement of central tendency between parametric and non-parametric tests. Nevertheless, all three towns have significantly deepened deposits corresponding to the burgh core and in the case of Lauder and Pittenweem, significantly deepened deposits in the Hinterland Near zone.

Statistical analysis also indicates significant interaction between individual ANOVA test factors, burgh and zone ($p<0.001$). This association implies that topsoil depth variation cannot be fully explained by either burgh or zone as factors in isolation. Moreover it can be argued the influence of one factor is dependant on the nature of the other factor. Accordingly it is suggested that although topsoil depth is consistently enhanced within the burgh core, the nature and extent of topsoil deepening in this area differs between burghs.

6.2 Soil pH

Spatial distributions of soil pH are presented for Lauder (Figure 58), Pittenweem (Figure 59) and Wigtown (Figure 60) at selected depths. Patterns in soil pH associated with discrete zones and depths are subsequently identified and comparisons between towns are made.

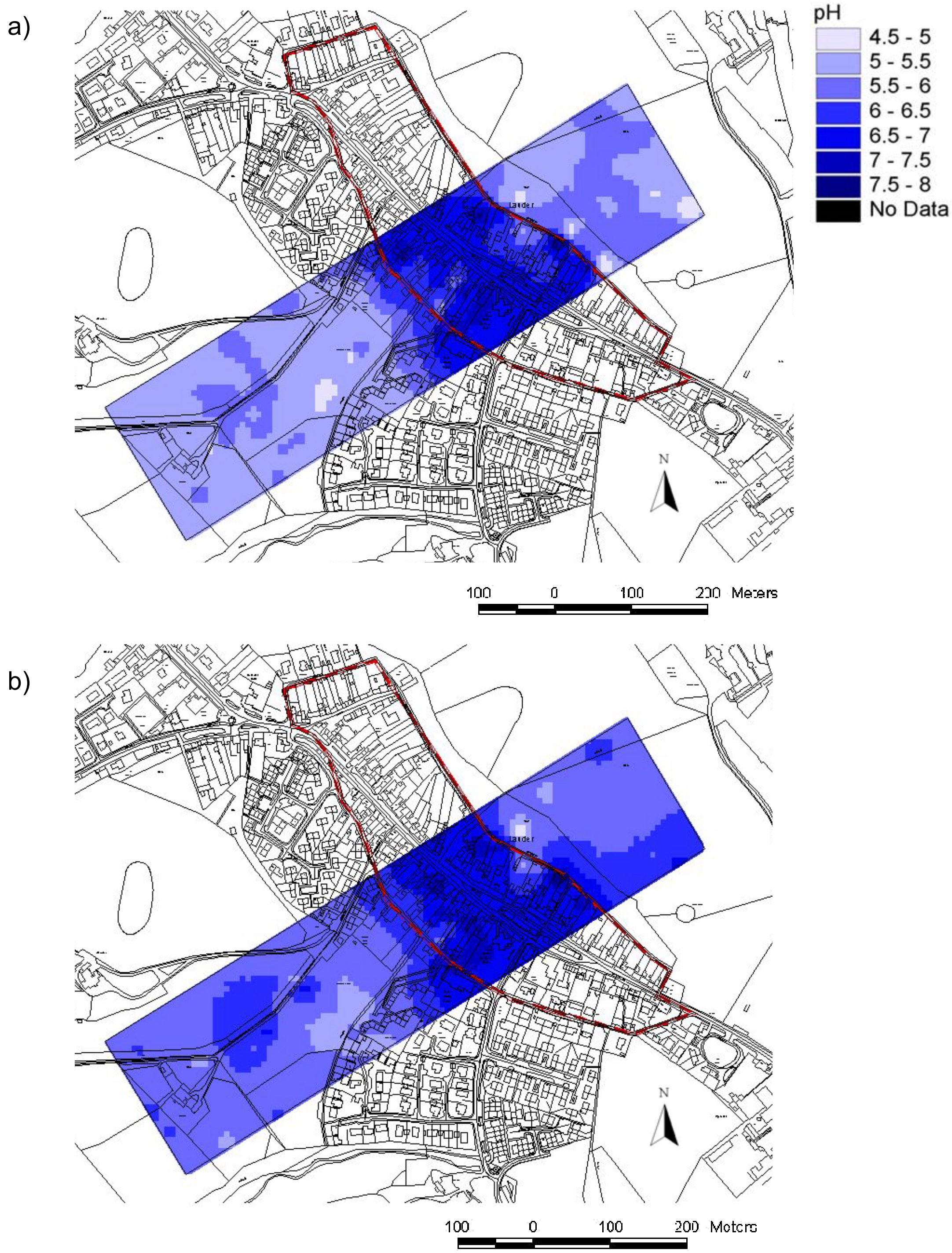


Figure 58: Spatial distribution of soil pH at Lauder (a) 0-20cm and (b) 20-40cm depth. Red boundary delimits 1862AD urban extent

a) b) c) d)

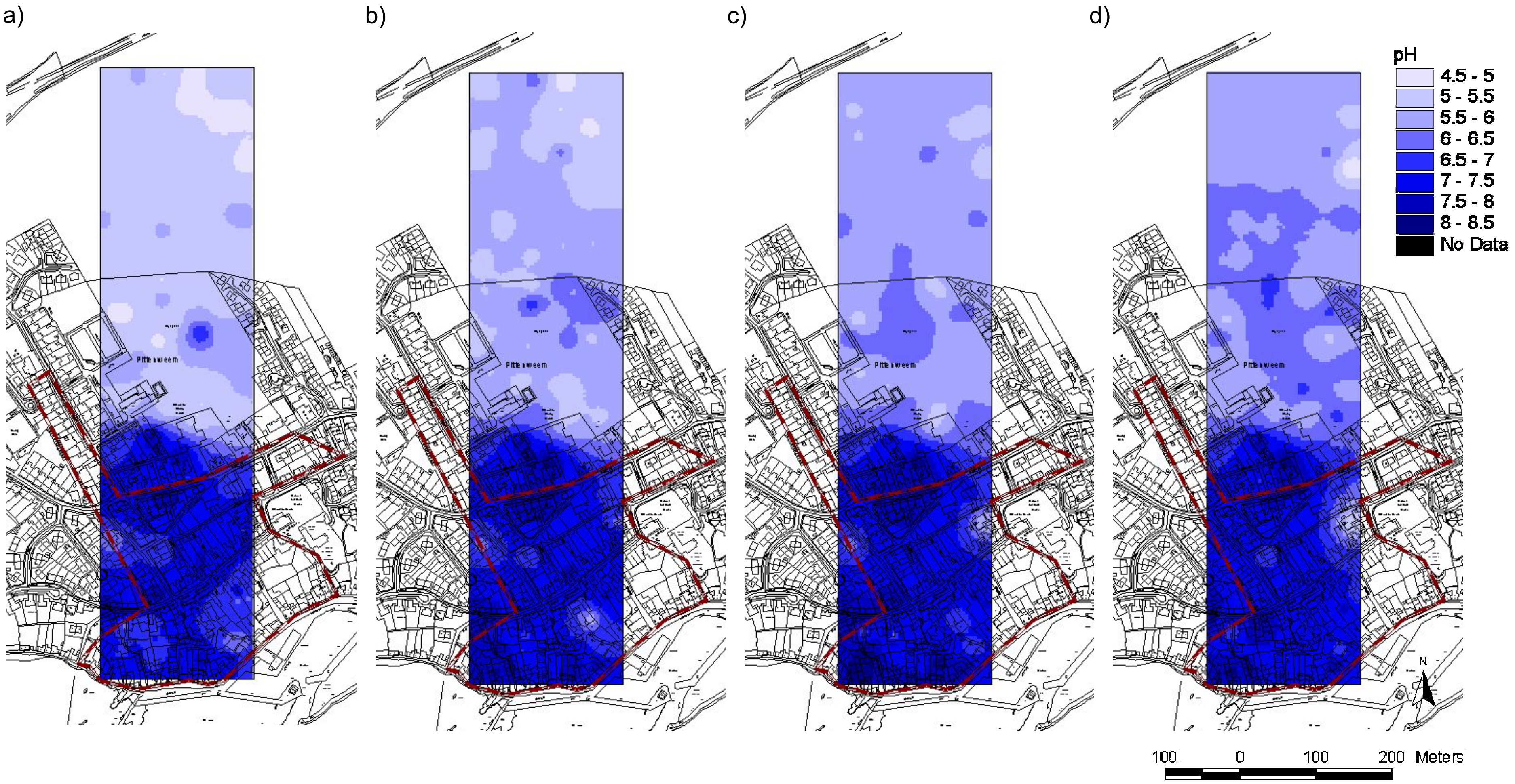


Figure 59: Spatial distribution of soil pH at Pittenweem (a) 0-20cm, (b) 20-40cm, (c) 40-60cm and (d) 60-80cm depth. Red boundary delimits 1855AD urban extent

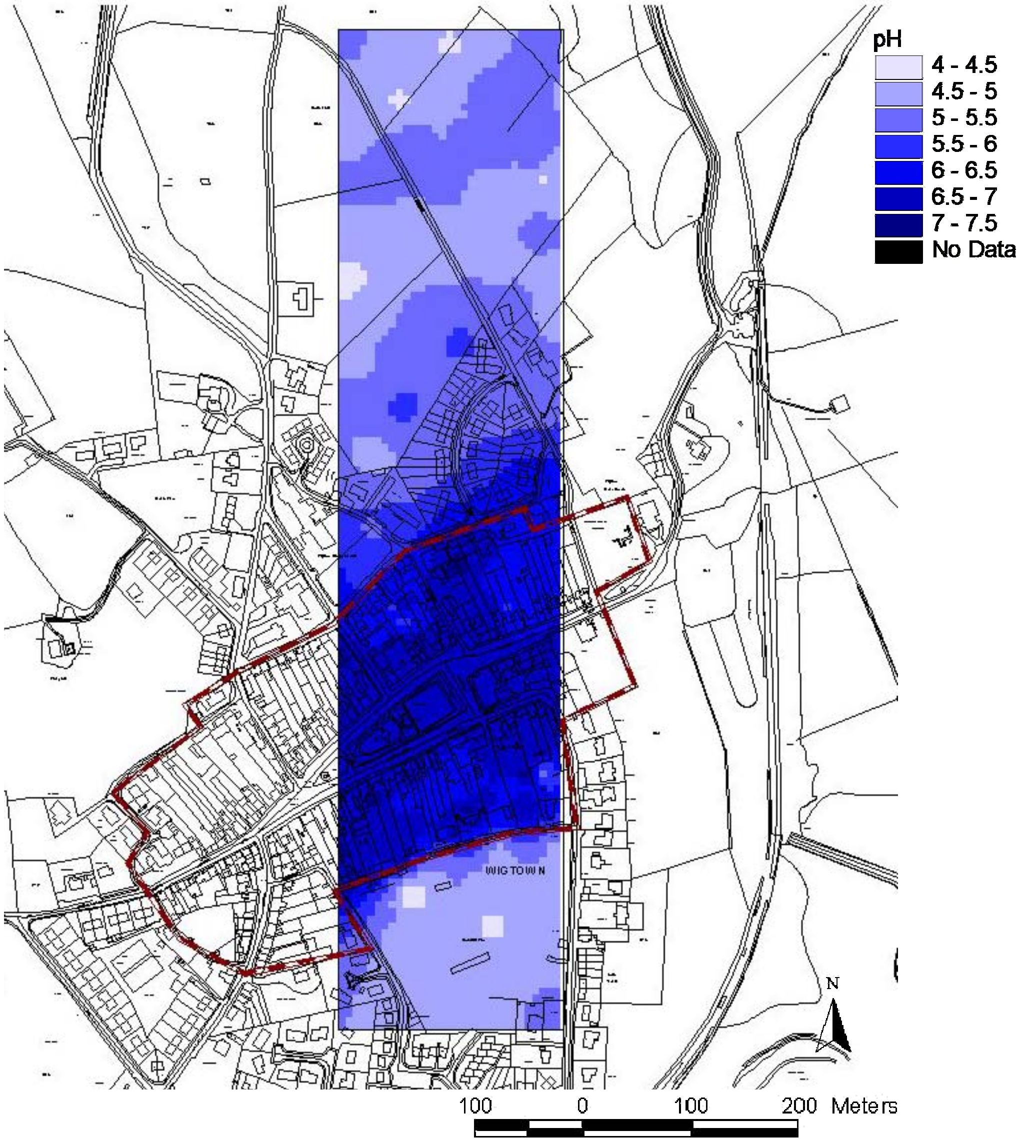


Figure 60: Spatial distribution of soil pH at Wigtown (0-20cm depth). Red boundary delimits 1850AD urban extent

6.2.1 Variation within Burghs

6.2.1.1 Zone

There is clear evidence for enhanced soil pH within the High Street zone at Lauder. The median soil pH of the High Street, Hinterland Near, Hinterland Far and Thirlstane zones is 6.9, 5.4, 5.3 and 5.4 respectively (Figure 61). There is no difference in soil pH between the Hinterland Near, Hinterland Far and Thirlstane zones, however these three zones are all significantly lower than the High Street zone ($p<0.001$). A distinct contrast between neutral soils associated with the burgh core and acidic hinterland soils is therefore identified.

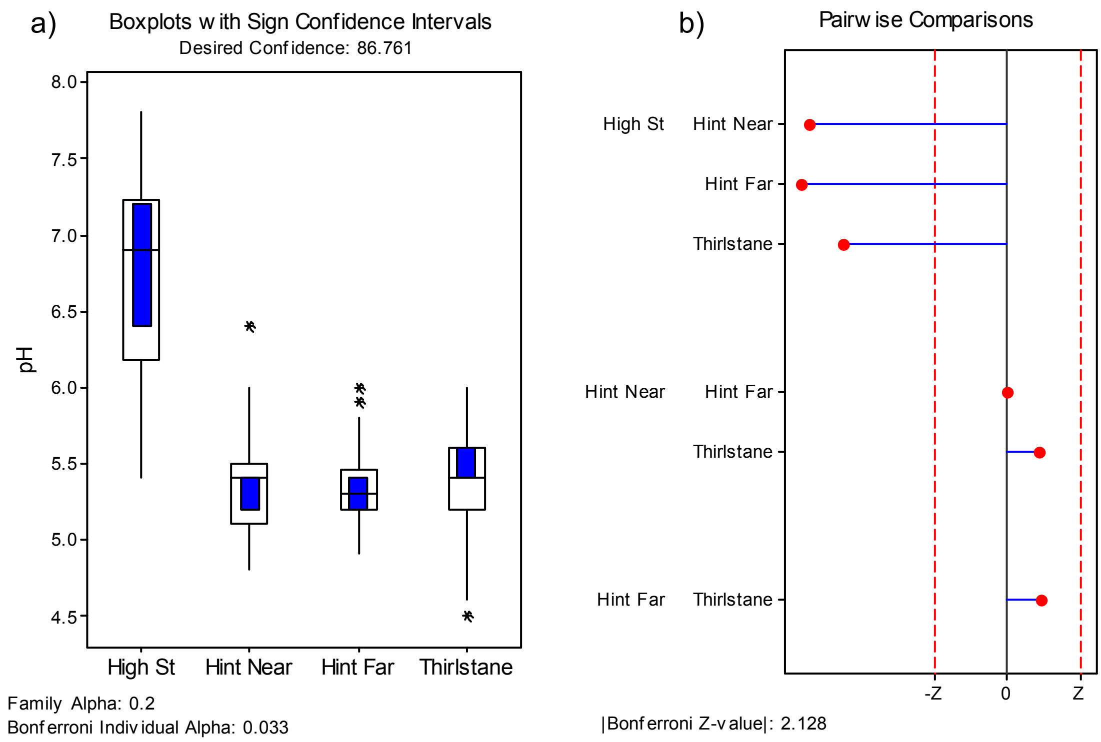


Figure 61: (a) Boxplot of median pH for individual zones at Lauder; boundaries of boxes represent interquartile range, blue shading indicates 86.761% confidence interval for median, outliers identified as *, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Lauder (0-20cm depth), Z values exceeding –Z or Z are significant at p<0.05 confidence level

The median soil pH of the Harbour, High Street, Hinterland Near and Hinterland Far zones at Pittenweem is 7.2, 7.05, 5.4 and 5.3 respectively. There is no statistical difference between the Harbour and High Street zones, however both these zones have a significantly higher soil pH than the Hinterland Near and Hinterland Far zones (p<0.001) (Figure 62b). Similar to results identified at Lauder, there is a clear distinction between neutral soils in the burgh core with acidic soils in the hinterland.

There is a significant difference in soil pH between the High Street, Hinterland Near and Showfield zones at Wigtown (p<0.001). The median soil pH of the High Street, Hinterland Near and Showfield zones is 6.9, 5 and 4.7 respectively (Figure 63a). The High Street has a neutral median soil pH which is significantly greater than the acidic Hinterland Near and Showfield zones (p<0.001). Additionally there is a significant difference between the Hinterland Near and Showfield zones (p<0.05), of which the Hinterland Near zone has slightly higher pH values. Nevertheless the principal trend at Wigtown is comparable to Lauder and Pittenweem in that there is a distinct contrast in soil pH between the burgh core and surrounding hinterland.

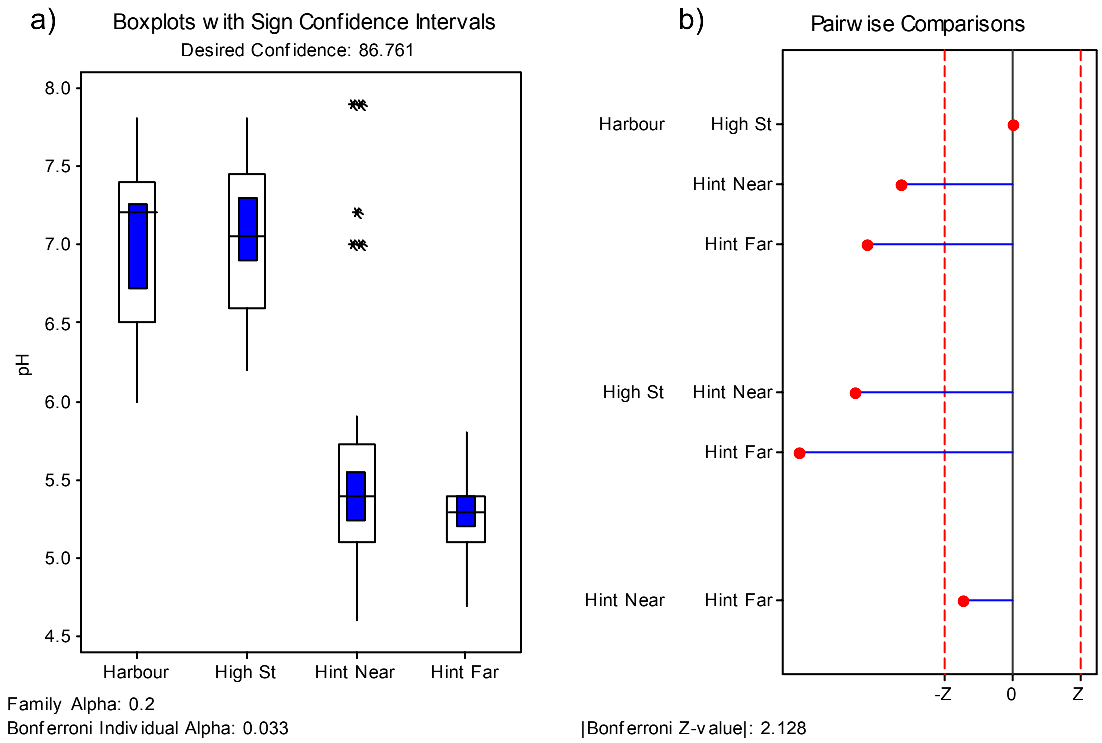


Figure 62: (a) Boxplot of median pH for individual zones at Pittenweem; boundaries of boxes represent interquartile range, blue shading indicates 86.76% confidence interval for median, outliers identified as *, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Pittenweem (0-20cm) using, Z values exceeding –Z or Z are significant at p<0.05 confidence level

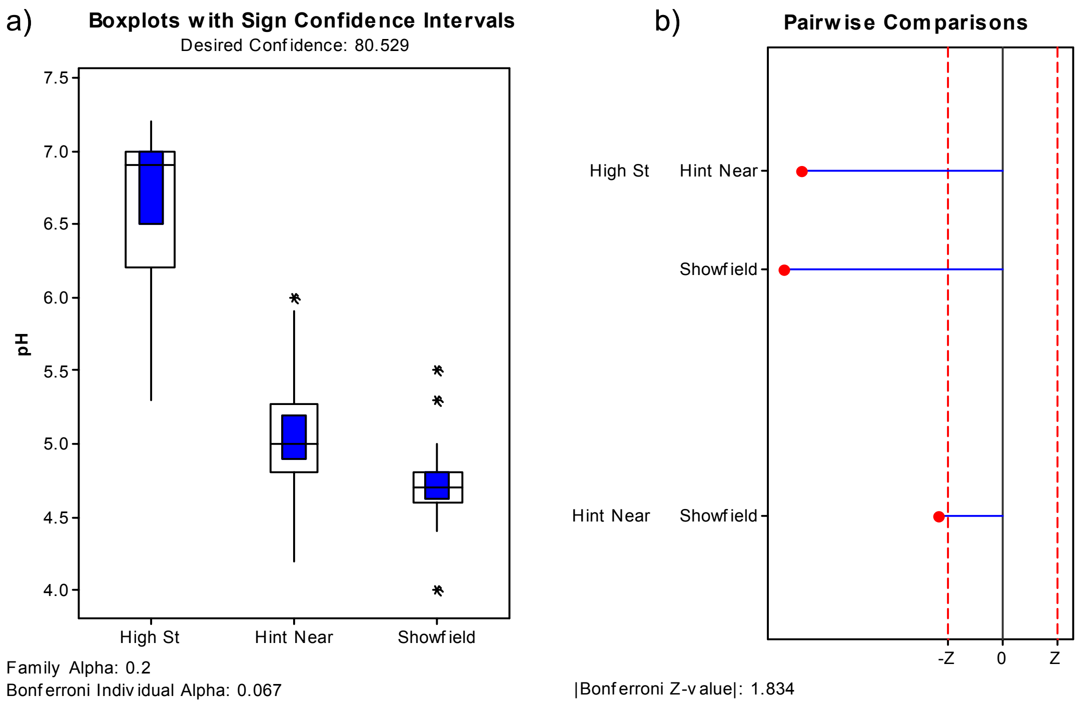


Figure 63: (a) Boxplot of median pH for individual zones at Wigtown; boundaries of boxes represent interquartile range, blue shading indicates 80.52% confidence interval for median, outliers identified as *, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Wigtown (0-20cm depth), Z values exceeding –Z or Z are significant at p<0.05 confidence level

6.2.1.2 Variation in pH with Depth

At Lauder it is identified that soil pH increases with depth. Results of Kruskal-Wallis statistical analysis indicate a significantly higher ($p<0.001$) median soil pH for 20-40cm compared to 0-20cm depth. In addition it is recognised that spatial trends identified for 0-20cm are apparent at 20-40cm depth (Figure 64), for example the High Street zone has a significantly higher ($p<0.001$) soil pH than the Hinterland Near, Hinterland Far and Thirlstane zones.

Results of a Two Way ANOVA undertaken using a GLM indicate a significant difference ($p<0.001$) in pH between zones at Lauder, where the High Street has significantly higher ($p<0.001$) pH values than the Hinterland Near, Hinterland Far and Thirlstane zones. These results support spatial trends identified using the appropriate non-parametric Kruskal-Wallis analysis and Dunn's test in section 6.2.1.1. Moreover in supplementation to results outlined in the above paragraph, 20-40cm is identified as having significantly higher pH values compared to 0-20cm ($p<0.001$).

Statistical analysis also indicates that there is no significant interaction between zone and depth at Lauder. It is therefore argued that while pH varies between depths, the nature of this variation between zones is consistent.

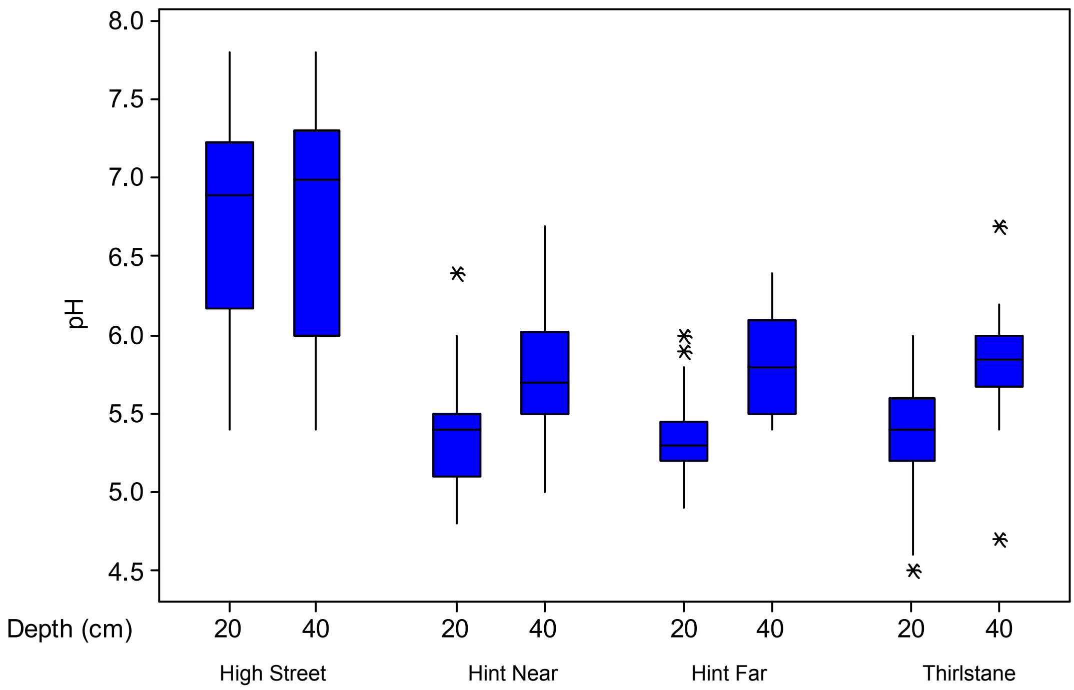


Figure 64: Boxplot of median pH for individual zones at Lauder for 0-20cm and 20-40cm depth; boundaries of boxes represent interquartile range, outliers identified as *

Similar to results obtained for Lauder, soil pH increases with depth at Pittenweem. Results of Kruskal-Wallis analysis and Dunn's test indicate a significantly higher soil pH for 20-40cm ($p<0.05$), 40-60cm ($p<0.001$) and 60-80cm depth ($p<0.001$) compared to 0-20cm. However, there is no statistical difference in soil pH between 20-40cm, 40-60cm and 60-80cm (Figure 65). In addition spatial trends noted for 0-20cm remain consistent at subsequent depths (Figure 66), for example there is a distinct contrast between the neutral burgh core and acidic hinterland zones at each successive depth.

Results of Two Way ANOVA undertaken using a GLM indicate that the Harbour and High Street zones have a significantly greater pH than Hinterland Near and Hinterland far zones. These results support spatial trends identified using the appropriate non-parametric Kruskal-Wallis analysis and Dunn's test in section 6.2.1.1. Moreover in supplementation to results outlined in the above paragraph 0-20cm has lower pH values than 20-40cm ($p<0.005$), 40-60cm ($p<0.001$) and 60-80cm ($p<0.001$).

Statistical analysis also indicates that there is no significant interaction between zone and depth at Pittenweem. Similar to results obtained for Lauder it is suggested that variation in pH between zones is consistent at successive depths.

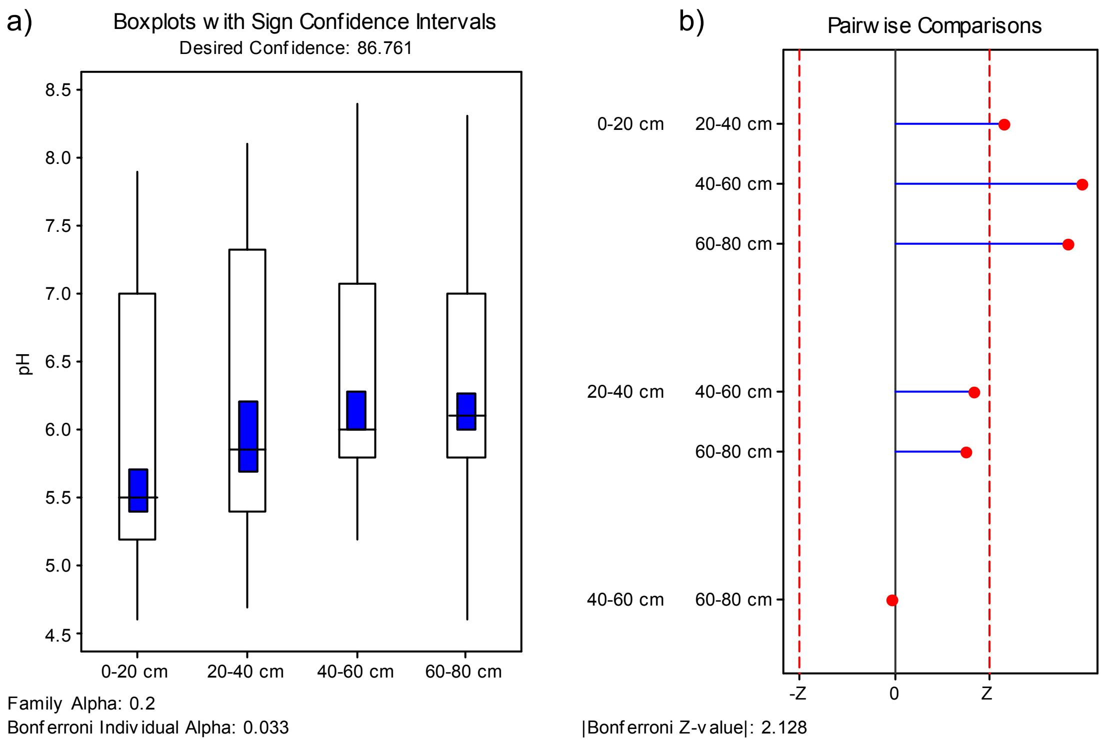


Figure 65: (a) Boxplot of median pH for 0-20cm, 20-40cm, 40-60cm and 60-80cm depth at Pittenweem; boundaries of boxes represent interquartile range, blue shading indicates 86.76% confidence interval for median, outliers identified as *, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual depths at Pittenweem, Z values exceeding –Z or Z are significant at p<0.05 confidence level

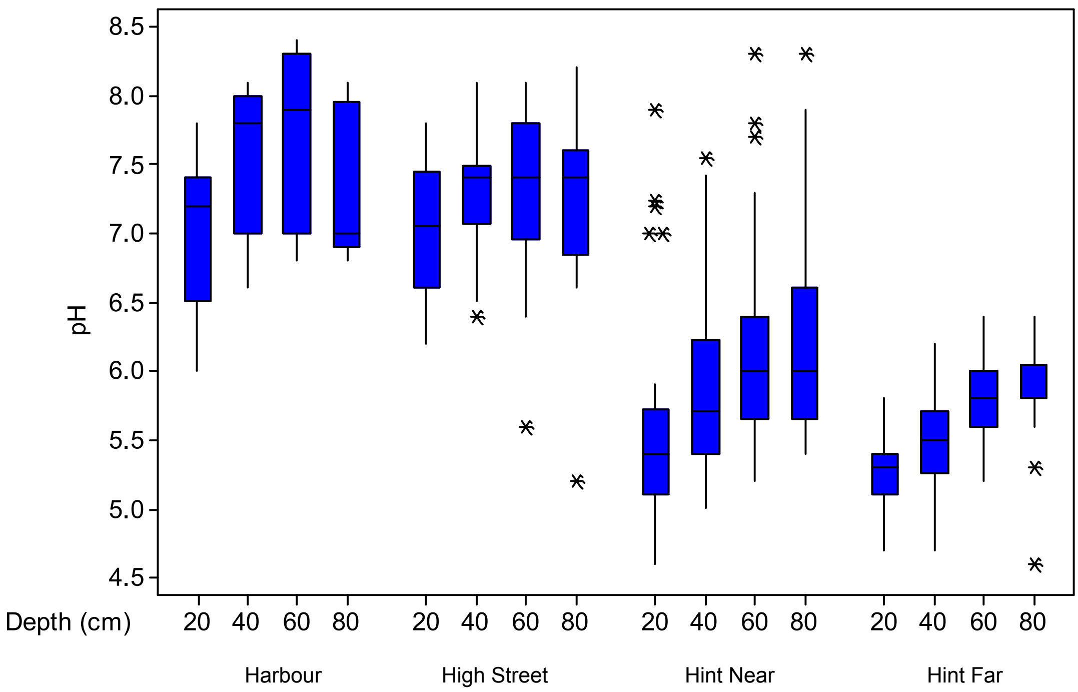


Figure 66: Boxplot of median pH for individual zones within 0-20cm, 20-40cm, 40-60cm and 60-80cm depth at Pittenweem; boundaries of boxes represent interquartile range, outliers identified as *

6.2.2 Variation between Burghs

The results of a Two Way ANOVA undertaken using a GLM indicate that mean soil pH is significantly different between burghs ($p<0.001$). Tukey-Kramer (95% confidence intervals) multiple comparisons reveal that the mean soil pH at Pittenweem is significantly greater than Lauder ($p<0.05$) and Wigtown ($p<0.001$). It is therefore recognised that mean soil pH differs between burghs.

Results presented in section 6.2.1.1 highlight a stark difference in soil pH between the burgh core and surrounding hinterland zones at each town. These findings are supported by ANOVA which verifies a significant difference in mean pH between the High Street and Hinterland Near zones ($p<0.001$). Tukey-Kramer multiple comparisons confirm a significantly higher mean pH for the High Street zone compared to Hinterland Near zone ($p<0.001$). It is therefore argued that all three towns exhibit similar patterns in spatial distributions of soil pH, where the burgh core is characterised by neutral pH values in contrast to the hinterland which is acidic.

Statistical analysis suggests that there is no interaction between the individual ANOVA test factors, burgh and zone. It is therefore argued that although differences in soil pH are identified between the High Street and Hinterland Near zones, the nature and extent of variation is consistent within each town.

6.3 Loss on Ignition

Spatial distributions of Loss on Ignition (% LOI) are presented for Lauder (Figure 67), Pittenweem (Figure 68) and Wigtown (Figure 69) at selected depths. Trends in LOI associated with discrete zones and depths are subsequently identified and comparisons between towns are made.

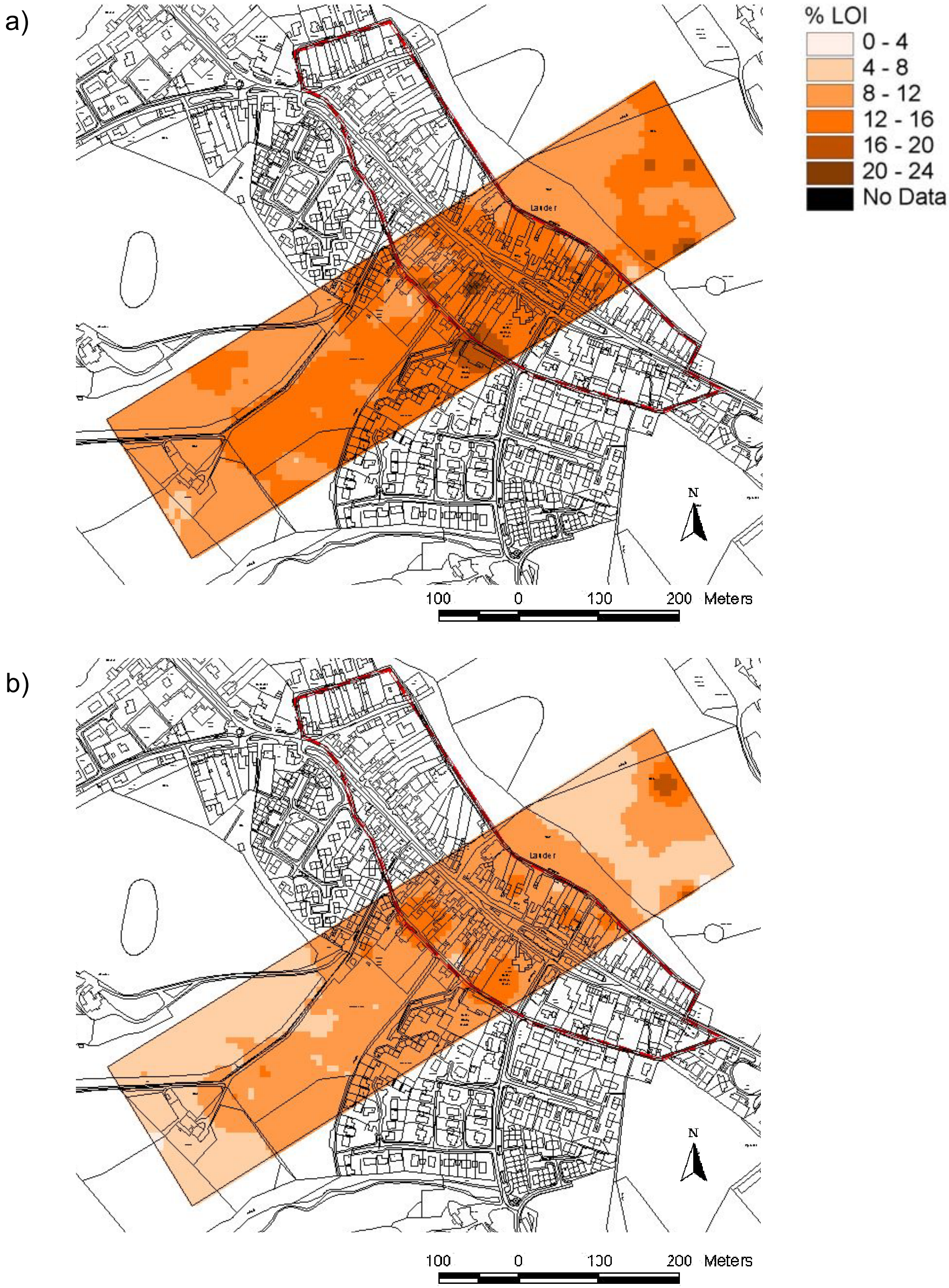


Figure 67: Spatial distribution of % LOI at Lauder (a) 0-20cm and (b) 20-40cm depth. Red boundary delimits 1862AD urban extent

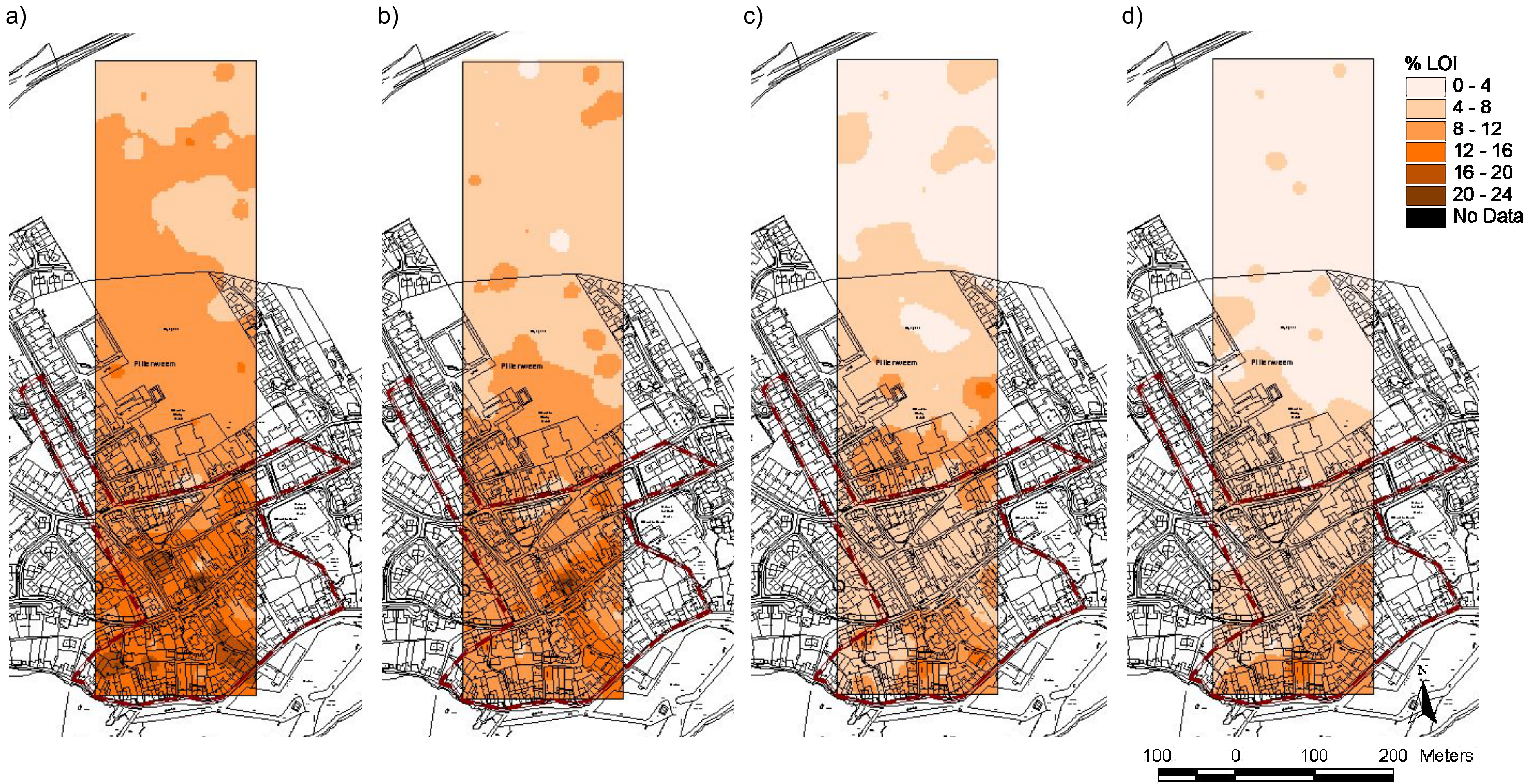


Figure 68: Spatial distribution of % LOI at Pittenweem (a) 0-20cm, (b) 20-40cm, (c) 40-60cm and (d) 60-80cm depth. Red boundary delimits 1855AD urban extent

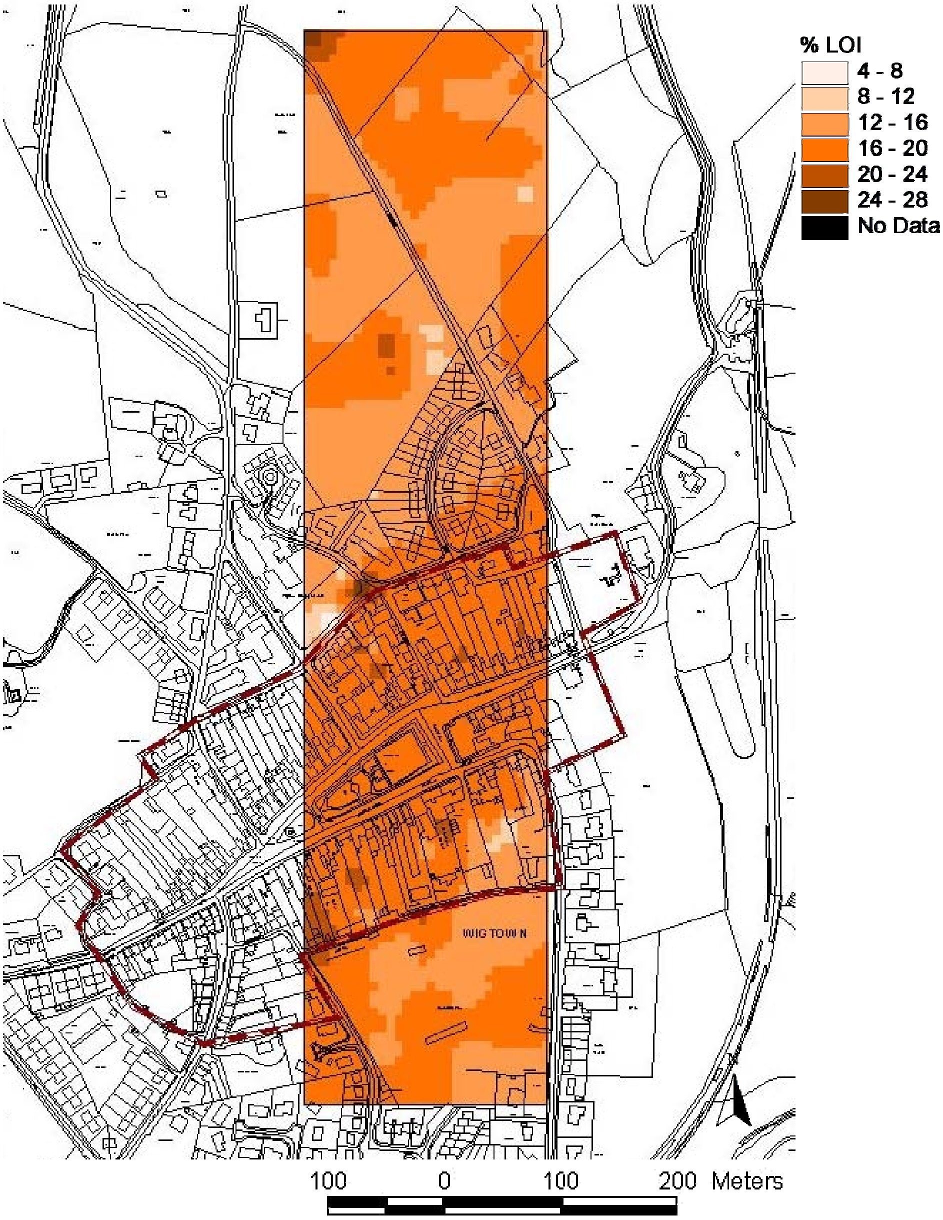


Figure 69: Spatial distribution of % LOI at Wigtown (0-20cm depth). Red boundary delimits 1850AD urban extent

6.3.1 Variation within Burghs

6.3.1.1 Zones

The median % LOI of the High Street, Hinterland Near, Hinterland Far and Showfield zones at Lauder is 13.88, 12.82, 10 and 11.37% respectively (Figure 70a). The High Street zone has significantly higher % LOI than Hinterland Far ($p<0.001$) and Thirlstane zones ($p<0.01$). Moreover the Hinterland Near zone has significantly higher % LOI compared to the Hinterland Far ($p<0.001$) and Thirlstane zones ($p<0.05$). However, there is no statistical difference between the High Street zone and Hinterland Near zone

(Figure 70b). These results provide clear evidence for increased levels of % LOI in the burgh core and land immediately adjacent to the historical burgh limits (Hinterland Near).

The median LOI of the Harbour, High Street, Hinterland Near and Hinterland Far zones at Pittenweem is 13.9, 12.8, 10.8 and 7.9% respectively (Figure 71a). The Harbour has significantly greater % LOI than the Hinterland Near ($p<0.01$) and Hinterland Far zones ($p<0.001$). Moreover, both the High Street and Hinterland Near zones have significantly higher % LOI compared to the Hinterland Far zone ($p<0.001$) (Figure 71b). There is no statistical difference in % LOI between the High Street and Harbour zones, and High Street and Hinterland Near zones. These results indicate enhanced % LOI in the burgh core and land immediately adjacent to the historical burgh limits (Hinterland Near). Furthermore variation between enhanced zones is noted, for example although there is no difference in median % LOI between the High Street and Harbour zones, and High Street and Hinterland Near zones, there is a significant difference between the Harbour and Hinterland Near zones. This supports the observation that the Harbour zone has the highest median % LOI, followed by the High Street and Hinterland Near zone.

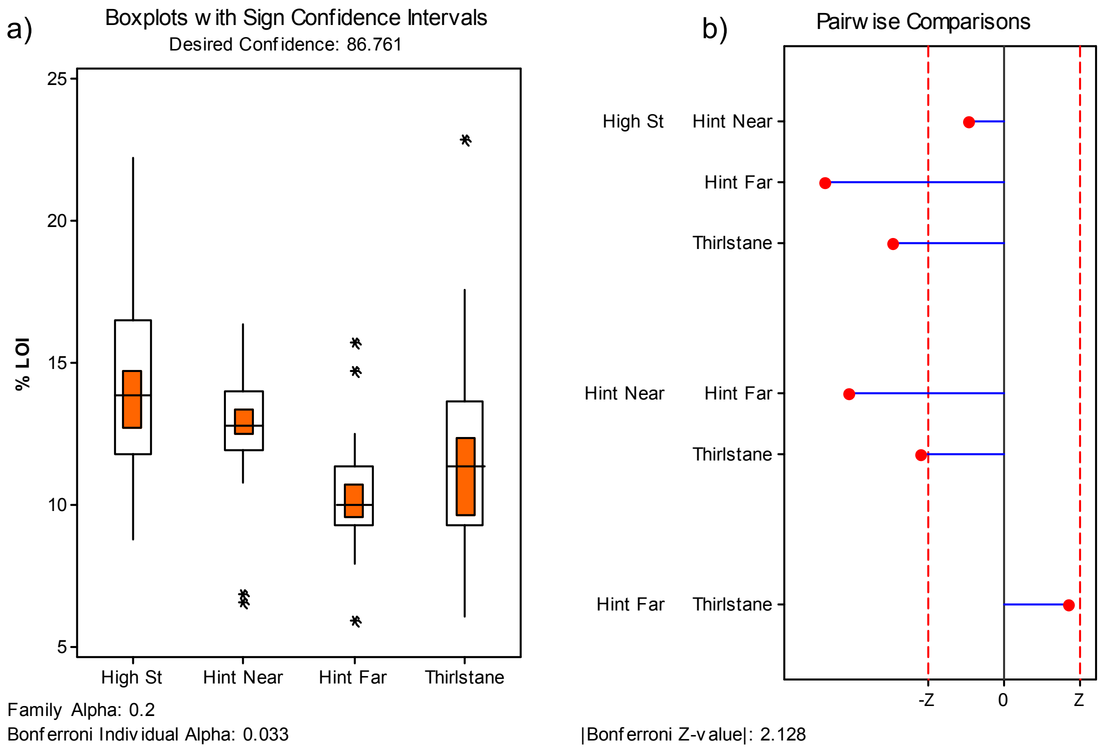


Figure 70: (a) Boxplot of median % LOI for individual zones at Lauder; boundaries of boxes represent interquartile range, orange shading indicates 86.761% confidence interval for median, outliers identified as *, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Lauder (0-20cm depth) , Z values exceeding –Z or Z are significant at p<0.05 confidence level

The mean % LOI of the High Street, Hinterland Near and Hinterland Far zones at Wigtown is 17.8, 15.6 and 16.1% respectively. Results of One Way ANOVA with Tukey-Kramer multiple comparisons indicate that the High Street has a significantly higher mean % LOI than the Hinterland Near zone ($p<0.05$). However, there is no statistical difference in % LOI between the High Street and Showfield zones. A boxplot of median LOI values at Wigtown is presented in Figure 72. Differences between median LOI values suggest a greater contrast between the High Street (18.3%) and Showfield (15.5%) zones in addition to minimal variation between the Hinterland Near and Showfield zones. Similar to results obtained for soil pH in section 6.2.1.1, a distinct contrast in % LOI is noted between the burgh core and surrounding hinterland.

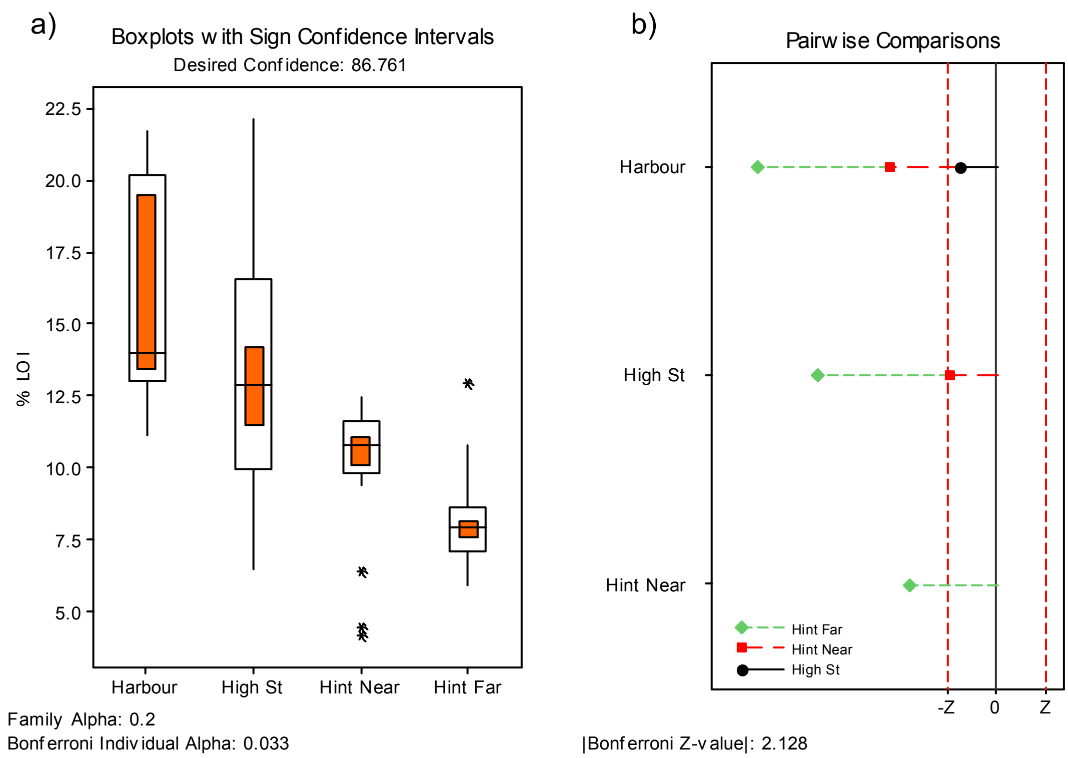


Figure 71: (a) Boxplot of median % LOI for individual zones at Pittenweem; boundaries of boxes represent interquartile range, orange shading indicates 86.761% confidence interval for median, outliers identified as *, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Pittenweem (0-20cm depth), Z values exceeding –Z or Z are significant at p<0.05 confidence level

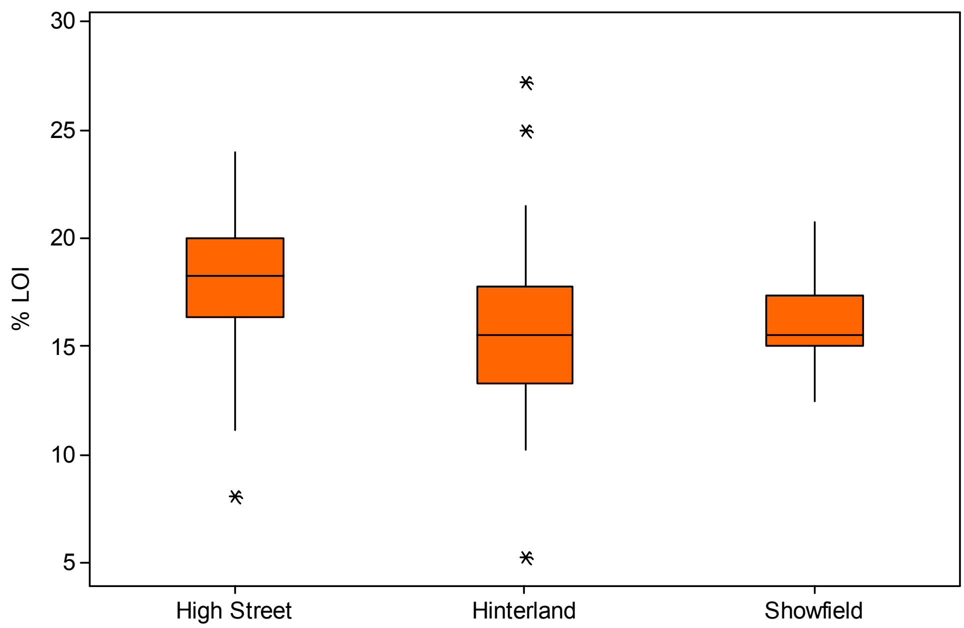


Figure 72: Boxplot of median % LOI for individual zones at Wigtown; boundaries of boxes represent interquartile range, outliers identified as *

6.3.1.2 Variation in LOI with Depth

It is identified that % LOI decreases with depth at Lauder. Results of Kruskal-Wallis statistical analysis with Dunn's test indicate a significantly higher ($p<0.001$) median % LOI for 0-20cm compared to 20-40cm depth. In addition, it is recognised that spatial trends identified at 0-20cm are not maintained at 20-40cm. The median % LOI for the High Street, Hinterland Near, Hinterland Far and Thirlstane zones at 20-40cm is 8.83, 7.03, 8.21 and 10.71% respectively (Figure 73). In contrast to trends identified at 0-20cm, there is no significant difference between the High Street and Hinterland Far zone, High Street and Thirlstane zone, and Hinterland Near and Hinterland Far zone. Moreover, at 20-40cm depth the Hinterland Near zone has a significantly higher % LOI compared to Thirlstane zone ($p<0.05$).

Results of a Two Way ANOVA undertaken using a GLM indicate a significant difference ($p<0.001$) in % LOI between zones at Lauder, where the High Street zone has a significantly higher % LOI than the Hinterland Far zone ($p<0.05$). Notably results from this analysis do not reveal a difference between the Hinterland Near zone with either the Hinterland Far or Thirlstane zone as identified using the appropriate non-parametric Kruskal-Wallis analysis and Dunn's test in section 6.3.1.1. This may reflect differences in the measurement of central tendency between parametric and non-parametric tests. Moreover, in supplementation to results outlined in the above paragraph, 0-20cm is identified has having a significantly higher % LOI compared to 20-40cm depth ($p<0.001$).

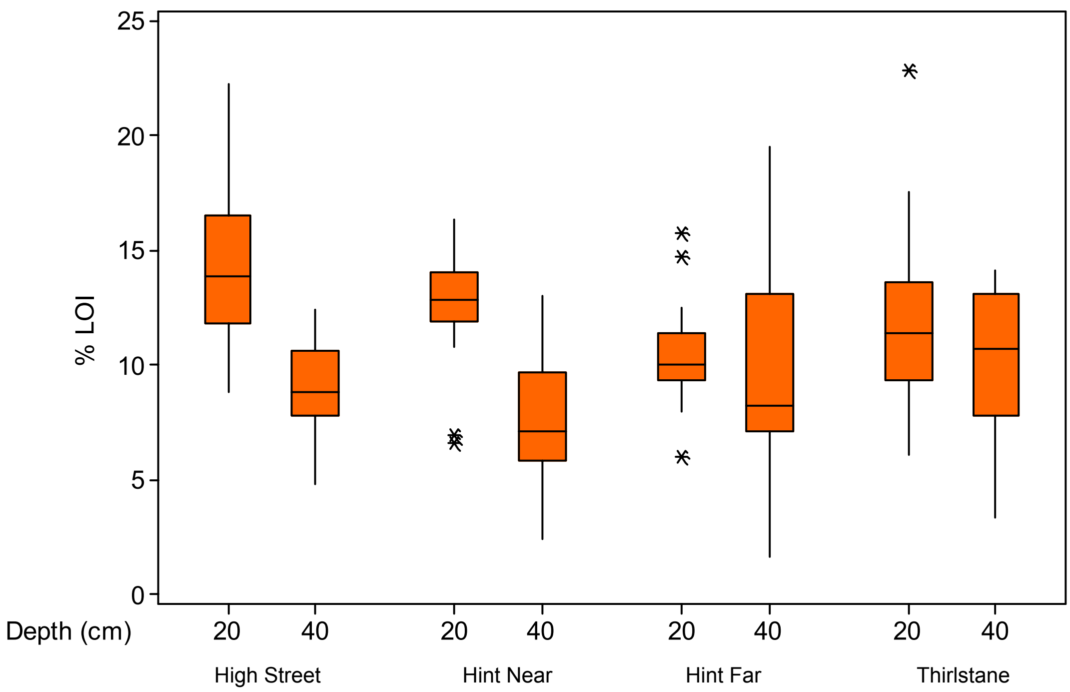


Figure 73: Boxplot of median % LOI for individual zones at Lauder for 0-20cm and 20-40cm depth; boundaries of boxes represent interquartile range, outliers identified as *

Statistical analysis indicates significant interaction ($p<0.001$) between the individual ANOVA test factors, zone and depth. This association implies that variation in % LOI at subsequent depth increments cannot be fully explained by zone as a factor in isolation.

The median % LOI for 0-20cm, 20-40cm, 40-60cm and 60-80cm depth at Pittenweem is 10.13, 7.86, 5.38 and 3.37% respectively. Results of Kruskal-Wallis analysis and Dunn's test indicate a significantly higher median % LOI for 0-20cm compared to each successive depth ($p<0.001$). Similarly 20-40cm has a significantly higher % LOI than both 40-60cm and 60-80cm ($p<0.001$). These results indicate a sustained decrease in % LOI associated with depth. In addition it is recognised that spatial trends identified at 0-20cm remain consistent at subsequent depths (Figure 74), for example at 40-60cm depth the Harbour zone has a significantly higher % LOI compared to the Hinterland Far zone ($p<0.001$). Moreover at 40-60cm depth both the High Street and Hinterland Near zones have significantly higher % LOI than Hinterland Far zone ($p<0.001$).

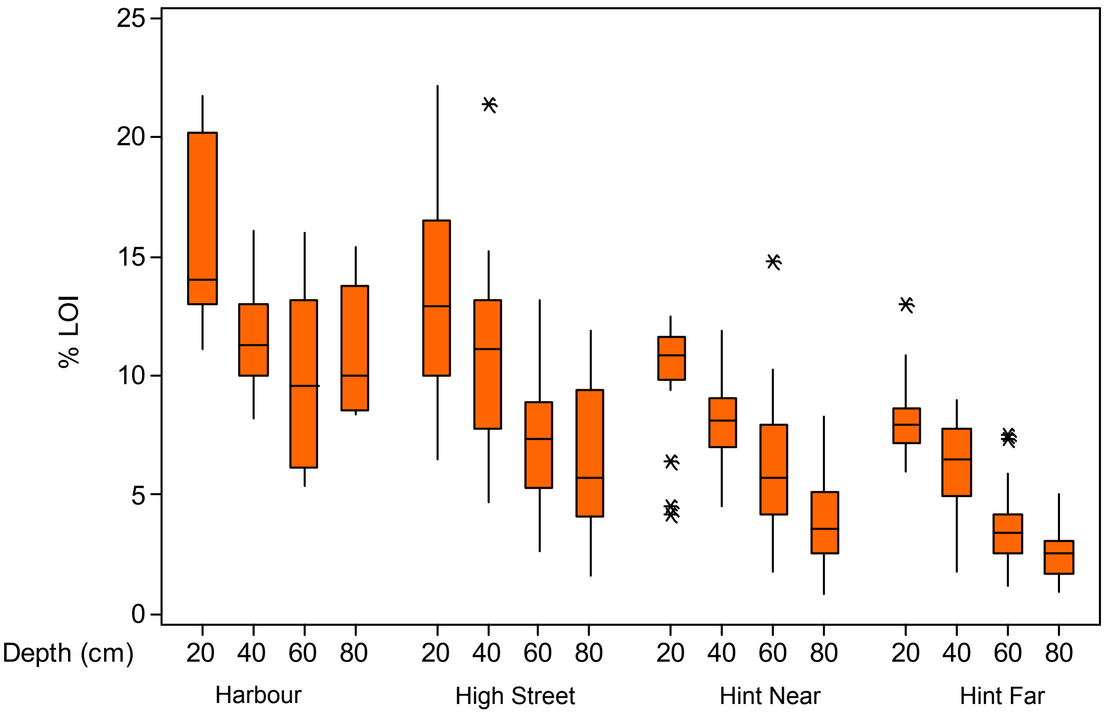


Figure 74: Boxplot of median % LOI for individual zones at Pittenweem for 0-20cm, 20-40cm, 40-60cm and 60-80cm depth; boundaries of boxes represent interquartile range, outliers identified as *

Results of a Two Way ANOVA undertaken using a GLM indicate that the Harbour, High Street and Hinterland Near zones have significantly higher % LOI compared to the Hinterland Far zone ($p<0.001$). These results support trends identified using the appropriate non-parametric Kruskal-Wallis analysis and Dunn's test in section 6.3.1.1. Moreover in supplementation to results outlined in the previous paragraph, 0-20cm has a significantly higher % LOI than 20-40, 40-60 and 60-80cm depths ($p<0.001$), 20-40cm has a significantly greater LOI than 40-60cm and 60-80cm ($p<0.001$), and 40-60cm has a significantly higher % LOI than 60-80cm ($p<0.05$).

In contrast to findings obtained at Lauder, statistical analysis using ANOVA indicates that there is no significant interaction between zone and depth at Pittenweem. This confirms the observed trend that variation in % LOI between zones is consistent at successive depths.

6.3.2 Variation between Burghs

The results of a Two Way ANOVA undertaken using a GLM indicate that mean % LOI is significantly different between burghs ($p<0.001$). Tukey-Kramer (95% confidence intervals) multiple comparisons reveal that Wigtown has a significantly higher mean LOI compared to both Lauder and Pittenweem ($p<0.001$). However, there is no statistical difference in mean % LOI between Lauder and Pittenweem.

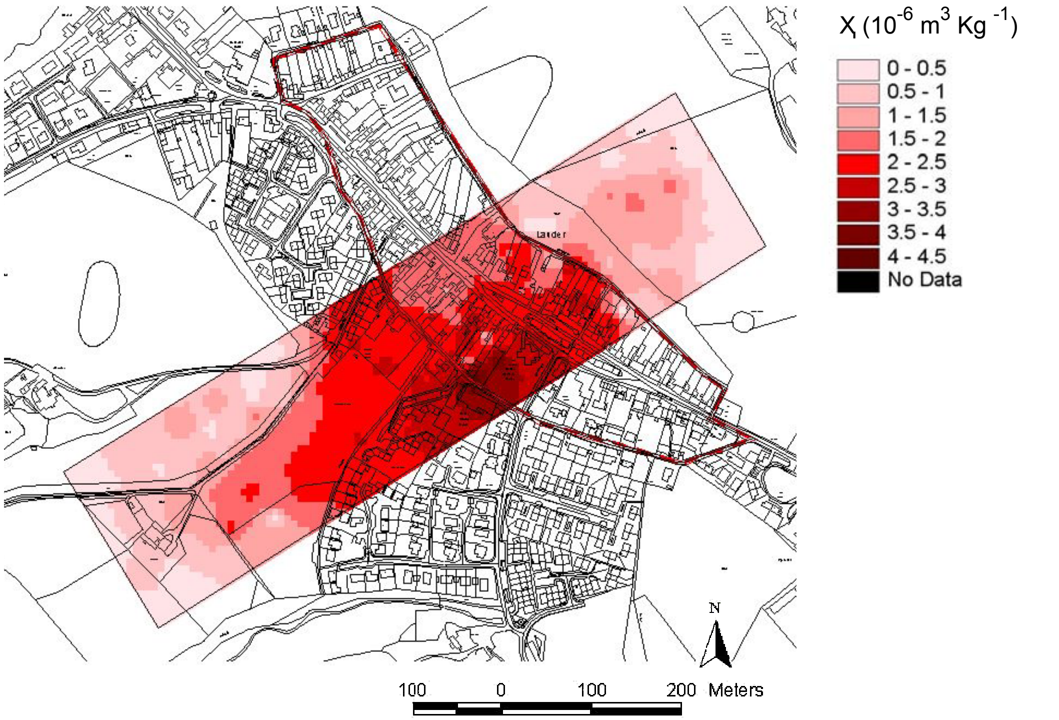
Results presented in section 6.3.1.1 indicate increased levels of % LOI within the burgh core of each town, and in the case of Lauder and Pittenweem enhancement within the Hinterland Near zone. These findings are supported by ANOVA which reveals a significant difference in % LOI between the High Street and Hinterland Near zones ($p<0.001$). Furthermore, Tukey-Kramer multiple comparisons confirm a significantly higher mean % LOI for the High Street zone compared to Hinterland Near zone ($p<0.001$). It is argued that spatial distribution of % LOI at Lauder and Pittenweem is characterised by decreasing % LOI values in association with distance from the burgh core.

Statistical analysis suggests that there is no interaction between the individual ANOVA test factors, burgh and zone. It is, therefore, argued that although differences in % LOI are identified between the High Street and Hinterland Near zones, the nature and extent of this variation is consistent in each town.

6.4 Magnetic Susceptibility

Spatial distributions of mass dependant magnetic susceptibility (χ) and frequency dependant magnetic susceptibility (χ_{FD}) are presented for Lauder (Figure 75), Pittenweem (Figure 76) and Wigtown (Figure 77).

a)



b)

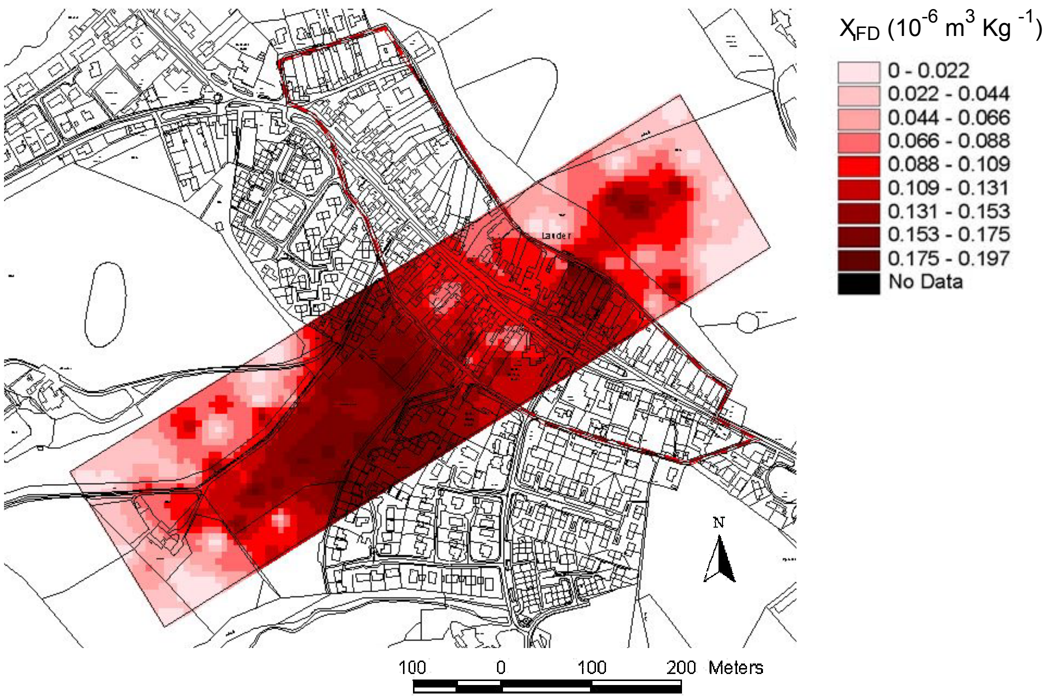


Figure 75: Spatial distribution of (a) χ ($10^{-6}m^3Kg^{-1}$) and (b) χ_{FD} ($10^{-6}m^3Kg^{-1}$) at Lauder. Red boundary delimits 1862AD urban extent

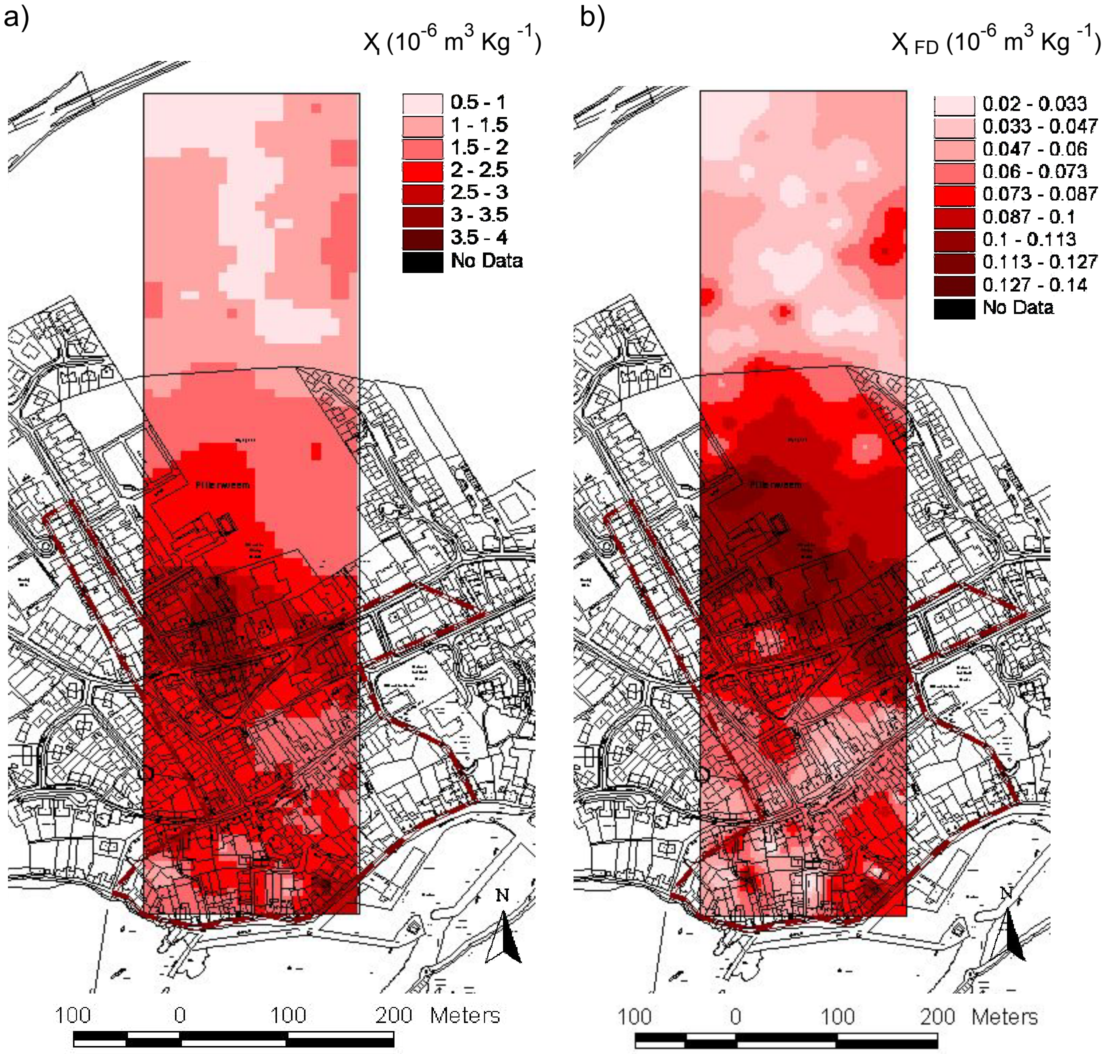


Figure 76: Spatial distribution of (a) X_l ($10^{-6}m^3Kg^{-1}$) and (b) X_{FD} ($10^{-6}m^3Kg^{-1}$) at Pittenweem. Red boundary delimits 1855AD urban extent

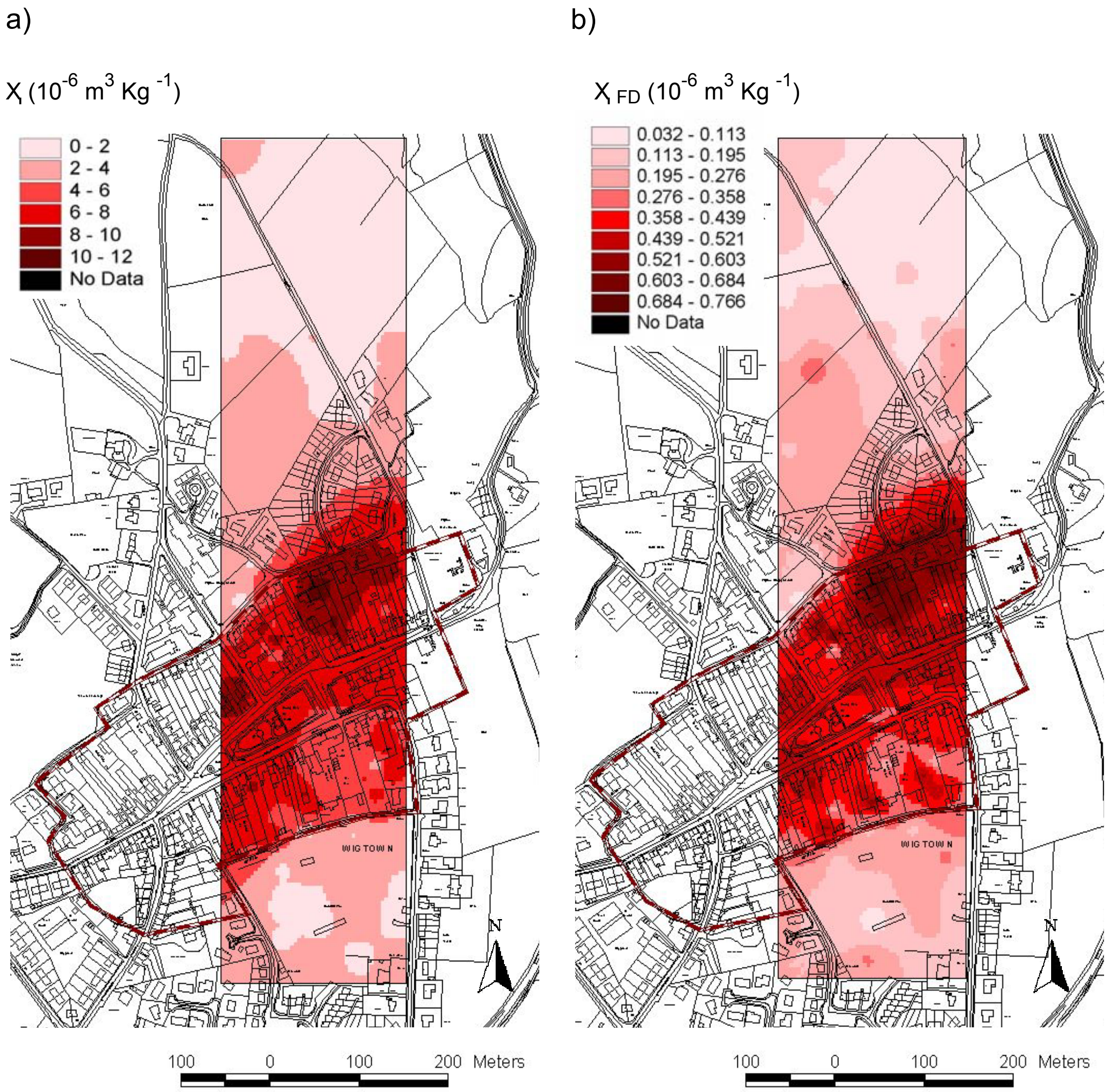


Figure 77: Spatial distribution of (a) χ ($10^{-6}m^3Kg^{-1}$) and (b) χ_{FD} ($10^{-6}m^3Kg^{-1}$) at Wigtown. Red boundary delimits 1850AD urban extent

6.4.1 Mass Dependant Magnetic Susceptibility (χ)

6.4.1.1 Variation within Burghs

The median χ of the High Street, Hinterland Near, Hinterland Far and Thirlstane zones at Lauder is 2.29, 2.17, 0.54 and 0.58 ($10^{-6}m^3Kg^{-1}$) respectively (Figure 78a). There is no statistical difference in median χ between the High Street zone and Hinterland Near zone. However, both High Street and Hinterland Near zones have significantly higher χ than the Hinterland Far ($p<0.001$) and Thirlstane zones ($p<0.001$) (Figure 78b). These results provide clear evidence for increased χ within the urban core and land immediately adjacent to the historical burgh limits (Hinterland Near).

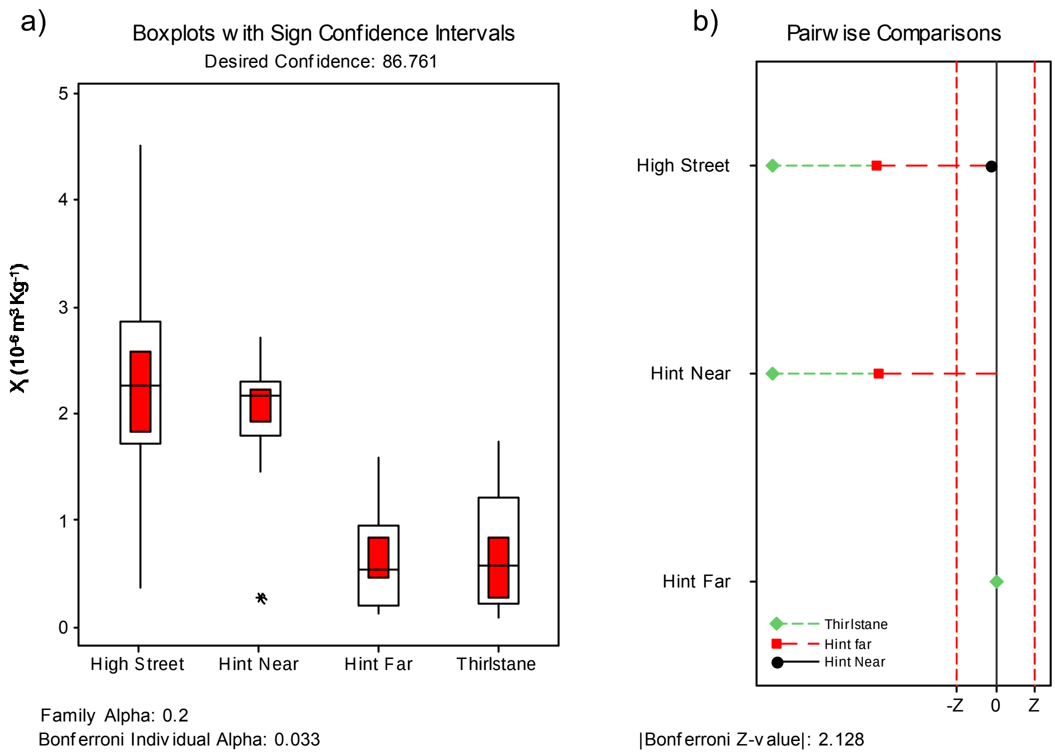


Figure 78: (a) Boxplot of median χ ($10^{-6}m^3Kg^{-1}$) for individual zones at Lauder; boundaries of boxes represent interquartile range, red shading indicates 86.761% confidence interval for median, outliers identified as *, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Lauder, Z values exceeding –Z or Z are significant at p<0.05 confidence level

The mean χ of the Harbour, High Street, Hinterland Near and Hinterland Far zones is 2.21, 2.03, 1.99 and 1.14 ($10^{-6}m^3Kg^{-1}$) respectively (Figure 79). Results of One Way ANOVA with Tukey-Kramer multiple comparisons indicate the Harbour, High Street and Hinterland Near zones all have a significantly higher mean χ than the Hinterland Far zone ($p<0.001$). However, there is no statistical difference in mean χ between the Harbour, High Street and Hinterland Near zones. Similar to results obtained for Lauder, elevated χ is noted within both burgh core and in the immediate hinterland (Hinterland Near).

There is a significant difference between the High Street, Hinterland Near and Showfield zones at Wigtown ($p<0.001$). The median χ of the High Street, Hinterland Near and Showfield zones is 7.26, 1.71 and 1.95 ($10^{-6}m^3Kg^{-1}$) respectively (Figure 80a). The High Street zone has a significantly higher ($p<0.001$) χ than both the Hinterland Near and Showfield zones (Figure 80b). There is no significant difference between the Hinterland Near and Showfield zones. These results indicate elevated χ within the burgh core at Wigtown.

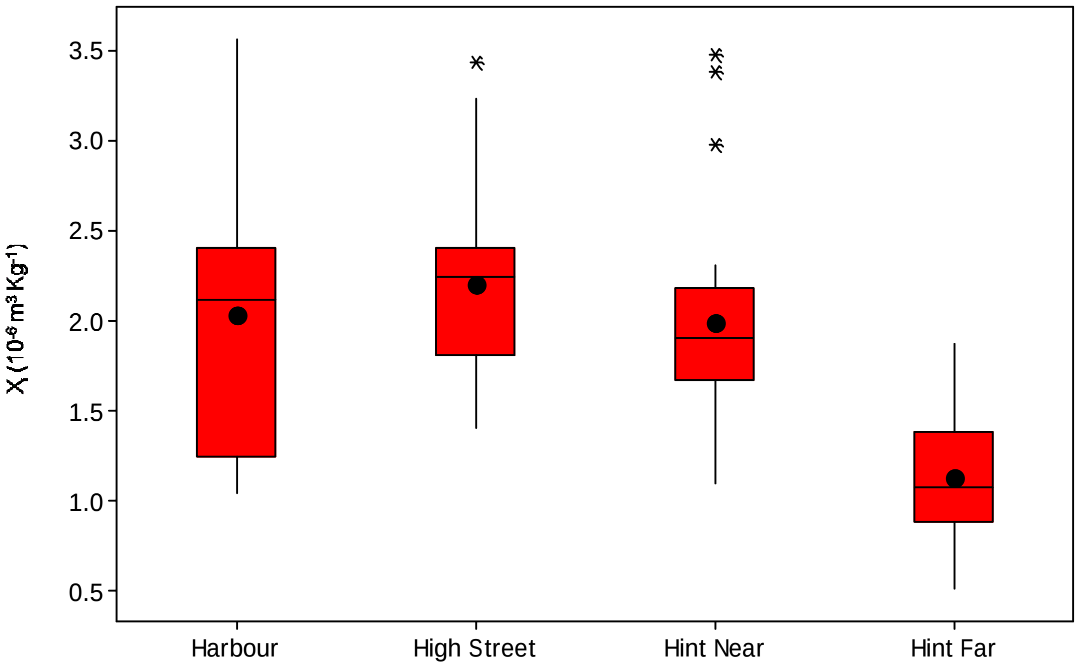


Figure 79: Boxplot of median and mean χ ($10^{-6}m^3Kg^{-1}$) for individual zones at Pittenweem; bar indicates median, black circle denotes mean, boundaries of boxes represent interquartile range, outliers identified as *

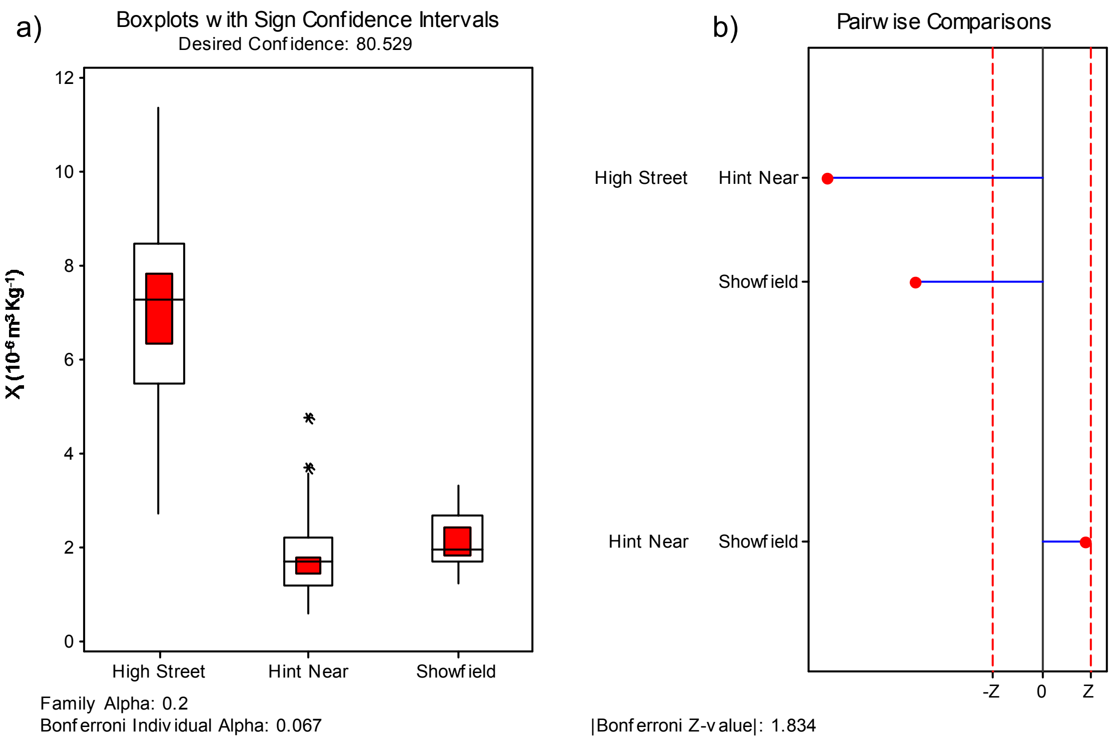


Figure 80: (a) Boxplot of median χ ($10^{-6}m^3Kg^{-1}$) for individual zones at Wigtown; boundaries of boxes represent interquartile range, red shading indicates 80.529% confidence interval for median, outliers identified as *, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Wigtown, Z values exceeding –Z or Z are significant at p<0.05 confidence level

6.4.1.2 Variation between Burghs

Results of a Two Way ANOVA undertaken using a GLM indicate that mean χ_l is significantly different between towns ($p<0.001$). Tukey-Kramer (95% confidence intervals) multiple comparisons reveal that mean χ_l at Wigtown is significantly higher than Lauder and Pittenweem ($p<0.001$). Additionally, there is no statistical difference in χ_l between Lauder and Wigtown. It should be noted that variation in mean χ_l between burghs does not necessarily reflect differences in the duration and intensity of anthropogenic enhancement. It is more likely that absolute differences indicate a contrast in underlying geology.

Results presented in section 6.4.1.1 indicate increased χ_l within the burgh core of each town, and in the case of Lauder and Pittenweem, enhancement within the Hinterland Near zone. This finding is supplemented by ANOVA which confirms a significant difference in mean χ_l between the High Street zone and Hinterland Near zone ($p<0.001$). Tukey-Kramer multiple comparisons indicate a higher mean χ_l for the High Street zone compared to the Hinterland Near zone ($p<0.001$). Conversely, results from Kruskal-Wallis pairwise comparisons suggest that there is no significant difference between the High Street and Hinterland Near zones at Lauder and Pittenweem. This discrepancy may reflect differences in measurement of central tendency between parametric and non-parametric tests. Nevertheless it is evident that all three towns have elevated χ_l in the burgh core, and in the case of Lauder and Pittenweem enhanced χ_l in land immediately adjacent to the historical burgh limits (Hinterland Near).

Statistical analysis indicates significant interaction ($p<0.001$) between the individual ANOVA test factors, burgh and zone. This association implies that variation in χ_l cannot be explained by either burgh or zone as factors in isolation. It is therefore argued that although a difference between the High Street and Hinterland Near zone is identified using ANOVA, the nature and extent of this difference is not consistent for all three burghs.

6.4.2 Frequency Dependant Magnetic Susceptibility (X_{FD})

6.4.2.1 Variation within Burghs

The median X_{FD} of the High Street, Hinterland Near, Hinterland Far and Thirlstane zones at Lauder is 0.12, 0.16, 0.05 and 0.04 ($10^{-6}m^3Kg^{-1}$) respectively (Figure 81a). The High Street has a significantly higher X_{FD} than the Hinterland Far ($p<0.001$) and Thirlstane zones ($p<0.01$). In addition, the Hinterland Near zone has a significantly greater median X_{FD} than the High Street ($p<0.05$), Hinterland Far ($p<0.001$) and Thirlstane zones ($p<0.001$) (Figure 64b). There is no statistical difference between the Hinterland Far and Thirlstane zones. These results reveal enhancement of X_{FD} in both the burgh core and in land adjacent to the historical burgh limits (Hinterland Near). Moreover, it is recognised that X_{FD} is significantly higher in the Hinterland Near zone in comparison to the burgh core.

Similar to trends identified at Lauder, enhancement of X_{FD} is noted within the burgh core and Hinterland Near zone at Pittenweem. The median X_{FD} of the Harbour, High Street, Hinterland Near and Hinterland Far zones at Pittenweem is 0.06, 0.07, 0.09 and 0.04 ($10^{-6}m^3Kg^{-1}$) respectively. The High Street has a significantly higher X_{FD} than the Hinterland Far zone ($p<0.01$). Moreover, the Hinterland Near zone has a significantly higher X_{FD} than both the High Street ($p<0.01$) and Hinterland Far zones ($p<0.001$) (Figure 82b). There is no statistical difference in X_{FD} between the Harbour zone with the High Street, Hinterland Near or Hinterland Far zones. This is attributable to pronounced data variability as indicated by a large interquartile range (Figure 82a). In addition, there is considerable overlapping between the Harbour zone confidence interval with the High Street, Hinterland Near and Hinterland Far zones. These results provide clear evidence for enhanced X_{FD} in the burgh core and land immediately adjacent to the historical burgh limits (Hinterland Near). In addition, it should be noted that X_{FD} is significantly higher in the Hinterland Near zone compared to the burgh core.

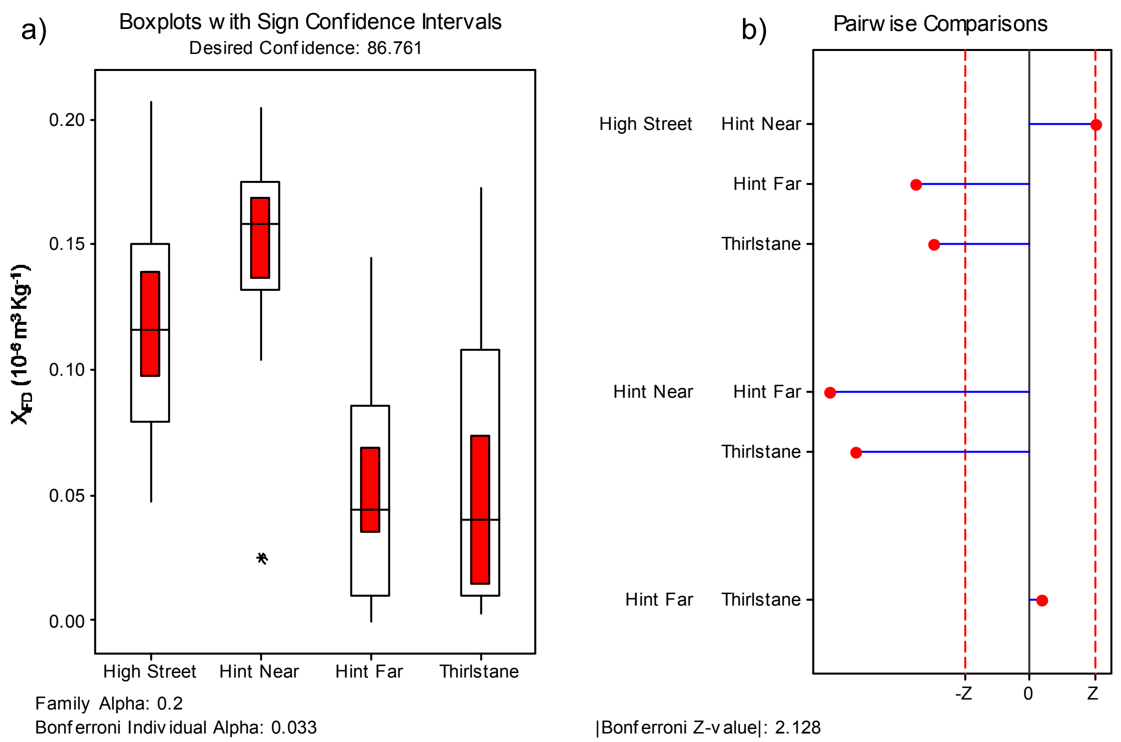


Figure 81: (a) Boxplot of median X_{FD} ($10^{-6}m^3Kg^{-1}$) for individual zones at Lauder; boundaries of boxes represent interquartile range, red shading indicates 86.761% confidence interval for median, outliers identified as *, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Lauder, Z values exceeding –Z or Z are significant at p<0.05 confidence level

The median X_{FD} of the High Street, Hinterland Near and Showfield zones at Wigtown is 0.47, 0.12 and 0.18 ($10^{-6}m^3Kg^{-1}$) respectively Figure 83a). The High Street has a significantly higher X_{FD} than the Hinterland Near ($p<0.001$) and Showfield zones ($p<0.001$) (Figure 83b). Additionally the Showfield zone has a significantly higher X_{FD} than the Hinterland Near zones ($p<0.05$). Despite the difference in X_{FD} between the Showfield and Hinterland Near zone, neither are enhanced in comparison to the High Street zone. It is, therefore, argued that these results highlight a clear contrast in X_{FD} between the burgh core and its hinterland.

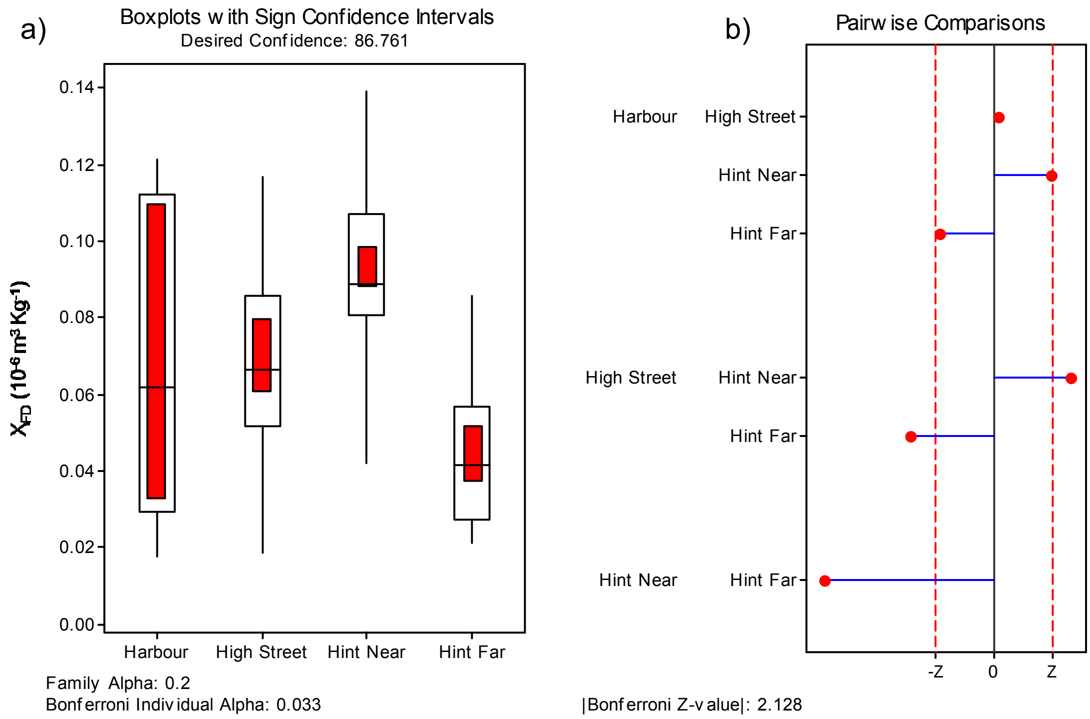


Figure 82: (a) Boxplot of median χ_{FD} ($10^{-6}m^3Kg^{-1}$) for individual zones at Pittenweem; boundaries of boxes represent interquartile range, red shading indicates 86.761% confidence interval for median, outliers identified as *, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Pittenweem, Z values exceeding –Z or Z are significant at p<0.05 confidence level

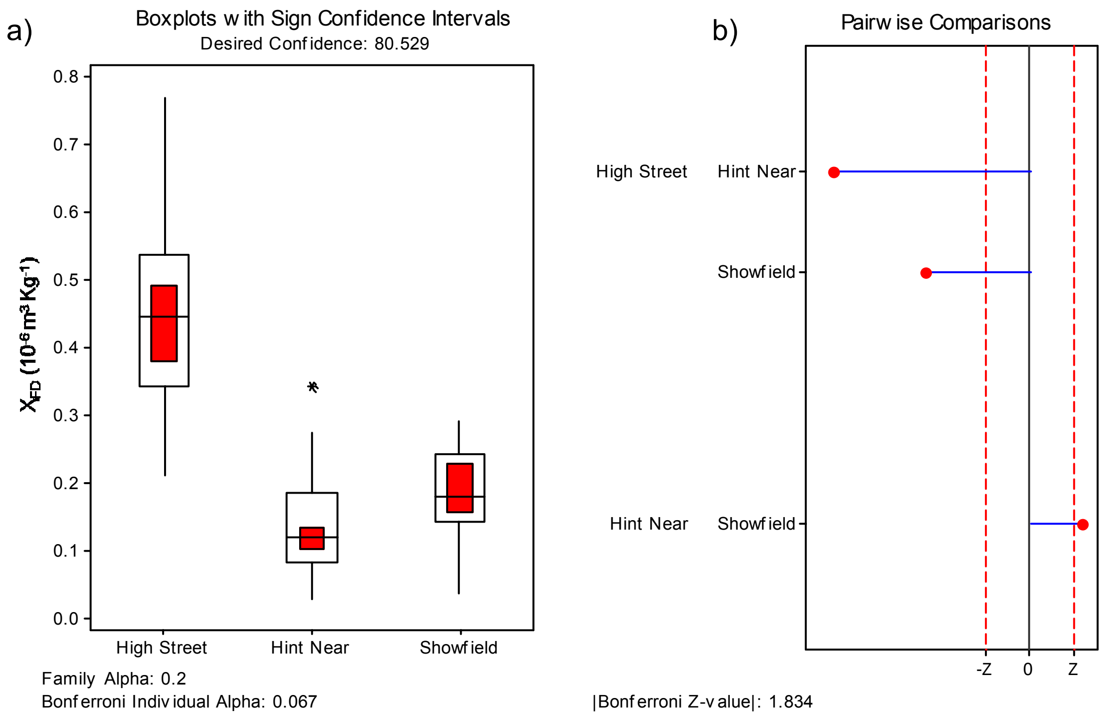


Figure 83: (a) Boxplot of median χ ($10^{-6}m^3Kg^{-1}$) for individual zones at Wigtown; boundaries of boxes represent interquartile range, red shading indicates 80.529% confidence interval for median, outliers identified as *, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Wigtown, Z values exceeding –Z or Z are significant at p<0.05 confidence level

6.4.2.2 Variation between Burghs

Results of a Two Way ANOVA undertaken using a GLM indicate that the mean χ_{FD} is significantly different between burghs ($p<0.001$). Tukey-Kramer (95% confidence intervals) multiple comparisons reveal that the mean χ_{FD} at Wigtown is significantly higher than Lauder and Pittenweem ($p<0.01$). Furthermore, Lauder has a significantly greater ($p<0.01$) mean χ_{FD} than Pittenweem.

Statistical analysis also reveals a significant difference between the High street and Hinterland Near zone ($p<0.001$). Results of ANOVA indicate significantly higher χ_{FD} for the High Street zone in comparison to the Hinterland Near zone ($p<0.001$). This finding is contradictory to trends identified for Lauder and Pittenweem in section 6.4.2.1 which are characterised by higher χ_{FD} in the Hinterland Near zone. This discrepancy arises from the computation of ANOVA which collectively tests High Street and Hinterland Near zone data for all three burghs. It is suggested that differences in the relationship between the High Street and Hinterland Near zone data between burghs may produce contradictory results to those obtained using Kruskal-Wallis analysis and Dunn's test.

Statistical analysis indicates significant interaction between the individual ANOVA test factors, burgh and zone. This finding supports results presented in 6.4.2.1 which reveal the occurrence of higher χ_{FD} in the Hinterland Near zone at Lauder and Pittenweem, and comparatively higher χ_{FD} in the High Street zone at Wigtown.

6.4.3 <u>Natural Variation of Magnetic Susceptibility</u>

Magnetic susceptibility of soil is influenced by a range of geological and pedological factors which determine Iron (Fe) content and abundance of magnetic minerals (Crowther 2003, Crowther and Barker 1995). Consequently areas of increased magnetic susceptibility can be attributed to environmental factors such as a change in underlying geology, and human activities. Correlation between Fe (mg/Kg) and χ ($10^{-6}m^3Kg^{-1}$) (Figure 84) shows a distinction between Wigtown and Lauder, and Wigtown and Pittenweem.

This finding supplements results presented in section 6.4.2.1, which indicate that there is no significant difference in mean χ between Lauder and Pittenweem, but do reveal a significant difference in mean χ between Wigtown with Lauder and Pittenweem. It is therefore suggested that variation in mean χ between burghs reflects differing geology. In addition it is apparent that there are different phases in the relationship between χ and Fe at Lauder and Wigtown. Further analysis of data indicates that there is separation of the High Street and Hinterland Near zones at Lauder, and High Street zone at Wigtown. This is in agreement with results presented in section 6.4.1.1. In the natural environment χ is largely determined by concentrations of ferrimagnetic minerals. It is therefore expected that variations in χ are strongly correlated with Fe concentrations. Results of Spearman Rank statistical analyses indicate a weak positive correlation between χ and Fe at Lauder (r_s 0.253), Pittenweem (r_s 0.206) and Wigtown (r_s 0.380). These results suggest that spatial distributions of χ are not closely related to Fe concentrations. It is therefore argued that trends in χ and χ_{FD} identified in sections 6.4.1 and 6.4.2, can be partially attributed to factors other than natural variation.

Comparison between 'reference' soil profile χ with functional zones in each burgh also confirm enhancement exceeding natural conditions. At Lauder χ is five times higher in the High Street (2.29) and Hinterland Near (2.03) zone compared to reference profile LA 7 (0.33). At Pittenweem χ is nearly double in the Harbour (2.04), High Street (2.21) and Hinterland Near (1.99) zones compared to reference profile PT 1 (1.01). Similarly χ is four times higher in the High street (7.06) zone at Wigtown in comparison to reference soil profile WG 5 (1.46).

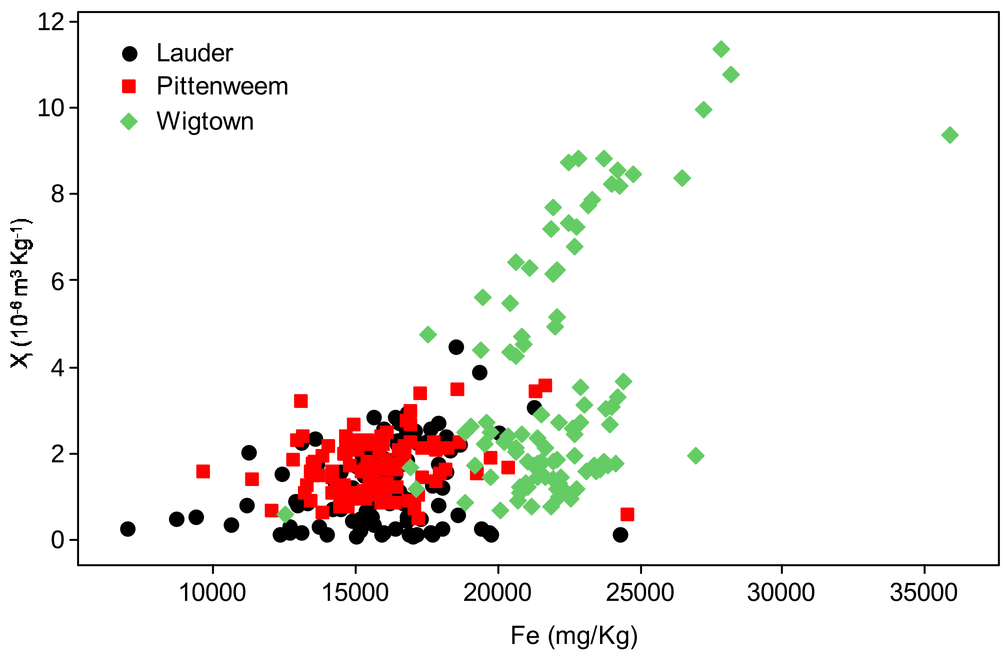


Figure 84: Scatterplot of Fe (mg/Kg) vs. χ ($10^{-6}m^3Kg^{-1}$) for Lauder, Pittenweem and Wigtown

6.5 Summary of Results: Soil Physical and Chemical Properties

The following section presents a brief summary of key trends in soil physical and chemical properties both within and between burghs. The significance of these results is discussed in section 8.1.1 and 8.2.1. Consideration is given to differences in soil modification between burgh cores and their hinterland as a result of past waste disposal.

6.5.1 <u>Variation within Burghs</u>

6.5.1.1 Lauder

Two zones are identified as important areas of interest at Lauder; the High Street zone and the Hinterland Near zone. Both of these zones are characterised by deepened topsoils, higher % LOI and enhanced mass dependant magnetic susceptibility (Table 10). Enhancement in X_{FD} is also noted within the High Street and Hinterland Near zones, however X_{FD} is comparatively higher in the Hinterland Near zone. Moreover a distinct contrast in soil pH is noted between these two zones. The High Street has characteristically neutral soils in comparison to Hinterland Near zone which is acidic.

6.5.1.2 Pittenweem

The Harbour, High Street and Hinterland Near zones are identified as important areas of interest at Pittenweem. These zones are characterised by deepened topsoils, enhanced mass dependant magnetic susceptibility and higher % LOI (Table 10). The Harbour zone has the highest % LOI, followed in succession by the High Street and Hinterland Near zones. Enhancement of X_{FD} is identified in all three zones at Pittenweem, however it should be noted that X_{FD} is comparatively higher in the Hinterland Near zone. Moreover a distinct contrast in soil pH is noted between the Hinterland Near zone which is acidic, with the Harbour and High Street zones which have neutral soil pH.

6.5.1.3 Wigtown

The High Street zone is identified as an important area of interest at Wigtown. Compared to the surrounding hinterland the High Street zone has deepened topsoils, a neutral soil pH, higher % LOI, and enhanced magnetic susceptibility and X_{FD} (Table 10).

6.5.1.4 Depth

Results presented in section 6.2.1.2 reveal a significant difference in soil pH between depths at Lauder and Pittenweem (Table 11). In both cases soil pH increases with depth whilst retaining spatial trends identified at 0-20cm, for example there is a consistent distinction between neutral soil pH values in the burgh core with acidic hinterland soils.

Results presented in section 6.3.1.2 show a decrease in % LOI associated with depth at both Lauder and Pittenweem, however, the relationship between zone and depth differs between these two burghs. Given the absence of interaction between depth and zone at Pittenweem it is argued that spatial trends identified at 0-20cm are consistent at successive depths. Conversely statistical interaction between depth and zone at Lauder signifies that variations in % LOI at subsequent depths are not fully attributable to differenced associated with zones.

Table 10: Summary of trends in soil physical and chemical properties identified at Lauder, Pittenweem and Wigtown

Measurement	Lauder	Pittenweem	Wigtown
Topsoil Depth (cm)	Deepened topsoil in burgh core (High Street zone) and immediate hinterland (Hinterland Near zone)	Deepened topsoil in burgh core (Harbour and High Street zones) and immediate hinterland (Hinterland Near zone)	Deepened topsoil in burgh core (High Street zone)
pH	Neutral pH in burgh core (High Street zone) and acidic pH in the hinterland (Hinterland Near, Hinterland Far and Thirlstane zones)	Neutral pH in burgh core (Harbour and High Street zones) and acidic pH in the hinterland (Hinterland Near and Hinterland Far zones)	Neutral pH in burgh core (High Street zone) and acidic pH in the hinterland (Hinterland Near and Showfield zones)
% LOI	Enhanced % LOI in burgh core (High Street zone) and immediate hinterland (Hinterland Near zone)	Enhanced % LOI in burgh core (Harbour and High Street zones) and immediate hinterland (Hinterland Near zone)	Enhanced % LOI in burgh core (High Street zone)
χ ($10^{-6}m^3Kg^{-1}$)	Enhanced χ in burgh core (High Street zone) and immediate hinterland (Hinterland Near zone)	Enhanced χ in burgh core (High Street zone) and immediate hinterland (Hinterland Near zone)	Enhanced χ in burgh core (High Street zone)
χ_{FD} ($10^{-6}m^3Kg^{-1}$)	Enhanced χ_{FD} in burgh core (High Street zone) and immediate hinterland (Hinterland Near zone). Enhancement greatest in Hinterland Near zone	Enhanced χ_{FD} in burgh core (High Street zone) and immediate hinterland (Hinterland Near zone). Enhancement greatest in Hinterland Near zone	Enhanced χ_{FD} in burgh core (High Street zone)

Table 11: Comparison of trends in pH and LOI associated with depth at Lauder and Pittenweem

Measurement	Lauder	Pittenweem
pH	Increase in pH associated with depth. Spatial trends present at 0-20cm occur at 20-40cm. No significant interaction between zone and depth	Increase in pH associated with depth. Spatial trends identified at 0-20cm are present at 20-40, 40-60 and 60-80cm depth. No significant interaction between zone and depth
% LOI	Decrease in % LOI associated with depth. Spatial trends identified at 0-20cm are not consistent at 20-40cm. Significant interaction between zone and depth	Decrease in % LOI associated with depth. Spatial trends identified at 0-20cm are present at 20-40, 40-60 and 60-80cm depth. No significant interaction between zone and depth

6.5.2 Variation between Burghs

All three burghs have deepened topsoil, higher % LOI, and enhanced magnetic susceptibility and χ_{FD} in zones corresponding to the burgh core (Harbour and High Street). Trends identified in the burgh core at Lauder and Pittenweem are also replicated in land immediately adjacent to the historical burgh limits (Hinterland Near), although it should be noted that χ_{FD} is comparatively higher in the Hinterland Near zone (Table 12). Moreover, a distinct contrast in soil pH is noted between the burgh core and Hinterland Near zone at all three burghs. The burgh core has characteristically neutral soil in contrast to the Hinterland Near zone which has typically acidic soils.

Table 12: Comparison of trends in soil physical and chemical properties identified at Lauder, Pittenweem and Wigtown

Measurement	Comparison between Burghs
Topsoil Depth (cm)	All three burghs have deepened topsoil deposits in the burgh core. Lauder and Pittenweem have deepened deposits in the immediate hinterland (Hinterland Near zone)
pH	All three burghs have higher a pH in the burgh core. All three burghs show a contrast between neutral pH in the old burgh core and acidic pH in the hinterland
% LOI	All three burghs have enhanced LOI in the burgh core. Lauder and Pittenweem have enhanced LOI in the immediate hinterland (Hinterland Near zone)
χ ($10^{-6}m^3Kg^{-1}$)	All three burghs have higher χ in the burgh core. Lauder and Pittenweem have enhanced χ in the immediate hinterland (Hinterland Near zone)
χ_{FD} ($10^{-6}m^3Kg^{-1}$)	All three burghs have enhanced χ_{FD} in the burgh core. Lauder and Pittenweem have enhanced χ_{FD} in the immediate hinterland (Hinterland Near). Enhancement of χ_{FD} is most pronounced in the Hinterland Near zone at Lauder and Pittenweem

7 Elemental Analyses

This chapter presents the results of a series of elemental analyses including multiple comparisons of anthropogencially significant elements, cluster analysis and discriminant analysis. Data are presented collectively for Lauder, Pittenweem and Wigtown to facilitate visual and statistical analysis.

7.1 Elemental Concentrations

The following section presents spatial distributions of selected elemental concentrations including, barium (Ba), calcium (Ca), lead (Pb), potassium (K), phosphorus (P), strontium (Sr) and zinc (Zn). These elements were selected for detailed analysis because of their utility in characterising areas of past human activity (Entwistle *et al.,* 2000a, Entwistle *et al.,* 2000b, Entwistle *et al.,* 1998, Wilson *et al.,* 2006a).

7.1.1 Barium

Spatial distributions of barium (Ba) are presented for Lauder (Figure 85), Pittenweem (Figure 86a) and Wigtown (Figure 86b). Patterns in Ba associated with zones are subsequently identified and comparisons between burghs are made.

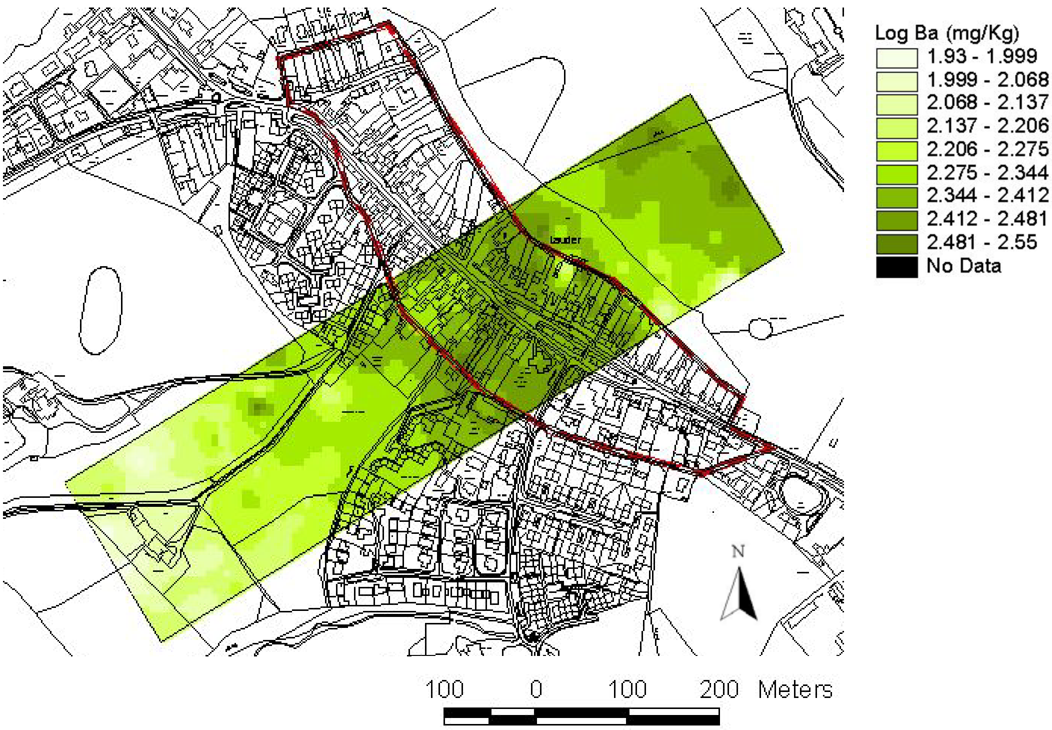


Figure 85: Spatial distribution of Log Ba (mg/Kg) at Lauder. Red boundary delimits 1862AD urban extent

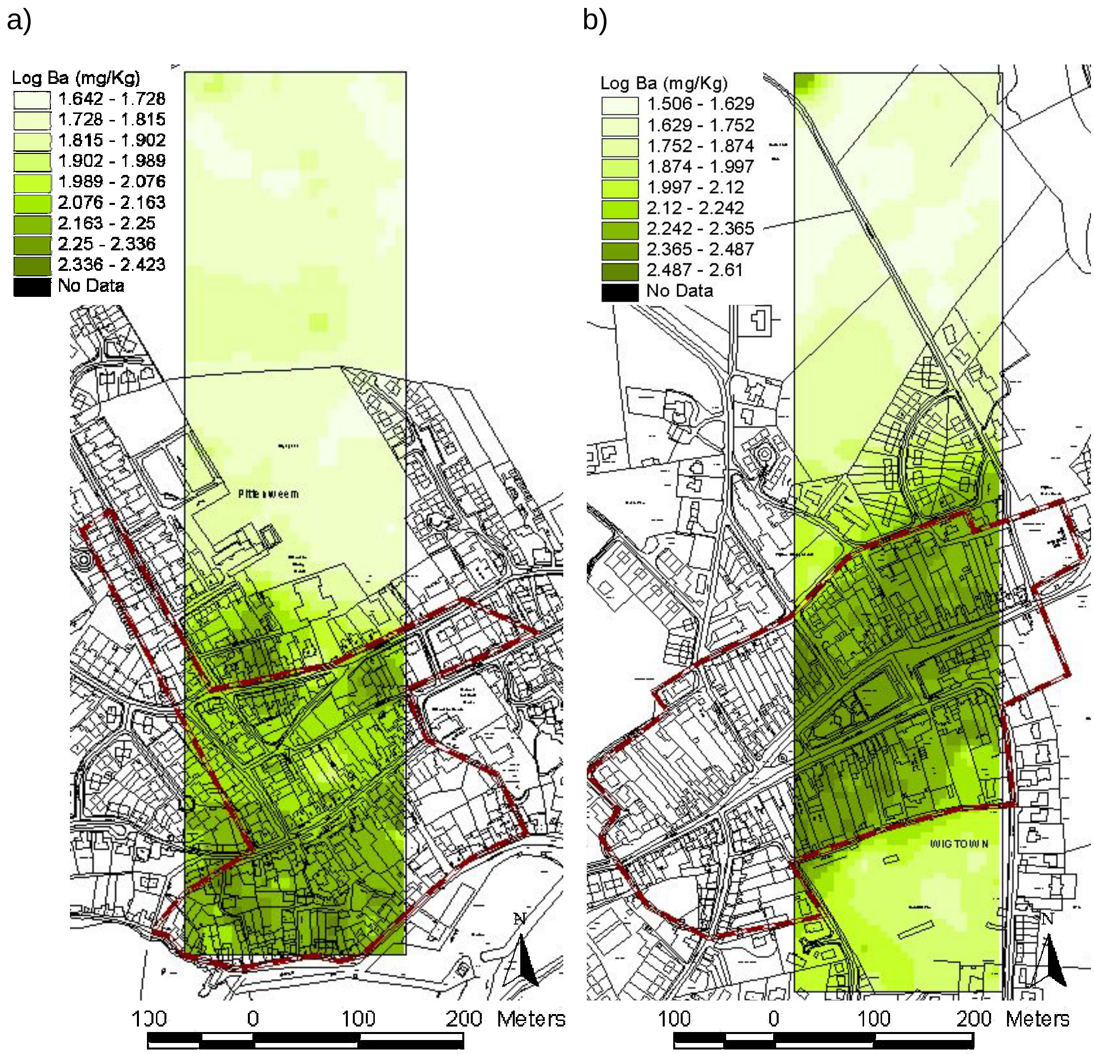


Figure 86: Spatial distribution of Log Ba (mg/Kg) at Pittenweem (a) and Wigtown (b). Red boundary delimits 1855AD and 1850AD urban extent respectively

7.1.1.1 Variation within Burghs

The mean Ba concentration of the High Street, Hinterland Near, Hinterland Far and Thirlstane zones at Lauder is 256, 189, 151 and 228 mg/Kg respectively (Figure 87). Results of One Way ANOVA with Tukey-Kramer multiple comparisons indicate that both the High Street and Thirlstane zones have significantly higher Ba than the Hinterland Near and Hinterland Far zones ($p<0.001$). Moreover, Ba is significantly higher in the Hinterland Near zone compared to the Hinterland Far zone ($p<0.001$). There is no significant difference in mean Ba concentration between the High Street and Thirlstane zones. These results indicate similar patterns of Ba enhancement in the burgh core and immediate hinterland north of Lauder (Thirlstane). To a lesser extent Ba is also enhanced in the immediate hinterland south of Lauder (Hinterland Near).

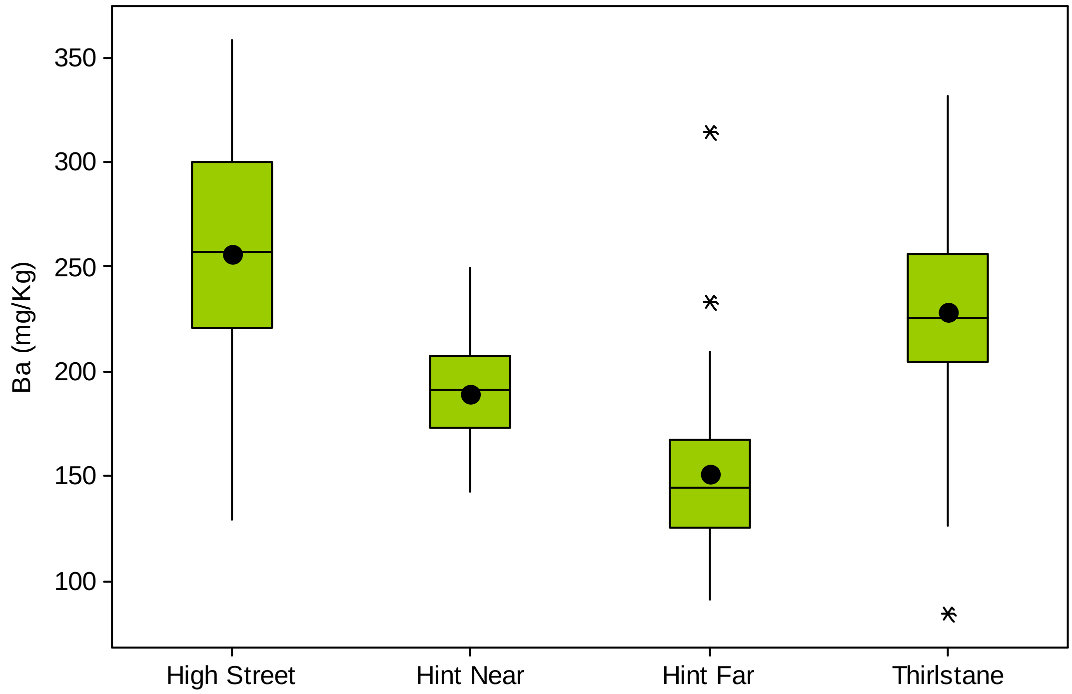


Figure 87: Boxplot of median and mean Ba (mg/Kg) for individual zones at Lauder; bar indicates median, black circle denotes mean; boundaries of boxes represent interquartile range, outliers identified as *

The median Ba concentration of the Harbour, High Street, Hinterland Near and Hinterland Far zones at Pittenweem is 153.4, 147.7, 62.5 and 61.6 mg/Kg respectively (Figure 88a). Both the Harbour and High Street zones have significantly higher Ba than the Hinterland Near and Hinterland Far zones ($p<0.001$) (Figure 88b). There is no significant difference in median Ba concentrations between the Harbour zone and High street zones. Similarly, there is no statistical difference in Ba between the Hinterland Near and Hinterland far zones. These results provide clear evidence of Ba enhancement within the burgh core at Lauder.

The median Ba concentration for the High street, Hinterland Near and Showfield zones at Wigtown is 236.6, 48.9 and 94.9 mg/Kg respectively (Figure 89a). The High Street zone has significantly higher Ba than the Hinterland Near and Showfield zones ($p<0.001$). In addition the Showfield zone has significantly higher Ba than the Hinterland Near zone ($p<0.001$) (Figure 89b). These results indicate enhanced levels of Ba in the burgh core and to a lesser extent the immediate hinterland south of Wigtown (Showfield).

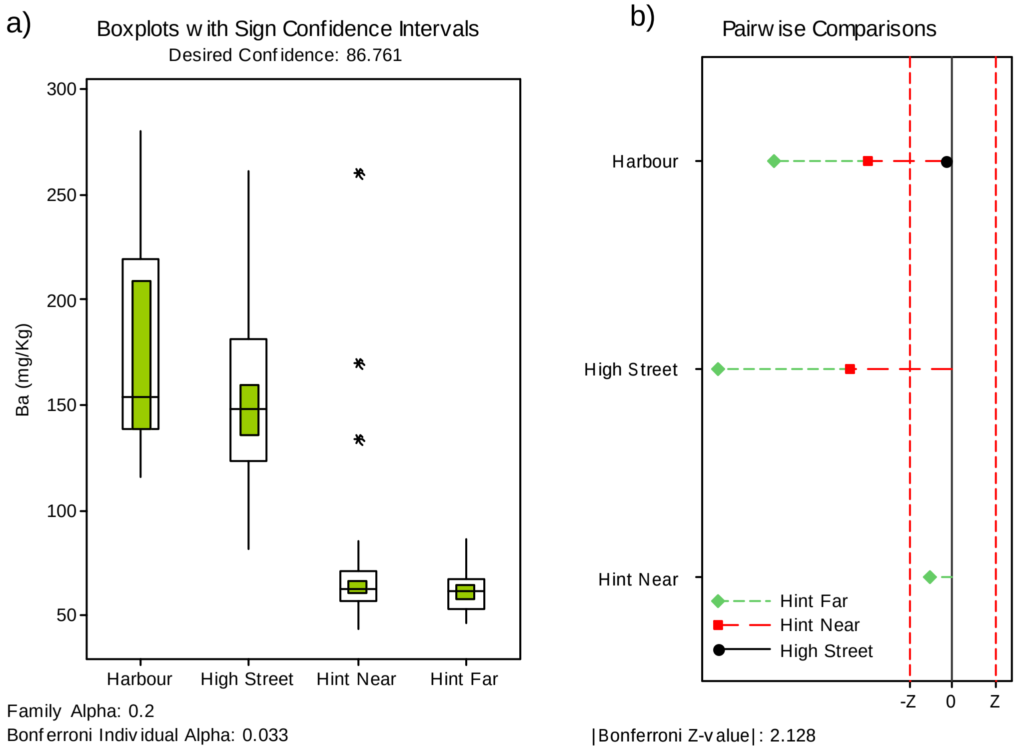


Figure 88: (a) Boxplot of median Ba (mg/Kg) for individual zones at Pittenweem; boundaries of boxes represent interquartile range, green shading indicates 86.761% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Pittenweem, -Z or Z are significant at p<0.05 confidence level

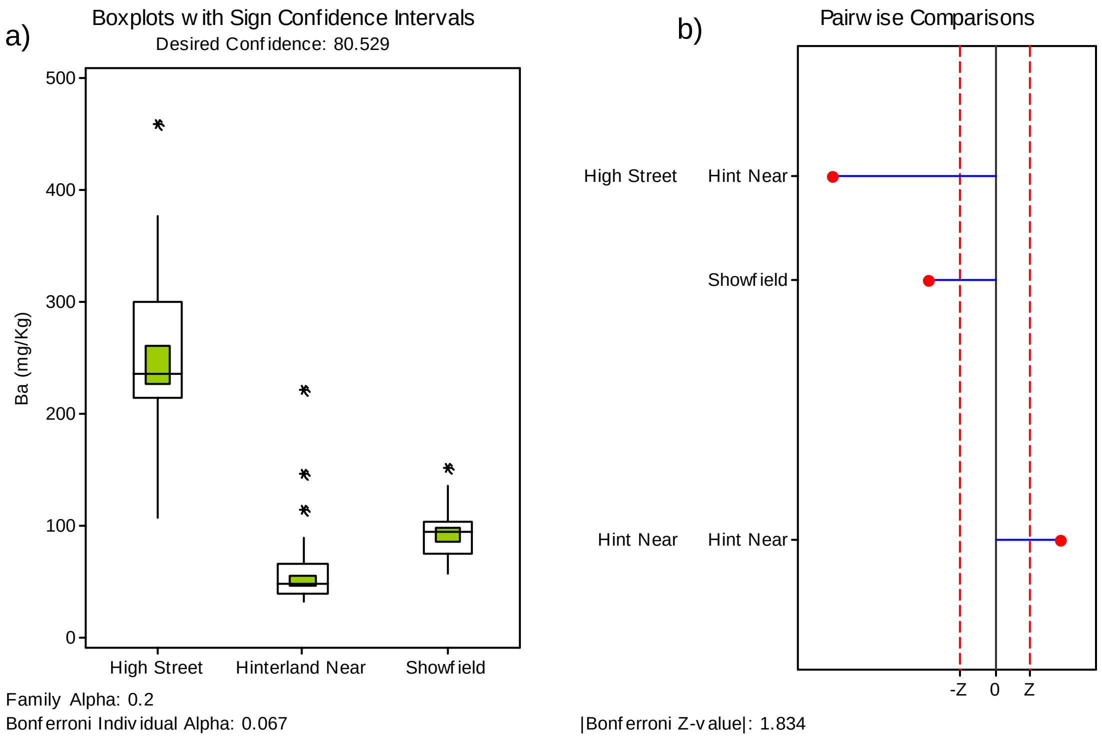


Figure 89: (a) Boxplot of median Ba (mg/Kg) for individual zones at Wigtown; boundaries of boxes represent interquartile range, green shading indicates 80.529% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Wigtown, -Z or Z are significant at p<0.05 confidence level

7.1.1.2 Variation between Burghs

All three burghs have enhanced levels of Ba in zones corresponding to the burgh core (Harbour and High Street). Enhancement of Ba is confined to Pittenweem's burgh core; however, both Lauder and Wigtown have additionally enhanced zones in the hinterland. Ba is enhanced in the immediate hinterland north of Lauder (Thirlstane) to a level comparable with the burgh core, and to a lesser extent in the immediate hinterland south of the historical burgh limits (Hinterland Near). Similarly Ba is enhanced in the immediate hinterland south of Wigtown (Showfield), albeit significantly less than the High Street zone.

7.1.2 Calcium

Spatial distributions of calcium (Ca) are presented for Lauder (Figure 90), Pittenweem (Figure 91a) and Wigtown (Figure 91b). Patterns in Ca associated with zones are subsequently identified and comparisons between burghs are made.

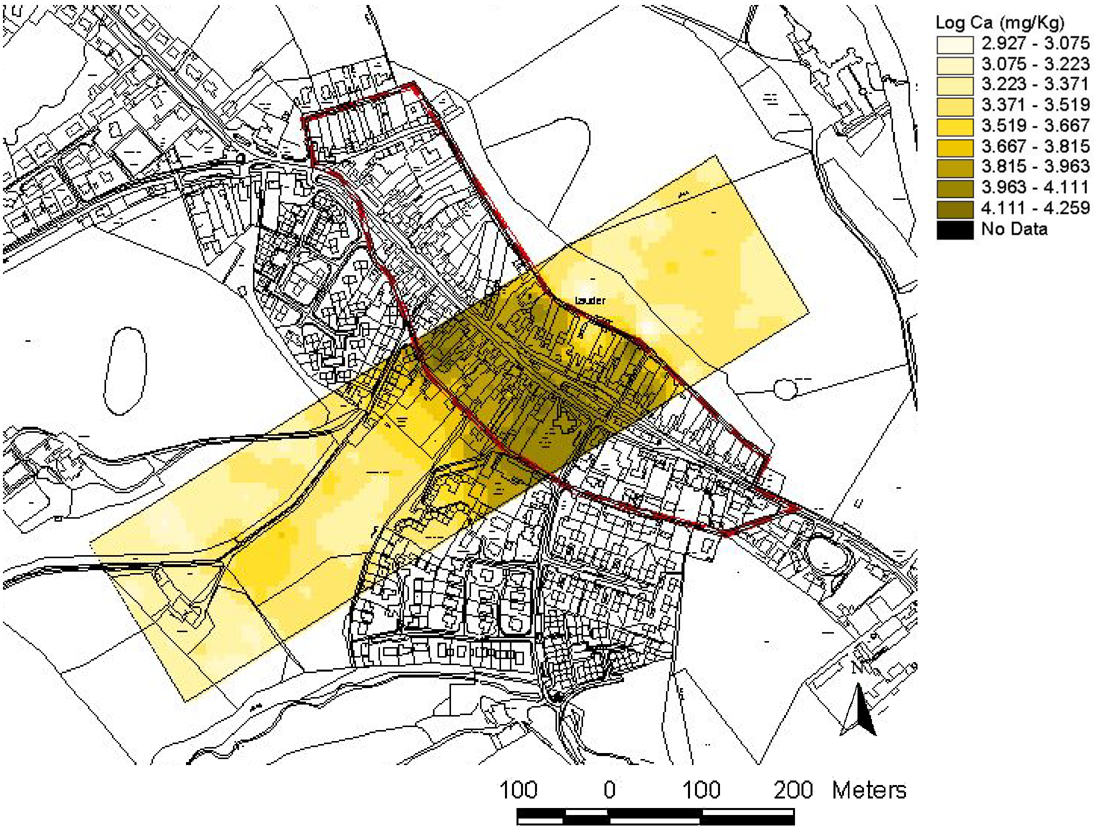


Figure 90: Spatial distribution of Log Ca (mg/Kg) at Lauder. Red boundary delimits 1862AD urban extent

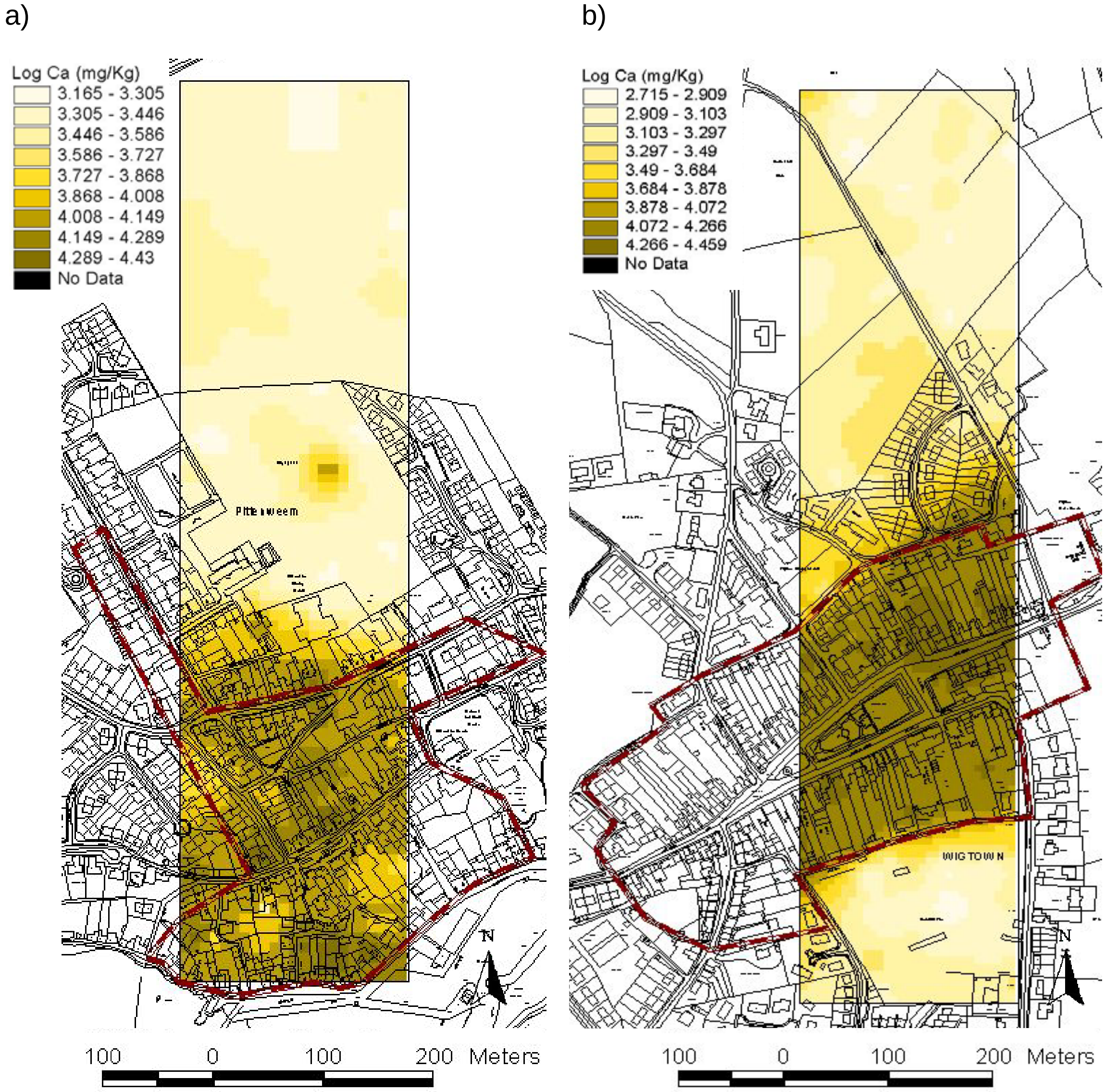


Figure 91: Spatial distribution of Log Ca (mg/Kg) at Pittenweem (a) and Wigtown (b). Red boundary delimits 1855AD and 1850AD urban extent respectively

7.1.2.1 Variation within Burghs

The median Ca concentration of the High Street, Hinterland Near, Hinterland Far and Thirlstane zones at Lauder is 9076, 2959, 1844 and 2458 mg/Kg respectively (Figure 92a). The High Street has significantly higher Ca than the Hinterland Near, Hinterland Far and Thirlstane zones ($p<0.001$). The Hinterland Near zone has significantly higher Ca than the Hinterland Far zone ($p<0.001$) (Figure 92b). However there is no statistical difference in median Ca concentrations between the Hinterland Near and Thirlstane zones. These results indicate enhancement of Ca within Lauder's burgh core. Elevated Ca levels are also identified in the immediate hinterland south of Lauder (Hinterland Near); however it should be noted that Ca concentrations in the Hinterland Near zone are significantly lower than the High Street zone.

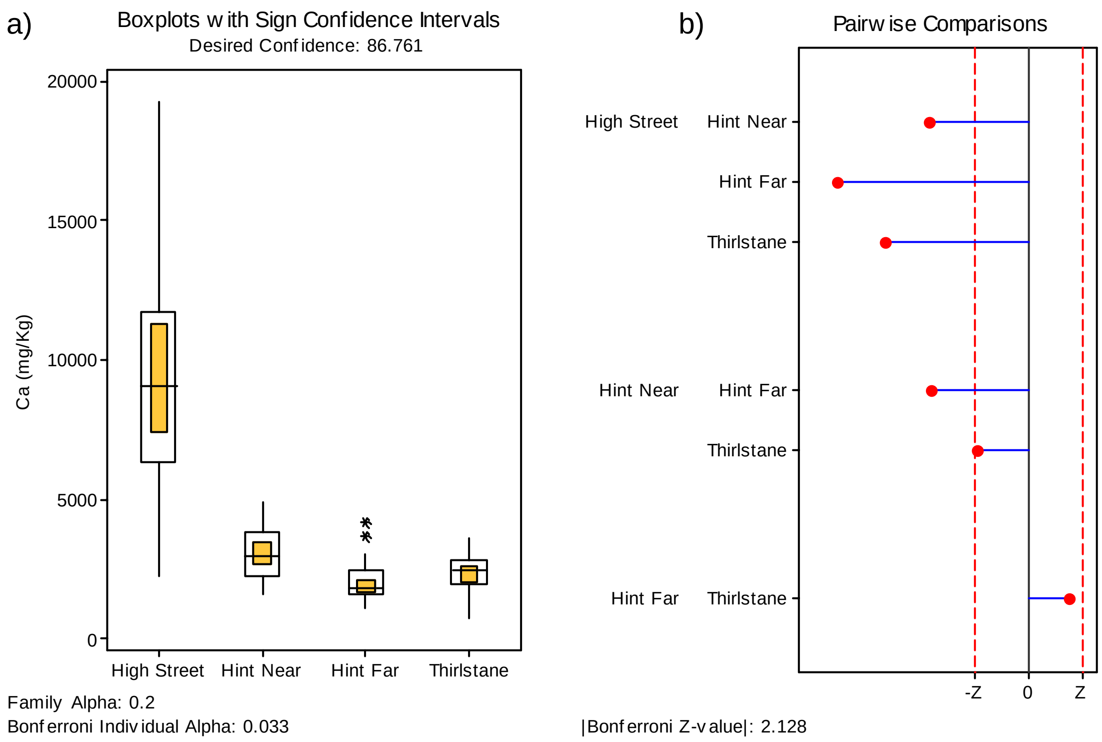


Figure 92: (a) Boxplot of median Ca (mg/Kg) for individual zones at Lauder; boundaries of boxes represent interquartile range, yellow shading indicates 86.761% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Lauder, -Z or Z are significant at p<0.05 confidence level

The median Ca concentration of the Harbour, High Street, Hinterland Near and Hinterland Far zones is at Pittenweem is 17414, 11756, 2580 and 2608.6 mg/Kg respectively (Figure 93a). Both the Harbour and High Street zones have significantly higher Ca than the Hinterland Near and Hinterland Far zones ($p<0.001$). There is no significant difference in median Ca concentrations between the Harbour and High Street zones. Moreover, there is no statistical difference in Ca concentrations between the Hinterland Near and Hinterland Far zones (Figure 93b). These results provide a clear indication of Ca enhancement within the burgh core at Pittenweem.

The median Ca concentration of the High Street, Hinterland Near and Showfield zones at Wigtown is 17038, 1522 and 1143 mg/Kg respectively (Figure 94a). The High Street has significantly higher Ca than the Hinterland Near and Showfield zones ($p<0.001$). In addition, there is no significant difference in median Ca concentrations between the Hinterland Near and Showfield zones. Similar to results identified at Pittenweem, there is distinct enhancement of Ca within the burgh core at Wigtown.

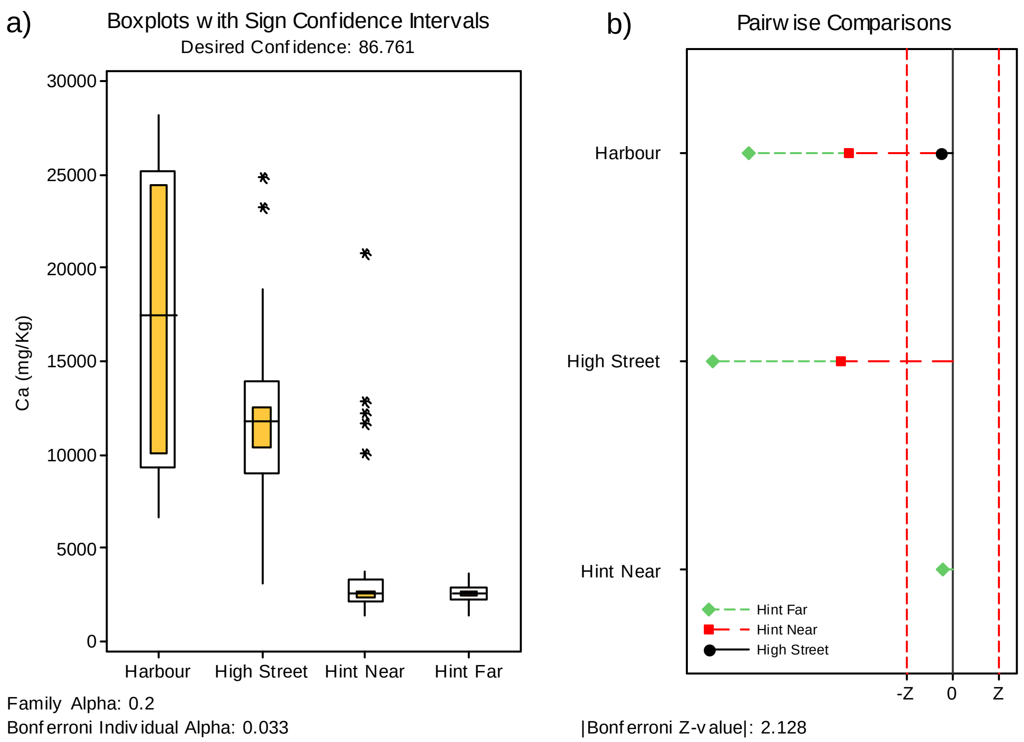


Figure 93: (a) Boxplot of median Ca (mg/Kg) for individual zones at Pittenweem; boundaries of boxes represent interquartile range, yellow shading indicates 86.761% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Pittenweem, -Z or Z are significant at p<0.05 confidence level

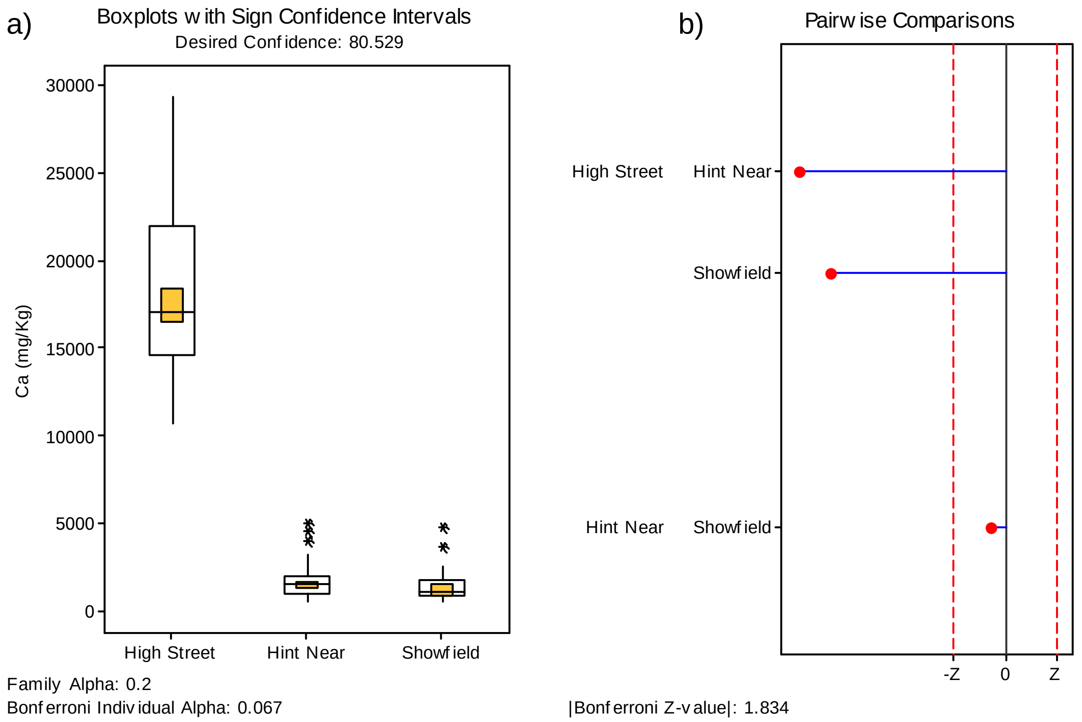


Figure 94: (a) Boxplot of median Ca (mg/Kg) for individual zones at Wigtown; boundaries of boxes represent interquartile range, yellow shading indicates 80.529% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Wigtown, -Z or Z are significant at p<0.05 confidence level

7.1.2.2 Variation between Burghs

Similar to trends identified for Ba in section 7.1.1, all three burghs have significant enhancement of Ca in zones within the burgh core (Harbour and High street). Increased Ca concentrations are characteristically limited to the burgh core within Pittenweem and Lauder. However, comparatively higher Ca levels are noted in the immediate hinterland south of Lauder (Hinterland Near). Nevertheless it should be noted that this area has a significantly lower median Ca concentration than the High Street zone.

7.1.3 Lead

Spatial distributions of lead (Pb) are presented for Lauder (Figure 95), Pittenweem (Figure 96a) and Wigtown (Figure 96b). Patterns in Pb associated with zones are subsequently identified and comparisons between burghs are made.

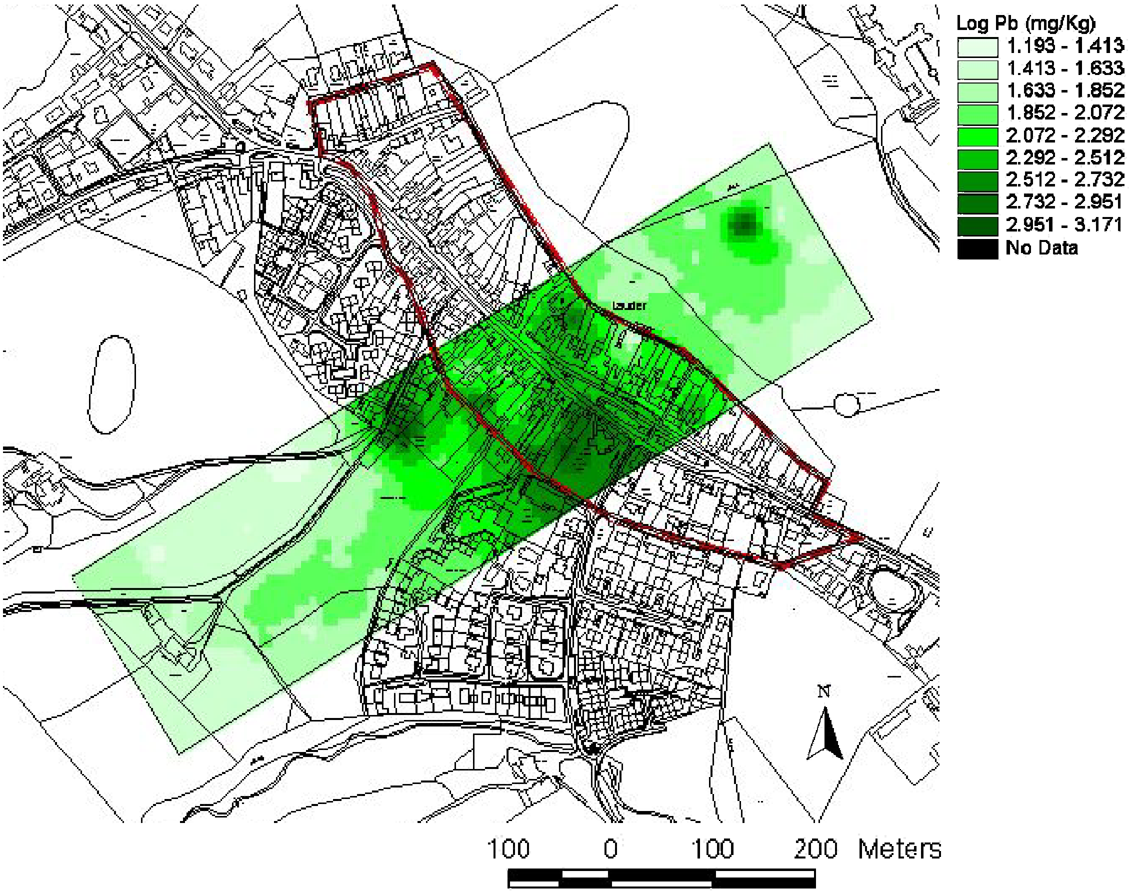


Figure 95: Spatial distribution of Log Pb (mg/Kg) at Lauder. Red boundary delimits 1862AD urban extent

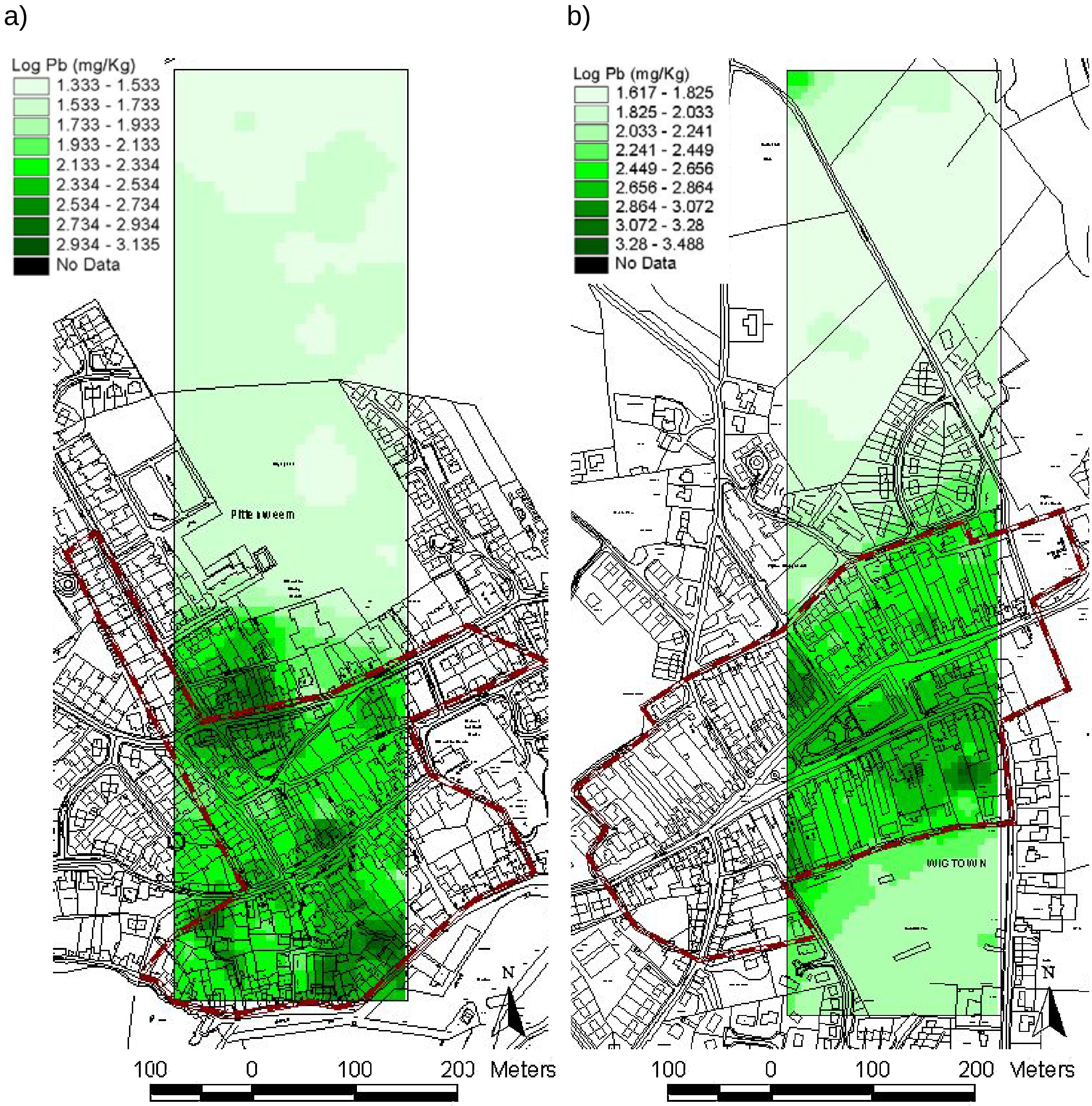


Figure 96: Spatial distribution of Log Pb (mg/Kg) at Pittenweem (a) and Wigtown (b). Red boundary delimits 1855AD and 1850AD urban extent respectively

7.1.3.1 Variation within Burghs

The median Pb concentration of the High Street, Hinterland Near, Hinterland Far and Thirlstane zones at Lauder is 209.9, 77.7, 32.35 and 59.1 mg/Kg respectively (Figure 97a). The High Street zone has significantly higher Pb than Hinterland Near ($p<0.05$), Hinterland Far ($p<0.001$) and Thirlstane ($p<0.001$) zones. The Hinterland Near zone has significantly higher Pb than Hinterland Far ($p<0.001$) and Thirlstane zones ($p<0.05$). Moreover, the Thirlstane zone has significantly higher Pb than the Hinterland Far zone ($p<0.001$) (Figure 97). These results indicate significant enhancement of Pb within the burgh core. To a lesser extent, elevated levels of Pb are also identified in the immediate hinterland south (Hinterland Near) and north of Lauder (Thirlstane).

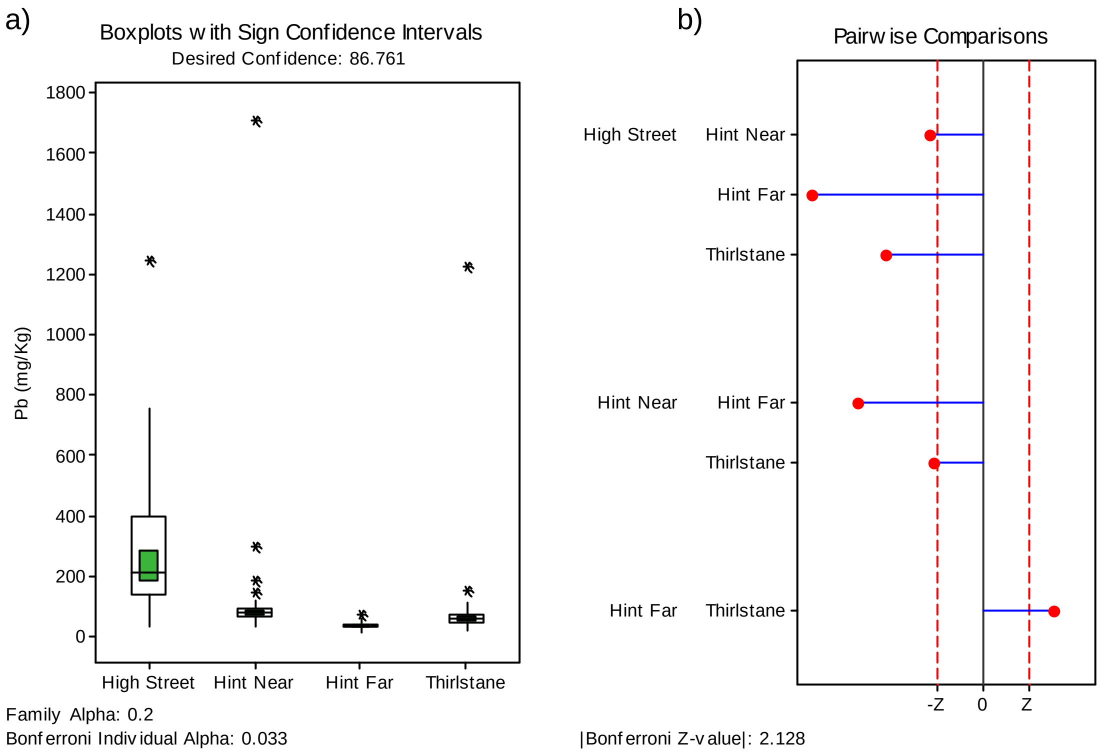


Figure 97: (a) Boxplot of median Pb (mg/Kg) for individual zones at Lauder; boundaries of boxes represent interquartile range, green shading indicates 86.761% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Lauder, -Z or Z are significant at p<0.05 confidence level

The mean Pb concentration of the Harbour, High Street, Hinterland Near and Hinterland Far zones at Pittenweem is 221, 182, 43.3 and 34.866 mg/Kg respectively (Figure 98). Results of One Way ANOVA with Tukey-Kramer multiple comparisons indicate that Pb levels are significantly higher in the Harbour zone compared to the Hinterland Near and Hinterland Far zones ($p<0.001$). Likewise the High Street zone has significantly higher Pb than the Hinterland Near and Hinterland Far zones ($p<0.001$). There is no statistical difference between the Harbour and High Street zones, and the Hinterland Near and Hinterland Far zones. These results provide clear evidence of enhanced Pb concentrations within Pittenweem's burgh core.

The median Pb concentration of the High Street, Hinterland Near and Showfield zones at Wigtown is 373.9, 63.18 and 151.31 mg/Kg respectively (Figure 99a). The High Street zone has significantly higher Pb than the Hinterland Near ($p<0.001$) and Showfield zones ($p<0.01$). Moreover, the Showfield zone has a significantly higher median Pb concentration compared to the Hinterland Near zone ($p<0.001$) (Figure 82b).

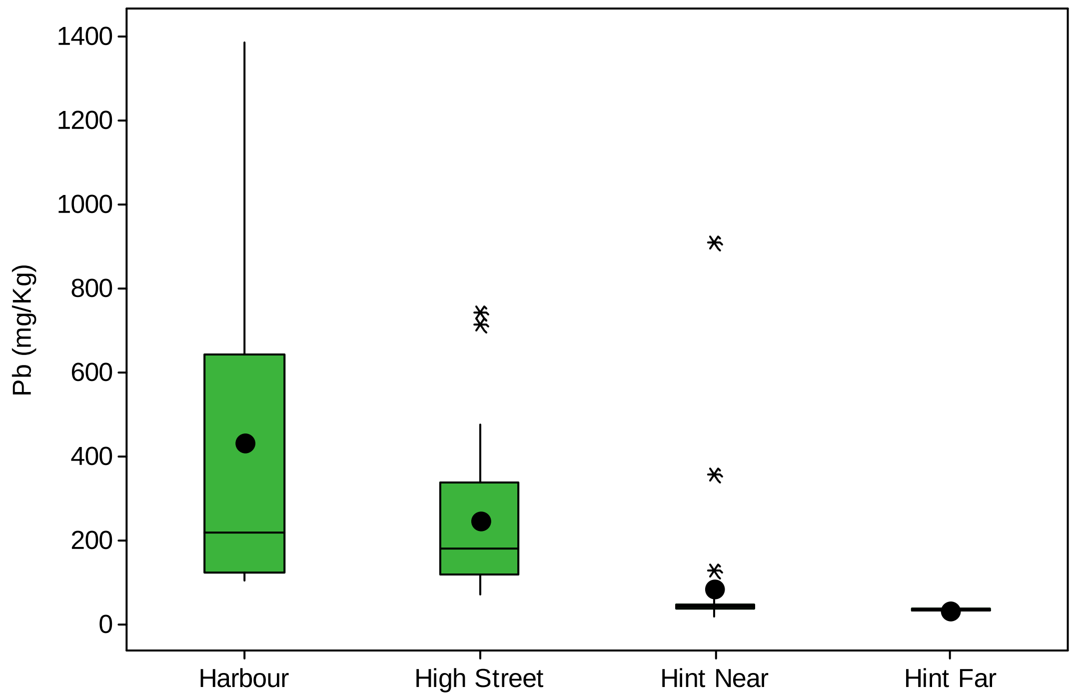


Figure 98: Boxplot of median and mean Pb (mg/Kg) for individual zones at Pittenweem; bar indicates median, black circle denotes mean; boundaries of boxes represent interquartile range, outliers identified as *

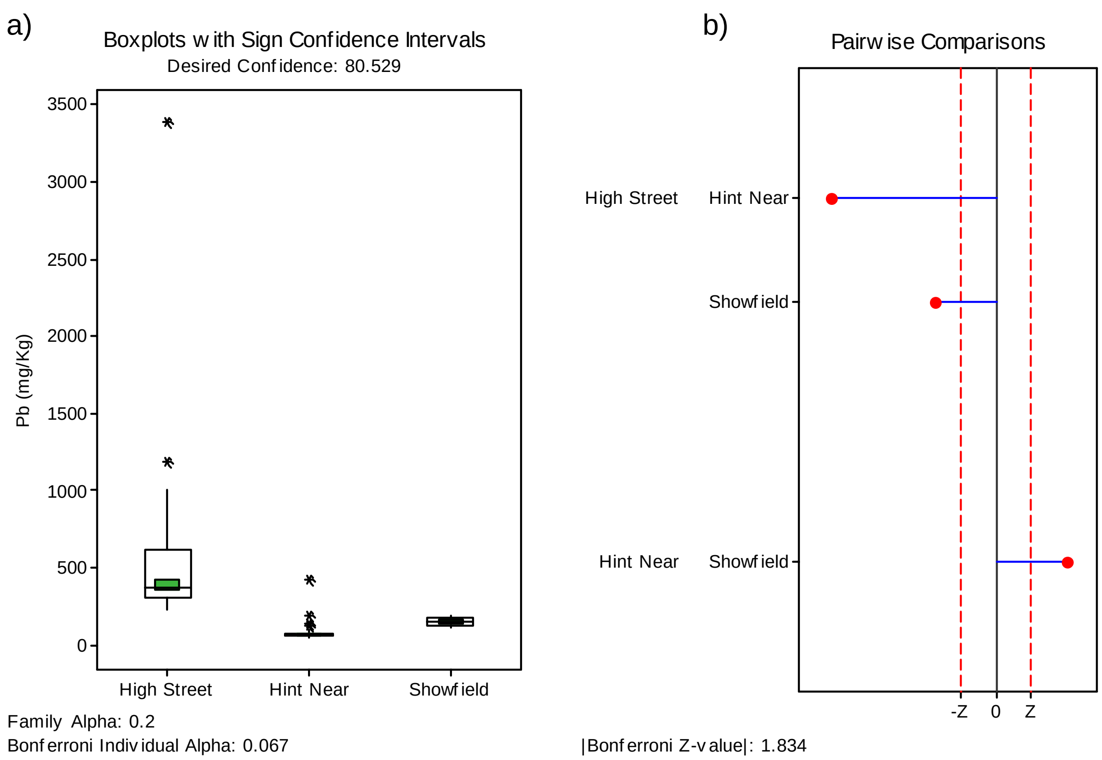


Figure 99: (a) Boxplot of median Pb (mg/Kg) for individual zones at Wigtown; boundaries of boxes represent interquartile range, green shading indicates 80.529% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Wigtown, -Z or Z are significant at p<0.05 confidence level

These results indicate enhanced Pb levels within the burgh core at Wigtown. To a lesser extent enhanced Pb levels are identified in the hinterland south of Wigtown (Showfield), however it should be noted that median Pb concentrations are significantly lower compared to the burgh core.

7.1.3.2 Variation between Burghs

All three burghs have significant enhancement of Pb concentrations in zones within the burgh core (Harbour and High Streets). Enhancement of Pb at Pittenweem is confined to the burgh core; however, both Lauder and Wigtown have additionally enhanced zones in the hinterland. Pb levels are elevated in the immediate hinterland south (Hinterland Near) and north of Lauder (Thirlstane). Similarly Pb is enhanced in the immediate hinterland south of Wigtown (Showfield). It should be noted that Pb concentrations in these hinterland areas are significantly less than the High Street zone.

7.1.4 Potassium

Spatial distributions of potassium (K) are presented for Lauder (Figure 100), Pittenweem (Figure 101a) and Wigtown (Figure 101b). Patterns in K associated with zones are subsequently identified and comparisons between burghs are made.

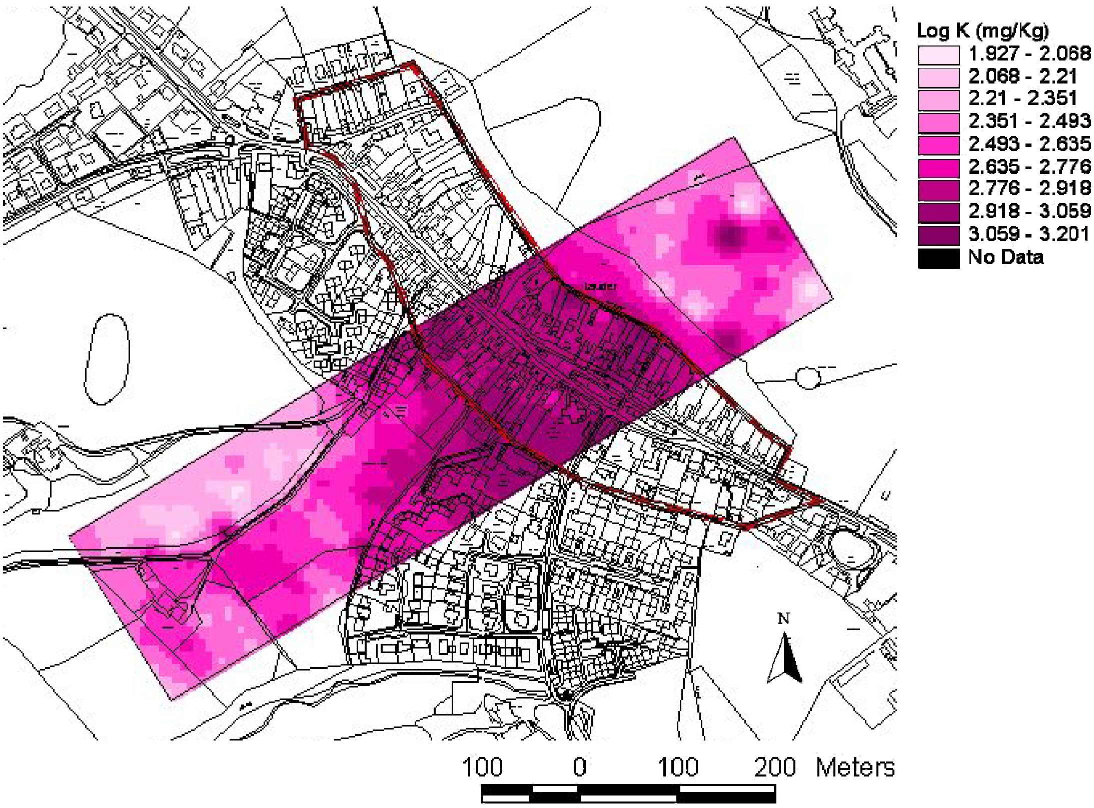


Figure 100: Spatial distribution of Log K (mg/Kg) at Lauder. Red boundary delimits 1862AD urban extent

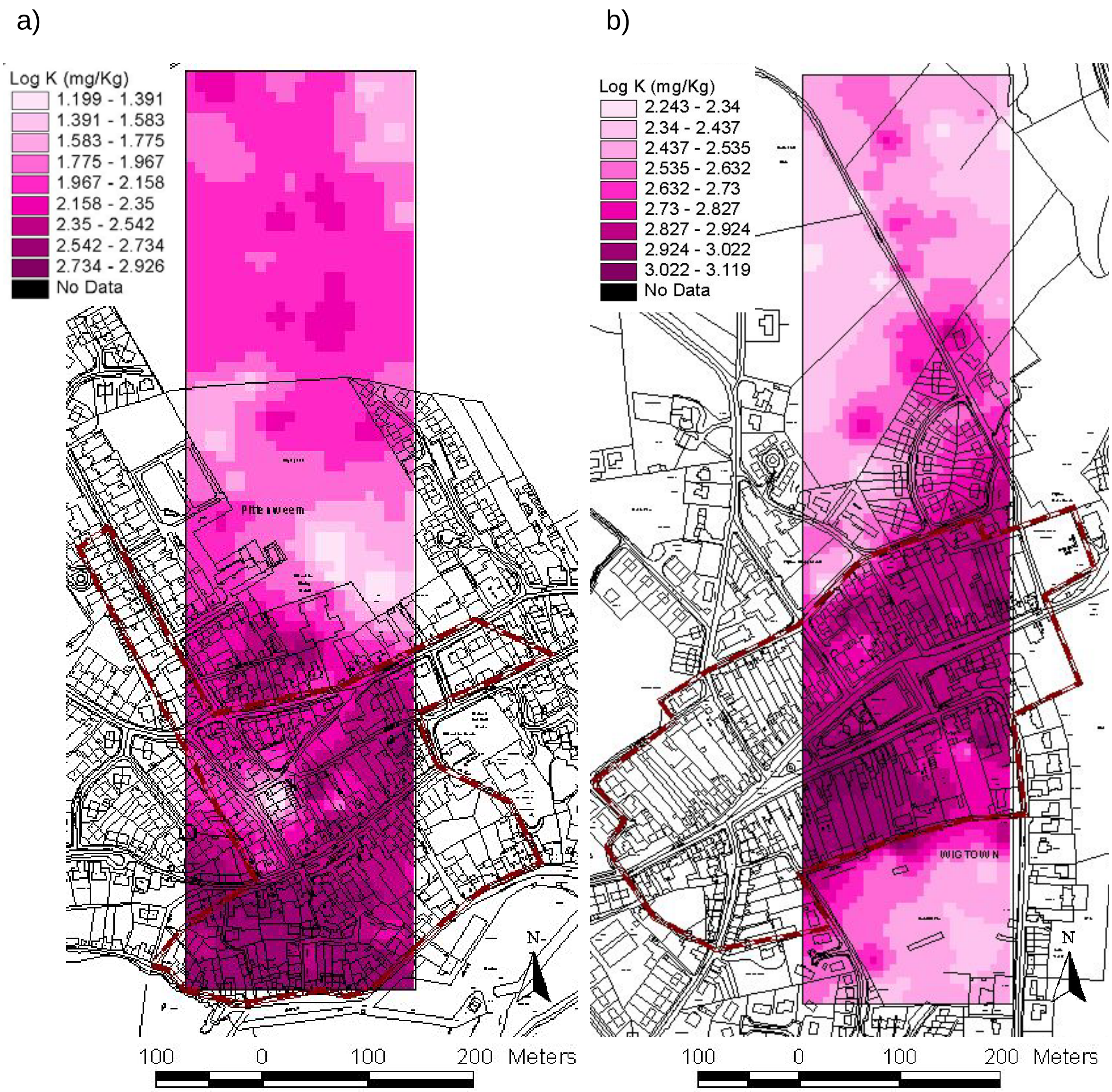


Figure 101: Spatial distribution of Log Pb (mg/Kg) at Pittenweem (a) and Wigtown (b). Red boundary delimits 1855AD and 1850AD urban extent respectively

7.1.4.1 Variation within Burghs

The median K concentration of the High Street, Hinterland Near, Hinterland Far and Thirlstane zones at Lauder is 854.3, 474.36, 205.6 and 284.6 mg/Kg respectively (Figure 102a). The High Street zone has significantly higher K than the Hinterland Near, Hinterland Far and Thirlstane zones ($p<0.001$). Moreover K is significantly higher in the Hinterland Near zone compared to the Hinterland Far zone ($p<0.001$) (Figure 102b). There is no statistical difference in K concentrations between the Hinterland Far and Thirlstane zones. These results provide evidence for enhancement of K in the burgh core. To a lesser extent K is also enhanced in the immediate hinterland south of Lauder (Hinterland Near).

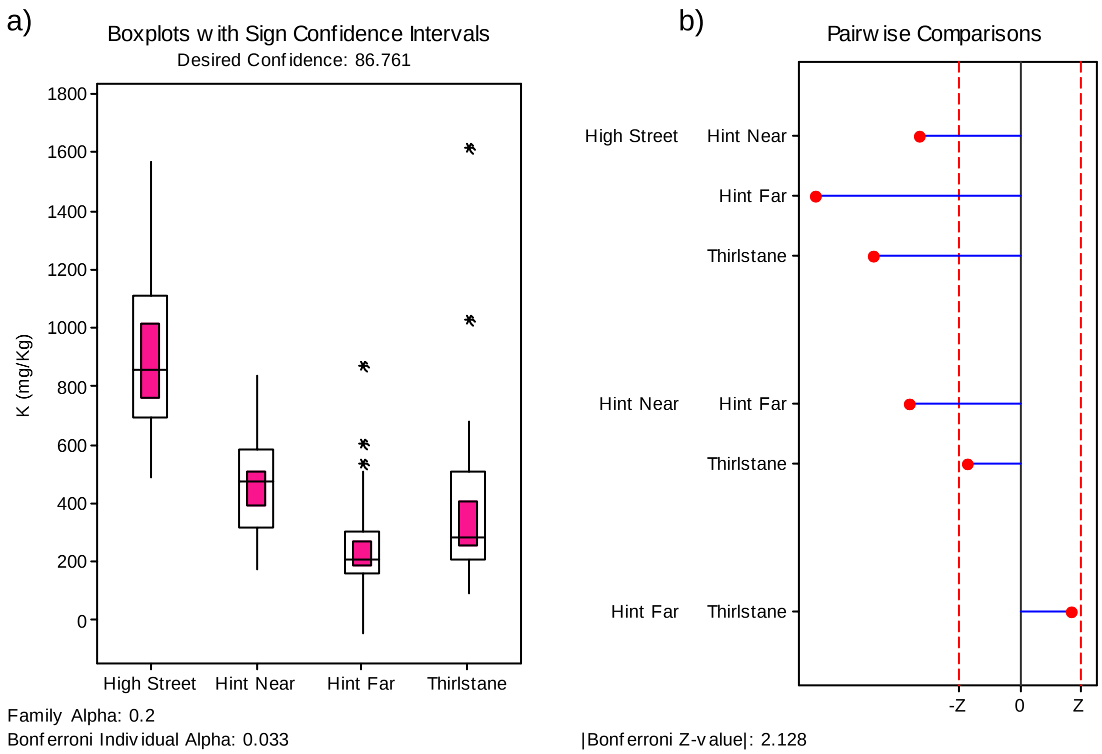


Figure 102: (a) Boxplot of median K (mg/Kg) for individual zones at Lauder; boundaries of boxes represent interquartile range, pink shading indicates 86.761% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Lauder, -Z or Z are significant at p<0.05 confidence level

The median K concentration of the Harbour, High Street, Hinterland Near and Hinterland Far zones at Pittenweem is 636, 348, 79. and 126 mg/Kg respectively (Figure 103a). The Harbour zone has significantly higher levels of K than the Hinterland Near and Hinterland Far zones ($p<0.001$). Likewise the High Street zone has significantly higher K than the Hinterland Near and Hinterland Far zones ($p<0.001$) (Figure 103b). There is no significant difference in median K concentrations between the Harbour and High Street zones, and the Hinterland Near and Hinterland Far zones. These results provide clear evidence for enhancement of K within Pittenweem's burgh core.

The median K concentration for High Street, Hinterland Near and Showfield zones at Wigtown is 870.2, 284.8 and 300.6 mg/Kg respectively (Figure 104a). The High Street zone has significantly higher K than the Hinterland Near and Showfield zones ($p<0.001$). There is no significant difference in median K between the Hinterland Near and Showfield zones (Figure 104b). Similar to results identified at Pittenweem, there is distinct enhancement of K within the burgh core at Wigtown.

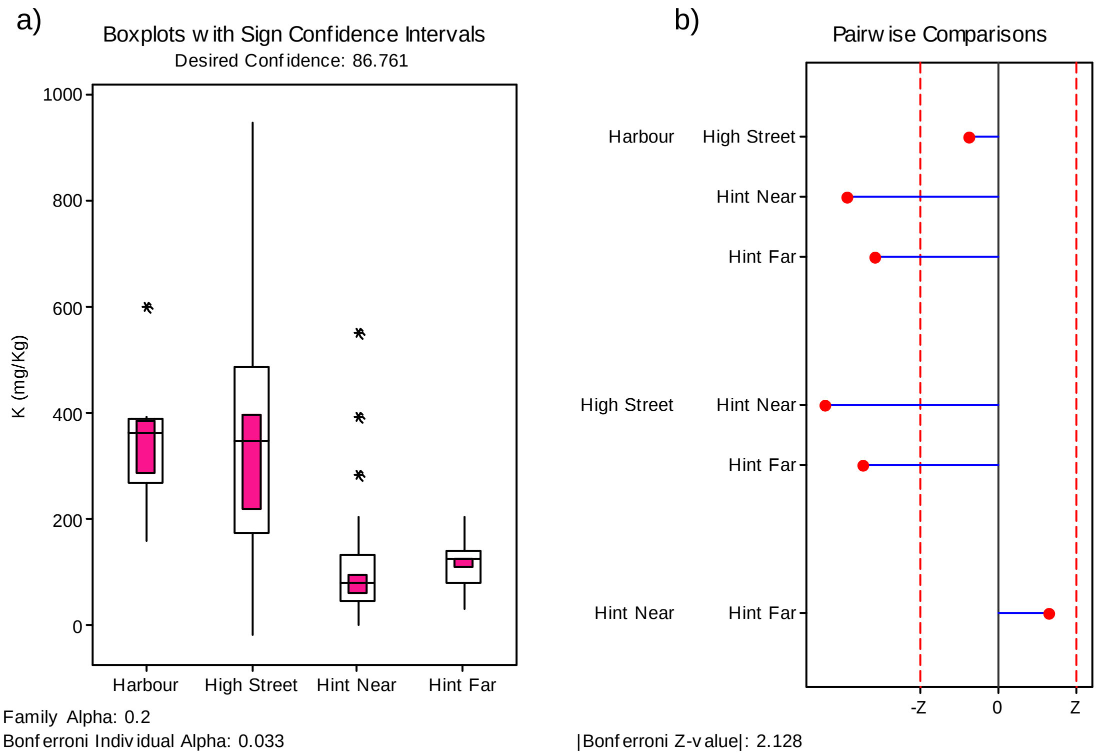


Figure 103: (a) Boxplot of median K (mg/Kg) for individual zones at Pittenweem; boundaries of boxes represent interquartile range, pink shading indicates 86.761% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Pittenweem, -Z or Z are significant at p<0.05 confidence level

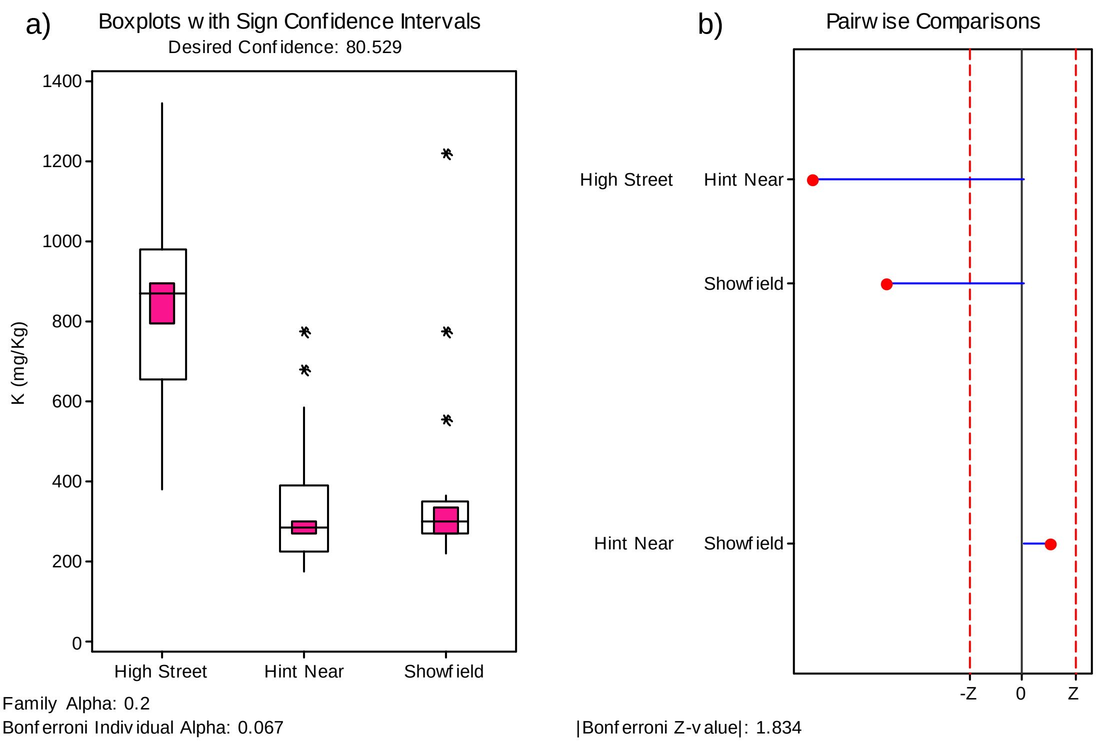


Figure 104: (a) Boxplot of median K (mg/Kg) for individual zones at Wigtown; boundaries of boxes represent interquartile range, pink shading indicates 80.529% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Wigtown, -Z or Z are significant at p<0.05 confidence level

7.1.4.2 Variation between Burghs

All three burghs have significant enhancement of K concentrations in zones within the burgh core (Harbour and High Street). Increased concentrations of K are confined to the burgh core in Pittenweem and Wigtown; however, elevated levels of K are identified in the immediate hinterland south of Lauder (Hinterland Near). It should be noted enhancement of K in the Hinterland Near zone is significantly less than the burgh core at Lauder.

7.1.5 <u>Phosphorus</u>

Spatial distributions of phosphorus (P) are presented for Lauder (Figure 105), Pittenweem (Figure 106a) and Wigtown (Figure 106b). Patterns in P associated with zones are subsequently identified and comparisons between burghs are made.

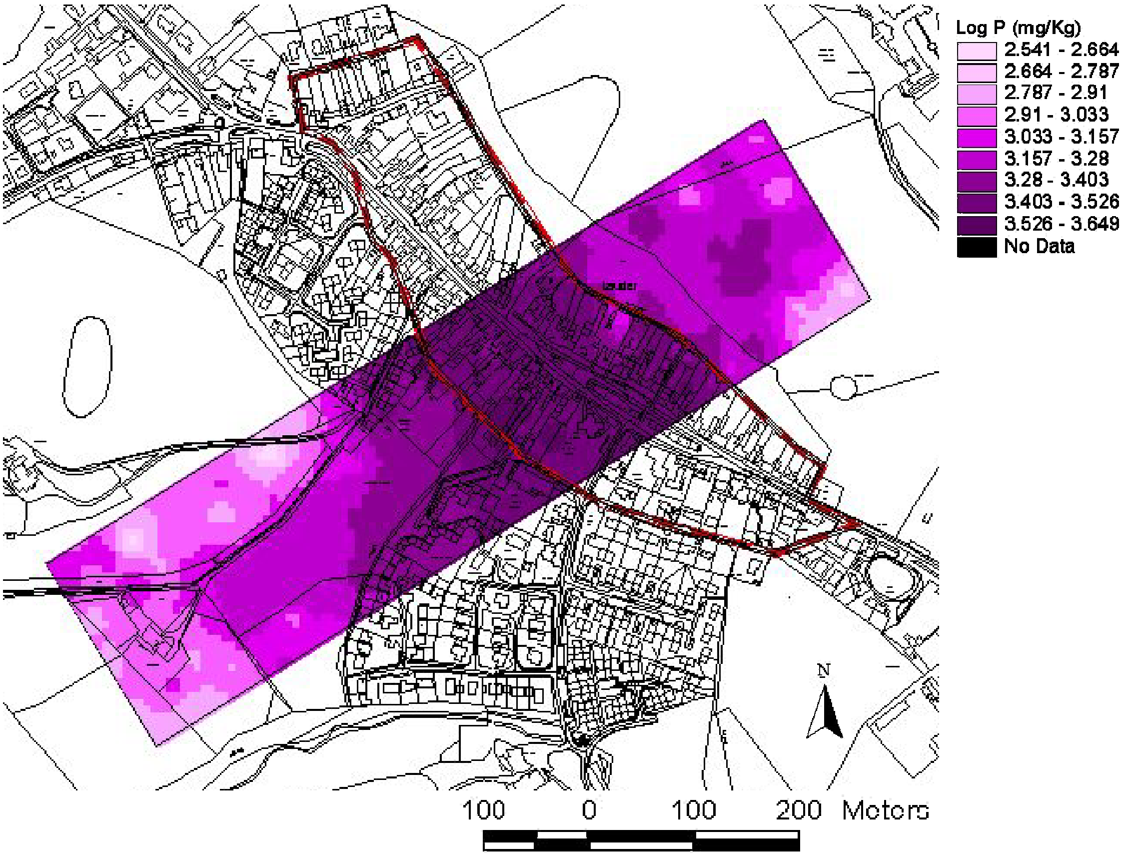


Figure 105: Spatial distribution of Log P (mg/Kg) at Lauder. Red boundary delimits 1862AD urban extent

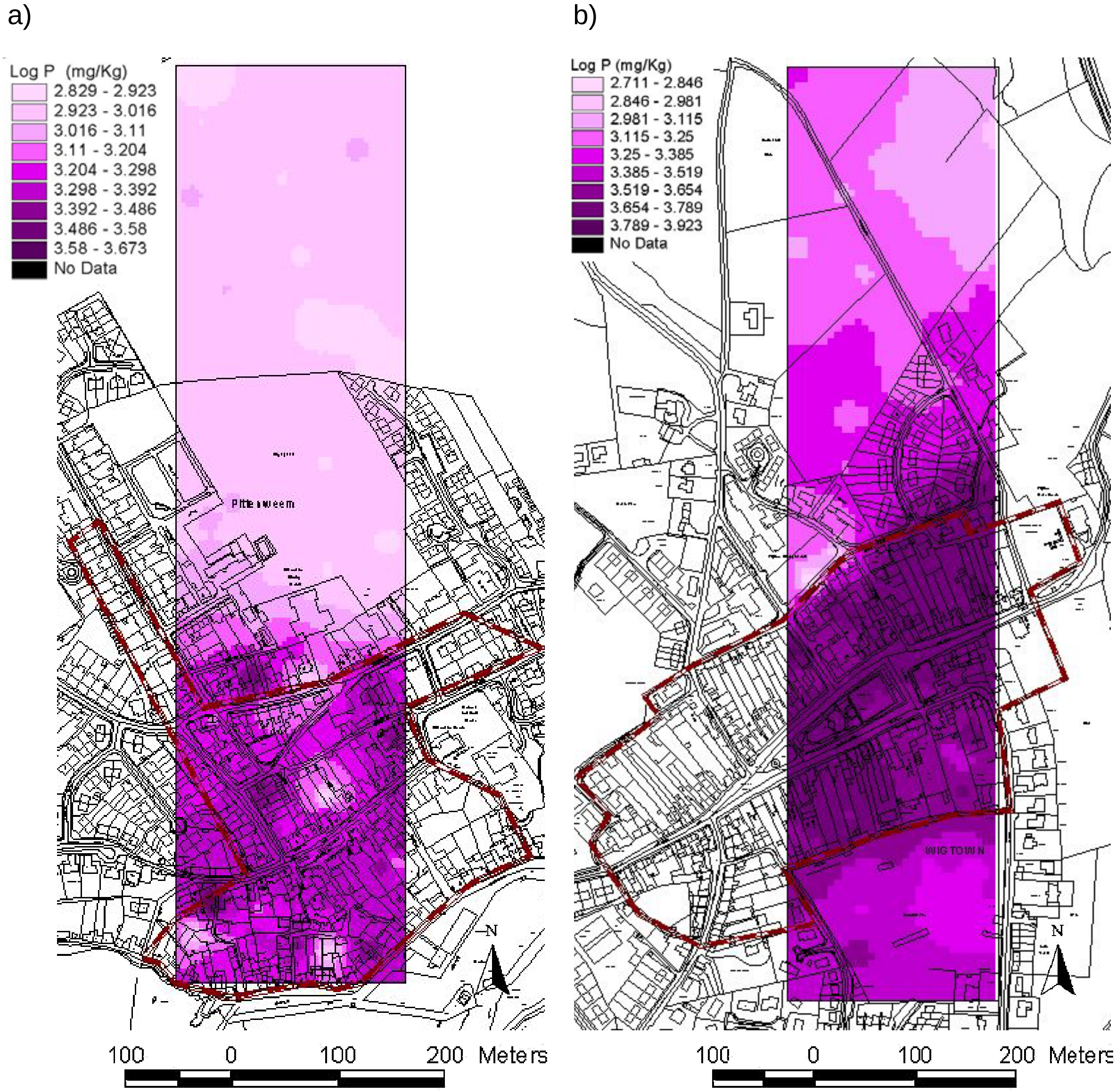


Figure 106: Spatial distribution of Log P (mg/Kg) at Pittenweem (a) and Wigtown (b). Red boundary delimits 1855AD and 1850AD urban extent respectively

7.1.5.1 Variation within Burghs

The median P concentration of the High Street, Hinterland Near, Hinterland Far and Thirlstane zones is at Lauder is 3129, 1798, 903.4 and 1658 mg/Kg respectively (Figure 107a). The High Street zone has significantly higher P than the Hinterland Near, Hinterland Far and Thirlstane zones ($p<0.001$). The Hinterland Near and Thirlstane zones have significantly higher median P concentrations than the Hinterland Far zone ($p<0.001$). Moreover, there is no significant difference in P between the Hinterland Near and Thirlstane zones (Figure 107b).

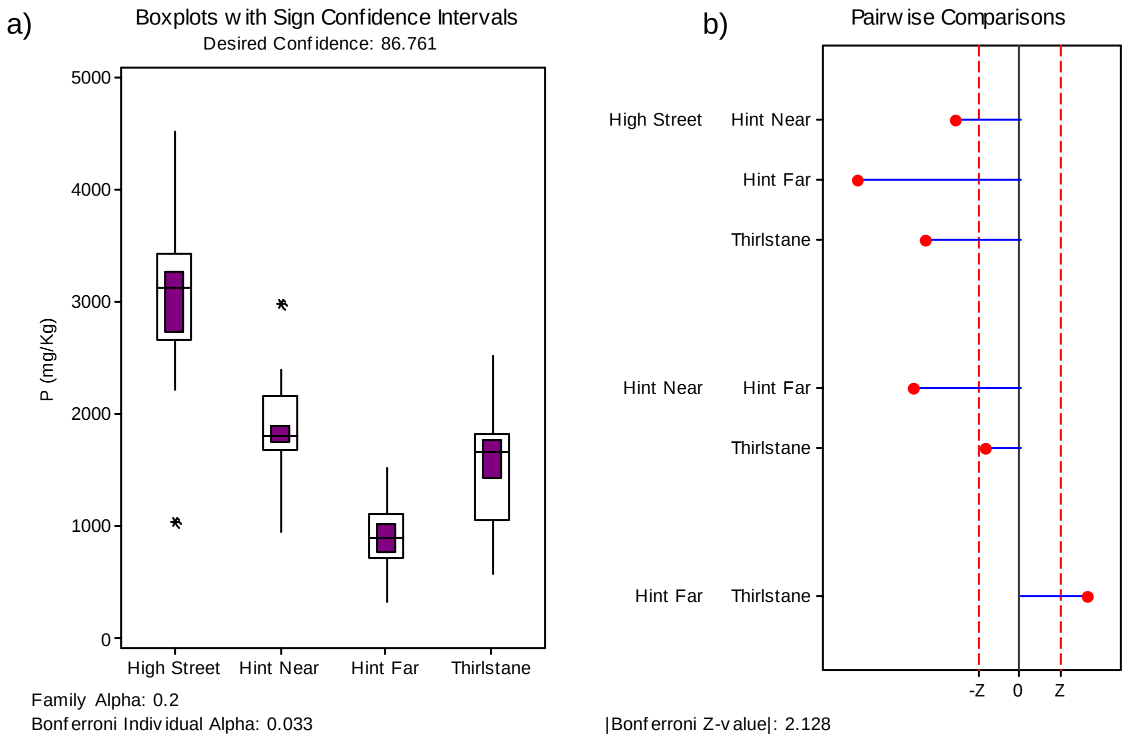


Figure 107: (a) Boxplot of median P (mg/Kg) for individual zones at Lauder; boundaries of boxes represent interquartile range, purple shading indicates 86.761% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Lauder, -Z or Z are significant at p<0.05 confidence level

These results indicate significant enhancement of P within the burgh core. Areas with elevated P are also identified in the immediate hinterland north (Thirlstane) and south (Hinterland Near) of Lauder, however it should be noted that P levels in these two areas are significantly lower than the High Street zone

The median P concentration of the Harbour, High Street, Hinterland Near and Hinterland Far zones at Pittenweem is 1741, 2147, 964.5 and 960.1 mg/Kg respectively (Figure 108a). The Harbour zone has significantly higher P than the Hinterland Near zone ($p<0.01$) and Hinterland Far zone ($p<0.05$). In addition, the High Street zone has significantly higher P levels than the Hinterland Near and Hinterland Far zones ($p<0.001$) (Figure 108b). There is no significant difference in median P concentrations between the Harbour and High Street zones. These results provide clear evidence for enhancement of P within Pittenweem's burgh core.

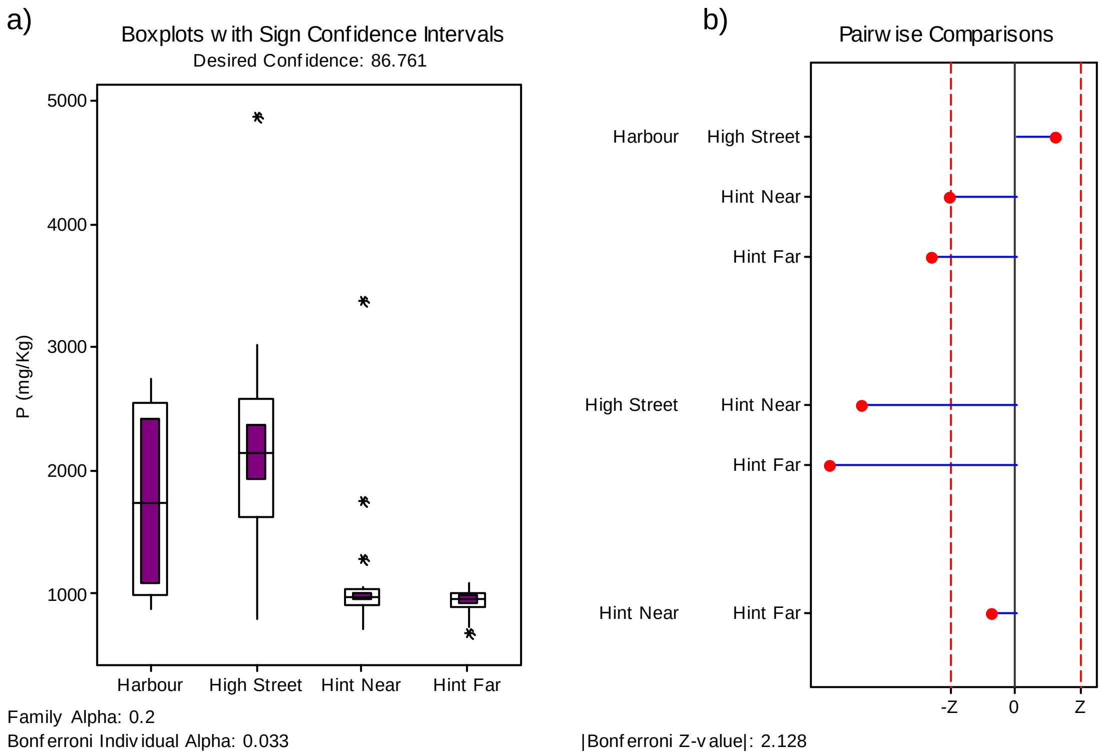


Figure 108: (a) Boxplot of median P (mg/Kg) for individual zones at Pittenweem; boundaries of boxes represent interquartile range, purple shading indicates 86.761% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Pittenweem, -Z or Z are significant at p<0.05 confidence level

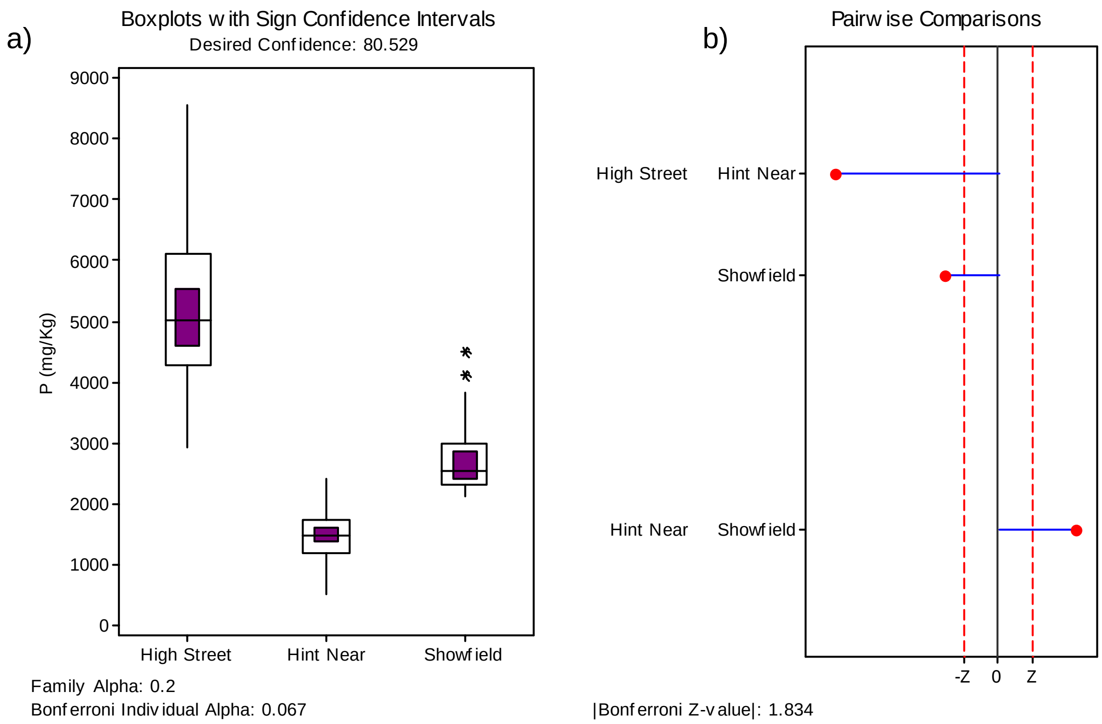


Figure 109: (a) Boxplot of median P (mg/Kg) for individual zones at Wigtown; boundaries of boxes represent interquartile range, purple shading indicates 80.529% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Wigtown, -Z or Z are significant at p<0.05 confidence level

The median P concentration of the High Street, Hinterland Near and Showfield zones at Wigtown is 5001, 1492.5 and 2553 mg/Kg respectively (Figure 109a). The High Street has significantly higher P than the Hinterland Near ($p<0.001$) and Showfield zones ($p<0.01$). In addition the Showfield zone has significantly higher P than the Hinterland Near zone ($p<0.001$). These results indicate significant enhancement of P within the burgh core. Moreover increased P is noted in the immediate hinterland south of Wigtown (Showfield), although it should be noted that P concentrations in this area are significantly lower than the High Street zone.

7.1.5.2 Variation between Burghs

All three burghs have significant enhancement of P concentrations in zones within their burgh cores (Harbour and High Streets). Enhancement of P at Pittenweem is confined to the burgh core; however, both Lauder and Wigtown have additionally enhanced zones in the hinterland. P levels are elevated in the immediate hinterland south (Hinterland Near) and north of Lauder (Thirlstane). Similarly P is enhanced in the immediate hinterland south of Wigtown (Showfield). It should be noted that P concentrations in hinterland areas within Lauder and Wigtown are significantly less than the High Street zone

7.1.6 Strontium

Spatial distributions of strontium (Sr) are presented for Lauder (Figure 110), Pittenweem (Figure 111a) and Wigtown (Figure 111b). Patterns in Sr associated with zones are subsequently identified and comparisons between burghs are made.

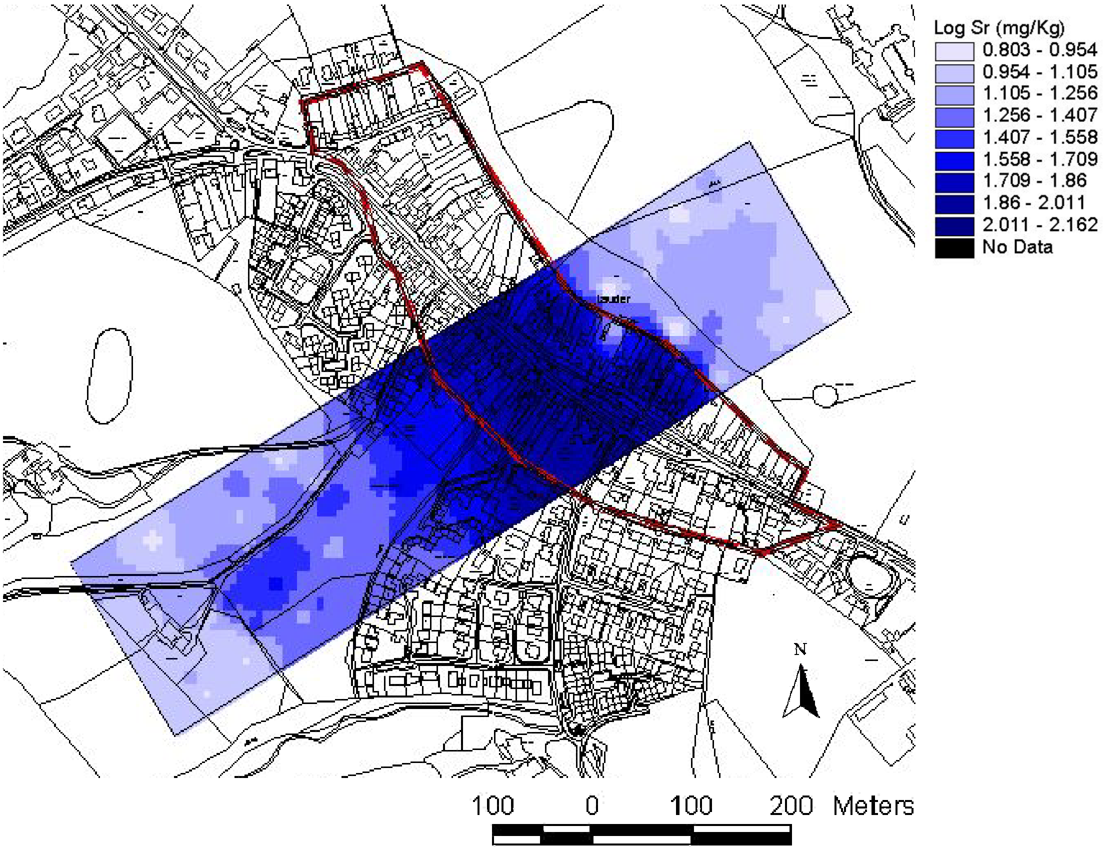


Figure 110: Spatial distribution of Log Sr (mg/Kg) at Lauder. Red boundary delimits 1862AD urban extent

a) b)

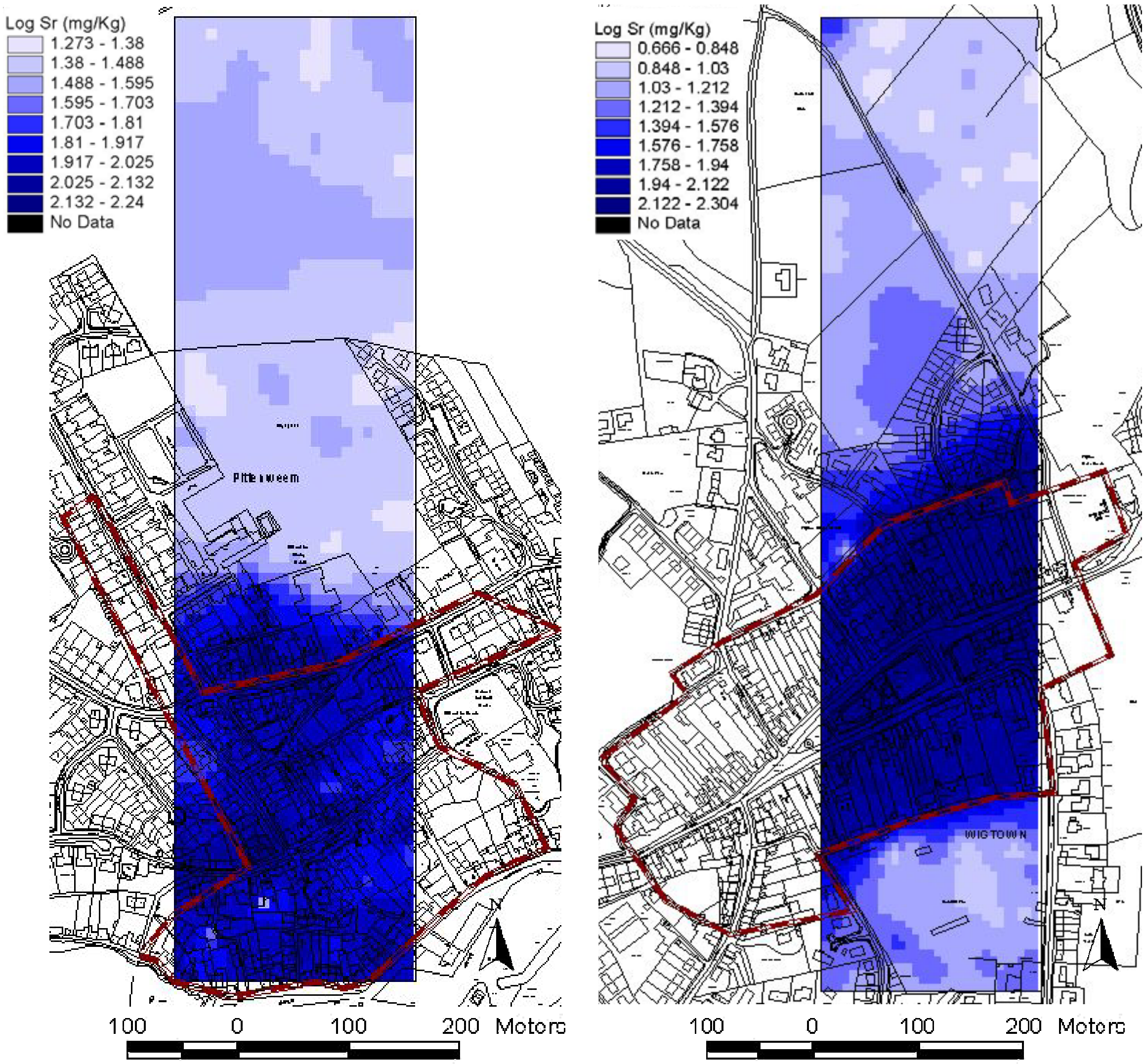


Figure 111: Spatial distribution of Log Sr (mg/Kg) at Pittenweem (a) and Wigtown (b). Red boundary delimits 1855AD and 1850AD urban extent respectively

7.1.6.1 Variation within Burghs

The median Sr concentration of the High Street, Hinterland Near, Hinterland Far and Thirlstane zones at Lauder is 78.4, 26.8, 12.1 and 13.4 mg/Kg respectively. The High street zone has significantly higher Sr than the Hinterland Near zone ($p<0.01$) and the Hinterland Far and Thirlstane zones ($p<0.001$) (Figure 112). In addition the Hinterland Near zone has significantly higher Sr than the Hinterland Far and Thirlstane zones ($p<0.001$). There is no significant difference between the Hinterland Far and Thirlstane zones. These results indicate enhancement of Sr in the burgh core and land adjacent to the historical burgh limits (Hinterland Near). However, it should be noted that enhancement is comparatively higher within the burgh core.

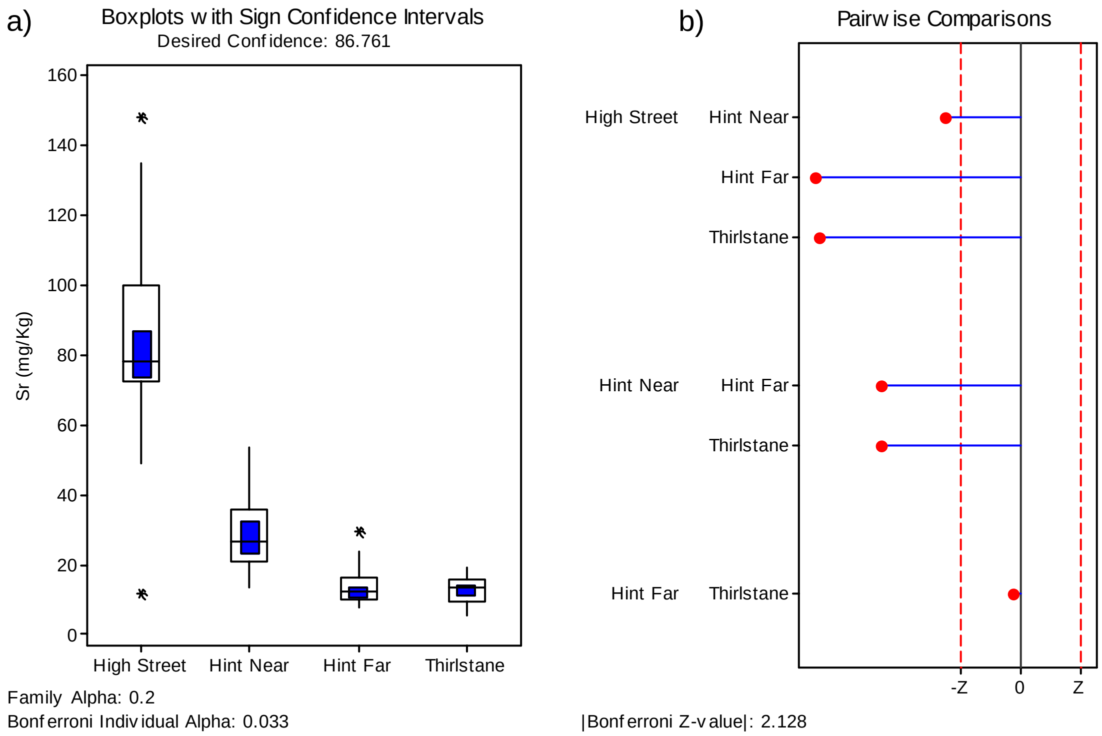


Figure 112: (a) Boxplot of median Sr (mg/Kg) for individual zones at Lauder; boundaries of boxes represent interquartile range, blue shading indicates 86.761% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Lauder, -Z or Z are significant at p<0.05 confidence level

The median Sr concentration of the Harbour, High Street, Hinterland Near and Hinterland Far zones at Pittenweem is 102.9, 91.5, 28.5 and 31.5 mg/Kg respectively (Figure 113a). The Harbour and High Street zones have significantly higher Sr levels than both the Hinterland Near and Hinterland Far zones ($p<0.001$). There is no significant difference in median Sr concentrations between the Harbour and High Street zones (Figure 113b). These results provide clear evidence for Sr enhancement within the burgh core.

The median Sr concentration of the High Street, Hinterland Near and Showfield zones at Wigtown is 153, 11.5 and 13.6 mg/Kg respectively (Figure 114a). The High Street has significantly higher Sr than the Hinterland Near and Showfield zones ($p<0.001$). There is no significant difference in median Sr concentrations between the Hinterland Near and Showfield zones (Figure 114b). These results indicate significant enhancement of Sr in Wigtown's burgh core.

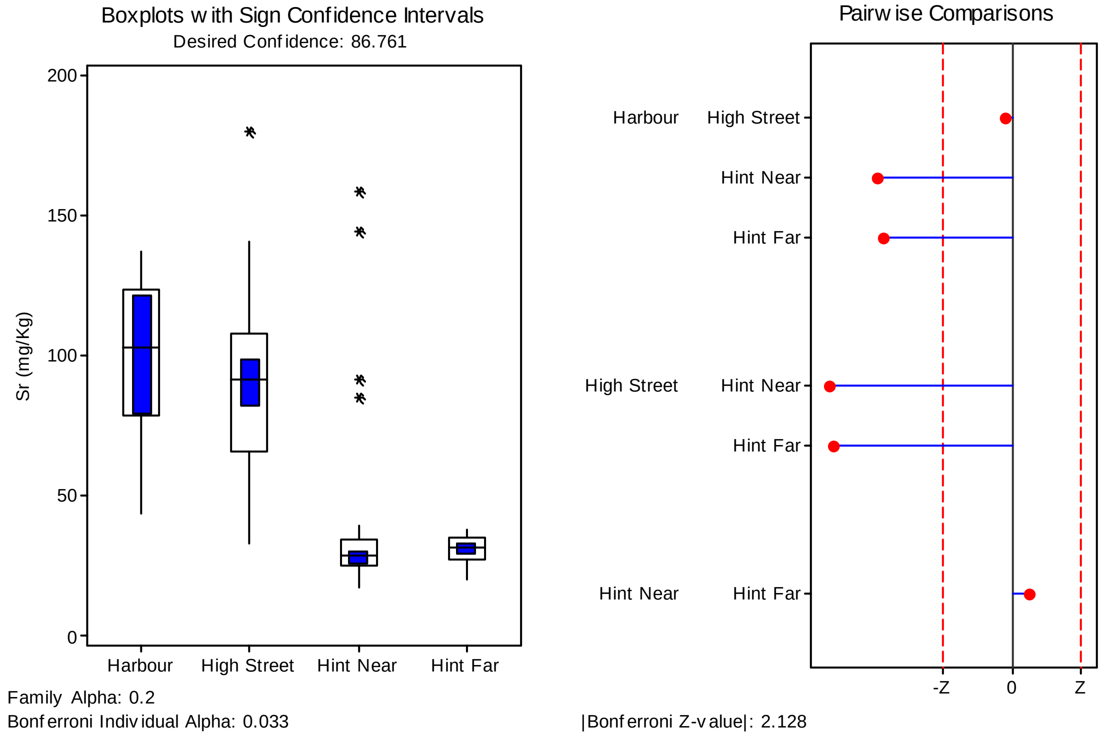


Figure 113: (a) Boxplot of median Sr (mg/Kg) for individual zones at Pittenweem; boundaries of boxes represent interquartile range, blue shading indicates 86.761% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Pittenweem, -Z or Z are significant at p<0.05 confidence level

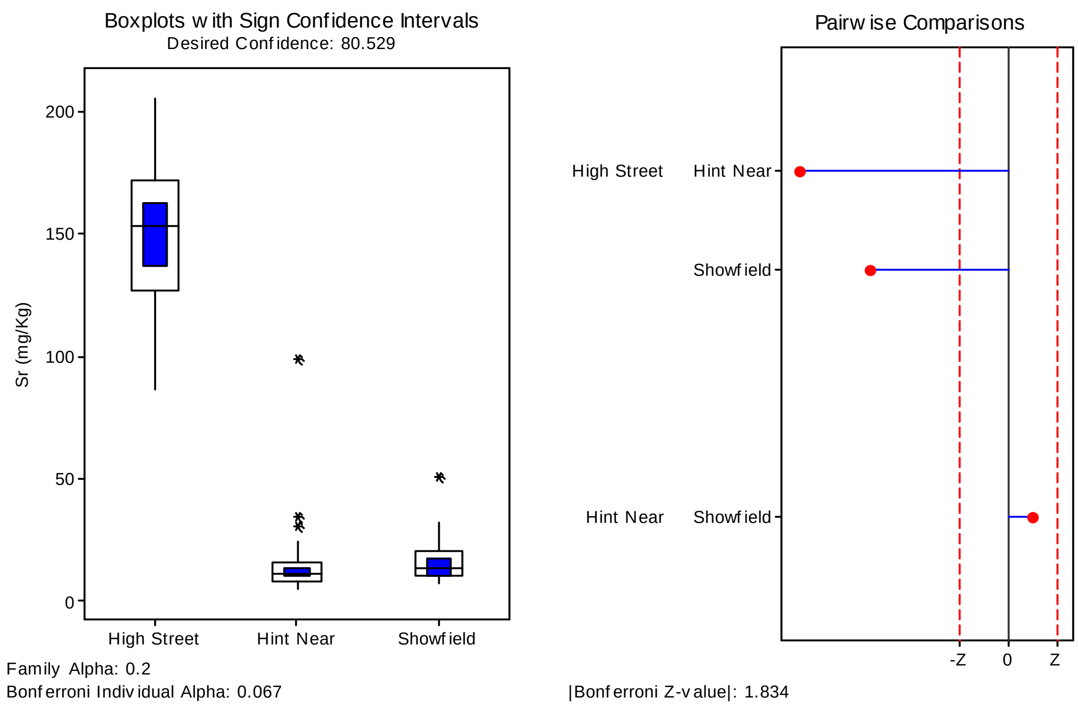


Figure 114: (a) Boxplot of median Sr (mg/Kg) for individual zones at Wigtown; boundaries of boxes represent interquartile range, blue shading indicates 80.529% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Wigtown, -Z or Z are significant at p<0.05 confidence level

7.1.6.2 Variation between Burghs

All three burghs have significant enhancement of Sr concentrations in zones within the burgh core (Harbour and High Street). Elevated Sr levels are confined to the burgh core in Pittenweem and Wigtown. However, an area with increased Sr concentrations is identified in the immediate hinterland south of Lauder (Hinterland Near). It should be noted that this area has a significantly lower median Sr concentration compared to the High Street zone.

7.1.7 Zinc

Spatial distributions of zinc (Zn) are presented for Lauder (Figure 115), Pittenweem (Figure 116a) and Wigtown (Figure 116b). Patterns in Zn associated with zones are subsequently identified and comparisons between burghs are made.

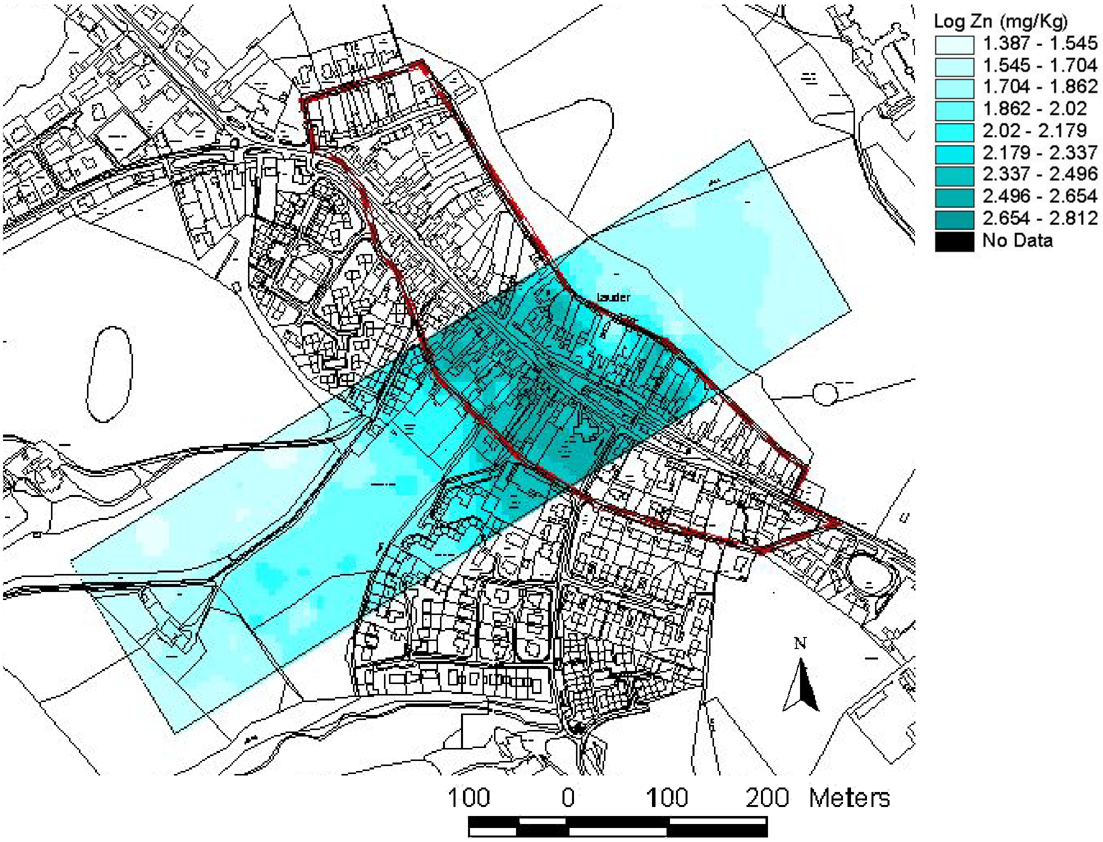


Figure 115: Spatial distribution of Log Zn (mg/Kg) at Lauder. Red boundary delimits 1862AD urban extent

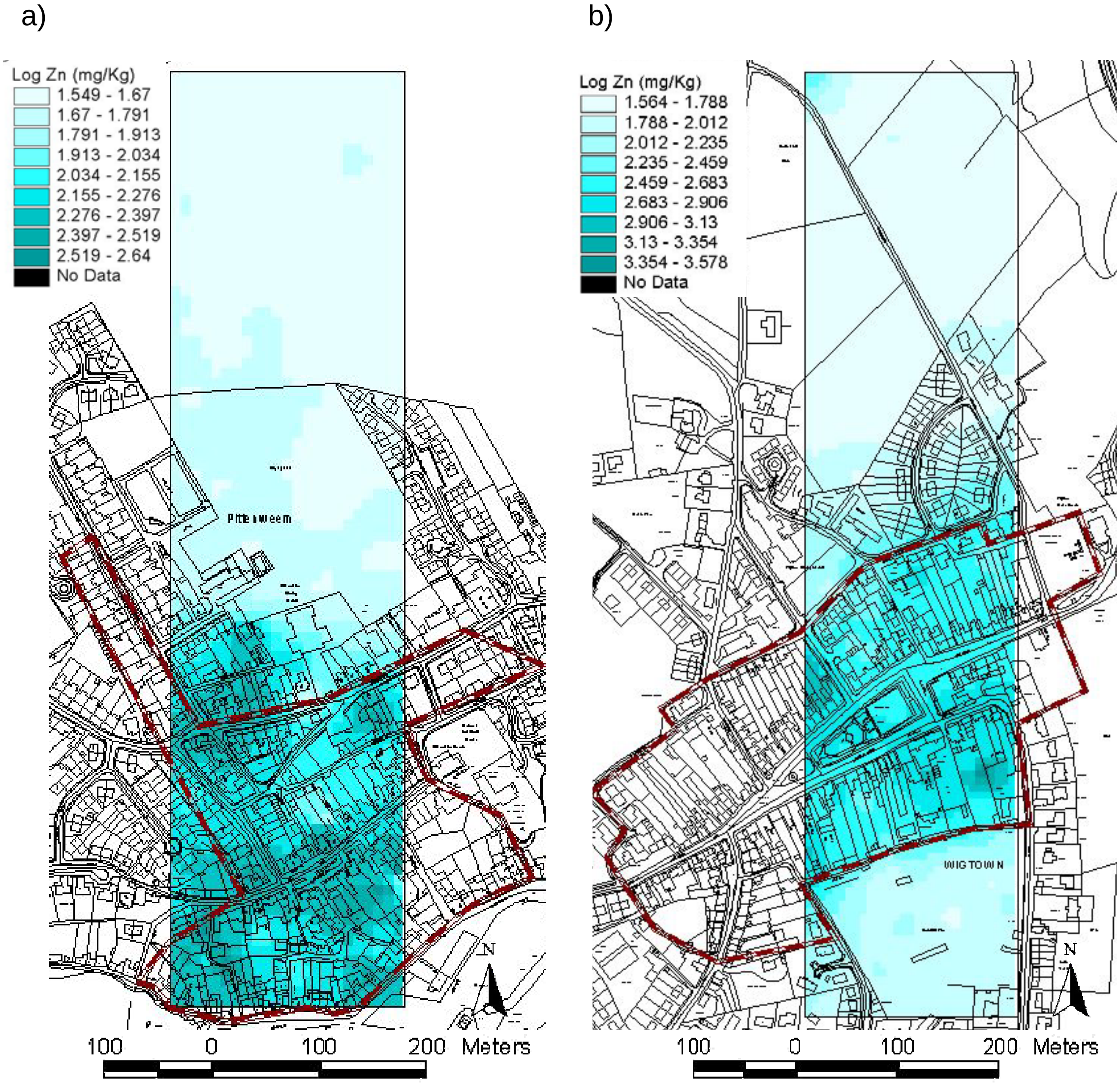


Figure 116: Spatial distribution of Log Zn (mg/Kg) at Pittenweem (a) and Wigtown (b). Red boundary delimits 1855AD and 1850AD urban extent respectively

7.1.7.1 Variation within Burghs

The median Zn concentration of the High Street, Hinterland Near, Hinterland Far and Thirlstane zones at Lauder is 267.8, 93.8, 45.32 and 53.2 mg/Kg respectively (Figure 117a). The High Street has significantly higher Zn than the Hinterland Near zone ($p<0.01$) and Hinterland Far and Thirlstane zones ($p<0.001$). In addition the Hinterland Near zone has significantly higher Zn than the Hinterland Far and Thirlstane zones ($p<0.001$) (Figure 117b). There is no significant difference between the Hinterland Far and Thirlstane zones. These results provide clear evidence for enhancement of Zn within the burgh core. Elevated Zn levels are also identified in land immediately adjacent to the historical burgh limits (Hinterland Near), although it should be noted that enhancement is significantly higher within the burgh core.

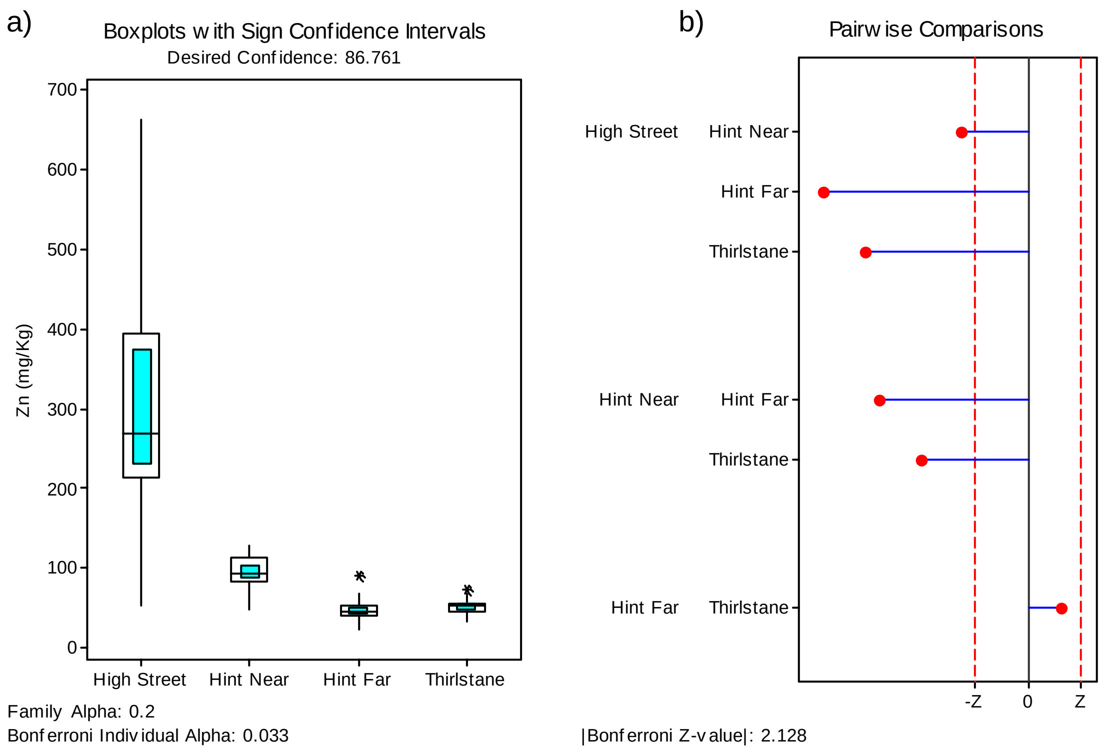


Figure 117: (a) Boxplot of median Zn (mg/Kg) for individual zones at Lauder; boundaries of boxes represent interquartile range, cyan shading indicates 86.761% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Lauder, -Z or Z are significant at p<0.05 confidence level

At Pittenweem the median Zn concentration of the Harbour, High Street, Hinterland Near and Hinterland Far zones is 205.3, 168.7, 49.3 and 41.7 mg/Kg respectively (Figure 118a). The Harbour zone has significantly higher Zn than the Hinterland Near ($p<0.05$) and Hinterland Far zones ($p<0.001$). Similarly the High Street zone has significantly higher Zn levels than the Hinterland Near and Hinterland Far zones ($p<0.001$) (Figure 118b). There is no statistical difference in median Zn concentrations between the Harbour and High Street zones. These results provide clear evidence for Zn enhancement within the burgh core. In addition, the Hinterland Near zone has significantly higher Zn than the Hinterland Far zone ($p<0.01$). Elevated Zn levels are therefore identified in land adjacent to the historical burgh limits at Pittenweem (Hinterland Near), although it should be noted that enhancement is significantly higher within the burgh core.

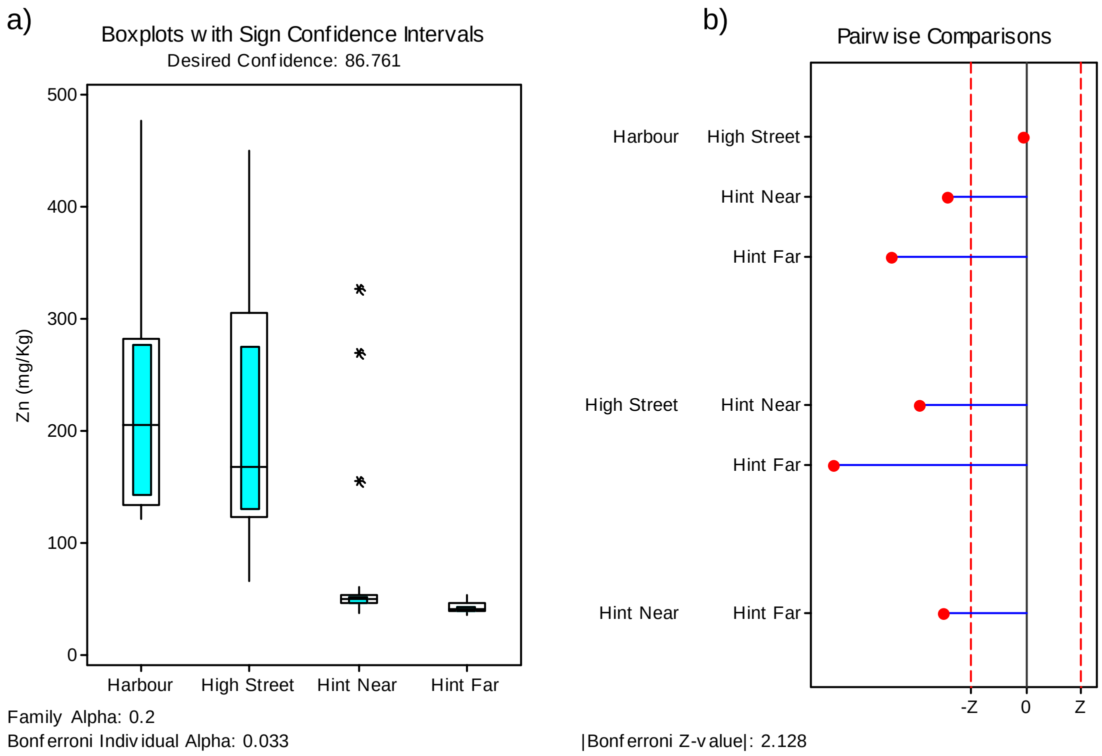


Figure 118: (a) Boxplot of median Zn (mg/Kg) for individual zones at Pittenweem; boundaries of boxes represent interquartile range, cyan shading indicates 86.761% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Pittenweem, -Z or Z are significant at p<0.05 confidence level

The median Zn of the High Street, Hinterland Near and Showfield zones at Wigtown is 418, 52.9 and 84.8 mg/Kg respectively (Figure 119a). The High Street zone has significantly higher Zn then the Hinterland Near and Hinterland Far zones ($p<0.001$). Moreover, the Showfield zone has significantly greater Zn than the Hinterland Near zone ($p<0.01$) (Figure 119b). These results indicate enhancement of Zn in Wigtown's burgh core and to a lesser extent the immediate hinterland south of Wigtown (Showfield).

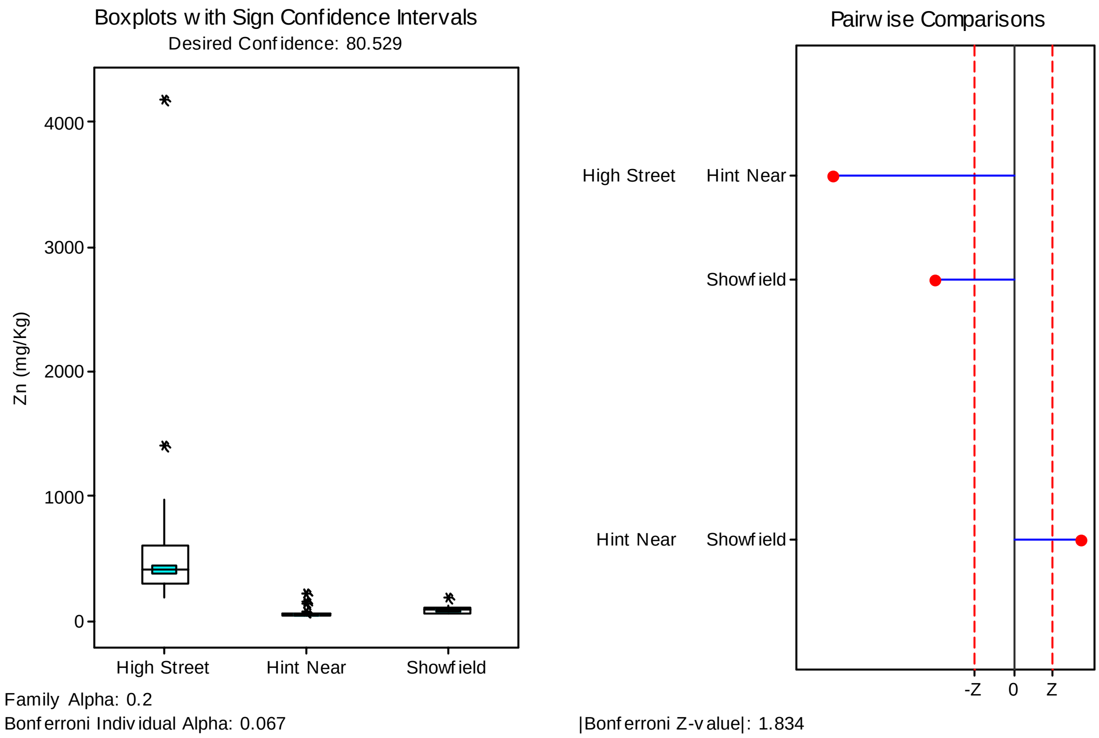


Figure 119: (a) Boxplot of median Zn (mg/Kg) for individual zones at Wigtown; boundaries of boxes represent interquartile range, cyan shading indicates 80.529% confidence interval for median, outliers identified as*, (b) Kruskal-Wallis analysis with Dunn's test multiple comparisons for individual zones at Wigtown, -Z or Z are significant at p<0.05 confidence level

7.1.7.2 Variation between Burghs

All three burghs have significant enhancement of Zn concentrations in zones within the burgh core (Harbour and High Street). In addition, elevated Zn concentrations are identified in land adjacent to the historical burgh limits at Lauder and Pittenweem (Hinterland Near). Enhanced Zn levels are also identified in the immediate hinterland south of Wigtown (Showfield). It should be noted that Zn enhancement in the aforementioned hinterland areas is significantly lower compared to the burgh core within each town.

7.2 Summary of Results: Elemental Concentrations

The following section presents a brief summary of key trends in selected elemental concentrations (Ba, Ca, Pb, K, P, Sr, and Zn) both within and between burghs. The significance of these results is discussed in section 8.1.2 and 8.2.2; specifically the utility of elemental concentrations as indicators of past waste disposal is considered.

7.2.1 Variation within Burghs

7.2.1.1 Lauder

The High Street, Hinterland Near and Thirlstane zones are identified as important areas of interest at Lauder. Both the High Street zone and Hinterland Near zone are characterised by significantly enhanced levels of Ba, Ca, Pb, K, P, Sr and Zn (Table 8). In addition, the Thirlstane zone has typically elevated concentrations of Ba, Pb and P. Elemental enhancement is statistically greatest within the High Street zone, followed by the Hinterland Near zone and Thirlstane zone in succession. These results indicate distinct elemental enhancement within the burgh core and to a lesser extent in the immediate hinterland south (Hinterland Near) and north (Thirlstane) of Lauder.

7.2.1.2 Pittenweem

Two zones are identified as important areas of interest at Pittenweem; the Harbour zone and High Street zone. These zones are characterised by significantly elevated levels of Ba, Ca, Pb, K, P, Sr and Zn (Table 8). There is no evidence for elemental enhancement within the hinterland at Pittenweem, with the exception of Zn which is slightly elevated in the Hinterland Near zone. These results provide clear evidence for elemental enhancement within the burgh core.

7.2.1.3 Wigtown

The High Street zone and Showfield zone are identified as important areas of interest at Wigtown. Similar to results obtained for Lauder and Pittenweem, the High Street zone is characterised by significantly enhanced concentrations of Ba, Ca, Pb, K, P, Sr and Zn. In addition, the Showfield zone has typically elevated levels of Ba, Pb, P and Zn (Table 13). Considering elemental enhancement is statistically highest within the High Street zone, these results indicate distinct elemental enhancement within the burgh core and to a lesser extent in the immediate hinterland south (Showfield) of Wigtown.

Table 13: Summary of trends in selected elemental concentrations identified at Lauder, Pittenweem and Wigtown

Element	Lauder	Pittenweem	Wigtown
Ba	Enhancement of Ba in burgh core (High Street zone) and immediate hinterland (Hinterland Near and Thirlstane zones). Enhancement greatest in burgh core and Thirlstane zone.	Enhancement of Ba in burgh core (Harbour and High Street zones).	Enhancement of Ba in burgh core (High Street zone) and immediate hinterland (Showfield zone). Enhancement greatest in burgh core.
Ca	Enhancement of Ca in burgh core (High Street zone) and immediate hinterland (Hinterland Near). Enhancement greatest in burgh core.	Enhancement of Ca in burgh core (Harbour and High Street zones).	Enhancement of Ca in burgh core (High Street zone).
Pb	Enhancement of Pb in burgh core (High Street zone) and immediate hinterland (Hinterland Near and Thirlstane zones). Enhancement greatest in burgh core.	Enhancement of Pb in burgh core (Harbour and High Street zones).	Enhancement of Pb in burgh core (High Street zone) and immediate hinterland (Showfield zone). Enhancement greatest in burgh core.
K	Enhancement of K in burgh core (High Street zone) and immediate hinterland (Hinterland Near). Enhancement greatest in burgh core.	Enhancement of K in burgh core (Harbour and High Street zones).	Enhancement of K in burgh core (High Street zone).
P	Enhancement of P in burgh core (High Street zone) and immediate hinterland (Hinterland Near and Thirlstane zones). Enhancement greatest in burgh core.	Enhancement of P in burgh core (Harbour and High Street zones).	Enhancement of P in burgh core (High Street zone) and immediate hinterland (Showfield zone). Enhancement greatest in burgh core.
Sr	Enhancement of Sr in burgh core (High Street zone) and immediate hinterland (Hinterland Near). Enhancement greatest in burgh core.	Enhancement of Sr in burgh core (Harbour and High Street zones).	Enhancement of Sr in burgh core (High Street zone).
Zn	Enhancement of Zn in burgh core (High Street zone) and immediate hinterland (Hinterland Near). Enhancement greatest in burgh core.	Enhancement of Zn in burgh core (Harbour and High Street zones) and immediate hinterland (Hinterland Near). Enhancement greatest in burgh core.	Enhancement of Zn in burgh core (High Street zone) and immediate hinterland (Showfield zone). Enhancement greatest in burgh core.

7.2.2 Variation between Burghs

All three burghs have enhanced concentrations of Ba, Ca, Pb, K, P, Sr and Zn in zones corresponding to the burgh core (Harbour and High street). Elemental enhancement is limited to the burgh core at Pittenweem however; trends in certain elements are identified within the hinterland at Lauder and Wigtown, albeit to a lesser magnitude. Elevated concentrations of Ba, Pb and P are noted in the immediate hinterland south (Hinterland Near) and north (Thirlstane) of Lauder, and in the immediate hinterland (Showfield) south of Wigtown. Moreover, enhanced concentrations of Ca, K and Sr are identified within the Hinterland Near zone at Lauder.

Table 14: Comparison of trends in selected elemental concentrations identified at Lauder, Pittenweem and Wigtown

Element	Comparison between Burghs
Ba	All three burghs have enhanced Ba in the burgh core Lauder and Wigtown have enhanced Ba in the immediate hinterland (Lauder: Hinterland Near and Thirlstane, Wigtown: Showfield).
Ca	All three burghs have enhanced Ca in the burgh core Lauder has enhanced Ca in the immediate hinterland (Hinterland Near).
Pb	All three burghs have enhanced Pb in the burgh core Lauder and Wigtown have enhanced Pb in the immediate hinterland (Lauder: Hinterland Near and Thirlstane, Wigtown: Showfield) .
K	All three burghs have enhanced K in the burgh core Lauder has enhanced K in the immediate hinterland (Hinterland Near).
P	All three burghs have enhanced P in the burgh core Lauder and Wigtown have enhanced P in the immediate hinterland (Lauder: Hinterland Near and Thirlstane, Wigtown: Showfield).
Sr	All three burghs have enhanced Sr in the burgh core Lauder has enhanced Sr in the immediate hinterland (Hinterland Near).
Zn	All three burghs have enhanced Zn in the burgh core Lauder and Pittenweem have enhanced Zn in immediate hinterland (Hinterland Near), Wigtown also has enhanced Zn in immediate hinterland (Showfield).

7.3 Multiple Comparisons

This section presents results obtained from a series of multi-element analyses including multiple comparisons, cluster analysis and discriminant analysis. Multi-element analyses were conducted for Lauder, Pittenweem and Wigtown using all 21 measured elemental concentrations.

7.3.1 <u>Lauder</u>

Average elemental concentrations of individual zones within Lauder are presented in Table 15. There is no significant difference in median Aluminium (Al) and Lithium (Li) concentrations between the High Street, Hinterland Near, Hinterland Far and Thirlstane zones. Accordingly these elements were excluded from subsequent multiple comparisons. The results of multiple comparisons between the High Street, Hinterland Near, Hinterland Far and Thirlstane zones at Lauder are summarised in Table 16. Zones with significant enhancement are highlighted (✓) and elements with similar spatial distributions are grouped accordingly.

Table 15: Average elemental concentrations (mg/Kg) of individual zones at Lauder (median used for non-parametric data, mean used for parametric data). Test indicates whether Kruskal-Wallis (KW) or One Way ANOVA (ANOVA) used to compare elemental concentrations between zones

Element	High Street	Hinterland Near	Hinterland Far	Thirlstane	Test	Test Statistic	P Value
Al	10128	10324	9889	9921	KW	H 6.95	0.073
Fe	16953	16324	15890	15149	KW	H 9.4	0.024
Mg	3835	2882.5	3027.2	3327.2	KW	H 29.21	<0.001
Ca	9076	2959	1844	2458	KW	H 66.32	<0.001
Na	103.9	44.51	44.51	44.51	KW	H 58.63	<0.001
K	854.3	474.6	205.6	284.8	KW	H 56.03	<0.001
Ti	35.37	11.791	11.791	11.791	KW	H 82.28	<0.001
P	3129	1798	903.4	1658	KW	H 77.47	<0.001
Mn	518.9	789.9	534.4	588.6	ANOVA	F 17.36	<0.001
Ba	257.6	191.8	144.9	225.4	ANOVA	F 30.75	<0.001
Co	22.4	20.2	20	21.8	KW	H 61.23	<0.001
Cr	46.7	25.2	13.3	16.8	KW	H 22.51	<0.001
Cu	16.2	14.4	15.6	14.6	KW	H 77.84	<0.001
Li	34.4	25.6	20.2	21.2	KW	H 6.8	0.078
Ni	2.8	2.4	1.8	2	KW	H 60.75	<0.001
Sc	78.4	26.8	12.1	13.4	KW	H 57.34	<0.001
Sr	78.4	26.6	12.1	13.4	KW	H 79.79	<0.001
V	23.3	20.8	17.8	21.8	KW	H 25.89	<0.001
Y	7.7	5.4	4.3	5.6	KW	H 65.27	<0.001
Zn	267.8	93.8	45.2	53.2	KW	H 86.39	<0.001
Pb	209.9	77.7	33.25	59.1	KW	H 72.81	<0.001

Table 16: Multiple comparisons for individual zones at Lauder (Dunn's test used for non-parametric data, Tukey-Kramer post-hoc analyses for parametric data)

Element	High Street	Hinterland Near	Hinterland Far	Thirlstane	Summary
Al					No significant difference between zones
Li					No significant difference between zones
Fe	✓				High Street has significantly higher Fe than Hinterland Far ($p<0.05$) and Thirlstane ($p<0.01$)
Na	✓				High Street has significantly higher Na than Hinterland Near, Hinterland Far and Thirlstane ($p<0.001$)
Mn		✓			Hinterland Near has significantly higher Mn than High Street, Hinterland Far and Thirlstane ($P<0.001$)
Ca	✓	✓			High Street has significantly higher Ca than Hinterland Near, Hinterland Far and Thirlstane ($P<0.001$) Hinterland Near has significantly higher Ca than Hinterland Far ($p<0.001$)
Co	✓	✓			High Street has significantly higher Co than Hinterland Far and Thirlstane ($p<0.001$) Hinterland Near has significantly higher Co than Hinterland Far and Thirlstane ($p<0.01$)
Cu	✓	✓			High Street has significantly higher Cu than Hinterland Near ($p<0.05$), Hinterland Far and Thirlstane ($p<0.001$) Hinterland Near has significantly higher Cu than Hinterland Far and Thirlstane ($p<0.001$)
K	✓	✓			High Street has significantly higher K than Hinterland Near, Hinterland Far and Thirlstane ($p<0.001$) Hinterland Near has significantly higher K than Hinterland Far ($p<0.001$)
Ni	✓	✓			High Street has significantly higher Ni than Hinterland Near ($p<0.01$), Hinterland Far and Thirlstane ($p<0.001$) Hinterland Near has significantly higher Ni than Hinterland Far and Thirlstane ($p<0.001$)
Sr	✓	✓			High Street has significantly higher Sr than Hinterland Near ($p<0.01$), Hinterland Far and Thirlstane ($p<0.001$) Hinterland Near has significantly higher Sr than Hinterland Far and Thirlstane ($p<0.001$)
Ti	✓	✓			High Street has significantly higher Ti than Hinterland Near, Hinterland Far and Thirlstane ($p<0.001$) Hinterland Near has significantly higher Ti than Hinterland Far ($p<0.001$)
Zn	✓	✓			High Street has significantly higher Zn than Hinterland Near, Hinterland Far and Thirlstane ($p<0.001$) Hinterland Near has significantly higher Zn than Hinterland Far and Thirlstane ($p<0.001$)
Mg	✓			✓	High Street has significantly higher Mg than Hinterland Near ($P<0.001$) and Hinterland Far ($p<0.001$) Thirlstane has significantly higher Mg than Hinterland Near ($p<0.01$) and Hinterland Far ($p<0.05$)
Cr	✓	✓		✓	High Street has significantly higher Cr than Hinterland Near and Hinterland Far ($p<0.001$) Hinterland Near has significantly higher Cr than Hinterland Far ($p<0.001$) Thirlstane has significantly higher Cr than Hinterland Near and Hinterland Far ($p<0.001$)
P	✓	✓		✓	High Street has significantly higher P than Hinterland Near, Hinterland Far and Thirlstane ($p<0.001$) Hinterland Near has significantly higher P than Hinterland Far ($p<0.001$) Thirlstane has significantly higher P than Hinterland Far ($p<0.001$)
Pb	✓	✓		✓	High Street has significantly higher Pb than Hinterland Near ($p<0.01$), Hinterland Far and Thirlstane ($p<0.001$) Hinterland Near has significantly higher Pb than Hinterland Far ($p<0.001$) and

					Thirlstane ($p<0.05$) Thirlstane has significantly higher Pb than Hinterland Far ($p<0.001$)
Sc	✓	✓		✓	High Street has significantly higher Sc than Hinterland Near ($p<0.05$), Hinterland Far and Thirlstane ($p<0.001$) Hinterland Near has significantly higher Sc than Hinterland Far ($p<0.001$) and Thirlstane ($p<0.05$) Thirlstane has significantly higher Sc than Hinterland Far ($p<0.05$)
Y	✓	✓		✓	High Street has significantly higher Y than Hinterland Near, Hinterland Far ($p<0.001$) and Thirlstane ($p<0.05$) Hinterland Near has significantly higher Y than Hinterland Far ($p<0.001$) Thirlstane has significantly higher Y than Hinterland Far ($p<0.001$)
Ba	✓	✓		✓	High Street has significantly higher Ba than Hinterland Near, Hinterland Far and Thirlstane ($p<0.001$) Hinterland Near has significantly higher Ba than Hinterland Far ($p<0.001$) Thirlstane has significantly higher Ba than Hinterland Far ($p<0.001$)
V	✓	✓		✓	High Street, Hinterland Near and Thirlstane all have significantly higher V than Hinterland Far ($p<0.001$)

Eight groups of elements with distinct patterns of spatial enhancement are identified at Lauder. The first group contains Al and Li which are relatively homogenous and show no pattern of spatial enhancement within the sample area. The second group is characterised by statistically higher levels of Fe and Na within the High Street zone. Although Na is significantly enhanced compared to the other three zones, there is no significant difference in Fe concentrations between the High Street and Hinterland Near zones. The third group identified is dominated by elevated Mn concentrations within the Hinterland Near zone. None of the other elements share a similar spatial distribution with Mn. The fourth group contains Mg which is highest within the High Street zone followed by the Thirlstane zone.

The fifth group comprises Ca, Co, Cu, K, Ni, Sr, Ti and Zn. Elements within this group are primarily enhanced within the High Street zone and to a lesser extent within the Hinterland Near zone. It can be argued that Ti does not necessarily belong in this group considering median values for the Hinterland Near, Hinterland Far and Thirlstane zones are all 11.791 mg/Kg. However results of multiple comparison analysis indicate a significant difference between the Hinterland Near zone and Hinterland Far and Thirlstane zones. This is because statistical analyses use all data within a zone not just the median value.

The sixth group includes Cr, P, Pb, Sc and Y. These elements are enhanced primarily within the High Street zone followed in succession by the Hinterland Near and Thirlstane zones. Similarly the seventh and eighth groups which contain Ba and V respectively are also enhanced within the High Street, Hinterland Near and Thirlstane zones. However, Ba is highest within the High Street zone followed by the Thirlstane zone and Hinterland Near zone, and V is statistically enhanced within all three zones.

7.3.2 Pittenweem

Average elemental concentrations of individual zones within Pittenweem are presented in Table 17. There is no significant difference in median Li and V concentrations between the Harbour, High Street, Hinterland Near and Hinterland Far zones. Accordingly these elements were excluded from subsequent multiple comparisons. The results of multiple comparisons between the Harbour, High Street, Hinterland Near and Hinterland Far zones at Pittenweem are summarised in Table 18. Zones with significant elemental enhancement are highlighted (✓) and elements with similar spatial distributions are grouped accordingly.

Table 17: Average elemental concentrations (mg/Kg) of individual zones at Pittenweem (median used for non-parametric data, mean used for parametric data). Test indicates whether Kruskal-Wallis (KW) or One Way ANOVA (ANOVA) used to compare elemental concentrations between zones

Element	Harbour	High Street	Hinterland Near	Hinterland Far	Test	Test Statistic	P Value
Al	5024	5659	6734	6544	KW	H 18.76	<0.001
Fe	17268	14981	16016	15331	KW	H 9.61	0.022
Mg	2708	2394	1887	1700.5	KW	H 33.65	<0.001
Ca	17417	11756	2580	2608.6	KW	H 53.07	<0.001
Na	267.1	244.8	89	59.35	KW	H 60.45	<0.001
K	363.9	348.1	79.1	126.57	KW	H 34.29	<0.001
Ti	64.9	82.5	70.75	47.17	KW	H 37.44	<0.001
P	1741	2147	964.5	960.1	KW	H 43.84	<0.001
Mn	441.4	395	480.2	294.3	KW	H 58.47	<0.001
Ba	153.4	147.7	62.5	61.6	KW	H 57.11	<0.001
Co	6.1	5.3	4.6	4.3	KW	H 39.76	<0.001
Cr	16.1	16	15	16.6	KW	H 15.48	0.001
Cu	44.2	44.1	23.5	23.4	KW	H 44.33	<0.001
Li	6	5.6	6.4	6.4	KW	H 1.29	0.732
Ni	27.5	24.7	19.6	18.8	KW	H 37.34	<0.001
Sc	2.3	2.8	2.6	2.6	KW	H 15.84	0.001
Sr	102.9	91.5	28.5	31.5	KW	H 51.2	<0.001
V	23.6	24.4	27.6	25.6	KW	H 6.76	0.080
Y	7.5	7.8	5.8	5.8	KW	H 38	<0.001
Zn	205.3	168.7	49.3	41.7	KW	H 66.29	<0.001
Pb	221	182	43.3	34.866	ANOVA	F 14.85	<0.001

Table 18: Multiple comparisons for individual zones at Pittenweem (Dunn's test used for non-parametric data, Tukey-Kramer post-hoc analyses for parametric data)

Element	Harbour	High Street	Hinterland Near	Hinterland Far	Summary
Li					No significant difference between zones
V					No significant difference between zones
Mn	✓	✓	✓		Hinterland Near has significantly higher Mn than High Street and Hinterland Far ($p<0.001$) Harbour and High Street have significantly higher Mn than Hinterland Far ($p<0.001$)
Ba	✓	✓			Harbour and High Street have significantly higher Ba than Hinterland Near and Hinterland Far ($p<0.001$)
Ca	✓	✓			Harbour and High Street have significantly higher Ca than Hinterland Near and Hinterland Far ($p<0.001$)
Cu	✓	✓			Harbour and High Street have significantly higher Cu than Hinterland Near and Hinterland Far ($p<0.001$)
K	✓	✓			Harbour has significantly higher K than Hinterland Near ($p<0.01$) and Hinterland Far ($p<0.001$) High Street has significantly higher K than Hinterland Near and Hinterland Far ($p<0.001$)
Ni	✓	✓			Harbour and High Street have significantly higher Ni than Hinterland Near and Hinterland Far ($p<0.001$)
P	✓	✓			Harbour has significantly higher P than Hinterland Near ($p<0.05$) and Hinterland Far ($p<0.01$) High Street has significantly higher P than Hinterland Near and Hinterland Far ($p<0.001$)
Pb	✓	✓			Harbour and High Street have significantly higher Pb than Hinterland Near and Hinterland Far ($p<0.001$)
Sr	✓	✓			Harbour and High Street have significantly higher Sr than Hinterland Near and Hinterland Far ($p<0.001$)
Y	✓	✓			Harbour and High Street have significantly higher Y than Hinterland Near and Hinterland Far ($p<0.001$)
Co	✓	✓	✓		Harbour has significantly greater Co than Hinterland Near ($p<0.01$) and Hinterland Far ($p<0.001$) High Street has significantly greater Co than Hinterland Far ($p<0.001$) Hinterland Near has significantly greater Co than Hinterland Far ($p<0.01$)
Mg	✓	✓	✓		Harbour has significantly higher Mg than Hinterland Far ($p<0.001$) High Street has significantly higher Mg than Hinterland Near ($p<0.05$) and Hinterland Far ($p<0.001$) Hinterland Near has significantly high Mg than Hinterland Far ($p<0.001$)
Na	✓	✓	✓		Harbour has significantly higher Na than Hinterland Near and Hinterland Far ($p<0.001$) High Street has significantly higher Na than Hinterland Near and Hinterland Far ($p<0.001$) Hinterland Near has significantly higher Na than Hinterland Far ($p<0.001$)
Ti		✓	✓		High Street has significantly higher Ti than Hinterland Far ($p<0.001$) Hinterland Near has significantly higher Ti than Hinterland far ($p<0.001$)
Zn	✓	✓	✓		Harbour has significantly higher Zn than Hinterland Near ($p<0.01$) and Hinterland Far ($p<0.001$) High Street has significantly higher Zn than Hinterland Near and Hinterland Far ($p<0.001$) Hinterland Near has significantly higher Zn than Hinterland Far ($p<0.01$)
Cr	✓	✓		✓	Harbour and High Street have significantly higher Cr than Hinterland Near ($p<0.05$) Hinterland Far has significantly higher Cr than Hinterland Near ($p<0.001$)
Sc	✓	✓			Harbour has significantly higher Sc than Hinterland Near and Hinterland Far ($p<0.001$) High Street has significantly higher Sc than Hinterland Far ($p<0.05$)

Al			✓	✓	Hinterland Near has significantly higher Al than Harbour ($p<0.05$) and High Street ($p<0.001$) Hinterland Far has significantly higher Al than Harbour ($p<0.001$) and High Street ($p<0.05$)
Fe	✓		✓		Harbour has significantly higher Fe than High Street ($p<0.05$) Hinterland Near has significantly higher Fe than High Street ($p<0.05$)

Seven groups of elements with distinct patterns of spatial enhancement are identified at Pittenweem. The first group contains Li and V which are relatively homogenous and show no pattern of spatial enhancement within the sample area. The second group is characterised by significantly higher levels of Mn within the Hinterland Near zone and to a lesser extent in the Harbour and High Street zones. None of the other elements share a similar spatial distribution with Mn.

The third group comprises Ba, Ca, Cu, K, Ni, P, Pb, Sr and Y. Elements within this group are significantly enhanced within the Harbour and High Street zones. There is no statistical difference in enhancement between these two zones.

The fourth group includes Co, Mg, Na, Ti and Zn. Typically these elements are primarily enhanced within the Harbour and High Street zones and to a lesser extent are elevated within the Hinterland Near zone. It could be argued that Ti should not be included within this group considering the Harbour is not statistically enhanced comparative to the Hinterland Near or Hinterland Far zones. However multiple comparisons indicate that there is no significant difference in Ti concentrations between the Harbour and High Street zone (Table 18).

The fifth group contains Cr and Sc. Statistical analysis indicates that Cr is enhanced within the Harbour, High Street and Hinterland Far zones and Sc is elevated in the Harbour and High Street zones. Nevertheless, median values of these two elements are relatively comparable between zones (Table 17). It is therefore suggested that these two elements do not show a distinct pattern of spatial enhancement within the survey area. The sixth and seventh groups contain Al and Fe respectively, of which Al is enhanced within the Hinterland Near and Hinterland far zones and Fe is elevated in the Harbour and Hinterland Near zones.

7.3.3 Wigtown

Average elemental concentrations of individual zones within Wigtown are presented in Table 19. There is no significant difference in median Al between the High Street, Hinterland Near and Showfield zones. Accordingly Al was excluded from subsequent multiple comparisons. The results of multiple comparisons between the High Street, Hinterland Near and Showfield zones at Wigtown are summarised in Table 20. Zones with significant elemental enhancement are highlighted (✓) and elements with similar spatial distributions are grouped accordingly.

Table 19: Average elemental concentrations (mg/Kg) for individual zones at Wigtown (median used for non-parametric data, mean used for parametric data). Test indicates whether Kruskal-Wallis (KW) or One Way ANOVA (ANOVA) used to compare elemental concentrations between zones

Element	High Street	Hinterland Near	Showfield	Test	Test Statistic	P Value
Al	12928	12886	12870	KW	H 1.84	0.399
Fe	22493	21479	22884	KW	H 9.9	0.01
Mg	5535.8	4903	4529	KW	H 36.35	<0.001
Ca	17038	1522	1143	KW	H 65.68	<0.001
Na	222.6	59.35	66.77	KW	H 65.82	<0.001
K	870.2	284.8	300.6	KW	H 56.59	<0.001
Ti	165.08	53.06	47.17	KW	H 61.15	<0.001
P	5001	1492.5	2553	KW	H 79.29	<0.001
Mn	967.4	673.8	867.4	KW	H 36.78	<0.001
Ba	236.6	48.9	94.9	KW	H 74	<0.001
Co	8.4	4.6	4.6	KW	H 58.49	<0.001
Cr	32.2	34.6	27	KW	H 16.82	<0.001
Cu	78.4	18.2	32.5	KW	H 73.20	<0.001
Li	7.4	7	5.3	KW	H 14.93	<0.001
Ni	42.2	24.8	22.2	KW	H 59.31	<0.001
Sc	3.2	1.8	2	KW	H 68.05	<0.001
Sr	153	11.5	13.6	KW	H 66.02	<0.001
V	37	30.8	22.1	KW	H 28.34	<0.001
Y	10.6	4.2	5	KW	H 66.08	<0.001
Zn	418	52.9	84.8	KW	H 74.57	<0.001
Pb	373.9	63.18	151.31	KW	H 76.51	<0.001

Table 20: Multiple comparisons for individual zones at Wigtown (Dunn's test used for non-parametric data, Tukey-Kramer post-hoc analyses for parametric data)

Element	High Street	Hinterland Near	Showfield	Summary
Al				No significant difference between zones
Fe	✓		✓	High Street has significantly higher Fe than Hinterland Near (p<0.01) Showfield has significantly higher Fe than Hinterland Near (p<0.05)
Ca	✓			High Street has significantly higher Ca than Hinterland Near and Showfield (p<0.001)
Co	✓			High Street has significantly higher Co than Hinterland Near and Showfield (p<0.001)
K	✓			High Street has significantly higher K than Hinterland Near and Showfield (p<0.001)
Mg	✓			High Street has significantly higher Mg than Hinterland Near and Showfield (p<0.001)
Na	✓			High Street has significantly higher Na than Hinterland Near and Showfield (p<0.001)
Ni	✓			High Street has significantly higher Ni than Hinterland Near and Showfield (p<0.001)
Sr	✓			High Street has significantly higher Sr than Hinterland Near and Showfield (p<0.001)
Ti	✓			High Street has significantly higher Ti than Hinterland Near and Showfield (p<0.001)
Cr	✓	✓		High Street has significantly higher Cr than Showfield (p<0.01) Hinterland Near has significantly higher Cr than Showfield (P<0.001)
Li	✓	✓		High Street has significantly higher Li than Showfield (p<0.001) Hinterland Near has significantly higher Li than Showfield (P<0.01)
V	✓	✓		High Street has significantly higher V than Hinterland Near (p<0.01) and Showfield (p<0.001) Hinterland Near has significantly higher V than Showfield (P<0.01)
Ba	✓		✓	High Street has significantly higher P than Hinterland Near and Showfield (p<0.001) Showfield has significantly P than Hinterland Near (p<0.001)
Cu	✓		✓	High Street has significantly higher Cu than Hinterland Near and Showfield (p<0.001) Showfield has significantly higher Cu than Showfield (p<0.001)
Mn	✓		✓	High Street has significantly higher Mn than Hinterland Near (p<0.001) Showfield has significantly higher Mn than Hinterland Near (p<0.001)
P	✓		✓	High Street has significantly higher P than Hinterland Near (p<0.001) and Showfield (p<0.01) Showfield has significantly P than Hinterland Near (p<0.001)
Pb	✓		✓	High Street has significantly higher Pb than Hinterland Near (p<0.01) and Showfield (p<0.001) Showfield has significantly higher Pb than Hinterland Near (P<0.001)
Sc	✓		✓	High Street has significantly higher Sc than Hinterland Near and Showfield (p<0.001) Showfield has significantly higher Sc than Hinterland Near (p<0.05)
Y	✓		✓	High Street has significantly higher Y than Hinterland Near and Showfield (p<0.001) Showfield has significantly higher Y than Hinterland Near (p<0.05)
Zn	✓		✓	High Street has significantly higher Zn than Hinterland Near and Showfield (p<0.001) Showfield has significantly higher Zn than Hinterland Near (p<0.01)

Four groups of elements with distinct patterns of spatial enhancement are identified at Wigtown. The first group contains Al and Fe. Al concentrations are relatively homogenous and show no pattern of spatial enhancement within the sample area. Fe is statistically enhanced within the High Street and Showfield zones; however, median values are relatively comparable between zones (Table 19). Accordingly it is suggested that Fe concentrations do not exhibit a distinct spatial distribution at Wigtown. The second group of elements comprises Ca, Co, K Mg, Na, Ni, Sr and Ti. These elements are characteristically enhanced within the High Street zone.

The third group of elements contains Cr, Li and V. Elements within this group are statistically enhanced within the High Street zone and Hinterland Near zone. There is no significant difference in Cr and Li between the High Street and Hinterland Near zones, though V is elevated to a lesser extent within the Hinterland Near zone. The fourth group of elements includes Ba, Cu, Mn, P, Pb, Sc, Y and Zn. These elements are primarily enhanced within the High Street zone and to a lesser extent are elevated within the Showfield zone.

7.4 Cluster Analysis

Cluster analysis was undertaken on all elemental data for Lauder, Pittenweem and Wigtown to simplify data sets and group together elements with similar spatial distributions.

7.4.1 <u>Lauder</u>

Seven elemental clusters with statistically distinct patterns of spatial enhancement are identified at Lauder (Table 21). The first cluster includes Al, Fe, Mg, Cr and Li (Figure 120). Although multiple comparisons indicate a significant difference in Fe, Mg and Cr between particular zones (section 7.3.1) it is argued that variation in median values between zones is relatively limited compared to other elements, for example Ca and P (Table 15). Moreover, considering Mg and Cr are 89.02% similar to Al, Fe and Li it suggested that these elements are characteristically heterogeneous with no real pattern of spatial enhancement at Lauder

Cluster 2 consists of Ca, Na, K, Ti, P, Co, Cu, Ni, Sc, Sr and Zn. These elements are significantly enhanced within the High Street zone and to a lesser extent are elevated within the Hinterland Near zone. This cluster is directly comparable with group four identified in section 6.3.1. Cluster 2 includes all elements present within group four and additionally incorporates Na, P and Sc. Na has similar characteristics to Ca, Ti, Sr and Zn (89% similarity), P is similar to K (88%) and Sc is similar to Co and Ni (94%). P and Sc are primarily enhanced within the High Street zone and are slightly elevated within the Hinterland Near zone. Conversely elevated Na levels are confined to the High Street zone. Cluster 3 comprises Mn which is significantly enhanced within the Hinterland Near zone. This cluster is comparable to group 3 identified in section 7.3.1.

Clusters 4 and 5 which contain Ba and V respectively are analogous to groups seven and eight. Ba is enhanced within the High Street, Thirlstane and Hinterland Near zones and is most similar to the cluster 2 element K (83% similarity). There is no significant difference in V between the High Street, Hinterland Near and Thirlstane zones, hence is 80.69% similar to cluster 1 elements which are not spatially enhanced. However, it is suggested that V was clustered independently on account of the High Street, Hinterland Near and Thirlstane zones being significantly higher than the Hinterland Far zone. Clusters 6 and 7 which contain Y and Pb respectively are primarily elevated within the High Street zone and to a lesser extent the in Thirlstane and Hinterland Near zones. Y is 80% similar to Ba and Pb is 75% similar to Mn.

Table 21 Summary of Cluster analysis amalgamation steps for elemental data at Lauder

Step	No. of Clusters	Similarity Level	Distance Level	Clusters Joined	New Cluster	No. Observations
1	20	96.4	0.071	20	17	2
2	19	95.2	0.095	15	11	2
3	18	94.9	0.100	17	7	3
4	17	94.7	0.105	16	11	3
5	16	91.7	0.165	14	2	2
6	15	91.3	0.172	7	4	4
7	14	91.1	0.176	2	1	3
8	13	89.8	0.202	5	4	5
9	12	89.1	0.217	11	4	8
10	11	89.9	0.200	13	4	9
11	10	91.8	0.163	8	4	10
12	9	88.3	0.233	6	4	11
13	8	88.3	0.233	12	3	2
14	**7**	**89.0**	**0.219**	**3**	**1**	**5**
15	6	80.6	0.386	18	1	6
16	5	80.6	0.386	19	10	2
17	4	83.1	0.337	10	4	13
18	3	84.5	0.308	4	1	19
19	2	75.2	0.494	21	1	20
20	1	66.9	0.661	9	1	21

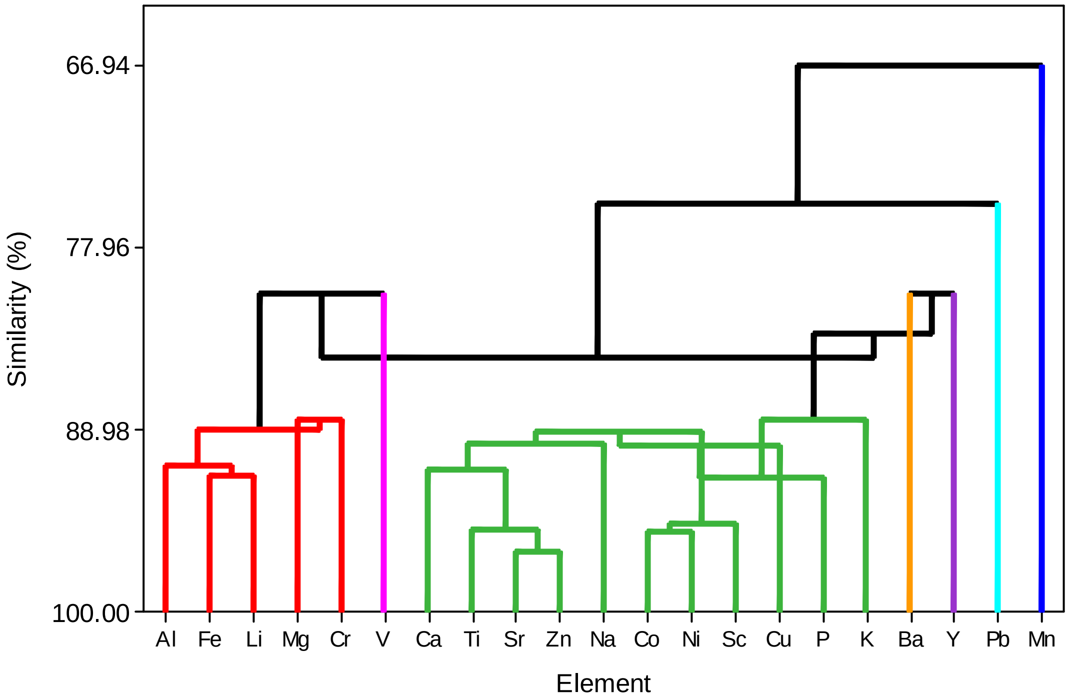


Figure 120: Dendrogram showing results of Cluster analysis for elemental data at Lauder. Seven main groups are identified; cluster 1 (red), cluster 2 (green), cluster 3 (blue), cluster 4 (orange), cluster 5 (magenta), cluster 6 (purple) and cluster 7 (cyan)

7.4.2 Pittenweem

Five elemental clusters with statistically distinct patterns of spatial enhancement are identified at Lauder (Table 22). The first cluster includes Al, V, Cr and Sc (Figure 121). Although multiple comparisons indicate a significant difference in Al, Cr and Sc between particular zones (section 7.3.2) it is argued that variation in median values between zones is relatively limited compared to other elements, for example Ba and Ca (Table 17). Moreover, considering Cr and Sc are 83 % similar to V and Al it is suggested that these elements are characteristically heterogeneous with no real pattern of spatial enhancement at Pittenweem.

Cluster 2 comprises Fe which is statistically elevated within the Harbour and Hinterland Near zones. This cluster is comparable to group 7 identified in section 6.3.2.

Cluster 3 contains Mg, Na, Ca, Sr, P, Cu, Ba, Zn, Co, Ni, Y, K, Pb and Ti. These elements are significantly enhanced within the Harbour and High Street zones. Moreover Co, Mg, Na, Ti and Zn are elevated to a lesser extent within the Hinterland Near zone. This cluster is directly comparable with groups three and four identified in section 7.3.2. The strongest similarities between elements within this group exist between Co and Ni (97%), Mg and Na (96%), Ca and Sr (94%), P and Cu (94%) and Ba and Zn (93%).

Cluster 4 comprises Mn which is significantly enhanced within the Hinterland Near zone. This cluster is comparable to group 2 identified in section 7.3.2. Cluster 5 contains Li, of which there is no distinct spatial enhancement pattern over the sample area. Li is 80 % similar to Mn and 80 % to Fe.

Table 22: Summary of Cluster analysis amalgamation steps for elemental data at Pittenweem

Step	No. of Clusters	Similarity Level	Distance Level	Clusters Joined	New Cluster	No. Observations
1	20	97.3	0.052	15	11	2
2	19	96.2	0.075	5	3	2
3	18	94.2	0.114	17	4	2
4	17	94.0	0.118	13	8	2
5	16	93.5	0.129	19	11	3
6	15	93.3	0.132	20	10	2
7	14	93.6	0.126	10	8	4
8	13	90.8	0.183	11	8	7
9	12	88.1	0.236	8	4	9
10	11	87.3	0.252	6	4	10
11	10	84.5	0.308	18	1	2
12	9	82.6	0.347	21	4	11
13	8	81.1	0.376	4	3	13
14	7	85.2	0.295	7	3	14
15	6	80.0	0.398	12	1	3
16	**5**	**83.4**	**0.330**	**16**	**1**	**4**
17	4	79.3	0.412	3	1	18
18	3	80.0	0.399	2	1	19
19	2	80.6	0.386	9	1	20
20	1	65.8	0.682	14	1	21

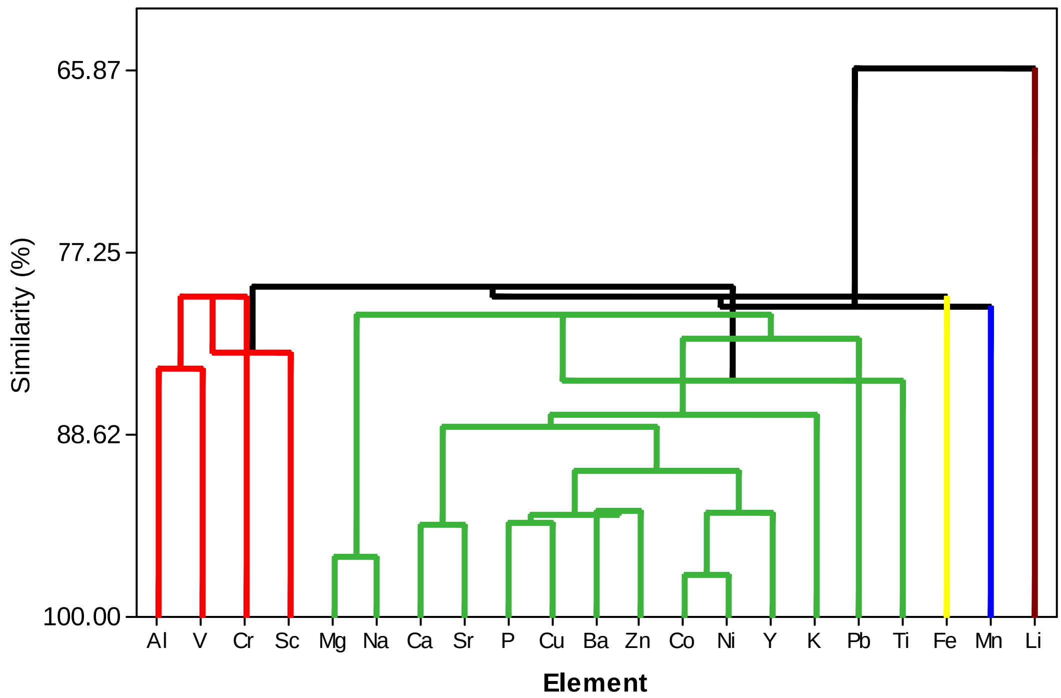


Figure 121: Dendrogram showing results of Cluster analysis for elemental data at Pittenweem. Five main groups are identified; cluster 1 (red), cluster 2 (yellow), cluster 3 (green), cluster 4 (blue) and cluster 5 (brown)

7.4.3 Wigtown

Six elemental clusters with statistically distinct patterns of spatial enhancement are identified at Lauder (Table 23). The first cluster is directly comparable to group 1 identified in section 7.3.3 in that it contains Al and Fe (Figure 122). Although multiple comparisons indicate a significant difference in Fe between particular zones (section 7.3.3) it is argued that variation in median values between zones is relatively limited compared to other elements, for example Ba, Ca and P (Table 19). Moreover, considering Fe is 81% similar to Al, it is suggested that these elements are characteristically heterogeneous with no distinct pattern of spatial enhancement at Wigtown.

The second cluster includes Mg, Ca, Na, K, Ti, P, Ba, Co, Cu, Ni, Sc, Sr, Y, Zn and Pb. These elements are all significantly enhanced within the High Street zone. In addition Ba, Cu, P, Pb, Sc, Y and Zn are elevated within the Showfield zone, albeit to a significantly lesser extent. This cluster is directly comparable with groups 2 and 4 identified in section 7.3.3, with the exception of Mn. The strongest similarities between elements within this cluster are Ca and Sr (98%), Sc and Y (98%), Co and Ni (96%) and Zn and Pb (99%).

Cluster 3 contains Mn which is significantly enhanced within the High Street and Showfield zones. Clusters 4, 5 and 6 comprise Cr, Li and V respectively. These elements are statistically elevated within the High Street and Hinterland Near zones. However, variation in median values is minimal especially when compared to elements in cluster 2. Moreover, considering Cr and V are 76% and 77% similar to cluster 1 elements Al and Fe it is argued that clusters 4, 5 and 6 do not exhibit a distinct spatial distribution at Wigtown.

Table 23: Summary of Cluster analysis amalgamation steps for elemental data at Wigtown

Step	No. of Clusters	Similarity Level	Distance Level	Clusters Joined	New Cluster	No. Observations
1	20	99.0	0.019	21	20	2
2	19	98.3	0.033	19	16	2
3	18	98.0	0.038	17	4	2
4	17	97.0	0.058	16	7	3
5	16	96.7	0.065	15	11	2
6	15	96.5	0.069	5	4	3
7	14	95.9	0.080	7	4	6
8	13	95.8	0.083	10	4	7
9	12	94.8	0.103	8	4	8
10	11	92.0	0.158	6	4	9
11	10	91.0	0.179	13	11	3
12	9	88.7	0.225	11	4	12
13	8	81.6	0.367	20	4	14
14	7	83.0	0.339	4	3	15
15	**6**	**81.1**	**0.376**	**2**	**1**	**2**
16	5	76.6	0.467	12	1	3
17	4	77.2	0.454	18	1	4
18	3	77.8	0.443	3	1	19
19	2	79.2	0.415	14	1	20
20	1	68.1	0.636	9	1	21

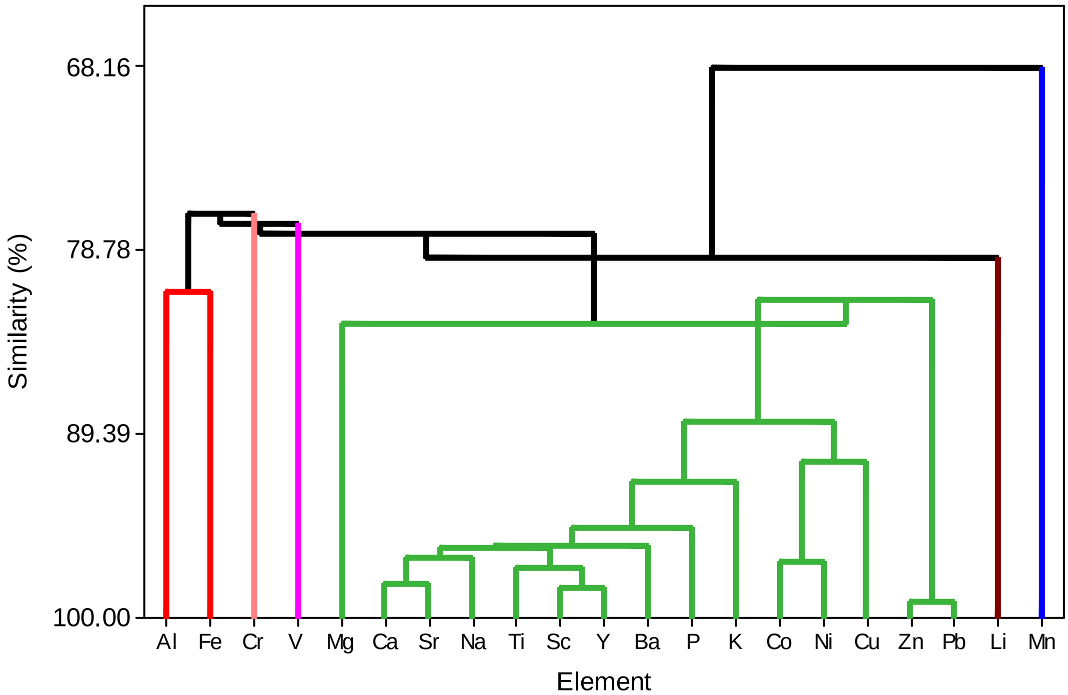


Figure 122: Dendrogram showing results of Cluster analysis for elemental data at Wigtown. Six main groups are identified; cluster 1 (red), cluster 2 (green), cluster 3 (blue), cluster 4 (coral), cluster 5 (brown) and cluster 5 (magenta)

7.5 Discriminant Analysis

Discriminant analysis was undertaken on all elemental data for Lauder, Pittenweem and Wigtown to investigate whether predicted classifications of sample points are similar to those observed. It is expected that zones with spatially distinct patterns of elemental enhancement will have a high percentage of observations correctly classified, for example 22 sample points (observations) are located within the High Street zone at Lauder (true zone), of which 21 (95.5%) were successfully predicted as belonging to the High Street zone (predicted zone).

7.5.1 Lauder

The results of discriminant analysis for zones within Lauder are presented in Table 24. The discriminant analysis identified the correct zone for 111 of 116 observations within the survey area (95.7%). The Hinterland Far zone has the highest probability of correct classification (97.2%) followed in succession by the Hinterland Near (96.8%), High Street (95.5%) and Thirlstane (92.6%) zones. The high accuracy of classification at Lauder suggests that zones can be successfully distinguished according to differences in their elemental concentrations.

Table 24: Summary of discriminant classification for individual zones within Lauder; 'true zone' indicates the location of observations (sample points), 'predicted zone' indicates the predicted location of observations, 'No. observations' indicates the total number of observations per zone and 'No. observations correct' signifies the number of observations correctly classified per zone

	True Zone			
Predicted Zone	**High Street**	**Hint Near**	**Hint Far**	**Thirlstane**
High Street	**21**	**0**	**0**	**0**
Hint Near	**0**	**30**	**1**	**1**
Hint Far	**1**	**1**	**35**	**1**
Thirlstane	**0**	**0**	**0**	**25**
No. Observations	**22**	**31**	**36**	**27**
No. Observations Correct	**21**	**30**	**35**	**25**
% Observations Correct	**95.5**	**96.8**	**97.2**	**92.6**

7.5.2 Pittenweem

The results of discriminant analysis for zones within Pittenweem are presented in Table 25. The discriminant analysis identified the correct zone for 91 of 96 observations within the survey area (94.8%). Similar to results obtained for Lauder, the Hinterland Far zone has the highest probability of correct classification (100%) followed by the Hinterland Near (78.6%) and High Street zones (70.8%). The high classification accuracy of hinterland zones indicates that these zones have differing elemental characteristics. Classification of the Harbour (50%) and High Street (70.8%) zones is less successful. 75% of misclassified observations within the harbour were assigned to the High Street zone and 57% of misclassified observations within the High Street were assigned to the Harbour Zone. This indicates that there are similarities in elemental concentrations present within Harbour and High Street zones.

Table 25: Summary of classification for individual zones within Pittenweem; 'true zone' indicates the location of observations (sample points), 'predicted zone' indicates the predicted location of observations, 'No. observations' indicates the total number of observations per zone and 'No. observations correct' signifies the number of observations correctly classified per zone

	True Zone			
Predicted Zone	**Harbour**	**High Street**	**Hint Near**	**Hint Far**
Harbour	**4**	**4**	**0**	**0**
High Street	**3**	**17**	**2**	**0**
Hint Near	**1**	**3**	**22**	**0**
Hint Far	**0**	**0**	**4**	**36**
No. Observations	**8**	**24**	**28**	**36**
No. Observations Correct	**4**	**17**	**22**	**36**
% Observations Correct	**50**	**70.8**	**78.6**	**100**

7.5.3 Wigtown

The results of discriminant analysis for zones within Wigtown are presented in Table 26. The discriminant analysis identified the correct zone for 95 of 99 observations within the survey area (96%). The High Street zone has the highest probability of correct classification (97%) followed in succession by the Showfield (88.9%) and Hinterland Near (85.4%) zones. The high accuracy of classification at Wigtown suggests that zones can be successfully distinguished according to differences in their elemental concentrations.

Table 26: Summary of classification for individual zones within Wigtown; 'true zone' indicates the location of observations (sample points), 'predicted zone' indicates the predicted location of observations, 'No. observations' indicates the total number of observations per zone and 'No. observations correct' signifies the number of observations correctly classified per zone

	True Zone		
Predicted Zone	**High Street**	**Hint Near**	**Showfield**
High Street	32	0	0
Hint Near	0	41	2
Showfield	1	7	16
No. Observations	33	48	18
No. Observations Correct	32	41	16
% Observations Correct	97	85.4	88.9

7.5.4 Discrimination between Burghs

7.5.4.1 High Street Zone

The results of discriminant analysis between High Street zones at Lauder, Pittenweem and Wigtown are presented in Table 27. Observations within each High Street zone were assigned to the correct burgh (100% accuracy) indicating that although similarities in elemental enhancement patterns are identified between burghs, there are distinctive differences in elemental concentrations between High Street zones.

Table 27: Summary of classification for the High Street zone at Lauder, Pittenweem and Wigtown; 'true burgh' indicates the location of observations (sample points), 'predicted burgh' indicates the predicted location of observations, 'No. observations' indicates the total number of observations within each High Street zone and 'No. observations correct' signifies the number of observations correctly classified per burgh

	True Burgh		
Predicted Burgh	**Lauder**	**Pittenweem**	**Wigtown**
Lauder	22	0	0
Pittenweem	0	24	0
Wigtown	0	0	33
No. Observations	22	24	33
No. Observations Correct	22	24	33
% Observations Correct	100	100	100

7.5.4.2 Hinterland Near Zone

The results of discriminant analysis between Hinterland Near zones at Lauder, Pittenweem and Wigtown are presented in Table 28. The Hinterland Near zone at Pittenweem has the highest percentage classification accuracy (100%) followed in succession by Lauder (96.8%) and Wigtown (95.8%). The high accuracy of classification suggests that there are distinctive differences in elemental concentrations between Hinterland Near zones.

Table 28: Summary of classification for Hinterland Near zones at Lauder, Pittenweem and Wigtown; 'true burgh' indicates the location of observations (sample points), 'predicted burgh' indicates the predicted location of observations, 'No. observations' indicates the total number of observations within each Hinterland Near zone and 'No. observations correct' signifies the number of observations correctly classified per burgh

	True Burgh		
Predicted Burgh	**Lauder**	**Pittenweem**	**Wigtown**
Lauder	**30**	**0**	**1**
Pittenweem	**1**	**28**	**1**
Wigtown	**0**	**0**	**46**
No. Observations	**31**	**28**	**48**
No. Observations Correct	**30**	**28**	**46**
% Observations Correct	**96.8**	**100**	**95.8**

7.6 Summary of Results: Multi-Element Analyses

The following section summarises the principal results of multi-elements analyses. The significance of elemental associations within and between burghs is discussed in section 8.1.2 and 8.2.2.

7.6.1 Variation within Burghs

7.6.1.1 Lauder

The results of multi-element analyses for zones within Lauder are summarised in Table 29. Both the High Street and Hinterland Near zones are characterised by significantly enhanced levels of Ca, K, Ti, Co, Cu, Ni, Sr, Zn, Ba, P, Pb, Sc and Y. In addition, the Thirlstane zone has typically elevated concentrations of Ba, P, Pb, Sc and Y. Elemental enhancement is statistically greatest within the High Street zone followed by the Hinterland Near zone and Thirlstane zone in succession. There is no significant enhancement within the Hinterland Far zone. These results indicate pronounced elemental enhancement within the burgh core at Lauder. Moreover, similarity in the range of elements enhanced in the High Street zone and Hinterland Near zone suggest comparable enhancement patterns between the burgh core and immediate hinterland south (Hinterland Near) of the historical burgh limits. There are two exceptions to this generalisation, Na which is limited to the burgh core and Mn which is restricted to the immediate hinterland south of Lauder (Hinterland Near). The immediate hinterland north (Thirlstane) of Lauder is typically enhanced in a smaller number of elements and to a lesser extent than the High Street and Hinterland Near zones.

Table 29: Summary of elemental enhancement within zones at Lauder; pink indicates enhancement within the High Street zone only, green indicates enhancement within Hinterland Near zone only, orange indicates enhancement within High Street and Hinterland Near zones, and blue indicates enhancement within High Street, Hinterland Near and Thirlstane zones

	Elements
High Street	Na Ca K Ti Co Cu Ni Sr Zn Ba P Pb Sc Y
Hinterland Near	Mn Ca K Ti Co Cu Ni Sr Zn Ba P Pb Sc Y
Hinterland Far	
Thirlstane	Ba P Pb Sc Y

7.6.1.2 Pittenweem

The results of multi-element analyses for zones within Pittenweem are summarised in Table 30. The Harbour and High Street zones are characterised by significantly enhanced concentrations of Ba, Ca, Cu, K, Ni, O, Pb, Sr, Y, Co, Mg, Na, Ti and Zn. There is no difference in the range of elemental concentrations or degree of enhancement between these two zones. Enhancement of Mn is restricted to the Hinterland Near zone. Moreover, the Hinterland Near zone has elevated concentrations of Co, Mg, Na, Ti and Zn. Elemental enhancement is statistically greatest within the Harbour and High Street zones followed by the Hinterland Near zone. There is no significant enhancement within the Hinterland Far zone. These results indicate pronounced elemental enhancement within the burgh core at Pittenweem. In addition, the immediate hinterland north (Hinterland Near) of the historical burgh limits is typically enhanced in a smaller range of elements and to a lesser extent that the Harbour and High Street zones.

Table 30: Summary of elemental enhancement within zones at Pittenweem; green indicates enhancement within the Hinterland Near zone only, orange indicates enhancement within the Harbour and High Street zones and blue indicates enhancement within the Harbour, High Street and Hinterland Near zones

	Elements
Harbour	**Ba Ca Cu K Ni P Pb Sr Y Co Mg Na Ti Zn**
High Street	**Ba Ca Cu K Ni P Pb Sr Y Co Mg Na Ti Zn**
Hinterland Near	**Mn Co Mg Na Ti Zn**
Hinterland Far	

7.6.1.3 Wigtown

The results of multi-element analyses for zones within Wigtown are summarised in Table 31. The High Street zone is characterised by significantly enhanced concentrations of Ca, Co, K, Mg, Na, Ni, Sr and Ti. These elements are restricted to the High Street zone; however, Ba, Cu, Mn, P, Pb, Sc, Y and Zn are elevated within the High Street and Showfield zones. Elemental enhancement is statistically greatest within the High Street zone followed by the Showfield zone. There is no enhancement within the Hinterland Near zone. These results indicate pronounced elemental enhancement within the burgh core at Wigtown. In addition, the immediate hinterland south (Showfield) of the historical burg limits is enhanced in a smaller range of elements and to a lesser extent that the High Street zone.

Table 31: Summary of elemental enhancement within zones at Wigtown; pink indicates enhancement within the High street zone only and orange indicates enhancement within the High Street and Showfield zones

	Elements
High Street	**Ca Co K Mg Na Ni Sr Ti Ba Cu Mn P Pb Sc Y Zn**
Hinterland Near	
Showfield	**Ba Cu Mn P Pb Sc Y Zn**

7.6.2 Variation between Burghs

All three burghs have enhanced concentrations of Ba, Ca, Na, K, Ti, Co, Cu, Ni, P, Pb, Sr Y and Zn within the High Street zone. This finding indicates comparable patterns of elemental enhancement between burgh cores. In addition, there are no discernable patterns in Al, Fe Cr, Li and V at Lauder, Pittenweem and Wigtown. Elemental enhancement is most pronounced within burgh cores; however enhancement is noted within certain hinterland zones, albeit to a lesser extent. Zones of enhancement are identified in the immediate hinterland south (Hinterland Near) and north (Thirlstane) of Lauder, in the immediate hinterland north of Pittenweem (Hinterland Near) and in the immediate hinterland south of Wigtown (Showfield). The range of elemental concentrations and magnitude of enhancement within these zones is characteristically diverse. It should also be noted that all three burghs have one zone which is not enhanced; namely the Hinterland Far zone at Lauder and Pittenweem, and the Hinterland Near zone at Wigtown.

8 The Impact of Waste Disposal on Soils in and Around Lauder, Pittenweem and Wigtown

This chapter examines the impact of waste disposal on urban anthrosols within and adjacent to Lauder, Pittenweem and Wigtown. The following discussion is centred on two contrasting areas of importance, the burgh core and its hinterland. The historical legacy of waste disposal within these two areas is considered and comparisons between burghs are made.

8.1 The Impact of Waste Disposal on Burgh Cores

8.1.1 Soil Modification

Deepened topsoils at Lauder, Pittenweem and Wigtown provide clear evidence for sustained application of waste material within burgh cores. Accumulation of topsoils can be explained through addition of waste rich in mineral material for example, turf used in building construction, ash from hearths, sand used in byres and sand associated with seaweed. Topsoils within burgh cores are characteristically neutral. It is suggested that deposition of calcium rich materials such as mortar, plaster and lime washes used in building construction, and shell and bone associated with kitchen waste account for the transformation of topsoils from acidic to neutral pH. Furthermore, it seems likely that these calcareous waste materials are reflected in enhanced concentrations of calcium within burgh cores.

High organic matter content and enhanced concentrations of phosphorus within burgh cores indicate addition of human and animal excreta, domestic refuse and fuel residues. It is proposed that sustained application of these materials resulted in the formation of hortic horizons within topsoils at Lauder, Pittenweem and Wigtown. According to the World Reference Base (WRB) for soil classification Hortic horizons reflect processes of deep cultivation, intensive fertilisation and/or sustained addition of human and animal wastes and other organic residues (FAO 2006). Enhancement of topsoil magnetic susceptibility within burgh cores signifies input of materials which have been heated to high temperatures, for example charcoal, ash and charred remains (fuel residues) resulting from burning of peat, wood, moss and coal in domestic and industrial hearths. Moreover, it is suggested that sherds of fired ceramic materials such as pottery and brick contribute to magnetic enhancement within burgh cores.

8.1.2 Elemental Signatures

Two elemental signatures are identified at Lauder, Pittenweem and Wigtown. Elements within first group (Al, Fe, Cr, Li and V) do not exhibit distinct spatial distributions, hence are not indicative of anthropogenic activity. It is proposed that elements within the second group (Ba, Ca, Na, K, Co, Cu, Ni, P, Pb, Sr, Ti, Y and Zn) are related to past anthropogenic activities given that they show consistent patterns of enhancement within burgh cores. It is suggested that enhanced concentrations of phosphorus reflect burning of woody material (Aston 1998), human and animal wastes, and domestic rubbish (Wilson *et al*., 2008). However, considering the wide range of enhancement within burgh cores it is difficult to assign individual elements to specific materials and activities.

Elemental enhancement within burgh cores can be attributed to multiple factors; concentration of elements through combustion of fuel in domestic and industrial hearths, industrial activities such as craft and metal working, deposition of building materials including mortar, plaster and lime, and disposal of human and animal wastes. Industries noted during the mid 16th century in Pittenweem brewing, fishing, butchery, tanning, cloth production, and gold, silver and iron smithing (Simpson and Stevenson 1981a). Certain industries such as tanning and metalworking produced wastes are associated with distinct elemental compositions; however, it is argued that elemental signatures are not readily identifiable due to pre-depositional integration of domestic and industrial wastes and post–depositional mixing of elements within the soil matrix.

8.1.3 Waste Materials

Micromorphological analysis of topsoils at Lauder, Pittenweem and Wigtown confirms that building materials, domestic rubbish and industrial wastes were routinely deposited within burgh cores. Waste materials types are largely consistent between burghs, for example bone, pottery, brick, clinker, slag, mortar, plaster and heated stones are present within all three burgh cores. In contrast shell is limited to Pittenweem and Wigtown. It is argued that shell reflects the historical legacy of fishing within these towns and their role as ports (Figure 123, Figure 124). It is likely that shell remains constituted kitchen waste given their location within back gardens and association with other domestic wastes. It is also recognised that shell was used as a fertiliser on local farms within Wigtown, for instance Duncan (1791-99) notes that shells ranging in price from 1s 4d per ton to 1s 6d and of various qualities were sold at Wigtown harbour.

Figure 123: Wigtown harbour (above) was used primarily as a fishing port between the 15th and 18th centuries (Simpson and Stevenson 1981b). The harbour fell into disuse in the early 19th century due to increasing sedimentation and was replaced by a new harbour 400m south of Wigtown (Image © Royal Commission on the Ancient and Historical Monuments of Scotland, Licensor www.scran.ac.uk)

Figure 124: The Old Boat Haven (left) was used as the main harbour of Pittenweem until 1541AD. It was carved into the rocky shoreline and its pier was used as a natural outcrop with a road cut into it. Pittenweem harbour (right) was built in 1541AD to accommodate expanding fishing fleets. The inner harbour comprises the west and east pier, both of which have been systematically rebuilt over the 17th to 19th centuries, and the outer harbour is enclosed by the south pier (Images © Royal Commission on the Ancient and Historical Monuments of Scotland, Licensor www.scran.ac.uk)

8.1.3.1 Harbour and High Street zones

Waste material types are consistent between the Harbour and High Street zones at Pittenweem; however, shell is more abundant within topsoils in the Harbour zone. It is expected that industries associated with fishing were situated within the harbour backlands. Cleaning and processing clams, mussels, cockles and whelks for local markets and export would have led to considerable quantities of waste. Bait preparation using shellfish may also explain why higher volumes of shell material occur within topsoils in the harbour zone. In addition the practise of cleaning and drying fishing nets suspended across the back gardens could have led to *in-situ* deposition of marine derived waste.

In contrast pottery, brick, mortar and plaster materials are more concentrated within the High Street zone. These materials became more important during the 17th century when buildings were increasingly made of stone and lime mortar. Utilisation of these materials would have depended on their availability and affordability. Houses within the High Street zone were primarily occupied by burgesses who were considerably wealthier than fisherman who rented cottages adjacent to the harbour (Horsburgh 1856). It is suggested that higher abundances of building waste reflects the social and economic disparity of inhabitants. Higher abundances of building waste can be attributed to earlier and more intensive utilisation of materials such as lime mortar and brick within the High Street zone. In contrast, the tradition of using turf and clay mortar for building repairs may have endured longer within the Harbour zone.

8.1.3.2 Topsoil Horizons

Fuel residue is present in upper and lower topsoil horizons at Lauder indicating continual deposition of waste materials produced through domestic and industrial combustion. Absence of coarse mineral material from lower topsoil horizons provides clear evidence for basic stratification of deposits within the burgh core. More recent inputs of domestic and industrial wastes and building debris suggest a change in either land use within the backlands or in the management and disposal of waste.

8.1.4 Fuel Residue

Fuel residue within topsoils at Lauder, Pittenweem and Wigtown provides clear evidence for sustained application of materials resulting from domestic and industrial combustion to soils within burgh cores. Fuel resources common to all three burghs include peat, turf and coal. The importance of peat deposits are reflected in the royal burgh foundation charter of Pittenweem (1546AD) which grants ownership of all surrounding moors to the burgesses and inhabitants of the town. Turf and peat are cited as the principal fuel resources at Lauder and Wigtown until the introduction of coal in the latter 18th century (Duncan 1791-99, Ford 1791-99). Moreover, Nairne (1791-99) reports that coal was progressively taken from seams underlying Pittenweem until industrialisation of coal extraction in 1770AD. It is expected that locally available fuel resources such as timber and mosses were exploited in addition to peat and coal at all three burghs despite lacking documentary evidence.

Types of fuel residue waste are consistent between burghs, for example charcoal, FR1, FR 2, FR 3, FR 4 & 6, FR 5 & 7, FR 8 & 9 and FR 10 inclusions are present within all three burgh cores. This indicates that similar fuel sources were exploited at Lauder, Pittenweem and Wigtown. However, results of micromorphological analysis reveal differences in principal fuel residue types between burgh cores. It is suggested that variation in fuel residues indicate preferential exploitation of certain fuel resources. It is equally probable that fuel residue types are linked to differences in firing temperatures and combustion processes associated with industrial activities. The effect of varying temperature on ceramics (Tobert 2007) and archaeological sediments (Berna *et al.,* 2007) is well documented. It therefore seems reasonable to suggest that changes in associated fuel residues are affected by similar processes. Furthermore, it is argued that post-depositional processes are not responsible for selective preservation of fuel residues given similarities in soil physical and chemical properties between burgh cores.

8.1.4.1 Harbour and High Street Zones

Fuel residue types are consistent between the Harbour and High Street zones at Pittenweem; however, FR 4 & 6, FR 5 & 7 and FR 8 & 9 are more abundant within the Harbour zone and FR 3 is greatest within the High Street zone. Differences in principal fuel types may reflect the social and economic disparity of inhabitants, for example burgesses within the High Street zone may have adopted the use of coal earlier than poorer residents of the Harbour zone. Analogous evidence from Wigtown highlights the relationship between social standing and fuel resources. Duncan (1791-99:485) notes ‘the common people, both in the town and country, burn peat, of which indeed there is abundance within this parish' and that 'the better sort of inhabitants within the town, though they used peat in their kitchens, burn coal in their rooms'. It is probable that variation in fuel residue types are linked to differences in firing temperatures and combustion processes associated with differing industrial activities between zones.

8.1.4.2 Topsoil Horizons

Fuel residue is present in upper and lower topsoil horizons within all three burghs. This indicates continual disposal of waste materials associated with domestic and industrial combustion. However, fuel residue is less abundant within lower topsoil horizons at Lauder and Wigtown. Differences in the concentration of fuel residue may reflect changing patterns in the availability and affordability of fuel resources, for example the introduction of turnpike roads at Lauder led to widespread adoption of coal as the main fuel resource during the latter 18th century (Ford 1791-99:77). It is also suggested that an increase in fuel waste could be linked to population growth or intensification within burgh cores. Ford (1791-99:74) notes a general increase in the population of Lauder since the opening of turnpike roads. Moreover, at Wigtown the population grew from 1032 in 1755AD to 1350 in 1793AD (Duncan 1791-99:488). Increasing industrialisation may account for increased deposition of fuel waste; however, industries such as coal, lime and woollen manufacturers were still lacking at both Lauder and Wigtown during the 1790s (Duncan 1791-99:485, Ford 1971-99:76).

8.2 The Impact of Waste Disposal on Burgh Hinterlands

This section focuses on the impact of waste disposal within the Hinterland Near zone at all three burghs, the Hinterland Far zone at Pittenweem and the Showfield zone at Wigtown. These zones correspond to the location of the burgh acres which were strips of arable land owned by burgesses (see section 2.3.4). The burgh acres, known as burgess acres at Lauder, were located immediately beyond the burgh core and extended to the common grazings (Romanes 1914, Johnston 1920) (Figure 125). There is no direct reference to the location of the burgh acres at Pittenweem although their existence is noted (Cook 1867, Leighton 1840, Webster 1819). It is suggested that the burgh acres extended over the Hinterland Near and Far zones given the delineation of land running parallel to burgage plots (Figure 126). This is supported by Leighton (1840:108) who states that 'the lands of Greendikes, Waterless and Coalfarm, lying to the north-west and west of the burgh are the property of Sir Wyndham Carmichael Anstruther, baronet' and that 'the other lands in the parish consist of burgh acres'. Similar to Lauder and Pittenweem the burgh acres at Wigtown were located immediately beyond the burgage plots within the burgh core (Duncan 1791-99:474, Brewster 1832: 521) (Figure 127).

Figure 125: Map of Lauder extracted from the 1747-1755AD William Roy Military Survey of Scotland © The British Library Board, Licensor www.nls.uk/roy/style.html. Red boundaries represent buildings and man-made structures and parallel hatching indicates cultivated land. Burgh acres are represented by the delineation of strips of land running parallel to burgage plots

Figure 126: Map of Pittenweem extracted from the 1747-1755AD William Roy Military Survey of Scotland © The British Library Board, Licensor www.nls.uk/roy/style.html. Red boundaries represent buildings and man-made structures and parallel hatching indicates cultivated land

Figure 127: Map of Wigtown extracted from the 1747-1755AD William Roy Military Survey of Scotland © The British Library Board, Licensor www.nls.uk/roy/style.html. Red boundaries represent buildings and man-made structures and parallel hatching indicates cultivated land. Burgh acres are represented by the delineation of strips of land running parallel to burgage plots north and south of Wigtown

8.2.1 Soil Modification

Deepened topsoils adjacent to the historical burgh limits at Lauder and Pittenweem provide clear evidence for sustained application of mineral material to the burgh acres. Accumulation of topsoils can be explained through addition of waste rich in mineral material, for example turf used in building construction, ash from domestic and industrial fires, sand used in animal byres and in the case of Pittenweem, sand associated with addition of seaweed. In contrast there is no evidence for topsoil deepening within the Hinterland Near and Showfield zones at Wigtown. This finding indicates that waste rich in mineral material was not routinely applied to the burgh acres. It is possible that waste may have been preferentially deposited within the burgh core or within the burgh acres beyond the extent of the survey area. Additionally, waste may have been sold for use as fertiliser to other burghs.

High organic matter and enhanced concentrations of phosphorus within the Hinterland Near zone at Lauder and Showfield zone at Wigtown indicate addition of human and animal excreta, domestic refuse and fuel resides. In the case of Lauder sustained application of such materials may explain the formation of hortic horizons within topsoils in the burgh acres. There is no association between organic matter and phosphorus within the Hinterland Near zone at Pittenweem. Considering its current use as managed grassland, elevated organic matter within the Hinterland Near zone may be the result of modern inputs such as decomposing plant matter. Phosphorus concentrations may have decreased due to past cultivation, for example intensive cropping which exceeds phosphorus deposition rates. Nevertheless it is possible that increased organic matter content may reflect past inputs such as animal dung; even though it is argued more modern sources of phosphorus are more likely.

Enhancement of topsoil magnetic susceptibility within the Hinterland Near zone at Lauder and Pittenweem and Showfield zone at Wigtown indicates input of materials which have been heated to high temperatures, for example charcoal, ash and charred remains (fuel residues) resulting from burning peat, wood, moss and coal in domestic and industrial hearths. Additionally sherds of fired ceramic materials such as pottery and brick may contribute to magnetic enhancement within the burgh acres.

8.2.1.1 Variation within Burgh Acres

The median depth of topsoils within the Hinterland Near and Hinterland Far zones at Pittenweem is greater than 50cm, thus providing evidence for the additional of mineral waste within the burgh acres. Nevertheless there is a significant difference in topsoil depth, organic matter and magnetic susceptibility between these two zones. It is proposed that the impact of waste diminishes with distance from the burgh core resulting in a distance decay effect across the burgh acres. Differences in the impact of waste disposal are also apparent within the burgh acres at Wigtown, for example enhancement of organic matter content and frequency dependant magnetic susceptibility is limited to the Showfield zone. This may reflect selective deposition of wastes such as fuel residue, domestic refuse and human and animal excreta to the burgh acres south of Wigtown.

8.2.2 <u>Elemental Signatures</u>

The Hinterland Near zone at Lauder is enhanced in elements associated with past anthropogenic activity (Ba, Ca, K, P, Pb and Zn). There is no difference in the range of elements enhanced between the burgh core and burgh acres thus indicating similarities in the nature of waste material inputs. It is suggested that domestic and industrial waste generated within the burgh core was deposited within the burgh acres at Lauder for the purpose of soil improvement. Elements enhanced within the Thirlstane zone include Ba, P and Pb; nevertheless, it is difficult to assign these elements to particular sources of waste or anthropogenic activities given their limited range. Land within this zone is associated with Thirlstane Castle (Figure 128). Thirlstane Castle was built in the 16th century AD on the original site of Lauder Fort and has been successively occupied until present day (Simpson and Stevenson 1981c). The grounds of Thirlstane Castle were primarily used for recreation (Cosens 1834-45), although more recently additional uses include keeping rare breed livestock and hosting horse trials.

Enhancement within the burgh acres at Pittenweem is limited to elevated concentrations of Mn, Co, Mg and Zn within the Hinterland Near zone. This is in contrast to the burgh core which is characterised by a range of anthropogencially significant elements (Ba, Ca, Na, K, Co, Cu, Ni, P, Pb, Sr, Ti, Y and Zn). Differences between these areas may reflect preferential deposition of certain wastes. It is possible that domestic and industrial waste generated within the burgh core was deposited within the burgh acres at Pittenweem; however, post-depositional processes such as leaching and past land management within the burgh acres may adversely affect elemental retention rates.

Figure 128: Aerial Image of Lauder showing (a) burgh core, (b) Hinterland Near zone, (c) Hinterland Far zone and (d) Thirlstane zone, image © Andrew Buchanan 2004, www.holy-cow.co.uk/

The Showfield zone at Wigtown is enhanced in a range of elements associated with past anthropogenic activity including, Ba, Cu, Mn, P, Pb and Zn. Comparable patterns of elemental enhancement within the burgh core and Showfield zone signify similar waste material inputs. It is noted that Ca, K and Sr are not elevated within the Showfield zone; this may be due to preferential leaching within the burgh acres. Moreover, absence of elevated elemental concentrations within the Hinterland Near zone support the proposal that waste was selectively applied to the burgh acres south of Wigtown (section 8.2.1.1).

8.2.3 Waste Materials

As discussed in section 8.1.3, building materials, domestic rubbish and industrial wastes were routinely deposited within burgh cores. Evidence for these materials within the burgh acres at Lauder and Wigtown is limited, suggesting selective application of waste material. In contrast pottery, brick, clinker, slag, mortar, plaster and heated mineral material occur within the burgh acres at Pittenweem. This indicates deposition of similar types of waste materials within the burgh core and burgh acres. Higher abundances of waste materials within the Hinterland Far zone may reflect preferential deposition of certain wastes away from the burgh core. It is also possible that post-depositional processes such as ploughing and tilling within the Hinterland Near zone resulted in increased fragmentation of exotic inclusions.

8.2.4 Fuel Residue

Fuel residue within the burgh acres at Lauder, Pittenweem and Wigtown provides clear evidence for addition of materials resulting from domestic and industrial combustion. In addition, fuel residue is identified within the Hinterland Far and Thirlstane zone at Lauder and Hinterland Far zone at Pittenweem. A distinction in fuel residue types between the burgh core and hinterland is noted at Lauder and Wigtown. Inclusions of charcoal, FR 2 and FR 10 are absent from the hinterland at both of these burghs suggesting preferential deposition of certain fuel residues within the burgh core. It is also possible that such materials could have been deposited in the hinterland but have either been subject to selective preservation or exist in abundances beyond the limit of detection. In contrast there is no difference in the nature of fuel residue between the burgh core and hinterland at Pittenweem. Fuel residue types are generally consistent between burghs, for example FR1, FR 4 & 6, FR 5 & 7 and FR 8 & 9 are present within all hinterland zones. Moreover there is no difference in the abundance of fuel residue types either within or between burgh hinterlands.

8.3 Waste Disposal

8.3.1 Burgh Core

Based on the micromorphological and chemical results there are general similarities in waste types between burgh cores, for example building materials, human and animal excreta, kitchen refuse, industrial wastes and fuel residue. Nevertheless, differences in waste materials are apparent between burghs. Principal fuel residue wastes vary between burghs reflecting differing fuel resources and/or industrial processes. In addition, the occurrence of shell at Pittenweem and Wigtown is indicative of industrial processes related to fishing.

Sustained addition of waste materials in burgh cores led to improvement of topsoil, facilitating widespread cultivation of garden soils. Production of crops was of economic importance; crops were needed for the sustenance of livestock and for sale at market. In addition, urban horticulture was socially significant. Given that backland plots were often divided and sublet, poorer inhabitants were able to reliably produce foodstuffs within a concentrated area thus enhancing food security.

Although it is accepted that soils in burgh cores reflect sustained deposition of waste materials, it is not possible to attribute any one method to their formation. It is likely that domestic refuse associated with individual households and mixtures of straw, sand and dung from byres were applied to the backlands as a convenient source of fertiliser. Considering the diversity of materials in burgh core topsoils, it is also suggested that middens comprising domestic and/or industrial wastes may have been periodically spread across the backlands. Potentially waste from dunghills may have been added to burgage plots; however, it is argued that they chiefly acted as stores of urban waste prior to redistribution within the hinterland.

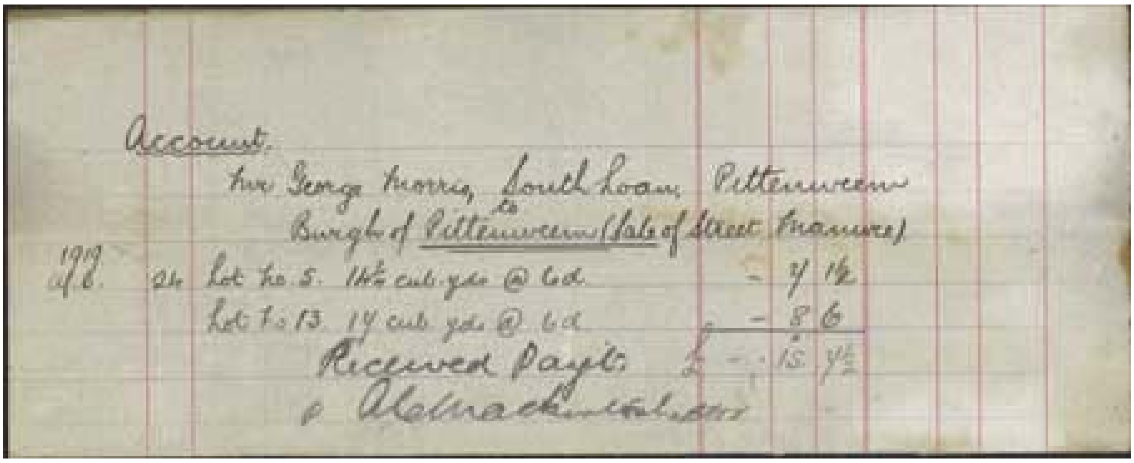
This discussion has focussed on the role of cultivation in the formation of ‘garden soils’ within burgh cores. Nevertheless, it is contested that such deposits reflect accumulation of sediments resulting from intensified occupation of the backlands (Carter 2001). Given the formation of hortic horizons within burgh cores it is argued that soils at Lauder, Pittenweem and Wigtown were formed predominantly through urban horticulture. In addition, it is proposed that intensified backland occupation would have led to growing demand for additional foodstuffs thus increasing cultivation rather than replacing it.

8.3.2 Hinterland

Sustained addition of waste materials to the hinterland at all three burghs resulted in enhanced soil fertility within the burgh acres. The degree of soil improvement within the burgh acres is reflected in its letting cost, for example Duncan (1791-99:479) notes that arable land arable land at Wigtown is let at 10 to 20 shillings per acre rising to between 50 shillings and 3 pounds within the burgh acres. Similarly, the burgh acres at Lauder are three to four times more expensive than arable land in the rest of the parish (Ford 1791-99:73). Crops provided an important source of revenue for burgesses and their success was vital for meeting the consumption needs of inhabitants and their livestock. The deliberate addition of burgh wastes would have improved the quality and yield of crops, in addition to improving sustainability of cultivation.

Although not conclusive, it is proposed that dunghills were routinely applied to soils within the burgh acres (see section 2.2.4). The application of dunghills would have resolved problems associated with the formation of dunghills in burgh cores, in particular their obstruction of thoroughfares (Cook 1867). In addition dunghills held an economic value hence were often traded or sold to farmers or confiscated by the burgh authorities (Figure 129). This is especially true at Pittenweem where legislation throughout the 17^{th} and 18^{th} centuries repeatedly cites forfeiture of dunghills without compensation (Cook 1867: 86, 99, 152). It is most likely that dunghills were transferred to the burgh acres using horse and cart although the additional use of labourers cannot be ruled out. In addition to dunghills it is acknowledged additional sources of fertiliser could be sought from the sea, for example shells of various qualities could be bought from Wigtown harbour for manure on farms (Duncan 1791-99). Similarly seaweed was gathered and collected from the beach at Pittenweem for sale to local farmers (Figure 130).

In agreement with Davidson *et al.,* (2006), soil improvement within the burgh acres reflects an early form of urban composting. This is particular resonant in light of agricultural reform during the 18^{th} and 19^{th} centuries. Past land management systems were considered ineffective; however, at Wigtown Duncan (1791-99:477) notes how ‘improvements to farms using manure have made it possible to raise bere barley. No bere was previously raised in this parish except for the burgh acres’.



Account.
Mr George Morris, South Loan, Pittenweem
to
Burgh of Pittenweem (Sale of Street Manure)
1919
24 Lot No. 5. 14¼ cub. yds @ 6d - 7/1½
Lot No 13. 17 cub yds @ 6d - 8/6
Received Payt £ - 15 7½

Figure 129 Invoice for the sale of 'street manure' at Pittenweem to a local farmer dating 1919 AD, dunghills were therefore a persistent feature in burgh cores (Image © Scottish Life Archive, Licensor www.scran.ac.uk)

Figure 130 Photograph of a man with a cart load of seaweed in the early 20th century Pittenweem. In previous centuries the right to collect seaweed was associate with land ownership, hence burgesses had rights to seaweed on particular stretches of beach (Image © National Museums Scotland, Licensor www.scran.ac.uk)

9 The Wider Significance of Waste Disposal in and Around Historic Small Towns

This chapter discusses the wider significance of waste disposal in and around historic small towns. Key study findings are presented and recommendations for further work are made accordingly. In addition, the significance of waste disposal in and around historic towns is discussed in reference to urban soil classification, rural-urban interactions and trends in archaeology.

9.1 Study Findings

9.1.1 Objective 1

The first objective of this study was to establish the nature and diversity of urban anthrosols in and near to historic small towns. It was found that soil characteristics are varied within and near to Lauder, Pittenweem and Wigtown (Hypothesis 1.1). Distinct patterns in spatial distributions of topsoil depth, pH, organic matter content, magnetic susceptibility and selected elemental concentrations are identified at all three burghs. Soil properties within and near to Lauder, Pittenweem and Wigtown are determined by sustained addition of waste materials (Hypothesis 1.2). Waste material inputs include human and animal excreta, domestic waste, industrial waste, building materials and fuel residues.

9.1.2 Objective 2

The second objective of this study was to characterise and account for the multiplicity of urban anthrosols in and near to historic small towns. It was found that urban anthrosol characteristics vary within burghs according to past functional zones (Hypothesis 2.1 and 2.2). The burgh core and burgh acres are important areas of interest at all three burghs. Soil modification is most pronounced within burgh cores reflecting a greater diversity and abundance of waste material inputs. Differences in urban anthrosol characteristics are evident between burghs. The nature and extent of soil modification differs between burgh acres. It is suggested that shell waste at Pittenweem and Wigtown is linked to their past function as fishing ports (Hypothesis 2.3). In addition variation in principal fuel residue types between burghs may indicate differences in resources exploitation and/or combustion processes associated with industry. Further work is needed to resolve this issue; it is recommended that visual and elemental comparisons of key fuel residue types should be made with reference materials.

9.1.3 Objective 3

The third objective of this study was to elucidate the processes associated with waste management and disposal in historic small towns. It is proposed that addition of waste materials to soils within and near to Lauder, Pittenweem and Wigtown was an effective waste management strategy. Waste disposal led to enhanced soil fertility within the burgh core and to a lesser extent the burgh acres at all three towns. This is important given that urban horticulture and arable farming was central to resource production in historic small towns. It was hypothesised that processes of waste disposal could be deduced from properties of soils (Hypothesis 3.1). This proposal was overly ambitious considering similarities in waste management strategies between burghs in addition to the impact of post-depositional processes. It is likely that direct waste deposition, storage and redistribution of midden waste, and storage and redistribution of dunghills were important modes of waste disposal at all three burghs. It is expected that differences in the nature and modes of waste management existed between burghs; however, this information could not be ascertained from soil properties alone (Hypothesis 3.2). It is recommended that detailed documentary analysis may resolve this issue.

9.1.4 Model Revision

A revised model of resource and waste material flow in historic towns is presented in Figure 131. In the context of this research the town zone corresponds to the built environment within burgh cores. This town encompasses areas characterised by urban-rural interaction and sectoral interactions, for example backlands were used for urban horticulture and animal rearing. The hinterland is a theoretical area of resource exploitation which differs from town to town. All three towns are similar in that the immediate hinterland encompasses the burgh acres, an area explicitly linked with urban inhabitants through processes of fertilisation, crop/vegetable growth and animal rearing, and procurement of foodstuffs. In addition each town exploited a wider area to acquire fuel sources and trade items, for instance Pittenweem had direct trading links with the continental Europe and Wigtown had contacts with Ireland and Cumbria. The burgh and its hinterland are linked by rural-urban fluxes of resources, goods and waste materials; hence, are not mutually exclusive zones.

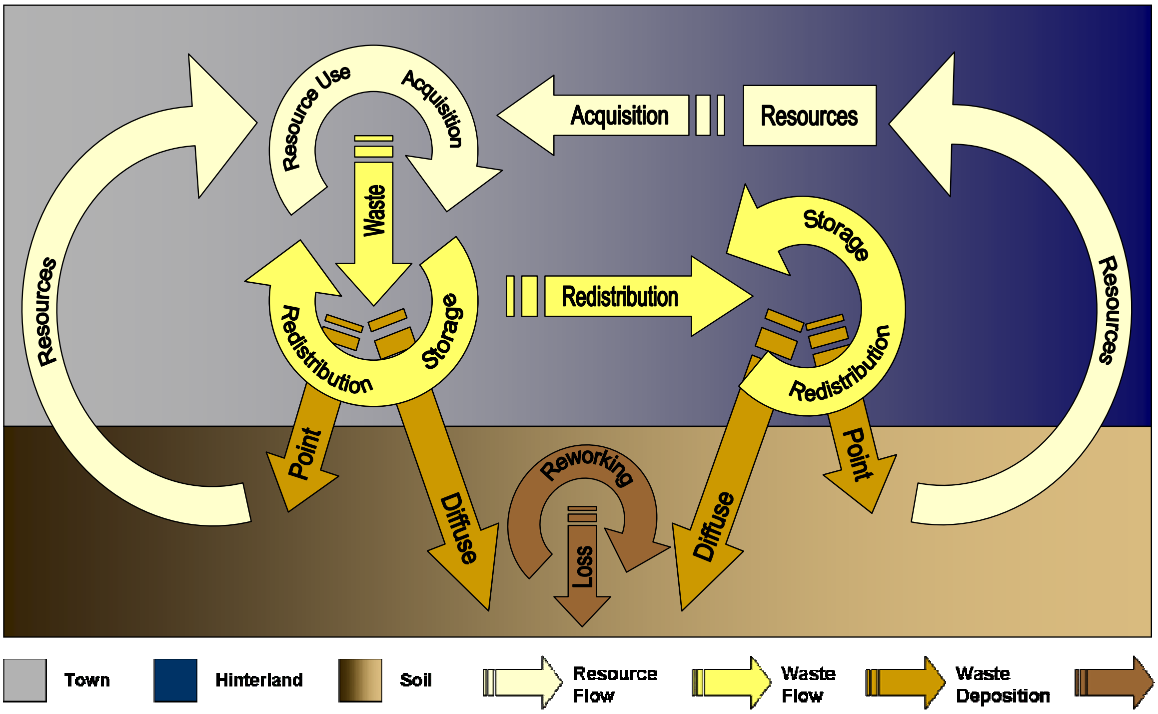


Figure 131: Revised flow model of resource and waste movement in historic small towns

Acquisition represents movement of materials from the hinterland to the town. These materials range from locally available natural resources to manufactured trade goods. Fuel sources were obtained from the hinterland in all three burghs through activities such as peat cutting, moss harvesting, coal mining and wood felling. The utilisation of these materials varied from town to town, and was dependant on a range of geographic and economic factors. Materials could also be acquired from within the town itself. There is geoarchaeological evidence in the form of hortic topsoils to suggest urban horticulture was an important source of foodstuffs within the burgh core at Lauder, Pittenweem and Wigtown. Acquired resources are incorporated into a cycle of use and re-use until they hold no remaining social or economic value.

Materials with no remaining economic or social value are classed as waste and transition to a cycle of waste management characterise by processes of storage and re-distribution. The two common storage mechanisms at all three burghs were middens in the backlands and dunghills in the main thoroughfares. The constituents of middens both within and between burghs remain unresolved given the homogeneous nature of backland topsoil deposits. It is possible that specific middens were used for differing waste types such as domestic and industrial rubbish. Dunghills are documented in all three burghs with repeated legislation referring to their nuisance. These dunghills were removed from the burgh either voluntarily through sale to burgesses or under forfeiture, and applied to the burgh acres as fertiliser. Processes of midden spreading in the backlands and dunghill movement to the burgh acres are classed as redistribution of waste.

Deposition of waste falls into two categories; point and diffuse. At all thee burghs there is evidence for point deposition of domestic/kitchen wastes in back gardens, for example bones, shell and pottery fragments. Similarly there is evidence for diffuse deposition in the form of hortic topsoil in burgh cores and modified topsoil in the burgh acres. Upon deposition waste is incorporated into the soil matrix and subject to reworking and system loss. One of the main limitation of the original flow model presented in chapter 3 (Figure 13) was that waste materials had no function upon incorporation into the soil matrix aside from involvement in post-depositional processes. Given that waste was used for soil improvement in the burgh acres it is argued that resource production and waste management within and near to historic towns were inextricably linked. Accordingly flow arrows linking soils to town and hinterland resource cycles are proposed as suitable model amendments (Figure 131).

9.2 Rural-Urban Interaction

9.2.1 Modern Significance of Rural-Urban Interaction

Parallels in the nature and management of organic wastes are evident between past and present urban environments. The main sources of organic waste in historic and modern towns include kitchen refuse, human excreta, and horticultural and agricultural waste. Similarities in urban organic waste management strategies are outlined in Table 32. Organic waste in Lauder, Pittenweem and Wigtown, comprised domestic/kitchen refuse, dung from urban livestock, human excreta and wastes from industrial processes. Whilst there are broad similarities in the nature of organic waste between burghs the volume of waste was likely to differ. The amount of waste produced would have depended on population size and livestock numbers.

In modern towns organic waste is dealt with in a variety of ways including; organised composting of solid and/or animal wastes prior to application, direct application of solid waste onto soil, and application of animal wastes onto soil. It is evident from this study that urban organic waste recycling is not a recent phenomenon. Waste management strategies in historic towns similarly involved composting, for example animal wastes and kitchen refuse in byres and middens.

Table 32: Comparison of urban organic waste recycling practises in modern and historic towns, modern examples taken from Cofie and Bradford (2006)

Modern Towns	Historic Towns
Use of fresh waste from vegetable markets, restaurants, hotels and food processing industries as feed for urban livestock	Use of kitchen refuse, waste from markets and waste from horticulture as feed for urban livestock
Direct application of solid waste on and into the soil	Application of human and animal waste to backlands and/or hinterland via dunghills
Mining of old waste dumps for application as fertiliser on farmland	Use of landfills not a key feature of historic towns
Application of animal manure such as poultry/pig manure and cow dung	Application of waste from stalled animals and other urban livestock to backlands and/or hinterland via dunghills
Direct application of human excreta or bio-solids to the soil	Application of human waste to backlands and/or hinterland via dunghills
Organised composting of solid waste or co-composting of solid waste with animal manure or human excreta	Accumulation of human and animal waste in middens and dunghills prior to soil application

Waste was applied directly to gardens in the burgh core and transported to the burgh acres for use as fertiliser. Composting and soil improvement remain key strategies in managing organic waste in modern towns; however, one of the key differences is the utilisation of human wastes. In the past there was limited awareness of dangers associated with using human faecal material as a source of compost. In contrast, human waste in contemporary towns is processed and disposed by means of urban sewerage systems which are subject to governmental regulations. Another difference in organic waste management between historic and modern towns is the use of landfill sites (Table 32). It is suggested that landfill sites were not in burghs for disposal of organic wastes given the economic and social value of waste as a fertiliser.

Urban horticulture is an activity deep-rooted in past urban environments. In Lauder, Pittenweem and Wigtown the ability to grow food within the urban area was vital in the supply of foodstuffs, especially for poorer inhabitants who could not afford to rent arable land in the burgh acres. Similarly cultivation in developing cities is increasingly seen as a key strategy for enhancing food security of present and future populations. This is especially resonant in urban environments currently lacking an environmentally sustainable solution to waste management of organic materials (Tixier and Bon 2006).

9.3 Soil Classification

This section discusses problems associated with mapping urban soils and classifying soils in historic small towns with specific reference to key findings at Lauder, Pittenweem and Wigtown.

9.3.1 <u>Mapping Urban Soils</u>

Conventional soil mapping is simplistic in its approach to urban soils, whereby soils are either assigned to local soil series or are omitted from soil classification maps completely. Soils in and near to Lauder are mapped as freely drained brown forest soil with low base status belonging to the Lauder (LA) soils series (Figure 132). However, results of this study indicate distinct changes in soil properties within and adjacent to Lauder through processes of anthropogenic modification. It is argued that hortic soils in the burgh core and burgh acres differ significantly from local soils. In Pittenweem and Wigtown soils within the burgh core are not mapped (Figure 133, Figure 134). Results from this study confirm the presence of hortic anthrosols at both burghs. It is suggested that such soils have clearly identifiable physical and chemical soil properties and should not be omitted from future classifications.

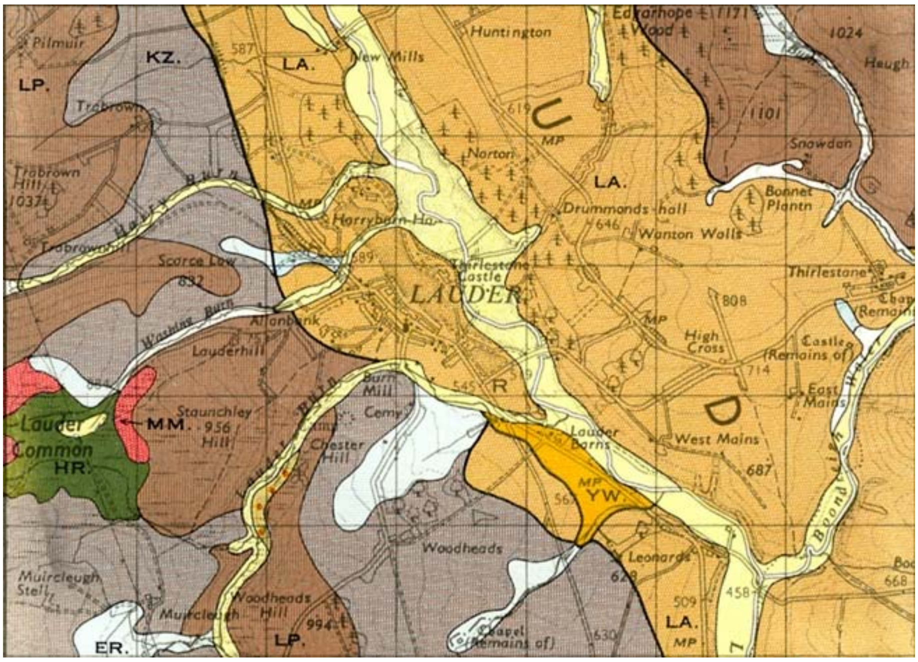


Figure 132: Soil map of Lauder © Soil Survey of Scotland 1959. Soils within and adjacent to Lauder are mapped as a freely drained brown forest soil with low base status belonging to the Lauder (LA) soil series

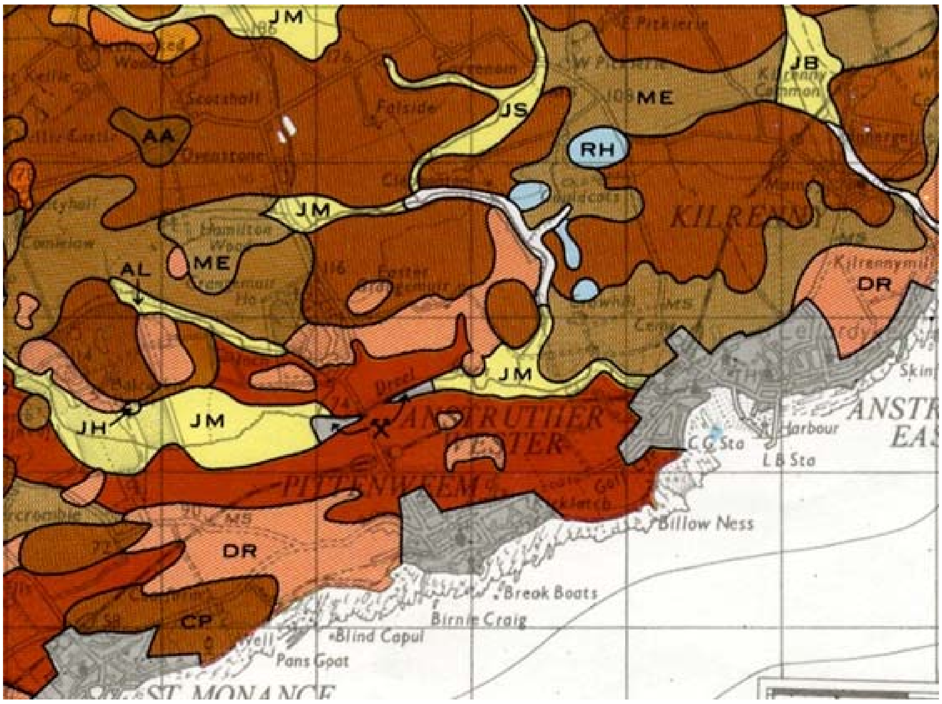


Figure 133: Soil map of Pittenweem © Soil Survey of Scotland 1975. Soils within Pittenweem are not classified and adjacent soils are mapped as an imperfectly drained brown forest soil belonging to the Quivox (QX) soil series

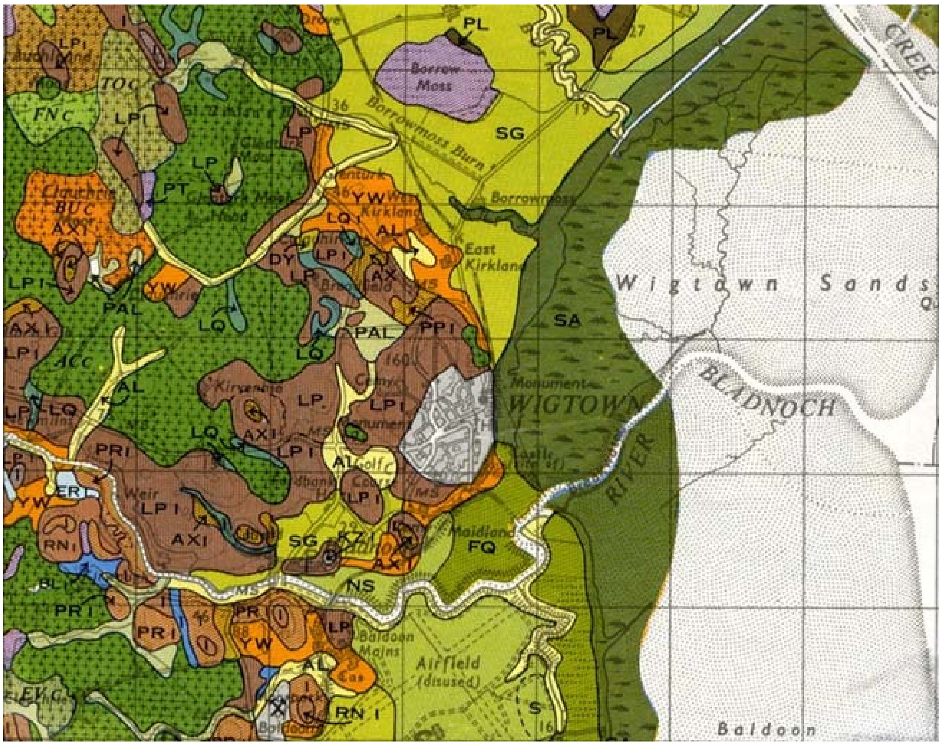


Figure 134: Soil map of Wigtown © Soil Survey of Scotland 1971. Soils within Wigtown are not classified and adjacent soils are mapped as a freely draining brown forest soil belonging to the Linhope (LP1) soil series

Soil within and near to Lauder, Pittenweem and Wigtown are modified through past waste amendments; hence differ from surrounding 'natural' soils. It is therefore recommended that soils associated with urban environments should be included in soil maps. This would require a comprehensive system of classification distinguishing between historic and modern soil modification (see section 9.3.2). Moreover, specific attention should be paid to soils modified through past and present urban activities which are not located in towns, for example historic improvement of arable land and modern refuse dumping on landfill sites.

9.3.2 Classification of Soils in Historic Towns

Classification of soils in historic towns is problematic due to conflicting terminology both within and between soil classification systems. Soils in and around Lauder, Pittenweem and Wigtown are classified as Anthrosols within the World Reference Base for Soil Resources (WRB) classification system despite the recent introduction of a Technosols (Urban/Mine) group (Table 33). It is argued that Anthrosols is more appropriate for soils in historic towns given they account for processes of waste disposal, soil improvement and cultivation. In contrast Technosols are concerned with waste amendments resulting from modern urban environments such as landfills, impermeable road surfaces and mine spoil. The Australian Soil Classification System makes a distinction between Hortic, Garbic and Urbic Anthroposols (Table 33). Under this system soils in burgh cores could potentially be classed as Hortic or Garbic Anthroposols. Similar to the WRB classification Urbic Anthroposols are not appropriate for classifying soils in historic towns. It is suggested that conflicting terminology is a result of modern definitions of urban and rural soil characteristics. In the past cultivation and associated improvements in soil fertility were urban features; however, these are currently viewed as rural qualities. Likewise, characteristics which are viewed as urban, such as industrial wastes and concrete pavements are modern in origin.

Table 33: Summary of soil classification terminology relevant to soils in historic towns (FAO 2006, Gong 1999, Isbell 2002, Nikolaevna and Vadimovna 2003)

System	Term	Definition
Australian	Hortic Anthroposol	Soils that have additions of organic residues such as organic wastes, composts and mulches that have been incorporated into the soil and have obliterated pre-existing pedological features.
Australian	Urbic Anthroposol	Mineral soil or regolithic materials that are underlain by land fill of a predominantly mineral nature.
Australian	Garbic Anthroposol	Mineral soil or regolithic materials that are underlain by land fill of manufactured origin and which is predominantly of an organic nature. These materials may be of domestic or industrial origin.
Chinese	Anthropic Surface Horizon	Diagnostic surface horizons that are the result of agricultural activities that have caused major changes in soil processes at or near to the soil surface.
Chinese	Cumulic Epipedon	Formed by long-term cultivation, applying manure or adding soil material rich in organic matter or other mud's to the soil.
Chinese	Mellowic Epipedon	Formed by planting vegetables and/or adding night soil, organic trash or manure to the soil under intensive cultivation and frequent irrigation over a long period.
World Reference Base for Soil Resources	Anthrosols	Soils that have been modified profoundly through human activities, such as addition of materials or household wastes, irrigation and cultivation.
World Reference Base for Soil Resources	Technosols (Urban/Mine Soils)	Soils whose properties and pedogenesis are dominated by their technical origin. They contain a significant amount of artefacts (something in the soil recognizable made or extracted from the earth by humans), or are sealed by technic hard rock.
World Reference Base for Soil Resources	Kitchen Soils	Anthrosols having a hortic horizon >50cm. Horizon is thoroughly mixed with original strata usually not preserved. Artifacts and cultural debris commonly occur.
Russian Urban Soil Classification System	Urbanozem	A genetically individual soil which combines properties of natural soils in neighbouring areas and specific properties developed in the urban environment.

It is proposed that the term Urbanozem within the Russian Urban Soil Classification System offers a suitable solution to soil classification in both historic and modern towns. This system theorises that urban soils develop in three major ways; on loose artificial deposits, on the cultural layer/anthropic material and by transforming natural soils (Figure 135). Further, it is suggested that evolution and transformation of urban soils is controlled by land-use, substrate type and time. The incorporation of time as a key factor in urban soil formation accounts for differing intervals of soil modification in ancient, historic and recent urban environments. Soils in and around Lauder, Pittenweem and Wigtown are formed by transforming natural soils and through development of a clearly identifiable cultural layer. These processes occurred over a time period spanning the medieval and early modern periods, prior to the introduction of sewerage. In contrast soils formed through recent activities such as urban landscaping are formed on loose artificial deposits and consolidate over tens of years. The former historical example and latter modern urban example are both accounted for under the term Urbanozem. It is argued that a more subjective approach to soil classification in historic environments is needed which takes into consideration site specific characteristics such as land use, period of use/occupation and geographical location.

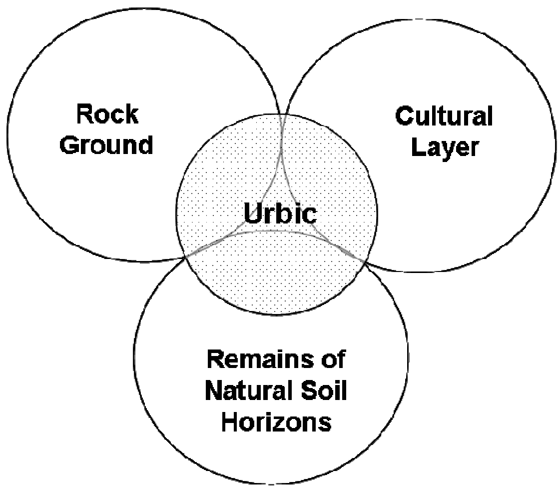


Figure 135 Formation of the Urbic horizon (Nikolaevna and Vadimovna 2003)

9.4 Soil: An Archaeological Resource

This section evaluates the contribution of soil as an archive of waste deposition and management within historic small towns. More specifically evidence obtained from the soils based cultural record is compared to information derived from archaeological excavation and documentary evidence.

9.4.1 Comparison of Soils and Archaeological Excavation

Archaeological excavation is primarily concerned with recovery of artefacts. Accordingly lack of artefacts is often interpreted as absence of archaeology, for example results of a watching brief at High Vennel, Wigtown indicate that no deposits relating to the medieval burgh core were located despite identification of deposits ranging in depth from 60 to 110 cm (Appendix 3). In contrast, results from this study suggest the occurrence of deposits modified through past waste amendments within the burgh core at Wigtown. The results of an archaeological evaluation at 64a High Street, Pittenweem infer deposits have little significance aside from containing limited ceramic finds (Appendix 4). Nevertheless analysis of soil pit PT 6 which is located in the garden of 64a High Street provides clear evidence for sustained addition of domestic and industrial wastes.

Concentrations of rubbish discovered on archaeological sites are usually referred to as middens regardless of their spatial characteristics and content. Misidentification of middens can be attributed to the site specific nature of urban excavation, for example excavations within the back garden at 5 Mid Shore, Pittenweem refer to a 17th century midden containing pottery, clay pipes, animal bones and miscellaneous ironwork (Martin 1978, Martin 1979). In comparison, analysis of soils within the burgh core indicates the occurrence of 'refuse rich' deposits. It is expected that spatially discrete middens are present in addition to widespread refuse rich soils within burgh cores. Confusion surrounding the use of these terms needs to be resolved, particularly in archaeology.

Both archaeology and soil analyses can be used to examine interaction between historic towns and their hinterland. One of the key advantages of excavation it that it enables recovery of artefacts which can be linked to source locations and assigned to specific periods in time. Ceramic finds from Pittenweem infer trading connections with mainland Europe in the 16th and 17th centuries (Figure 136). Moreover, soil analyses enable investigation into the relationship between towns and their local hinterland through resource and waste material flow.

Figure 136: Selected pottery finds from Pittenweem. First row (left to right), 16th century AD Valencian Lustreware bowl (Spain), 17th AD century pottery from Saintonge (south-west France), 17th century cooking pots (north Germany), 17th century AD earthenware skillets (Scotland). Second row (left to right), 17th century AD Green Glazed jars (Scotland), 17th century AD Loire Ware Jugs (west France), 17th century AD Westerwald AD monochrome stoneware (Germany), 17th century AD Westerwald polychrome stoneware (Germany) (Images © Colin J Martin, Licensor www.scran.ac.uk)

9.4.2 Comparison of Soils and Documentary Evidence

It can be argued that analysis of soils is unnecessary for investigating resource and waste material flow in historic towns particularly in cases where documentary evidence is abundant. However, historical sources are restricted to what contemporaries deemed important at the time, for example legislation, taxation and issues relating to the nobility. Consequently historical sources in this study were used to support discussions based on soil analyses rather than as a primary research tool. It is suggested that the historical legacy of soil enables insight into activities such as waste disposal and soil improvement not generally accounted for by other means.

9.4.3 Conservation

Urban archaeology is rescue driven favouring maximum recovery of artefacts within a limited timeframe; accordingly urban deposits are often overlooked. This study shows that urban soils contain a wealth of information not readily available through excavation or documentary analysis alone. It is proposed that sampling urban soils should be a routine procedure in archaeological excavation to promote comparisons between sites and supplement information derived from finds. Conservation in historic towns is heavily centred on preserving surviving structures such as statues, churches and civic buildings; however, it is argued that 'monumentalism' does not represent the daily experience of urban life in the past. Conversely, soils represent a unique and valuable archive of everyday life which has largely been ignored. It is argued that soil is as important as individual artefacts and should be treated as such in respect to issues of heritage and conservation. It is recognised that this is not an easy task considering soils lay beneath existing communities. In addition, further discussion is needed to resolve preservation and utilisation strategies.

9.5 Summary of Key Findings and Future Recommendations

9.5.1 Summary of Key Findings

Urban anthrosols in and around Lauder, Pittenweem and Wigtown have been modified through sustained addition of waste. Soil modification is most pronounced in burgh cores resulting in the formation of hortic soil horizons. Soils within all three burgh cores are characterised by deepened topsoil, neutral pH, increased organic matter content, enhanced magnetic susceptibility and elevated elemental concentrations such as calcium, phosphorus and potassium. These amended soil physical and chemical properties are attributable to a variety of wastes. Deepened topsoil indicates accumulation of mineral rich materials such as turf, ash from hearths, sand added to byre waste, and sand associated with seaweed. Increased organic matter content and elevated phosphorus concentrations suggest addition of animal and human excreta, and domestic rubbish. Modification of soil pH from acidic to neutral conditions imply deposition of calcium rich materials such as mortar, plaster and lime washes used in building construction, and shell and bone associated with kitchen waste. Furthermore magnetic enhancement of topsoils indicates addition of materials heated to high temperatures such as domestic and industrial fuel residues. The nature and extent of soil modification within burgh acres is more varied. At Lauder hortic soils were identified in the burgh acres suggesting pronounced soil modification through cultivation. Deepened topsoil in the burgh acres at Pittenweem provided evidence for application of mineral rich waste materials in the past. Moreover, magnetic and elemental enhancement (barium, phosphorus, lead, zinc) within the burgh acres south of Wigtown revealed historic soils based anthropogenic signal.

Although processes associated with waste disposal could not be deduced directly from urban anthrosol properties, micromorphological analyses provided an insight into the nature and distribution of deposited wastes. Waste materials were most abundant and varied in burgh cores comprising domestic waste, animal waste, building materials and fuel residues. These materials were found to varying extents in the burgh acres at all three burghs; however, they were notably less abundant. Variation in urban anthrosol characteristics between burghs is attributed to differing industries and patterns of resource exploitation, for example marine waste associated with fishing was only identified in coastal burghs. Similarly, variation in the abundance of marine waste and building materials within the burgh core at Pittenweem may reflect differences in the location of industries associated with fishing, and contrasting building traditions.

Sustained addition of waste materials to soils within and around Lauder, Pittenweem and Wigtown was an effective waste management strategy. Waste disposal in burgh cores was likely to be a combination of direct application and midden spreading in back gardens. This led to enhanced soil fertility which was important in the development of urban horticulture; particularly for poorer inhabitants who did not have access to arable farm land adjacent to the burgh. Dunghills acted as temporary stores of waste in the main thoroughfares of Lauder, Pittenweem and Wigtown. These dunghills were systematically transported to the burgh acres for further use as a fertiliser; hence, an early form of urban composting.

9.5.2 Recommendations

Discussions presented in sections 9.1, 9.2 and 9.3 highlight future areas of research in which the findings of this study could be applied. In the first instance, there is a need for re-evaluation of traditional soil classification and soil mapping in relation to historic and urban soils. It is suggested that the Russian Urban Soil Classification outlined in section 9.3.2 could be used to better understand historic urban soils given that it encompasses time and humans as a key factors in soil formation. It is also recommended that future soil maps should include urban soils as distinct entities rather than omitting or misclassifying them, although the outcome will largely be dependant on the soil classification system used. Another significant contribution of this study is that it highlights the role of soils in historic towns as unique archives of past human activities. As discussed in section 9.4, soils based cultural records contain information not readily available in documentary sources. Furthermore they provide an additional environmental context to archaeological finds. It is argued that soil and artefacts are equally important, hence exploration of soils based cultural records should be a future consideration in urban heritage and conservation strategies. Implementation of this recommendation will be dependant on the ability of individual archaeologists, planners and conservationists to recognise the importance of soils as a record of the human past. It is anticipated that the Soil Analysis Support System for Archaeologists (SASSA) developed at the University of Stirling will serve as a useful introduction for archaeologists and curators with limited geoarchaeological knowledge.

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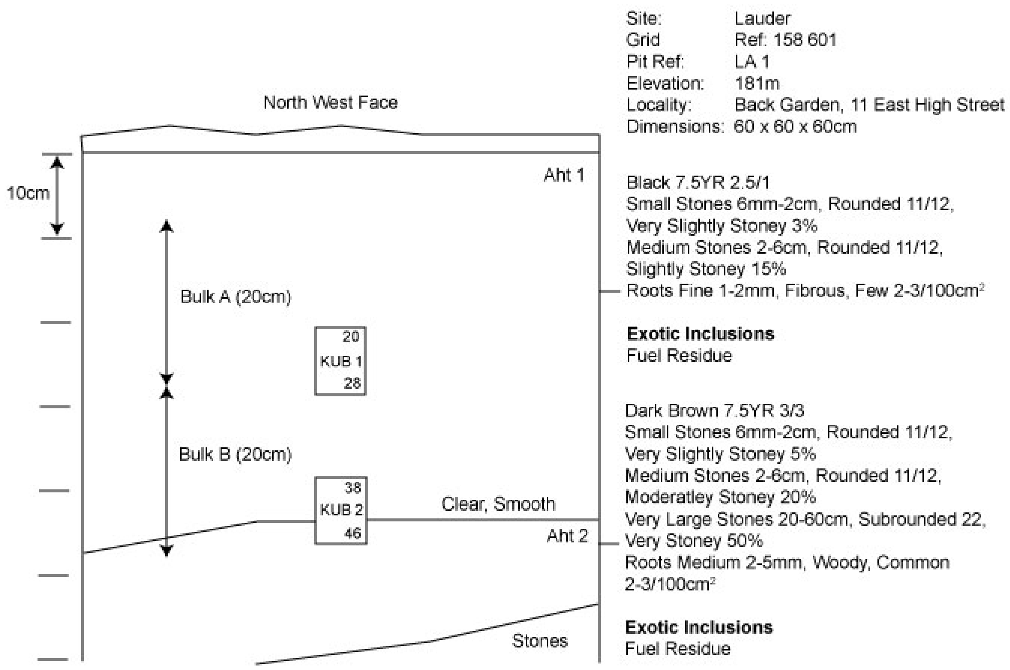
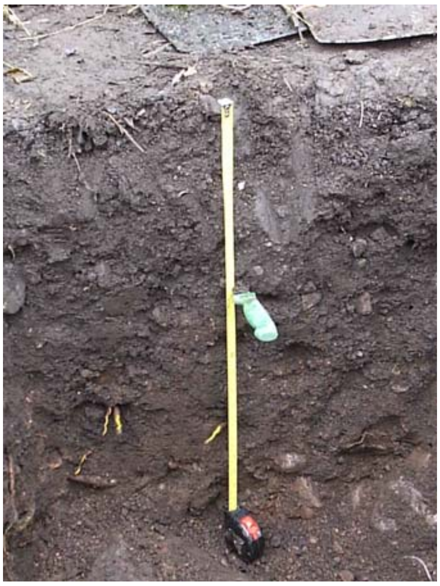
Appendix 1: Soil Profile Descriptions

Soil profile descriptions and field sketches are presented for soil pits at Lauder, Pittenweem and Wigtown.

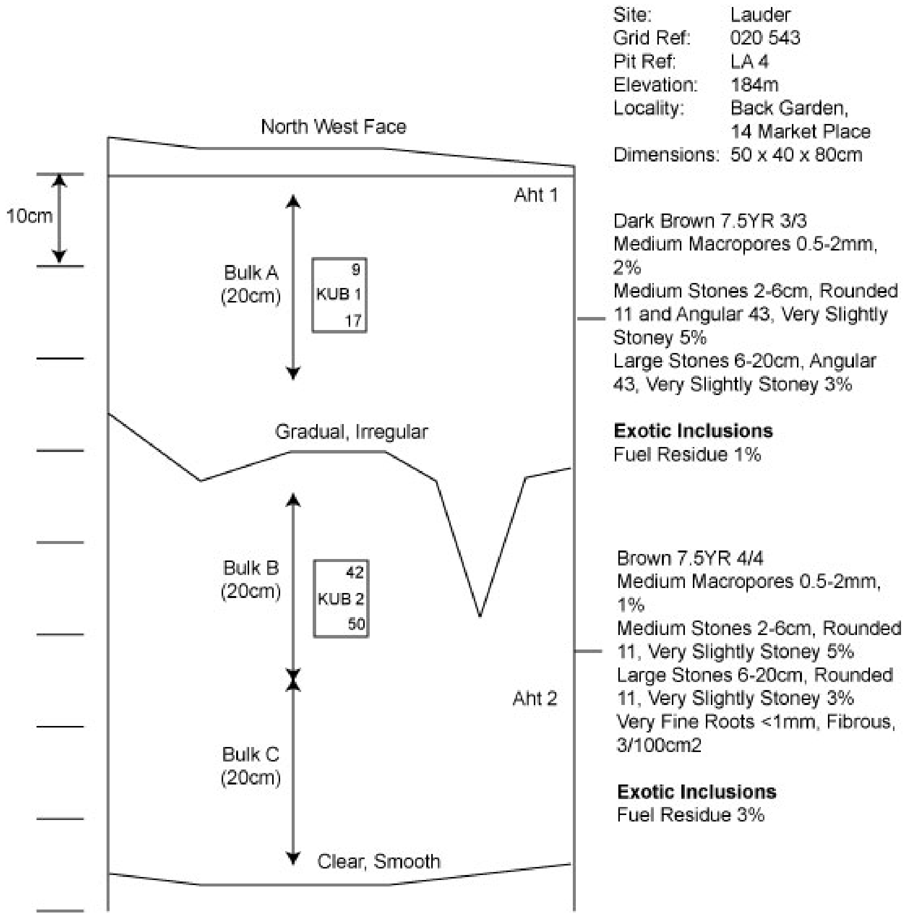
Lauder

High Street Zone



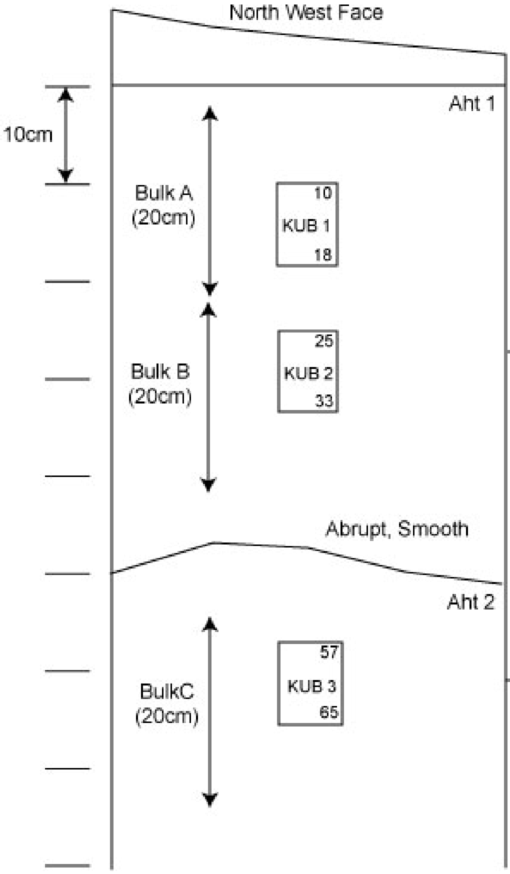


Profile description and photographs (knife inserted at 25cm) of soil pit LA 1



Profile description and photographs (knife inserted at 30cm) of soil pit LA 4

Site: Lauder
Grid Ref: 090 646
Pit Ref: LA 6
Elevation: 128m
Locality: Back Garden, Overgrown
Dimensions: 40 x 50 x 80cm



Black 7.5YR 2.5/1
Fine Macropores 0.5-2mm, 0.5%
Small Stones 6mm-2cm, Angular 43,
Very Slightly Stoney 1%
Medium Stones 2-6mm, Rounded 11,
Very Slightly Stoney 4%
Very Fine Roots <1mm, Fibrous, Many
$20/100cm^2$
Medium Roots 2-5mm, Woody, Many
$>5/100cm^2$

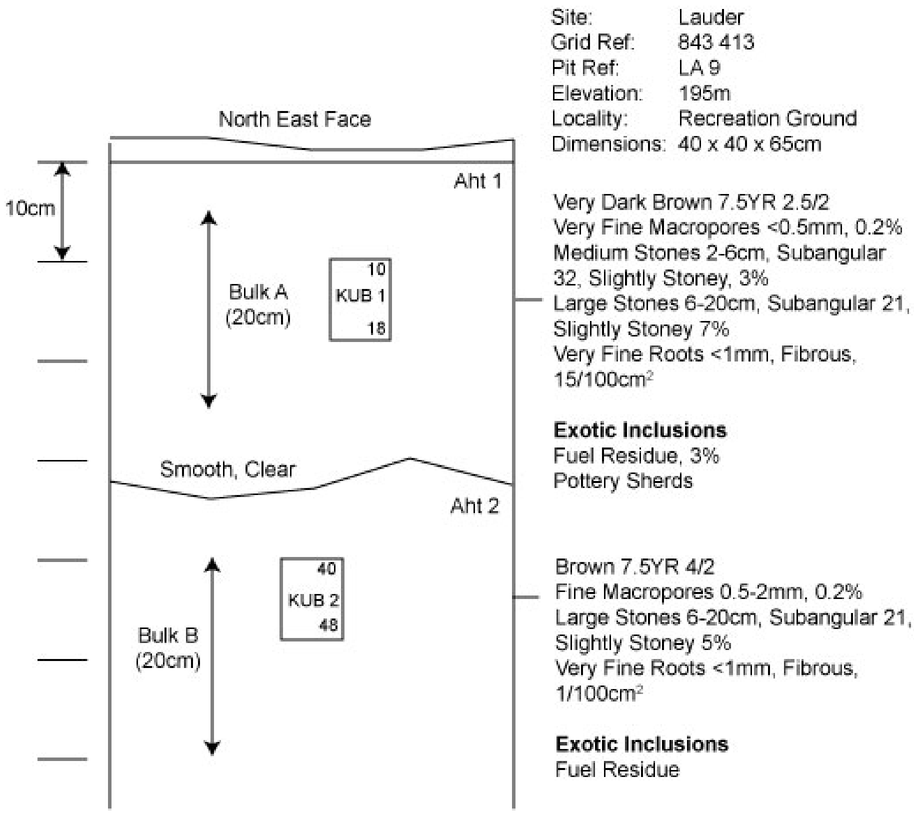
Exotic Inclusions
Pottery/Brick Sherds
Fuel Residue 3%

Dark Brown 7.5YR 3/3
Fine Macropores 0.5-2mm, 0.5%
Medium Stones 2-6mm, Rounded 11,
Very Slightly Stoney 4%
Large Stones 6-20cm, Subangular 32,
Stoney 30% (only below 77cm)

Exotic Inclusions
Pottery/Brick Sherds
Fuel Residue 3%

Profile description and photographs (knife inserted at 15cm) of soil pit LA 6

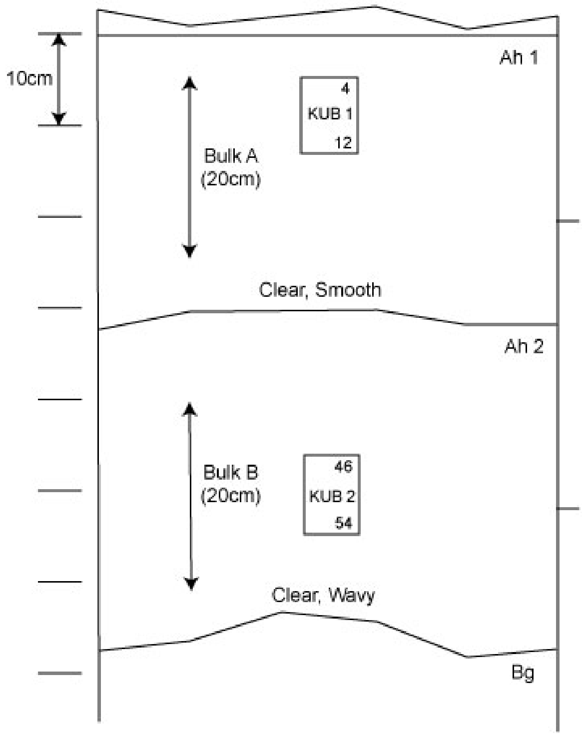
Hinterland Near Zone



Profile description and photographs (knife inserted at 25cm) of soil pit LA 9

Hinterland Far Zone

Site: Lauder
Grid Ref: 658 274
Pit Ref: LA 2
Locality: Rear of Manse
Dimensions: 50 x 90 x 75cm



Dark Reddish Brown 5YR 3/3
Fine Macropores 0.5-2mm, 0.5%
Very Small Stones 2-6mm, Sub-rounded and Subangular 22/32, Very Slighlty Stoney 2%
Medium Stones 2-6mm, Sub-rounded and rounded 22/11, Very Slightly Stoney 2%
Very Fine Roots <1mm, Fibrous, Many 30/100cm^2

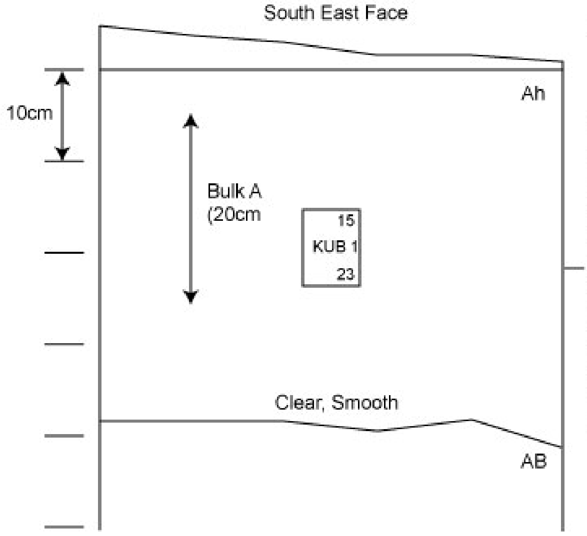
Exotic Inclusions
Fuel Residue, 1-3cm, 2%

Dark Reddish Brown 5YR 3/4 with patches of Yellow Red 7.5YR 6/8 throughout, 5-15mm, Common 10%
Fine Macropores 0.5-2mm, 0.5%
Medium Stones 2-6mm, Sub-rounded and Rounded 22/11, Very Slightly Stoney 5%
Large Stones 6-30cm, Sunbangular and Subrounded 24/41, 10%
Very Fine Roots <1mm, Fibrous, Few 2-3/100cm^2

Exotic Inclusions
Fuel Residue, 1-3cm, 2%

Profile description and photographs (knife inserted at 30cm) of soil pit LA 2

Site: Lauder
Grid Ref: 710 468
Pit Ref: LA 3
Elevation: 186.5m
Locality: Empty field belonging to Allanbank, animals not kept at present
Dimensions: 50 x 50 x 50cm

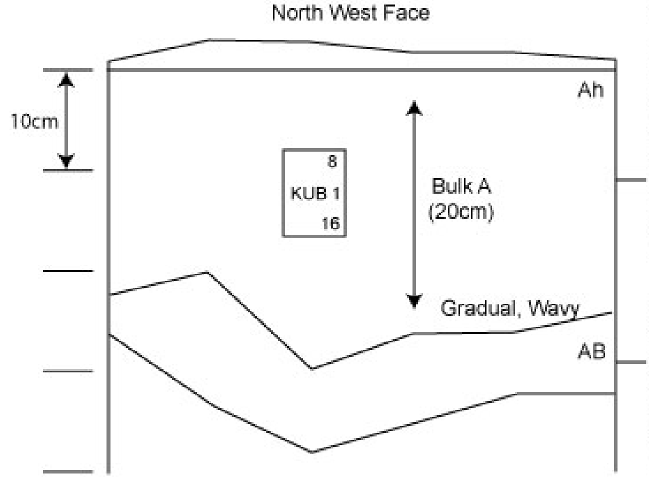


Dark Brown 7.5YR 3/3
Very Fine Macropores <0.5mm, 0.5%
Very Small Stones 2-6mm, Subrounded and Subangular 21/22/32, Very Slightly Stoney 3%
Small Stones 6mm-2cm, Subrounded and Subangular 21/22/32, Very Slightly Stoney 3%
Medium Stones 2-6cm, Subrounded and Subangular 21/22/32, Slightly Stoney 7%
Large Stones 6-30cm, Subrounded and Sub-angular 21/22/32, Very Slightly Stoney 3%
Very Fine Roots <1mm, Fibrous, Many (upper 20cm) 50/100cm^2
Very Fine Roots <1mm, Fibrous, Common (below 20cm), 20/100cm^2

Profile description and photographs (knife inserted at 25cm) of soil pit LA 3

Thirlstane Zone

Site: Lauder
Grid Ref: 230 677
Pit Ref: LA 5
Elevation 177.2m
Locality: Grounds of Thirlstane Castle
Dimensions: 50 x 60 x 40cm



Ah

Brown 7.5YR 4/2
Fine Macropores 0.5-2mm, 1%
Very Small Stones 2-6mm, Subrounded and Subangular 21/31/32, 3%
Small Stones 6mm-2cm, Subrounded and Subangular 21/31/32, 3%
Medium Stones 2-6cm, Rounded 11, 1%
Very Fine Roots <1mm, Fibrous, Many 100/100cm^2

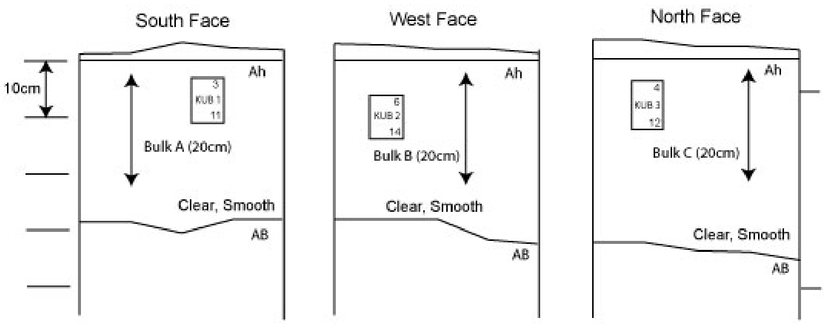
AB

Brown 7.5YR 5/3
Fine Macropores 0.5-2mm, 0.3%
Small Stones 6mm-2cm, Subrounded and Subangular 21/31/32, 3%
Medium Stones 2-6cm, Rounded and Subrounded 11/21 and Subangular 32, 1%
Very Fine Roots <1mm, Fibrous, Few 5/100cm^2

Profile description and photographs of soil pit LA 5

'Reference' Soil Profile

Site: Lauder
Grid Ref: 908 571
Pit Ref: LA 7
Locality: Unused Field
Dimensions: 40 x 40 x 45cm



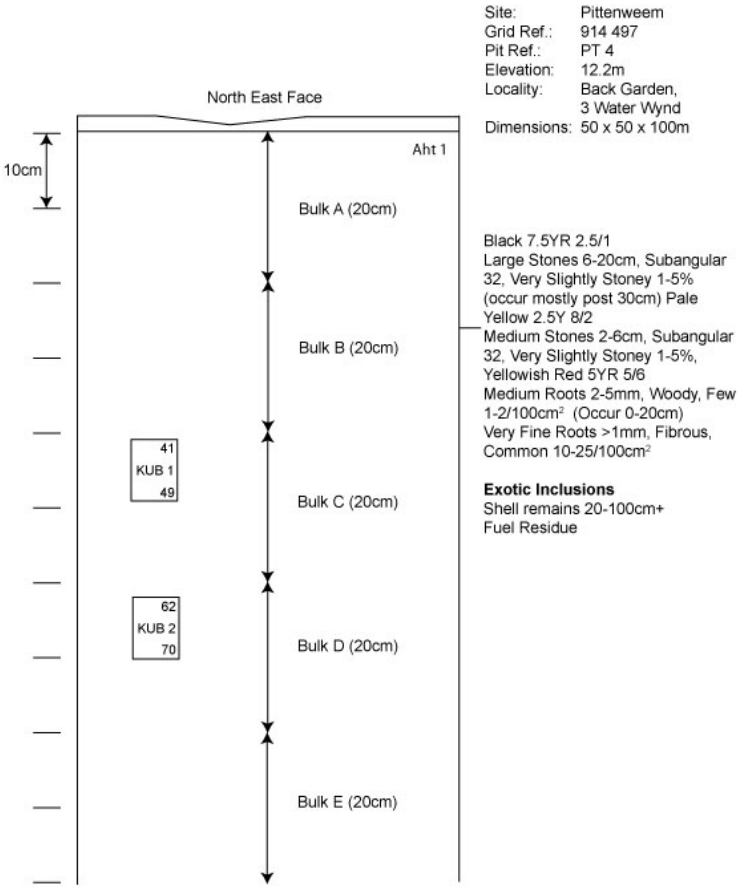
Reddish Brown 5YR 4/4
Medium Macropores, 0.5%
Small Stones 6mm-2cm, Subangular 32/31, Very Slightly Stoney 5%
Medium Stones 2-6cm, Subangular 32/31, Very Slightly Stoney 3%
Large Stones 6-20cm, Subangular 32/33, Slightly Stoney 10%
Very Fine Roots <1mm, Fibrous, Many 10-25/100cm^2

Reddish Yellow 5YR 6/6
Fine Macropores 0.5-2mm, 0.5%
Large Stones 6-20cm, Subangular 32/33 and Angular 44, 40-50%
Very Large Stones 20-60cm (last 5cm only), Subangular 32, 40%
Very Fine Roots <1mm, Fibrous, Few 3/100cm^2

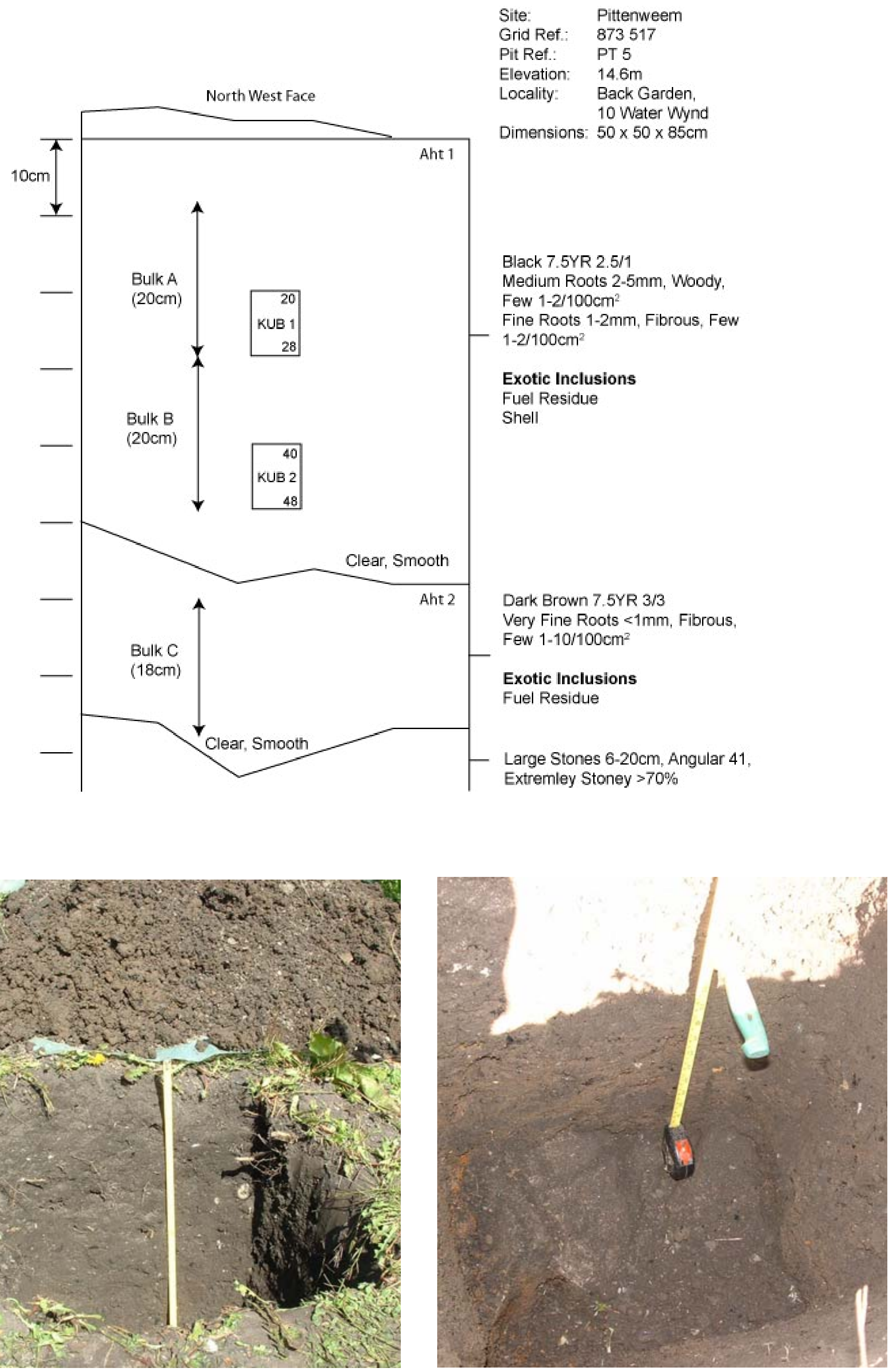
Profile description and photographs (knife inserted at 15cm) of soil pit LA 7

Pittenweem

Harbour Zone

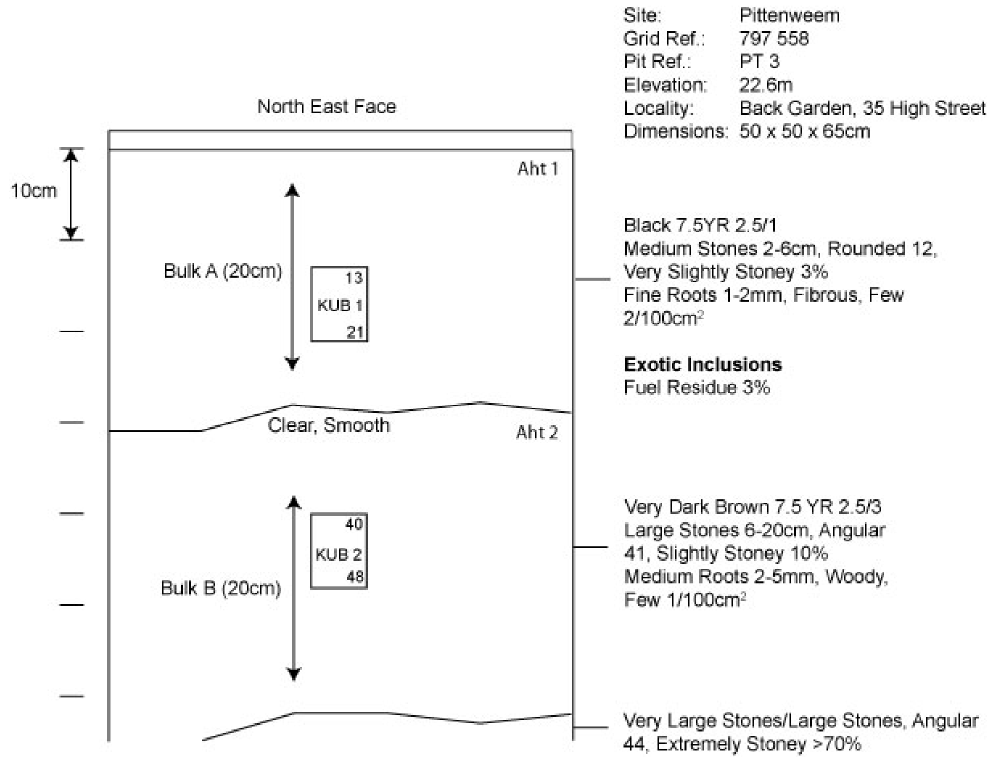


Profile description and photographs (knife inserted at 50cm) of soil pit PT 4

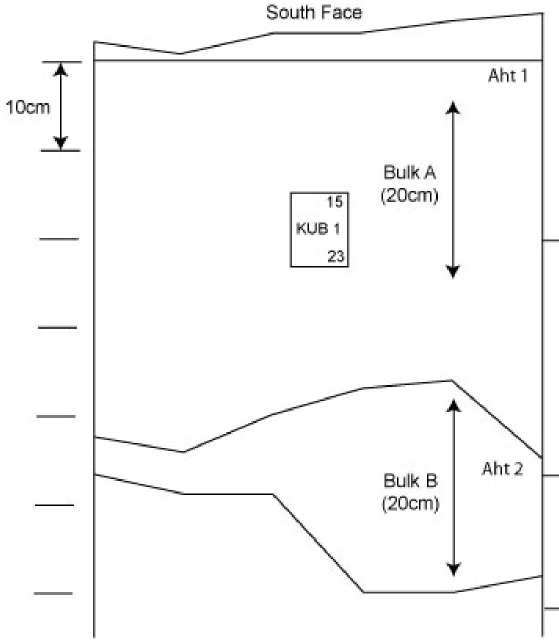


Profile description and photographs (knife inserted at 50cm) of soil pit PT 5

High Street Zone



Profile description and photographs (knife inserted at 30cm) of soil pit PT 3



Site: Pittenweem
Grid Ref.: 680 481
Pit Ref.: PT 6
Elevation: 17m
Locality: Garden associated with 64A High Street
Dimensions: 50 x 50 x 65cm

Black 7.5YR 2.5/1
Small/Medium Stones, Subangular 31, Very Slightly Stoney <1%
Fine roots 1-2mm, Fibrous, Common 10/100cm^2

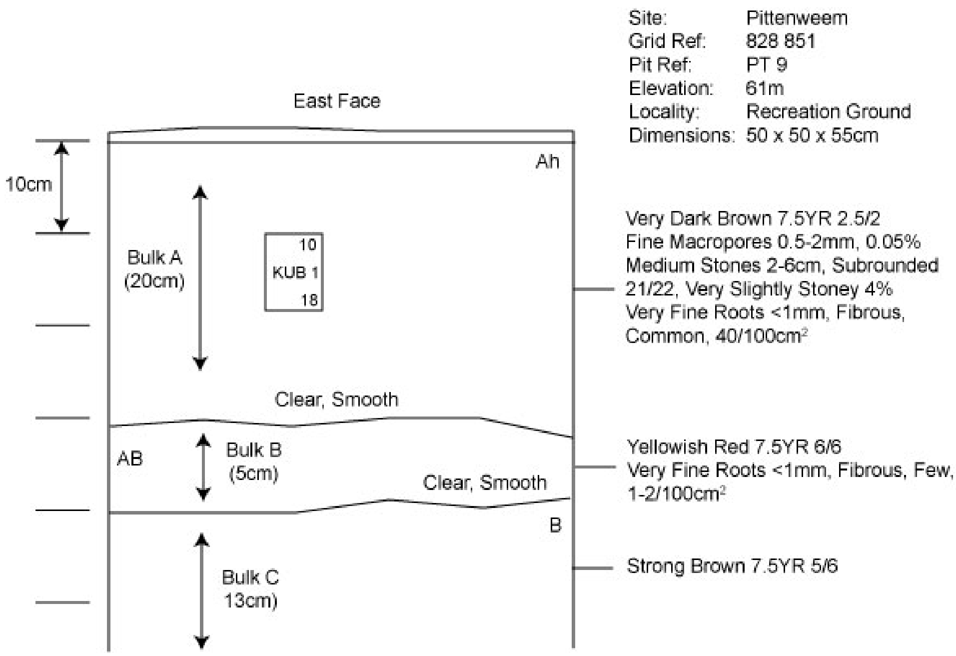
Dark Brown 7.5YR 3/3
Small Stones, Rounded 12, Very Slightly Stoney <1%

Exotic Inclusions
Fuel Residue

Very Large Stones, Subangular 12, Very Stoney 95%

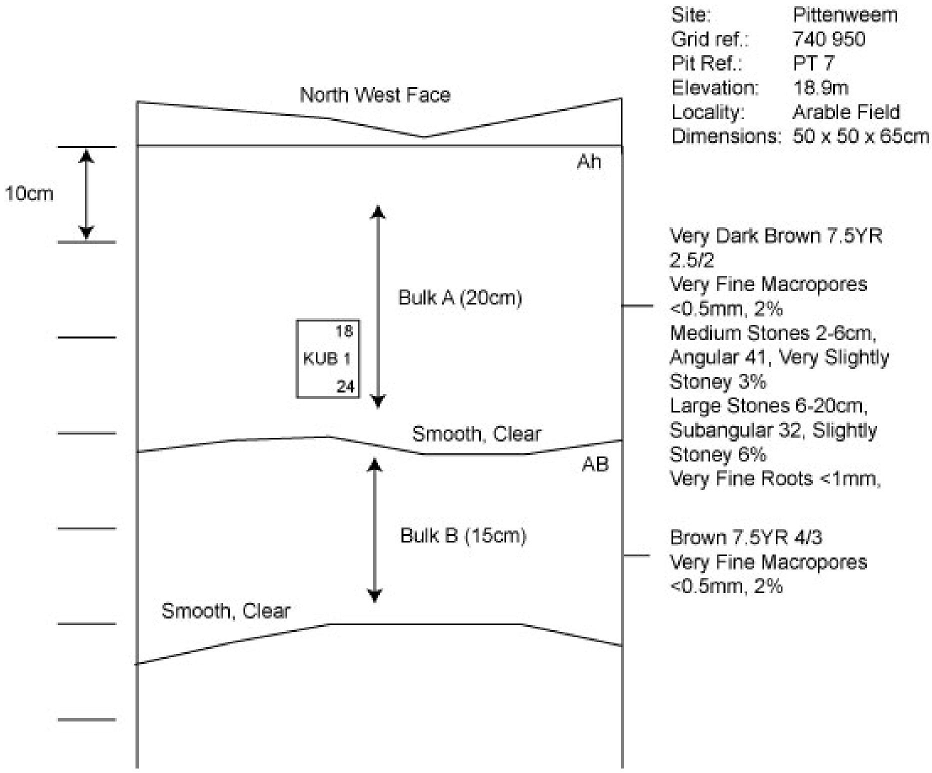
Profile description and photographs (knife inserted at 50cm) of soil pit PT 6

Hinterland Near Zone

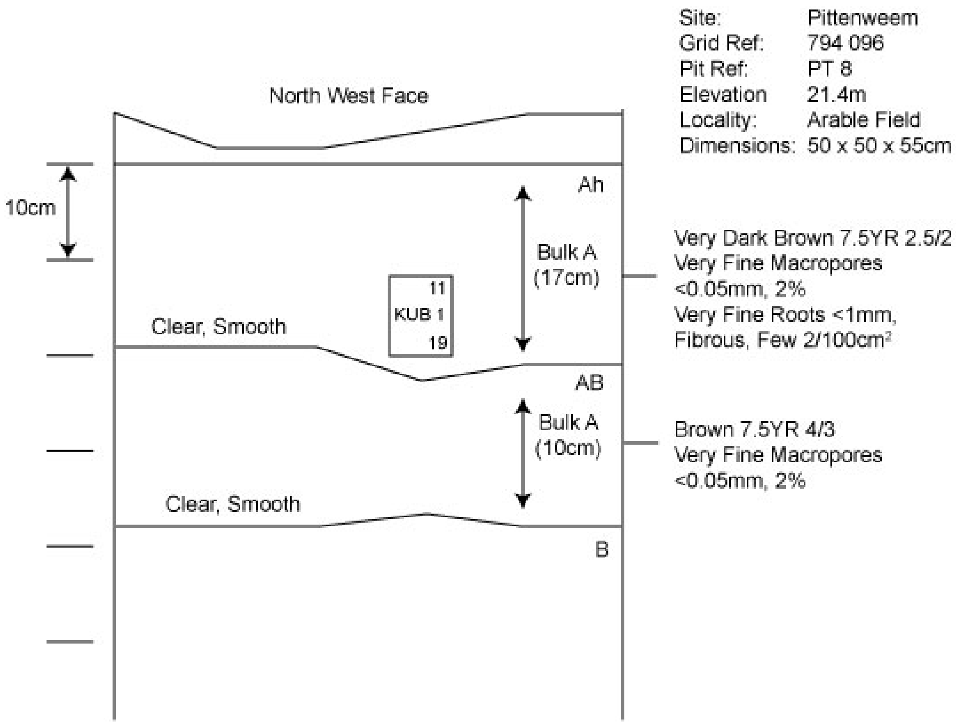


Profile description and photographs (knife inserted at 15cm) of soil pit PT 9

Hinterland Far Zone



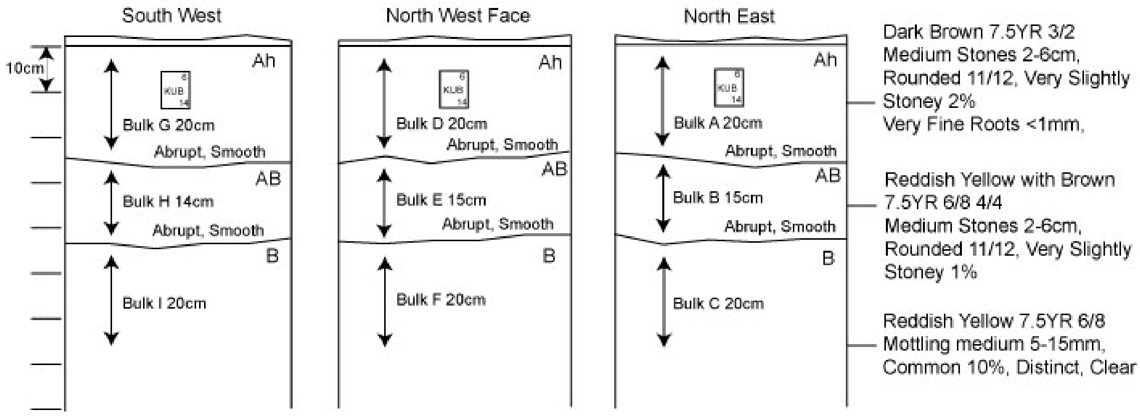
Profile description and photographs (knife inserted at 30cm) of soil pit PT 7



Profile description and photographs of soil pit PT 8

‘Reference’ Soil Profile

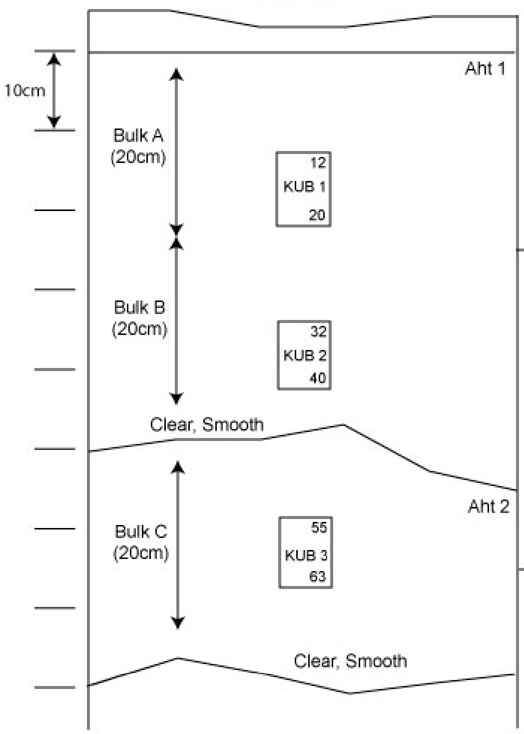
Site: Pittenweem
Grid Ref.: 773 192
Pit Ref.: PT 1
Elevation: 20.9m
Locality: Boundary of Survey Area
Dimensions: 50 x 50 x 80cm



Profile description and photographs (knife inserted at 22cm) of soil pit PT 1

Wigtown

High Street Zone



Site: Wigtown
Grid Ref: 343 234
Pit Ref: WG 1
Elevation: 29m
Locality: Back Garden, 21 South Main Street
Dimensions: 50 x 50 x 80cm

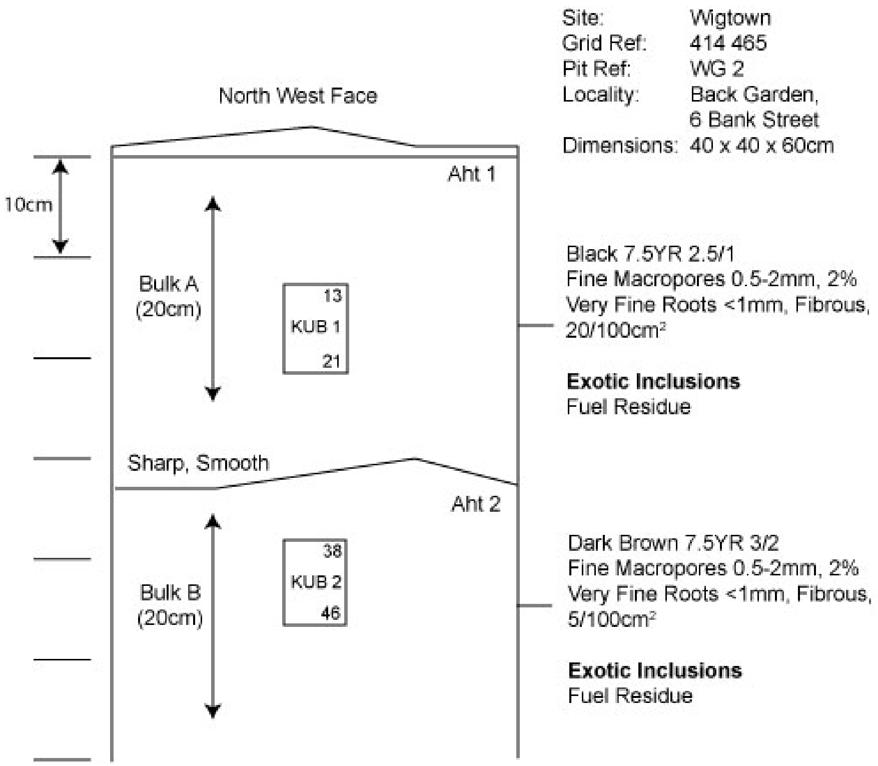
Black 7.5YR 2.5/1
Fine Macropores 0.5-2mm, 0.5%
Small Stones, Subangular 32,
Very Slightly Stoney 2%
Very Fine Roots <1mm, Fibrous,
Many 100/100cm^2
Medium Roots 2-5mm, Fleshy,
Common 3/100cm^2
Medium Roots, Woody, 1/100cm^2

Exotic Inclusions
Fuel Residue 2%
Shell
Pottery Sherds

Very Dark Brown 7.5YR 2.5/2
Fine Macropores 0.5-2mm, 0.02%
Medium Stones, Subangular 31,
Very Slightly Stoney 3%
Large Stones, Rounded 11 and
Subangular 31, Very Slightly
Stoney 5%
Very Fine Roots <1mm, Fibrous,
Few 2/100cm^2

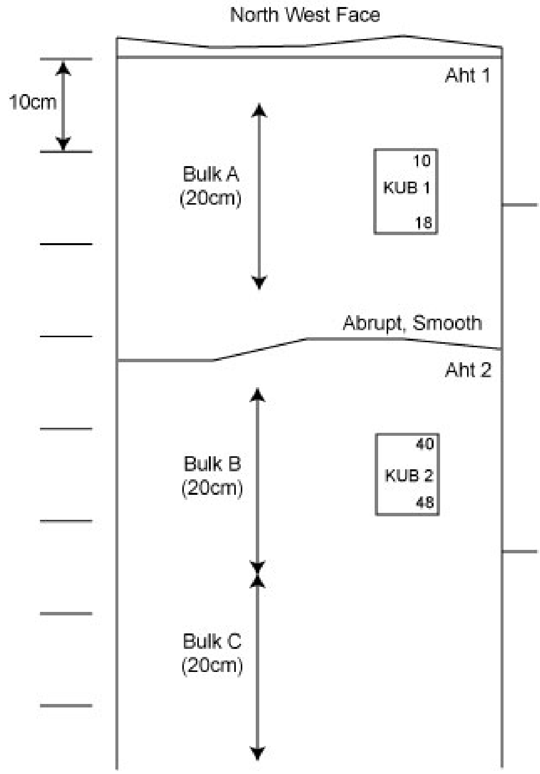
Exotic Inclusions
Fuel Residue 2%
Shell
Pottery Sherds

Profile description and photographs (knife inserted at 30cm) of soil pit WG 1



Profile description and photographs (knife inserted at 30cm) of soil pit WG 2

Site: Wigtown
Grid Ref: 479 470
Pit Ref: WG 3
Locality: Back Garden, 18 Bank Street
Dimensions: 40 x 40 x 75cm



Black 7.5YR 2.5/1
Fine Macropores 0.5-2mm, 0.5%
Medium Stones 2-6cm, Rounded 11, Very Slighlty Stoney 3%
Fine Roots 1-2mm, Woody, Few 7/100cm^2

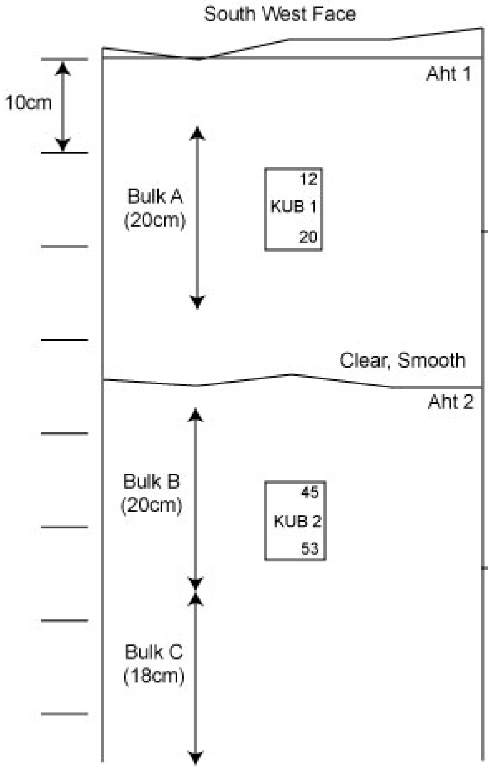
Exotic Inclusons
Fuel Residue

Very Dark Brown 7.5YR 2.5/1
Fine Macropores 0.5-2mm, 0.3%
Large Stones 20-60cm (last 10cm only), Rounded 11, Very Slightly Stoney 4%
Very Fine Roots <1mm, Fibrous, Few 2/100cm^2

Exotic Inclusons
Fuel Residue
Pottery Sherds

Profile description and photographs (knife inserted at 30cm) of soil pit WG 3

Site: Wigtown
Grid Ref: 294 393
Pit Ref: WG 4
Elevation: 44m
Locality: Back Garden, 13 North Main Street
Dimensions: 40 x 40 x 75cm



Black 7.5YR 2.5/1
Fine Macropores 0.5-2mm, 0.5%
Medium Stones 2-6cm, Subangular 31, 2%
Very Fine Roots <1mm, Fibrous, 50/100cm^2

Exotic Inclusions
Fuel Residue
Pottery Sherds

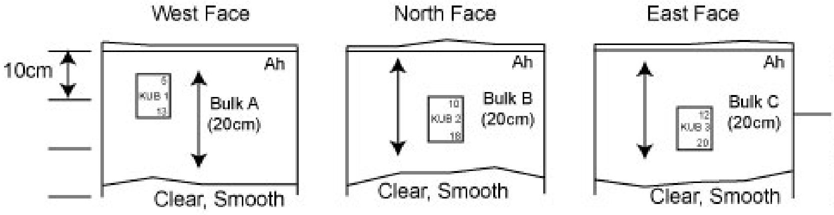
Very Dark Brown 7.5YR 2.5/2
Fine Macropores 0.5-2mm, 0.5%
Medium Stones 2-6cm, Subangular 31, 2%
Very Fine Roots <1mm, Fibrous, 1/100cm^2

Exotic Inclusions
Fuel Residue
Pottery Sherds

Profile description and photographs (knife inserted at 30cm) of soil pit WG 4

'Reference' Soil Profile

Site: Wigtown
Grid Ref: 329 951
Pit Ref: WG 5
Locality: Pasture
Dimensions: 40 x 40 x 30cm



Brown 7.5YR 4/3
Medium Macropores 2-5mm, 0.5%
Small Stones, Subangular 31/32, Very Slightly Stoney 5%
Medium Stones, Subrounded 21 and Subangular 31, Slightly Stoney 15%
Large Stones, Subrounded 21 and Sunangular 31, Slightly Stoney 10%
Very Fine Roots <1mm, Fibrous, 50/100cm²

Profile description and photographs of soil pit WG 5

Appendix 2: Micromorphology Summary Tables

Thin section micromorphology descriptions of topsoil deposits in Lauder, percentage abundance estimates of coarse mineral and organic anthropogenic material and pedofeatures are simplified as; <2% t (trace), 2-5% ●, 5-10% ●● and 10-15% ●●●

				Coarse Mineral Material (>10μm)							Coarse Organic Material (>10μm)												Fine Organic Material (<10μm)		Pedofeatures					Structure					
Zone	Thin Section	Depth (cm)	Horizon	Shell	Bone	Pottery/Brick	Clinker/Slag	Mortar/Plaster	Heated Mineral	Fine Mineral Material (<10μm)	Organ Residue	Tissue Residue	Lignified Tissue	Charcoal	FR 1	FR 2	FR 3	FR 4 & 6	FR 5 & 7	FR 8 & 9	FR 10	% FR (10-255μm)	Cell Residue	Amorphous Red	Excremental (Spheroidal) 50-100μm	Excremental (Mamilliate)	Fe Impregnated Siltstone Nodule	Fe Nodule	Fe Impregnated Amorphous Organic	% Void Space	C:F Ratio (% Coarse)	C:F Related Distribution	Microstructure	Coarse Material Arrangement	Groundmass b fabric
High Street	LA 1/1	20-28	Aht 1		t		t		t	brown/dark brown; dotted		t	t	t	●●	t	t	●	t	●		10.6	t		t	t	t		t	30	58	close porphyric	vughy, channel and chamber	random	stipple-speckled
High Street	LA 1/2	38-46	Aht 1			t	t	t		brown/dark brown; dotted		t	t		●		t	●●	t	●		16.3	t		t		t		t	25	60	close porphyric	channel and chamber	random	stipple-speckled
High Street	LA 4/1	9-17	Aht 1					t		brown/dark brown; dotted		t	t	t	●●	t	t	●●	t	●		12.6	●		t	t			t	31	57	close porphyric	channel and chamber	random	stipple-speckled
High Street	LA 4/2	42-50	Aht 2							brown; dotted		t	t	t	●		t	●●	t	●	t	17.2	t							27	56	close porphyric	channel and chamber, vughy	random	stipple-speckled
High Street	LA 6/1	10-18	Aht 1						t	dark brown; dotted	t	t			●		●	●	t	●		13.4	t		t				t	32	64	close porphyric	channel and chamber	random	stipple-speckled
High Street	LA 6/2	25-33	Aht 1					t	t	brown/dark brown; dotted	t	t			●●		t	●		t		10.8	t		t	t	t			32	53	close porphyric	channel and chamber, vughy	random	stipple-speckled
High Street	LA 6/3	57-65	Aht 2							brown/dark brown; dotted		t	t	t	t		t	t	t	●		14.2	t		t		t			28	60	close porphyric	channel and chamber, vughy	random	stipple-speckled
Hint Near	LA 9/1	10-18	Aht 1						t	brown; dotted		●			●		t	●	t	t		29.8	t		t	t	t			23	52	close porphyric	channel and chamber	random	stipple-speckled
Hint Near	LA 9/2	40-48	Aht 2							brown/red brown; dotted		t	t	t	t			t		●		50.2	t	t	t					19	55	close porphyric	channel and chamber	random	stipple-speckled
Hint Far	LA 2/1	4-12	Ah 1							red brown; speckled		●	t		t				t	t		38.3	t		t		t			13	58	close porphyric	channel and chamber	random	stipple-speckled
Hint Far	LA 2/2	46-54	Ah 2							red brown, speckled		t			t					t		58.6					t	t		20	54	close porphyric	channel and chamber	random	stipple-speckled
Hint Far	LA 3/1	15-23	Ah				t			brown; dotted		t			t		t	●	t	t		27.8	t		●		t			32	56	close porphyric	channel and chamber	random	stipple-speckled
Thirlstane	LA 5/1	8-16	Ah							brown; dotted		●	t		t			t	t	t		45.7	t		t		t			28	55	close porphyric	channel and chamber	random	stipple-speckled
Reference	LA 7/1	2-22	Ah							red/red brown; speckled		●			t		t	t		t		37.8	t		t					27	60	close porphyric	channel and chamber	random	stipple-speckled
Reference	LA 7/2	2-23	Ah							red/red brown; speckled		t			t		t	t		t		52.6	t		t					22	59	close porphyric	channel and chamber	random	stipple-speckled
Reference	LA 7/3	2-24	Ah							red/red brown; speckled		t			●		t	t		t		28.7	t		t			t		32	60	close porphyric	channel and chamber	random	stipple-speckled

Thin section micromorphology descriptions of topsoil deposits in Pittenweem, percentage abundance estimates of coarse mineral and organic anthropogenic material and pedofeatures are simplified as; <2% t (trace), 2-5% ●, 5-10% ●● and 10-15% ●●●

				Coarse Mineral Material (>10µm)							Coarse Organic Material (>10µm)													Fine Organic Material (<10µm)			Pedofeatures							Structure					
Zone	Thin Section	Depth (cm)	Horizon	Shell	Bone	Pottery/Brick	Clinker/Slag	Mortar/Plaster	Heated Mineral	Fine Mineral Material (<10µm)	Organ Residue	Tissue Residue	Lignified Tissue	Fungal Spores	Charcoal	FR 1	FR 2	FR 3	FR 4 & 6	FR 5 & 7	FR 8 & 9	FR 10	% FR (10-255µm)	Cell Residue	Amorphous Red	Amorphous Yellow	Excremental (spheroidal) c50-100µm	Excremental (mamilliate)	Fe Impregnated Siltstone Nodule	Fe Nodule	Fe Impregnated Amorphous Organic	Organic Coating (monomorphic)	Organic Coating (heated)	% Void Space	C:F Ratio (% Coarse)	C:F Related Distribution	Microstructure	Coarse Material Arrangement	Groundmass b fabric
Harbour	PT 4/1	41-49	Aht 1	t	t	t		t	t	brown/dark brown; dotted		t	t		t	●●	t	t	●	●	●		15.9	t	t	t	t		t			t		44	50	close porphyric	vughy	random	stipple-speckled
Harbour	PT 4/2	62-70	Aht 1			t	t	t	●	brown/dark brown; dotted	t	t	t			●●	t	t	●●	●●	●		4.0	t				t	t					32	57	close porphyric	vughy	random	stipple-speckled
Harbour	PT 5/1	20-28	Aht 1	●	t	t	t	●	t	brown/dark brown; dotted		t	t		t	●●		t	●	●●	t	t	10.5	t	t	t	t		t				t	30	55	close porphyric	vughy, channel and chamber	random	stipple-speckled
Harbour	PT 5/2	40-48	Aht 1	t	t	t	t	t	t	brown/dark brown; dotted		t	t		t	●●●		●	●	●	●	t	9.2	t	t	t			t			t		22	59	close porphyric	vughy, channel and chamber	random	stipple-speckled
High Street	PT 3/1	13-21	Aht 1		t	●	t	t	t	brown/dark brown; dotted	t	t	t			●●	t	●	t	t	●		13.3	t	t		t	t	t		t		t	29	57	close porphyric	vughy	random	stipple-speckled
High Street	PT 3/2	40-48	Aht 2	t		t	t	●●	●	brown/dark brown; dotted	t	t	t		t	●●	t	t	t	t	t		13.6	t	t	t	t	t	t	t	t		t	33	57	close porphyric	vughy	random	stipple-speckled
High Street	PT 6/1	15-23	Aht 1		t	t	t	●	●	brown/dark brown; dotted		t			t	●●●	t	t	●	t	●	t	6.6	t	t		t	t	t	t		t		34	57	close porphyric	vughy, channel and chamber	random	stipple-speckled
Hint Near	PT 9/1	10-18	Ah						t	brown/dark brown; dotted		t			t	●●		t	t	t	t		25.8	t			t	t	t	t				49	63	close porphyric	vughy	random	stipple-speckled
Hint Far	PT 2/1	22-30	Ah			t	t	t	t	brown/dark brown; dotted	t	●	t			●●	t	t	t	t	t		7.7	t	t				t		t		t	22	53	close porphyric	channel and chamber, vughy	random	stipple-speckled
Hint Far	PT 7/1	18-24	Ah			t		t	t	brown/dark brown; dotted		t				●●	t	t	t	t	t		20.9	t	t				t	t				20	55	close porphyric	channel and chamber, vughy	random	stipple-speckled
Hint Far	PT 8/1	11-19	Ah			t	t		t	brown; dotted		●			t	●●	t	t	●	t	●	t	23.9	t					t	t			t	25	54	close porphyric	vughy, channel and chamber	random	stipple-speckled
Reference	PT 1/1	6-14	Ah							brown/dark brown; dotted		●	t			●	t		t		t		26.9	t	t		t		t	●				15	58	close porphyric	channel and chamber, vughy	random	stipple-speckled
Reference	PT 1/2	6-14	Ah			t			t	brown/dark brown; dotted		●		t		●	t	t	t		t		17.2	t	t		t			t	t			17	54	close porphyric	channel and chamber, vughy	random	stipple-speckled
Reference	PT 1/3	6-14	Ah					t	t	brown/dark brown; dotted		●				●		t	t	t	●	t	11.7	t	t					t	t			16	54	close porphyric	channel and chamber, vughy	random	stipple-speckled

Thin section micromorphology descriptions of topsoil deposits in Wigtown, percentage abundance estimates of coarse mineral and organic anthropogenic material and pedofeatures are simplified as; <2% t (trace), 2-5% ●, 5-10% ●● and 10-15% ●●●

				Coarse Mineral Material (>10µm)							Coarse Organic Material (>10µm)											Fine Organic Material (<10µm)			Pedofeatures						Structure					
Zone	Thin Section	Depth (cm)	Horizon	Shell	Bone	Pottery/Brick	Clinker/Slag	Mortar/Plaster	Heated Mineral	Fine Mineral Material (<10µm)	Organ Residue	Tissue Residue	Lignified Tissue	Charcoal	FR 1	FR 2	FR 3	FR 4 & 6	FR 5 & 7	FR 8 & 9	FR 10	% FR (10-255µm)	Cell Residue	Amorphous Red	Amorphous Yellow	Excremental (spheroidal) 50-100µm	Excremental (mamilliate)	Fe Impregnated Siltstone Nodule	Fe Nodule	Fe Impregnated Amorphous Organic	Organic Coating (heated)	% Void Space	C:F Ratio (% Coarse)	C:F Related Distribution	Microstructure	Coarse Material Arrangement	Groundmass b fabric
High Street	WG 1/1	12-20	Aht 1			t	t	●	t	brown/dark brown; dotted		t	t		●●	t	t	●●●	●	●		12.6	●		t		t					42	58	close porphyric	vughy	random	stipple-speckled
High Street	WG 1/2	32-40	Aht 1	t	t	t		t	t	brown; dotted		t	t		●●	t	t	●●●	t	●	t	7.4	t			t						32	58	close porphyric	channel and chamber, vughy	random	stipple-speckled
High Street	WG 1/3	55-63	Aht 2							brown/red brown; dotted		t	●	t	●●		t	●	t	t		19.6	t				t		t			34	56	close porphyric	vughy, channel and chamber	random	stipple-speckled
High Street	WG 2/1	13-21	Aht 1	t		t	t	t	t	dark brown; dotted		t	t	t	●●	t		●●	t	●	t	10.0	●			t	t		t		t	34	55	close porphyric	channel and chamber, vughy	random	stipple-speckled
High Street	WG 2/2	38-46	Aht 2	t	t			t		brown; dotted		t	t		●		t	●●●	t	●	t	7.7	t			t	t	t	t			34	59	close porphyric	channel and chamber	random	stipple-speckled
High Street	WG 3/1	10-18	Aht 1	t	t		t		t	brown/dark brown; dotted		t	t	t	●		t	●●		●		4.7	t				t	t				33	60	close porphyric	channel and chamber	random	stipple-speckled
High Street	WG 3/2	40-48	Aht 2		t	t			t	brown; dotted		t	t		t		t	t	t	●		28.5	t					t				22	56	close porphyric	channel and chamber	random	stipple-speckled
High Street	WG 4/1	12-20	Aht 1	t	●		t	t		brown/dark brown; dotted	t	t			●		t	●●●	t	●		5.9	t	t		t						32	60	close porphyric	channel and chamber, vughy	random	stipple-speckled
High Street	WG 4/2	45-53	Aht 2	t	t		t			brown; dotted		t		t	●			●	t	●●		14.5	t						t			28	58	close porphyric	vughy, channel and chamber	random	stipple-speckled
Reference	WG 5/1	5-13	Ah							brown; speckled		●			t			t		t		19.6	t			t	t					32	57	close porphyric	channel and chamber	random	stipple-speckled
Reference	WG 5/2	10-18	Ah							brown; speckled		t	t		●			●	t	t		17.8	t			t	t	t		t		33	57	close porphyric	channel and chamber	random	stipple-speckled
Reference	WG 5/3	12-20	Ah							brown; speckled		t			●			●	t	t		16.5	t			t		t	t	t		31	60	close porphyric	channel and chamber	random	stipple-speckled

Appendix 3: Watching Brief at High Vennel, Wigtown

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SUAT SITE ARCHIVE RECORD — SITE CODES: WG01

REGION	DISTRICT	TOWN
DUMFRIES AND GALLOWAY	WIGTOWN	WIGTOWN

ADDRESS	HIGH VENNEL	Watching Brief ☑	DATES: 11th August 1992
		Trial Excavation ☐	
		Extended Excavation ☐	
NAT.GRID	NX 4300 5500	FUNDING	HS

Supervisor & Team: Derek Hall

Method of Excavation: Watching brief.

O.S. ⊼ Height: N/A — Location: N/A

Site TBM ① N/A
② N/A
③ N/A

Deposits ☐	100 –	(499)	None	Plans	☑	Trench location plan.
Cuts ☐	500 –	(899)	None	Sections	☑	S1 – sketch sections of trench.
Walls ☐	900 –	(999)	None	Photos · BW	☑	Record shots
Interfaces ☐	001 –	(099)	None	: Colour	☑	Record shots.

Finds	None	Samples ☐	N/A.
Pot. ☐	None		
Bone ☐	None		
Other ☐	None		

	D+E	Informal	Interim	Level III	Level IV
Reports Intended	☑	☐	☐	☐	☐
Completed	☐	☐	☐	☐	☐

Summary: Observation of contractors foundation trenches revealed dark brown silty clay sitting on natural crushed stone. This deposit varied in depth from 0.60m at the NW end of the site to 1.10m at the SE end. This deposit was homogenous and contained the occ sherd of 19th C ceramic. No deposits relating to the medieval burgh were located.

Name: Derek Hall — Date: 12/8/92.

Appendix 4: Archaeological Evaluation of 64a High Street, Pittenweem © Scotia Archaeology

The following report is an archaeological evaluation of 64a High Street Pittenweem conducted by Scotia Archaeology, 11/11/04.

Introduction

This report describes the results of an archaeological evaluation undertaken prior to the construction of a new domestic residence to the immediate east of 64 High Street, Pittenweem, Fife. The evaluation was a condition attached by Fife Council to ensure that any surviving archaeological record was taken into consideration during the proposed development. It was understood that should features or deposits of archaeological significance be uncovered during the evaluation a further phase of mitigation fieldwork might be required by the planning authority. The field evaluation was carried out on 9th November 2004 by John Lewis of Scotia Archaeology, on behalf of Mr James Martin. Before fieldwork commenced, a desk assessment of the site was undertaken by John Terry, also of Scotia Archaeology.

The Site

The site, which was centred on NO 5468 0248, lay at the western limit of the medieval burgh and comprised a triangular area of ground measuring approximately 22m east/west by a maximum 15m north/south. It was defined on its west by 64 High Street, its north by a stone wall separating it from the High Street and its south-east by a wall on West Wynd, a footpath leading down to the shore. The solid geology of the area consists of calciferous sandstone measures of Carboniferous age, over which lie late glacial drift deposits of alluvium, mostly sand and clay. At the time of the evaluation, the site was covered with rough grass and other vegetation.

The Desk Assessment

Pittenweem is first mentioned in written records dating to c1143 when David I granted Petenweme and Inverrin (St Monans) to the Priory of May (Lawrie 1905, 120) although it did not achieve burgh status until 1526 (Pryde 1965, 57). The layout of Pittenweem’s centre has changed little since the 16th century, many of the burgage plots still being visible (Simpson & Stevenson 1981, 9). Recent developments have concentrated on the east and west extremities of the village, beyond the limits of the medieval burgh.

Archaeological investigations in Pittenweem have been limited to excavation within the garden of 5 Midshore (NO 548 025) where a 17th-century midden, containing Dutch, French and local wares (DES 1978, 7), overlay a stone-built wynd and associated structures believed to date to the early 16th century. Some 12th-century pottery was recovered from levels below these features (DES 1979, 10).

A few archaeological sites have been identified within a short distance of the site: pits and other features, possibly associated with coal extraction, are visible in aerial photographs at NO 540 024; a former gasworks stood at NO 5452 0245; and two Edward I pennies were retrieved by metal detector at NO 5435 0235.A study of early editions of Ordnance Survey maps (1855, 1895, 1914, 1938 and 1965) showed no changes within the site itself over the past 150 years.

The Evaluation

The principal aim of the evaluation was to determine whether there were any structures, features or deposits relating to the medieval burgh or its post-medieval expansion within the area of proposed development. This consisted of the excavation of three trenches, covering a total area of $8m^2$ which comprised 5% of the site. All trenches were excavated by hand. They were left open at the end of the excavation.

Trench 1

Trench 1, located near the centre of the site, measured 5m east/west by 1m wide. Below the turf, was up to 0.6m of very dark, humic topsoil which overlay a thin layer of lighter, more clayey soil, possibly the result of bioturbation, and very thin lenses of undisturbed glacial clay. Bedrock was exposed at a depth of 0.5-0.8m, dipping slightly towards the west but steeply towards the south. It was very friable and fractured easily, resembling deliberately laid masonry in places although its natural origins were in no doubt. Three sherds of pottery were retrieved from the base of the topsoil in Trench 1, two rim sherds of post-medieval reduced ware and one body sherd of post-medieval oxidised ware.

Trench 2

This small trench was located towards the north-east corner of the site and measured 2m north/south by 1m wide. The dark humic topsoil was 0.35-0.40m deep and overlay glacial deposits of coarse yellow sand and pale brown clay. Bedrock was not exposed in Trench 2.

Trench 3

Trench 3, which measured 1m square, was located near the north boundary of the site. Topsoil was 0.40-0.45m deep and overlay about 0.1-0.2m of rubble which included fragments of brick and 19th-century pottery. Below the rubble lay glacially deposited sand.

Conclusions

No evidence of any pre-19th-century structures or features was uncovered in any of the trenches. Although three sherds of post-medieval pottery (perhaps dating to the 17th century) were retrieved, they were found in garden soil and were clearly in a residual context, there being nothing to suggest that they formed part of a midden. On this evidence, it is believed that extending the investigation within the area adjacent to 64 High Street, Pittenweem would reveal little, if anything, of archaeological significance.

References

DES *Discovery & Excavation in Scotland*, Council for Scottish Archaeology. Edinburgh

Lawrie, A C 1905 *Early Scottish Charters Prior to 1153*. Glasgow

Pryde, G S 1965 *The Burghs of Scotland*. London

Simpson, A T & Stevenson, S 1981 *Historic Pittenweem: the archaeological implications of development* (= Scottish Burgh Survey). Edinburgh