The hidden archive of historical human inhumations locked within burial soils

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Abstract

The study of soils within an archaeological context is often limited to the examination of landscapes and the environmental impact anthropogenic interactions have on their formation. Similarly, archaeological research into human inhumations has mainly focused on the rituals surrounding death, whilst determining socio-cultural practices and perceptions. The majority of research into the interactions of human interment and its effects on the surrounding soil has been limited to macromorphological investigation and elemental analysis. Historic human burials and their degradation products have not, to date, been investigated with regards to their impact on soil pedogenic processes.

This research explores the hypothesis: soils and sediments immediately associated with the decomposition of human interment serve as valuable and under-utilised archaeological record. Grave soils were analysed using micromorphological and associated techniques to aid in the understanding of pedogenic processes and elemental composition of the grave soils incorporating burial remains. The analysis provided a comprehensive inventory of information regarding the archaeological inhumations within the burial soil through the spatial analysis of soil features in relation to the body.

The analyses was undertaken on the undisturbed soil samples collected from around both single inhumations at sites in Mechelen, Belgium, Syningthwaite priory, England and South Leith, Edinburgh, and mass grave burials collected from Ridgeway, England and Fromelles, France, with control areas also being sampled, so effects of human decomposition of soil pedogenesis could be studies. Micromorphological analysis identified distinct patterns of pedality and depositional pedofeature development associated with the skull and pelvis sample regions around the burial, whilst also determining differences in pedogenesis to that of the control samples. SEM-EDS inorganic elemental analysis provided mapping of the degradation products emanating from the burials and migrating into the surrounding soil matrix, with elevated levels in depositional pedofeatures and fine material incorporated in all burials investigated, but particularly in soils from the skull and pelvic regions.

Micromorphological analysis of soil thin sections from contexts of archaeological human inhumation can aid the detection of degradation products from the burial and identify artefacts derived from pre-burial treatment, some of which are no longer visible to the naked eye.

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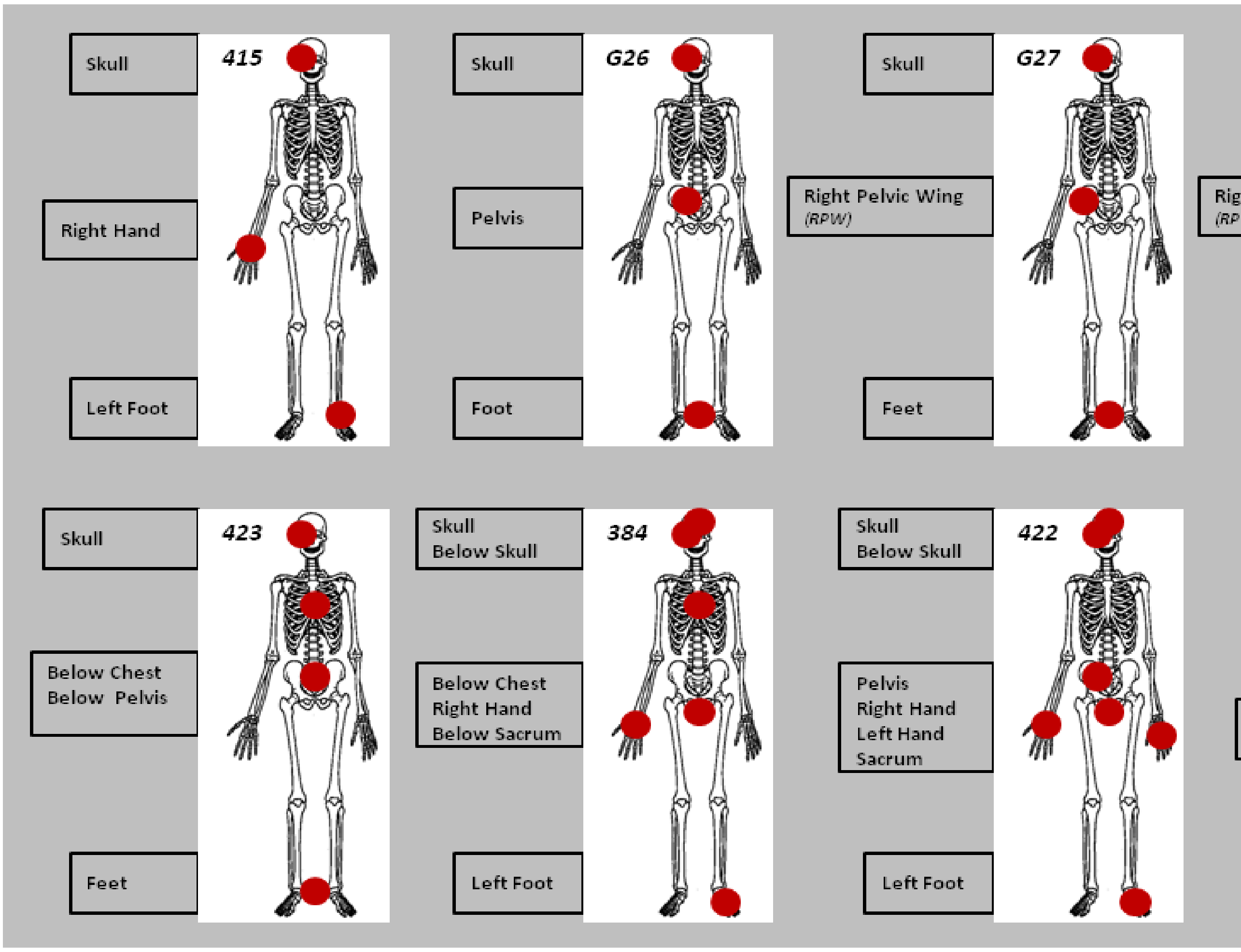
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Declaration of Originality

This is to certify that, to the best of my knowledge, the content of this thesis has not been submitted for any degree or other purposes and the information contained within is original. I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged.

Additional Data

All raw data relating to the micromorphological observations and SEM-EDs analysis presented in this thesis has been stored on Excel spread sheets and are contained in the CD attached within the back cover of the thesis.

1 Discovering the unutilised archaeological information in grave soils

1.1 Introduction

This study examines the effects of decay from human remains in soils from historical archaeological graves. The study is part of a European Research Council (ERC) project, "'*Interred with their bones' – linking soils micromorphology and chemistry to unlock the hidden archive of archaeological human burials" (InterArChive).* The *InterArChive* project investigates the unexplored archive of archaeological human interment within soils and sediments, through the combination of soil micromorphology and chemistry (Usai *et al.* 2014).

1.1.1 The *InterArChive* project

The *InterArChive* project aims is to assess the nature of both archaeological and historical burial records preserved at the micro-scale within grave soils, particularly where physical organic and inorganic remains are no longer visible. The project is aimed at demonstrating the application of micro-analysis to human burials can provide a scientific approach effective in maximising the information obtained from the burial environment. This can enhance the cultural and physical information attained whilst offering a better understanding to specific site contexts (Usai *et al.* 2014). *InterArChive's* methodology is focused on measuring the effects of human inhumation products and grave-goods on a range of burial soils and sediments, appraising the resulting soil/sediment modifications. The new sampling and analysis procedures provide an invaluable contribution to archaeological excavation and forensic investigations. The information collected from the burial soils will offer new information regarding the interaction of the burial content and soil, whilst recovery pertaining to practices and processes undertaken during human burial will open-up a new field of research. To achieve this, the project has developed a unique sampling strategy to maximise the retrieval of archaeological and historical information encapsulated in the soil. The examination of the graves takes into account all funerary practice, cultural and environmental information, and the preservation/movement of grave residues and organic matter from the body into the soil.

1.1.2 Aims and objectives of *InterArChive*

The rationale for *InterArChive* implies that decomposed organic material from human bodies or funerary goods may still be present in the soil although not visible to the naked eye, and may hold some microscopically identifiable form or chemically recognisable signature in the soil. A pilot project, analysing Bronze Age burials, was undertaken by the *InterArChive* project in Yemen, where preliminary investigation identified microscopic remains in the soils around the human burial remains (Usai *et al.* 2010). The main aims and objectives of the *InterArChive* project were:

1. To observe, classify and interpret micromorphological features in different burial soils based on physical and chemical characteristics. This was achieved through micromorphological and chemical analysis of samples from burials in a range of environments.
2. To understand possible degradation processes that may have led to the features observed in archaeological samples. This was realised by comparing archaeological samples with samples from the experimental burial of piglets undertaken at the beginning of the project.
3. To understand the preservation of inhumation and burial features in the burial soils, by identifying chemical signatures in the soil.
4. To improve the recovery of samples from archaeological burials, by developing a standard, yet flexible sampling strategy for soils in human inhumations.
5. To develop and enhance the laboratory techniques for the analysis of the burial soils. This was achieved by testing which methods provide the most useful information, and then developing a standardised methodology for integrating micromorphological and chemical analyses.
6. To reveal the hidden archive of information in burials through identifying signatures of:
    - Pre-burial treatment
    - Perishable artefacts
    - Diet
    - Morbidity
    - Drug-use
    - Cause of death
    - By-products of body decay
    - Burial artefacts and clothing

Investigation of human burials was, therefore, applied through multidisciplinary projects within the complimentary fields of geoarchaeological and organic chemistry to enable the interpretation of physical remains at the macro-, micro and nano-observational scales.

1.1.3 Aim of this thesis

The archaeological study of soil contexts in relation to human inhumation are often limited to the observation of stratigraphic layers, colour, texture, particle size and mineralisation and to the "provenance" of the artefact in the excavation site (Gradusova and Nesterina 2009 63; Renfrew and Bahn 2001 50; Brady and Weil 2008; Grant *et al.* 2008 146). This may in some areas extend to the 'sub-set' examination of archaeological soils, to ascertain phosphate fluctuation, elemental composition and dating through optical stimulated luminescence (French 2003 47). The effects of soil texture on the management of burials and burial sites has been highlighted forensically, in relation to the potential contamination of localised water courses and the significant variations in their pathways within different soil types (Williams *et al.* 2009 98). Investigations of specific macro and micro features and components in the soil and their pedogenesis within an archaeological context have been largely focused on cultivation and the relative techniques employed on anthropogenic occupation layers and their effects on the immediate environment, the development of landscape features with their contextual significance and the development of soil features through bioturbation factors(Courty *et al.* 1989 130; Matthews 2000; Davidson *et al.* 2010b; Kooistra 1991; McGovern *et al.* 2007). Existing data on the interaction of decaying burials resting in and on the "surrounding soil environment" is comparatively modest (Stokes *et al.* 2009). Procedures for the rudimentary sampling of the soils in an archaeological burial have been suggested, however the system was initiated as a forensic tool (Goldberg and Macphail 2006 192). Forensic investigations of the chemical signature of decay products of inhumation and clandestine burial in the surrounding soil have been carried out, where these studies centred upon soil particle size and inorganic trace element analysis, utilising x-ray fluorescence (XRF) of small soil samples to characterise unique components and changes in the soil (Carter and Tibbett 2008 281).

This thesis aims to investigate the effects archaeological, specifically historical, human inhumation has on the soil environment. The main focus of this thesis was to investigate burial soils through analysis of the micromorphological and inorganic elements of soils. The burials investigated were from the historic periods, starting from the 9-10th century Anglo-Saxon burials in Britain, through to 1916 burials of The Great War on mainland Europe. The rationale behind the sampled of specific sites was a result of the availability of burial excavations during the initial stages of the *InterArChive* project. All samples were collected by the principal investigators of the *InterArChive* project, between 2008 and 2010, priory to start of this PhD search. The investigation integrated the development and changes in funerary practice regarding the textiles used to clothe the body, positioning of the body, grave goods and inhumations vessels. A primary desk top investigation formed the initial examination into forms of burials pertaining to the archaeological sites being examined.

Thus, the objectives of this research were to better understand historical funerary practices, therefore enabling the sampling and analytical protocols to be developed subsequently maximising the identification of retained burial degradation signatures in the soil.

The initial investigation and sampling was carried out using the multidisciplinary analytical techniques of soil micromorphological analysis and inorganic chemical assessment of the soil. This project endeavours to investigate grave soils dating to the historic period found in different parts of northern Europe in relation to different funerary practices and preparation, thus gaining an understanding of the unseen micromorphological and chemical record that remains in the soil. Ultimately, this thesis will reveal the pathways of decay products and their resulting forms, while understanding the effects human inhumation has on pedogenic processes that take place in the studied soil environments.

1.2 Soils in archaeological burials

In order to understand the relationships between soil features and the burial and decay of archaeological human remains, it is necessary to understand the formation, function and properties of soil on the macro- and micro-scales. It is important that a thorough comprehension of soil characteristics and their pedogenesis is achieved, allowing for a greater knowledge of the function artefacts have in soil development, whilst the soil provides possible indication of provenance and their potential preservation (Beik 1963 207). In fact, although the surface of the soil can appear undisturbed, time may have changed soil's properties and nature through the intervention of many different factors, and modification or additions to the soil anthropogenically, consequently altering the physical pedogenic processes and the chemical soil environment. Thus, it can be suggested that the pathways of soil evolution, in an archaeological context, can affect the preservation and interpretation of cultural records and artefacts, while also being influenced by the deposition of archaeological remains (Holliday 1992 101; 2004 1). It is, therefore, necessary to ascertain the characteristics that may develop through time within the soil and the environmental factors that contribute to their formation.

1.3 Soil formation

The Russian soil scientist, V. V. Dokuchaev established the concept of soil as a natural body that develops, evolves and is more than just a by-product of parent material weathering (1873, as cited by Schaetzl and Anderson, 2009 5). His ideas centred upon four main factors, all of which control soil formation: climate, age; sub-soil, and organisms. Dokuchaev's theory was built upon by Jenny (1941) who determined five soil forming factors: climate; topography, biota, parent material; and time, with all factors being functionally related. Viewed independently, each factor may work mutually, to varying degrees, forming a complex heterogeneous open system, "linked to each other by the chain of their functional relationship" (Jenny 1941; Crocker 1952 145). Thus, all soil forming factors control the direction and the speed of soil genesis, making soil a complex system with individual dynamics relating to the physical and chemical properties (Kubiena 1970 8). Hence, soil formation occurs through weathering of parent material and the incorporation of organic matter, with climate and landscape having an important role in development. Often, the most significant factor is time, as this is generally required to develop a definable soil horizon. There is a distinct difference between sediments and soils: although both may contain organic/inorganic material, sediments develop through erosion, transportation and deposition whilst soils are developed in a static environment where aggregation and degradation have formed equilibrium (French 2003 36). Unlike soils, sediments can form in a matter of minutes as they are deposited through different depositional mechanisms such as wind, water or gravity.

In some cases landscapes have experienced several thousand years of management, through anthropogenic processes such as cultivation and building, with little regard to how this would affect soil properties (Courty *et al.* 1989; Tiessen *et al.* 1994; Adderley *et al.* 2010). In fact, it has been suggested that the alterations that take place in soils such as organic matter additions and the manipulation of landscapes act, to an extent, as one of the main soil forming factors, with other factors such as climate and topography being only secondary (Kubiena 1970 70). In relation to this, anthropogenic factors have been defined as the sixth and possibly the most influential soil forming factors, however, this could be defined under the biota category of soil forming factor, thus reaffirming Jenny's(1941) five factors of soil formation (Dudal *et al.* 2002b; French 2003 38). Regardless of which factors are more involved in pedogenesis, it is crucial to consider that they are continuously being adjusted through both external and internal environmental conditions (Gerrard 1992 10). It is, therefore, necessary to determine which environmental conditions influence the physical properties of soil, thus determining the manner degradation products from human inhumations have subsequently affected soil formation.

1.3.1 Soil properties

The properties of soil have a great influence on the movement of organic matter, water and air on and through the soil body (Brady and Weil 2008 121). Analysis of soil properties through macromorphological analysis of texture, sorting and colouration, and micromorphological analysis of soil thin sections can help determine past environmental conditions, moisture regimes and vegetations affecting fundamental pedogenesis. Soil is not isolated, but an integral part of all landscapes and has no distinct demarcations between different profiles, forming graduated boundaries of differentiation.

1.3.1.1 *Texture*

Soil texture is determined by its relative quantities of sand, silt and clay. The texture of soil is an important factor when considering soil development and the rates of organic matter decay. The finer the soils texture the greater potential for water and nutrient retention. Clay may often be the most dominant component, with silt and sand lesser constituents. As a result of the water retaining properties of clays, small amounts can have a marked effect on the way a soil will behave. Thus, soils rich in clay may have low levels of biota as a result of the tendency of clay to contain high levels of water and low quantities of air-filled pore space (Brady and Weil 2008 110). The texture of soil determines its water content and thus its cation and nutrient retention, with larger surface areas, such as are found in soils with granular peds, having a greater influence on the levels of nutrients and water held within. For thousands of years man has endeavoured to manipulate soil texture in order to enhance soil features for cultivation (Oram 2011). This is because different soil textures could induce either retention or loss of water or vital nutrients for the prevision of plant growth (Simpson *et al.* 2004). Similarly, it is possible that in graveyards the manipulation of soil texture, by digging of burial pits or the amalgamation of different soil types during the process of backfill may alter soil water retention or the mobility of organic and other components. Such changes are likely to result in the characteristics and behaviour of soils/sediments within graves being different from those of soil from the surrounding areas.

1.3.1.2 *Soil colour*

Colour may be affected by changes in pedogenesis differing in soil macro-and micro-environments. The variation of colour within soil has been, in many cases, employed as a diagnostic tool for classification (Courty *et al.* 1989 35), and is used by field archaeologists as an analytical tool in the identification of soil stratigraphy (Cornwall 1958 182). In particular, colour in the form of silhouettes or horizons of a soil profile has been advocated as the ‘primary guide’ for the delineation between archaeological evidence and localised soil nature, as in the case of some inhumations where stains or silhouettes were still evident even though residue of human body decay left in the soil could not be visually recognised (Biek 1963 108). In surface soil horizons, darker colours can indicate the accumulation of non-humified organic matter and humus (Birkeland 1984 12). Colour can be an indirect measurement of soil fertility, organic matter content and soil water provision (Viscarra Rossel *et al.* 2006). The identification of soil colour is undertaken normally using a combination of hue, value and chroma according to the Munsell Colour chart, thus allowing a degree of standardisation of colour description. Such determination of soil colour is, however, subjective and open to interpretation unless applied through highly refined quantitative image analysis, which may determine subtle variations in colour (Munsell 2009). The utilisation of these methods can indicate a range of processes including clay rubification as a result of heating (Adderley *et al.* 2002). It must be noted, however that this would only determine broad differences in colouration, with difference in preparation and thickness of samples, as well as the type and determination of light sources all being contributory factors that effect colour verification and interpretation.

The oxidisation processes that affect iron (Fe) and manganese (Mn) in the soil have the most important role in colour development in some instances (Brady and Weil 2008). The soil colour resulting from oxidation of Fe may range from red-brown to yellow, whilst Mn may be dark purple to black in colour (Lindbo *et al.* 2010 138). The 'gleying' of soil can indicate that waterlogging conditions prevail through the greying of soil and the appearance of iron nodules/mottles (USDA-NRCS 2010). When waterlogging is not permanent, seasonal reducing conditions may be present. Mottling results from the redox reactions of metal ions, with initial solubility of Fe and Mn oxides (hence removing of pigment in the soil) and their subsequent precipitation in oxidised forms into areas of high concentration, causing gleying[1], normally observed in B and C-horizons. Once the Fe and Mn become solidified mottles, intensely pigmented areas occur (Schaetzl and Anderson 2009 381). In many instances the mottles are used to identify the hydrological properties of the soil after field work is being undertaken (USDA-NRCS 2010). Pigments and colouration in soil and sediments may be affected by texture and dominant particle size, with smaller surface area grains retaining greater depth of colour as a result of their surface area to

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[1] **Gleying** takes place in soil within seasonally waterlogged areas where anaerobic conditions occur, during this process iron compounds are reduced and translocated into areas of high iron concentrations, such as mottles/redoximorphic nodules, leaving a grey colour in the surrounding soil (Lindbo *et al*. 2010 138; USDA-NRCS 2010).

volume ration being greater (Schaetzl and Anderson 2009 17). Soil colours have also been interpreted as the product of the various coatings that attach to soil particles, whether they are from organic matter or oxidised Fe and Mn (Schaetzl and Anderson 2009 17).

1.3.1.3 *Structure*

Soil structure is defined as the arrangement of peds and pores and therefore relates directly to the texture of the soil and the proportion of the constituents incorporated in correspondence with the void spaces (Oades 1984; Brewer and Sleeman 1988). Dynamic pedogenic features induced by biological activity, climate, weathering, and soil management may determine the translocation/accumulation prevalent in the development of the soil structure and stability (Brady and Weil 2008). Through disturbance, the shape, formation and further development of the soil structure can be interrupted or changed. This is extremely relevant to the study of soils within inhumations, as primary components of the soil may be altered, resulting in levels of aggregation varying between non-disturbed site controls and soils sampled in the grave cut controls and around the burials. It would be assumed the site control samples would not be affected by increased levels of organic matter from the burials, so providing a comparison to samples collected from the burial where higher organic matter levels would be expected.

The physical formation of soil structure can be isolated to several natural forces: shrinking and swelling caused by hydrological wetting and drying; freeze thaw; the movement of biota through the body of the soil; and anthropogenic forces such as tillage (Oades 1993). Peri-glacial and intense frost action for example, can result in sorting of rock fragments within the soil, pushing them toward the surface in an "'upfreezing'" action, thus altering the structural dynamics (Schaetzl and Anderson 2009 264). Studies on soil aggregate stability have shown that polysaccharides produced by micro-organisms, together with the actions of fungal hyphae, may function as binding agents (Kiem and Kandeler 1997). These however, are only temporary binding agents that may endure in the soil for several months or years. Their retention is determined by other soil properties such as pH, which affects bioturbation levels and ion exchange capacities (Brady and Weil 2008 270; French 2003 14). It was initially thought humic components , resistant to further decomposition and synthesis in the soil, were the main, "persistent" binding agents of soil aggregates (Cresser *et al.* 1993 46). Instead, humic components have reduced persistence in the soil depending on pH and the renewed input of organic matter, thus encouraging biological activity and in turn temporary binding agents (Courty *et al.* 1989 133). Studies thus far have indicated that the aggregation of soil and the formation of soil structure depend not on one factor, but several; with soil organic matter (SOM), soil biota and soil micro aggregates part of a feedback mechanism that drives aggregation and soil structure (Six 2004). The culmination of soil structural development can be the formation of horizons, the layering of dynamically linked soil components, which normally run sub-parallel to the ground surface. Young sediments and soils may not necessarily have well defined horizons, whilst older, advanced, well-developed soils may demonstrate more distinct boundaries and well defined features. Soils are, however, dynamic bodies with horizons undergoing transformation and development in all directions. Within an archaeological context, nevertheless, anthropogenically induced disturbance acts to alter the dynamics of the soil, often significantly amalgamating primary soil horizons.

Climatic shrinking/swelling-induced structural development may be expressed in different degrees within each horizon. The forces that occur during wetting and drying of clay minerals restructure the internal shape and orientation of colloids (Tessier *et al.* 1990; Oades 1993; Buol *et al.* 1997 138). Shrinking and swelling normally occurs to a higher degree within soils that have a high content of smectite clays, the main constituent of vertisols (Courty *et al.* 1989 151; Schaetzl and Anderson 2009 72). High intensity disturbance from this process is particularly evident in vertic soils, where high levels of expanding clay induced cracking and movement can be identified. Stresses caused by shrinking and swelling may not only rearrange fine particles, but can also produce friability and fragmentation leading to the formation of voids, cracks and fissures (Dalrymple and Jim 1984). Through the fragmentation of the soils basic structural units develop. Blocky ped development normally occurs in the lower B-horizons in part as a result of the presence of shrinking/swelling translocated or *in situ* clay minerals (Buol *et al.* 1997), the most important component in the formation of blocky peds being their cohesion and chemical bonding (Birkeland 1984 15). The horizons within the soil are layers that differ in their content and characteristics to the adjacent layers, with B-horizons normally associated with the deposition of clay minerals and iron (Fe) oxides (Brady and Weil 2008 10). The weight of overlying soil on the lower horizons lends itself to the formation of larger prismatic peds,. in part because of the pressure exerted on the soil aggregates, in comparison to smaller blocky peds that may form in the lower and upper profiles, the latter locations exerting less pressure as there is less weight. Biota can be a very important factor in the formation of ped shape and size, with smaller more granular peds often being dominant at the surface. Bioturbation and the growth of roots from plants form bio-pores, normally called channels, allow the infiltration rain and percolation of standing water (Oades 1993; Stoops 2003b).

However, not only is pH a key factor in the development of granular peds by soil biota, as extremes of acidity or alkalinity will reduce their presence in the soil, but so too is the presence of organic matter (Canti 2003). Granular pedology is seen not only in fertile brown earth soils but also in sandy soils due to the nature of the quartz grains, greater levels of aggregation of soil colloids and increased bioturbation that make up the soil components, whilst also providing one of the key elements in soil texture.

1.3.1.4 *Biota*

Soil biota, the soil fauna and flora are classed as bioturbation factors agents that enhance soil development through mixing and aggregation of the soil components (Schaetzl and Anderson 2009 239). This latter activity may be a significant factor in the detection of decompositional materials within and around the inhumation, as it may determine the pathway taken by decomposing burial material. Animals that live in the soil have great influence on the soil fabric through metabolising organic matter, homogenising all fractions and moving through the body of the matrix (Babel 1975 422). There are various factors that control the number and size of the soil fauna and flora: oxygen, temperature; moisture; pH; and organic matter. Thus, the classification and location of soils are of great significance and may determine levels of bioturbation, with soils of temperatures < 4^0C (biological zero) having little activity. Microbes, meso- and macro-fauna are extremely important, not only in relation to the processes of soil development but also for the wider ecosystem, influencing the species of plants that grow and the fate of man-made waste (Young 2004). Human inhumation can be classed as a waste product. The disposal and decomposition of human remains is, therefore, primarily determined by the direct and indirect actions of soil biota.

Soil fauna play an important part in the neo-formation and movement of soil components and are the main factor influencing decomposition of organic matter (Kooistra and Pulleman 2010 397). Most soil fauna are dependent on oxygen for respiration either in the form of oxygenated water or through the air gaps that formed within soil voids. However, Oades (1984) refers to soil micro-organisms as “aquatic,” due to their transportation through an aquatic medium, so determining that both water and oxygen are required by soil fauna. The importance of soil fauna in the formation of soil structure and stability, has been investigated through a series of experimental treatments, and by investigating the formation of soil aggregates and the development of voids through fauna movement (Davidson and Grieves 2006). This latter function of soil fauna is essential to the formation of voids and peds within the soil, and so the role of soil biota may be significant in the movement of fluids from the interred human body through the burial environment. The creation of burrows by several species of earthworm for example *Lumbricus terrestris the* common earthworm, a common species of soil fauna can occur not only at the surface of the soil but also at depth. The key limiting dispersal factor to the presence of soil biota is pH, with soil crumb shaped aggregates being reduced in acidic conditions due to the lack of bioturbation (Wood 1989 109). The presence of soil fauna within a grave is determined by the level of soil fauna present in the backfilled, derived from the grave cut, and through faunal penetration into the soil cut from the surrounding undisturbed soils into a favourable environment. Thus, the presence of soil fauna is not determined by the burial itself but by the presence of soil fauna already in the localised region of the burial.

Calcium carbonate nodules up to 2.5mm in diameter found at different depths can be attributed in many soils to earthworm activity, through the digestion of organic matter and the synthesis of calcium (Canti 2001). Excrement from soil fauna can be found in areas of high organic matter content such as that of wood and other plant residues (Babel 1975). This may suggest that there could be elevated levels of soil faunal activity in and around inhumations interred in coffins manufactured with organic material such as wood and also direct non-coffin interments as the decomposing body is an extensive source of organic matter. The presence of soil fauna in soils surrounding the burials may be particularly prevalent in graveyards were soil organic matter levels have been elevated by in interment of both coffin wood and the decomposing remains.

Microbial attack on human burials, especially in the early stages of autolysis, is the main decomposition agent, with the by-product being soil stabilising polysaccharides (Forbes 2008a). The introduction of a decomposing cadaver to soil can increase the amount of CO_2, and therefore soil acidity, suggesting that microbial respiration may be the cause of decomposition due to added organic matter (Stokes *et al.* 2009). The initial increase in the acidic conditions of the soil around the early stages of decomposition by microbes could reduce the concentrations of other soil fauna, especially during autolysis. The alkalinity and acidity of the soil can be a key factor in the development of the decomposer community within the grave. Soil with an acid pH of 3.0-3.5 or alkalinity of >7.5 are typically colonised by fungal decomposers, in comparison to bacterial colonies that develop in neutral soils (pH 6-7) (Haslam and Tibbett 2009). In the burial environment, not only does the human body degrade, but also grave goods place in the grave cut to the decomposing organic and inorganic matter components. Wood, normally the main material in the manufacture of historical coffins, is often primarily attacked by fungi, due to initial decreases in pH levels affecting microbial decomposition during the early stages of decomposition, although the *Pseudomonas* group of bacteria has also been identified as a wood decomposer (Babel 1975 400). This could suggest that the decay processes not only occur within the coffin as a result of internal microbial attack, but also the exterior soil interface of the interment was degraded. The external attack on the cadaver from carrion biota such as the bluebottle fly depositing eggs on the deceased can start immediately, as the time from death to burial of the body may range from one to three days depending on the town (Cox 1996) region or country the death took place in and religious stimuli. Insect larvae on entering the grave can have a putrefying effect on localised areas of the body, burial and surrounding pre-burial environment and can, in many instances be responsible for the total degradation of the soft tissue of the dead body (Janaway 1987; Anderson and Cervenka 2002 174). The changes that take place in the grave through the putrification and subsequent degradation of the body can have subsequent effects on the surrounding environment, depositing residual organic matter onto the soil/burial-resting-plane interface, and into the soil pores (Dabour and Harvey 2008 113).

1.3.1.5 *Movement and formation of materials*

Percolation in soils generally occurs through water movement, one of the main transport processes for fine materials. The velocity of water and, in some cases, the level of disturbance on the land surface can determine the particle size fraction being moved through the soil (Courty *et al.* 1989 133). Soil structure can also be a key factor affecting the movement of material, with soil biota and root channels providing access to lower horizons, whilst water and biota provide the mechanism for transportation (Usai 2001a). Climatic and seasonal variations increase the leaching of soluble materials from the upper horizons (Canti 2001 87), with smaller particles, such as clay being translocated to different depths, accumulating in the lower sub-soil. Movement of materials can, however, be recognised at a micromorphological scale through the analysis of particle size and the frequency and development of “textural pedofeatures” (Stoops 2003b; Bullock *et al.* 1985). These are formed as a result of mechanical transportation of fine soils material such as silts/clays down the soil profile, and appear as coatings deposited on/near void surfaces and on/near coarse grains and can therefore indicate soil surface activity and water movement (FitzPatrick 1993a). Within archaeological contexts, translocation of fine material from the surface down the lower horizons may be affected by the type and arrangement of pore spaces. Translocation of fine soil material may also affect buried archaeological evidence, with relative climatic, environmental and anthropogenically induced changes at the soils surface affecting the buried sediments/soils surrounding the artefacts.

1.4 Application of soil micromorphology to archaeological investigation

The normal geoarchaeological, and in recent years archaeological, approach to soils in an archaeological context has been to field sample and study on-site stratigraphy, and sieve finds for small artefacts, while chemically and physically determining the soil composition in the laboratory (Davidson *et al.* 1992; Grant *et al.* 2008 43). One question that needs to be asked is: if a site is bulk-sampled and only analytical techniques such as pH, particle size, flotation and chemical composition are undertaken on the soil, will the results give a true indication of its internal organisation, and so the pedogenic processes affecting an archaeological site? Such a classical archaeological approach is in stark contrast to that of some forensic archaeological investigation, where emphasis is also placed on the development of the soil and the surrounding area (Hunter 1999). Forensic investigators may not only observe and record site/crime scenes to obtain contextual information, but at times endeavour to adapt sampling strategies and incorporate various avenues of investigation, with soil being the interface with the crime scene (Pye 2007 186). Early investigative techniques employed in forensics were concerned primarily with post-mortem activities, palynology and the prior utilisation of land (Pye 2007 5). More recently, however, a growing body of literature has been published which illustrates the development and incorporation of decompositional activity and products at a microbial level within the soil, so enhancing the comprehension of the interface between burial medium and the subject under investigation (Hopkins *et al.* 2000; Forbes 2008a).

Whilst archaeological investigation and the application of macro-soil analysis may provide vast amounts of culturally valuable material, augmenting this with forensically based micro-investigation may assist in attaining a higher resolution of cultural and ecological information (Gerrard 1992; Bryant and Holloway 1983). The combination of physical and elemental analyses has been demonstrated on several sites by the application of multidisciplinary investigations. A 1998 examination of mounds surrounding St. Boniface Church, Papa Westray, Orkney (Branch *et al.* 2005) demonstrated the value of multi-layered investigation. Landscape investigation was coupled with pollen analysis, zooarchaeology and micromorphology to determine the formation processes at the time of excavation, while enhancing understanding of cultural practice and land utilisation (Branch *et al.* 2005 53). The investigation determined natural depositional processes from anthropogenic midden material and suggested that the area had seen a change in land utilisation from cultivation to food processing, identified by zooarchaeological bone recognition. It may also be a way of preserving data by becoming a "permanent archive" of a site and its stratigraphic significance (Macphail and Goldberg 1995), long after all other evidence has been removed, through the archive of soil thin sections. For this reason, it is essential that the potential information held in the surrounding soil is identified and interpreted, not only on an archaeological basis, but through multi-disciplinary studies. Qualitative and quantative information attained from analysis of the soil medium, may reveal physical, palaeoenvironmental and mineralogical data pertinent to the research question (Stoops 2010). Similarly, multi-disciplinary investigation was carry out at the archaeological excavation at Xeropolis, Greece, where chemical and micromorphological analysis were undertaken (Davidson *et al.* 2010a). The results of this analysis gave clear indications of site formation processes, establishing differentiations in the utilisation of a tell site over multiple periods of time. Investigations of micro-scale carbonate nodules in three different soils also confirmed the importance of micromorphological techniques, allowing formation of the pedofeatures to be understood within the investigative context (Kovda 2003).

Soil micromorphology is the study of undisturbed soil/sediments on a microscopic scale (Stoops). During some of the first applications of the technique on undisturbed soils, several pedogenic units, as seen in thin sections were identified through comprehension of pedogenic processes on a micromorphological scale and characterised fossil soils in an archaeological context (Dalrymple 1958). Enhanced application of micromorphology in an archaeological context was facilitated by the development of specific nomenclature, first put forward by Brewer (1976). These techniques developed into a powerful tool, with a growing body of literature employing these investigative methods and applying them to archaeological sites, while utilising a descriptive approach and interpretation that may be applied to in-depth analysis (Stoops 2003b; Davidson *et al.* 1992). Micromorphology may therefore provide enrichment to the understanding of anthropogenic and environmental processes in archaeology.

Cornwall (1958 188) was one of the first published works to amalgamated the two disciplines of archaeology and micromorphology. He stated that archaeology was initially preoccupied with human artefacts and not with the contextual surrounding, asserting that the soil/sediments containing and covering the artefacts can give vast amounts of cultural information. Soil below and sediments around the artefact could help answer questions such as: how long have they been there and what effects can this particular environment have on the burial its artefacts and their preservation potential? The author was able to employ micromorphological techniques in the reconstruction of past environments, and to identify archaeological anthropogenic features initially from a macro-scale and then by the application of micromorphological thin section analysis.

It has been suggested that there are few specific areas of focus within archaeology that have employed soil micromorphological analysis, including: ancient cultivation, the interpretation of anthropogenic materials and of palaeosols (Adderley *et al.* 2010; Stoops 2010; Macphail and Goldberg 2010; Usai 1996). For example, micromorphological techniques were applied to "disseminate the man-made from the natural" in the investigation into land management (1989) at Castello di Uscio, Italy (Courty *et al.* 1989 124). The methodology inferred that previous cultivation methods were distinguishable from the occupational phases that had occurred on the site and similar investigations have also taken place in Northern England at Hadrian's Wall where cultivation marks were determined to precede Roman military activity through the identification of paleosols(Usai 2001b). Clay films on peds or lining of voids can often result from translocation of clay particles (Birkeland 1984 187). Later investigations expanded on this subject by looking at issues affecting the development of *agricutans* or *dusty coatings* made of sand, silt and clay, their translocation, and whether this always results from past and present agricultural activity or not (Courty *et al.* 1989 321; Macphail *et al.* 1990; Usai 2001a). Through micromorphological investigation, pedogenic and anthropogenic processes leading to development of pedofeatures suggested that dusty clay coatings - textural pedofeatures formed through the deposition of soil fine material suspended in soil water on the surface of coarse material and void spaces - can form whenever unvegetated or disturbed soil surfaces are exposed (Kuhn *et al.* 2010 221; Usai 2001a). This study is pertinent to the investigation of human inhumation by showing that dusty coatings deep in the soil give indication of surface activity, disturbance and translocation of silt/sand/clay, and prompts the question on whether they may also carry human degradation products to different positions within the graves. The effects of human intervention on soil ecology may, in some cases, suggest that undisturbed subsoil horizons may be attributed to old 'relic' soils such as 'pre-podzolic', brown soil profiles" that have not been affected by surface leaching or the removal of vegetation due to their depth (Courty *et al.* 1989 187). This work was augmented by further evidence that not only disturbance can be identified, but previous land use may be hypothesised.

Similarly, the on-going experimental earthwork at Wareham, Dorset provided evidence of macro- and micro-pedogenesis and its effects on and by archaeological artefacts, with Bell *et al.* (1996) documenting their detailed investigation that focused particularly on soil development (Macphail *et al.* 2003). The development of soil components, in particular soil organic matter, has been investigated in great detail, with observations drawn on the morphology of soil organic matter (SOM) and its characterisation through plant and faunal residue, organic fine substances and mineral elements (Babel 1975 458). This single factor, the determination of SOM morphology, may be a key indicator in the detection of plant organic matter. A limitation, however, can be the insufficient quality of the thin sections or the length and difficulty of their preparation (Stoops 2003b 16).

However, more recent applications of soil micromorphology as a key analytical tool have been applied to the study of human detritus decomposition and biological activity through the analysis of the sol structure development (Leigh 2001; Van Veen and Kuikman). This was demonstrated at the 2007 excavation of Bronze Age burials at Saphar-Kharaba, Georgia (Kvavadze *et al.* 2010). Information was retrieved from under the body both for micromorphology and pollen analysis. Here, soil samples were taken from under the long bones, where there was vital undisturbed soil. This soil proved to have been protected and so provided a greater understanding of soil properties before burial and the flesh degradation took place.

The effects of human decomposition and bioturbation on soil structure at a micro-scale, indicating translocation routes of artefacts and degradation products (Oades 1993), provide greater insight into the importance of micromorphology when dealing with archaeological sediments and soils. Micromorphology can help determine and assess the influences of roots and fauna on the coherence of the archaeological stratigraphic sequences (Grave and Kealhofer 1999). The relationship between pedoturbation and soil morphology has been investigated on a micro-scale by applying micromorphological techniques and image analysis software to the determine the voids created by roots and soil fauna (Bruneau *et al.* 2004). The same techniques have been employed to identify evidence of manuring practices in relation to the type of organic fragments, and also as a method of validation for ethnographic information pertaining to land management (Adderley *et al.* 2006). Image analysis through both operator observation and software systems can comprehensively provide greater micromorphology evidence by adding quantitative and qualitative information through a two-fold approach (Bryant and Davidson 1996; Adderley *et al.* 2006).

The observations described above in this review indicate that micromorphology is a key proxy indicator in the collation of archaeological evidence, although interpretation of micromorphological features can "vary according to the needs of the field they apply to" (Kubiena 1970 7). On the other hand, there has been a lack of multidisciplinary investigation encompassing micromorphology as a key input factor to expand physical and chemical analysis undertaken in the evaluation of the soil within an archaeological context (Stoops 2010 6).

1.5 Features of historic burials

Following the discussion in Sections 1.4 it appears that micromorphology may provide a tool to systematically study human inhumations and the effects of burials on pedogenic processes. However, to appreciate the materials that are found within a burial context it is first necessary to understand the differences in funerary practice that have occurred. The following sections describe aspects of such difference in materials from the Early Medieval Britain to the end of the Great War (9^{th}- 20^{th} century).

1.5.1 Early Medieval period

The early Medieval period is characterised by an absence of specific burial rituals in both cremations and inhumations. Death and internment during the early Anglo-Saxon (5^{th}-9^{th} century AD) period in England was commemorated and celebrated without characteristic national or regional patterns, however, there were variations in the use of cremation (Williams 2011). It has been suggested Anglo-Saxon burials of this period derive from the multicultural influences of Scandinavia and Northern Europe, and although themes of local commonality and social identity may be highlighted through burial practice, many explanations are limited in their understanding of topographic constraints (Williams 2011). Many of the bodies during this period of burial were clothed, the practice of adornment being more common in female rather than male burials (Dickinson 2010). Although this is a generalised statement, excavations undertaken on the Anglo-Saxon cemetery at Butler's Field, Gloucestershire by Oxford Archaeology in 1985, enforces this view point (Boyle *et al.* 1998). The graveyard, thought to have been in use between the 5^{th} and 8^{th} centuries AD, produced grave goods associated predominantly with female interment. By the 8^{th} century AD there was a movement away from grave goods and towards burial within Christian graveyards, especially for members of holy orders and high status patrons. It was further suggested that AD 700 roughly marked the point when with the advent of Christian burial practices changed through England , Wales, France and Italy, with a move away from the placing of grave goods into the burials (Samson 1999). However, contrasting interpretations suggest that the early Christian church in Europe did not completely dismiss the utilisation of grave goods (Geake 2005). The possible movement away from grave goods, however, caused problems for the archaeologist, initially making the dating of burials difficult. The introduction of radio-carbon dating of human bones and organic material in and around the inhumation has to a certain extent alleviated the gravity of this problem (Zadora-Rio 2003). There can, however be problems with this approach, especially in the utilisation of wood to date graves, as the wood may initially have been appropriated from older sources, thus potentially skewing the dates of interment and burial ritual interpretations.

Religion, principles and belief structure, as already suggested, are not exhaustive in explaining the factors that determine burial rituals. Indeed, the development of Christianity throughout Western Europe was only one of the pivotal points in the change to burials and post-mortem deposition of humans. It was not until the 10th and 11th centuries AD in England and France that burial in Christian churchyards became commonplace for all, not only clergy, patrons and those of high status (Slesak *et al.* 2010). However, this view of all the dead being buried in church grounds has been challenged by new evidence that indicates the transition towards churchyard burials was slow, with status in the community being a key factor to burial position near the church, and in some cases within the church (Hadley 2001 17). It has been suggested that until the 10th century AD the church did not stipulate the form of, or area where a burial must be performed (Hadley 2010). Environmental constraints, due to a high concentration of communities served by only a single church could have been a factor regarding burials up to the 10th century AD, especially in centres of high human population (Spennemann 1999).The grave, however, may illustrate the standing of the person within their particular society with depth and geographical position being in the forefront of the thinking of the family of the deceased. The re-use of burial sites has been well documented by Williams (1998) who demonstrates that early Anglo-Saxon burials were often found on the earlier sites of prehistoric or Roman buildings and shrines such as the site in Eccles, Kent, revealing the importance of particular monuments to a community through their regeneration. This is similar to earlier practice demonstrated in Bronze Age burials with the utilisation of pre-existing ditches and pits within sacred areas (Parker Pearson 1999). Burials from the late Anglo-Saxon period may, in many cases, be affected by disturbance due to the successive use of a burial plot by a series of interments from the same family or by the impingement of building due to the expansion of an ecclesiastical centre.

Materials used in the construction of the coffins during the Anglo-Saxon period varied dramatically, dependent on both the area and the status of the deceased. Stone and wood were the favoured materials of construction but there were many materials placed into the coffin base such as chalk and charcoal, which may have been used as an absorbent material (Hadley 2010 297). Stones were often placed under and around the heads of the deceased up until the 11th century AD. In some reports, the stones were used even where the head had been removed prior to burial, possible due to execution by means of decapitation (Hadley 2010 120).

1.5.2 Late Medieval period

By the Late Medieval period, in the 12th to 15th centuries AD, it was unusual that burials deviated from the standard burial practice within a church graveyard with graves oriented in a west-east alignment (Hadley 2001 112). Death was 'profitable', with many parish churches of the time denying burial rights to their surrounding chapels, necessitating long journeys to the graveyard (Daniell 1999 88). Many of the higher status burials would in fact have taken place within the confines of the church building, the belief being that the body would be nearer to God and in some cases of some saints their relic would be housed in the churches (James 1989 29). Coffins of this period were normally made of wood, with the body laid out in a supine arrangement and the hands generally placed over the body in a praying position. The excavation of the Augustinian Priory in Hull illustrates that the wood most commonly used at this time and in this area was imported Baltic Oak, possibly due to proximity to the port (Hadley 2001 115). During this time plague recurrently affected half of the European population and so in some cases the disposal of bodies could have met with rejection, due to the 'severe pestilence' (Daniell 1999 194). In turn, the care, attention to detail and status of the burial would have been of less importance, as is demonstrated by the 2001 recovery of plague victims from a mass grave on the site of the Old Royal Mint in London (Waldron 2001).

1.5.3 Post Medieval period

Burial during the reign of Charles II in England had been regulated by the Acts of Parliament (Burial in Woollens Acts: 1666-1680), which stated that any clothing or lining materials on the body or coffin must be "made of Sheeps Wooll onely". The Acts intended to decrease the imports of wool and use of other materials and to encourage the manufacture of woollen textiles. Penalties for disregarding this act were met with a five-pound fine or selling of the goods of the deceased as compensation. This Act of Parliament was eventually repealed in 1815 (Janaway 1993). The coffins of this time were increasingly made of wood, iron or lead, and in some cases several different types of coffin were placed one inside the other as discovered during the excavation of Christ Church, Spitalfields, which contained burials from 1729 to 1857 (Reeves and Adams, 1993 64). Many of the coffins and their remains provided a clear record of funerary practices from the early 18th century AD through to the mid 19th century AD when burial ceased in the under church crypt (Reeves and Adams, 1993 7). The burials at the Spitalfield site provided evidence of the burial good placed within the coffins, the type of coffin employed during this period and the processes of decay that occurred not only to the content of the coffin but the coffin itself. Elm was the main wood utilised in the burials at Spitalfields, accounting for up around 75 percent of wood coffins, although pine was also used. The earlier coffins had been covered with different materials such as silk velvet and wool, with a change around the 19th century to wooden faced coffins owing to the development of wood polishing techniques (Janaway 1993). During this period the interval between death and burial was extended with the development of a funerary industry, thus the involved processes of bureaucracy , attention to the elaborate burial arrangements and apprehension of the family of the deceased before interment (Cherryson *et al.* 2012 38).

1.5.4 The Victorian influence

The Victorians invested heavily in the burial of their families with funerary arrangements that were both financially and visually ostentatious. Due to industrialisation, mass-produced, intricate and grandiose burial adornment were craved by the grieving Victorian family (Richmond 1999). The development of luxurious burial practices was not new having roots in the 17th century, but was facilitated by a broadening and deepening of the professional funerary companies, by then providing all the services required for the deceased (Janaway 1993). This is not to say that undertakers were benefiting financially from the industry, as much of the work and manufacture was sub contracted, such as the manufacture of shrouds and garments. Bodies were normally dressed in mass produced clothing, which in the 19th century originated from the Lancaster mills (Richmond 1999). It was rare for the family to request the deceased wear their own garments. Coffins were filled in many cases with absorbent material such as sawdust, this provided retention of fluids emanating from the body before burial. Funerary arrangements were in many cases elaborate, so the interval between death and burial could be lengthy with decomposition fluids building up in the coffin (Cherryson *et al.* 2012 38). Even in the 19th century wool was a favoured material for the clothing provided for the corpse with the normal attire being a cap, shirt like shroud and modesty garments (Janaway 1993). The funerary practices of the

Victorians continued into later periods, but in the latter part of the 20th century burial has become more minimalist, with cremation taking president over interment (Pearson 1982 107).

1.5.5 Factors of interment

Regardless of the nature of the remains and goods interred, remains that are laid to rest in a coffin environment and then covered in soil will decompose in a different manner to grave goods interred directly into or on the soil (Dent *et al.* 2004). This was highlighted in the Spitalfields project report, where coffins had been buried in a crypt under the church, in a non-soil environment (Reeves and Adams 1993 7). Decomposition varied at this site due, in part, to the differing materials and intact state of many of the coffins, carrion reduction and absence of soil pressure. The number of cadavers may also be a factor in decomposition rates. The quantity of burials that have been laid to rest within a particular area of soil can affect rates, with the concentration of interments speeding up decomposition due to putrefying microbes already present in the locale (Carter and Tibbett 2008). Increased microorganism levels in the soil could be attributed to the amount of nutrients made available through the introduction of human tissue. However, this can also be said of the non-soil burial environments as the stacking of coffins in crypt burials can affect decomposition rates even at the lowest levels as a result of pressure and putrification liquids leaking down the coffin pile, as seen in Spitalfields crypt burials (Cox 1996) Multiple soil burials may, however, also affect soil pH, with low levels of microorganisms being present in acidic soils. Finally, the time that has elapsed from burial to the time of an archaeological or forensic exhumation, the "post-burial interval," must also be considered when looking at the effects of burial on the soil (Forbes 2008b 225). Thus, as mentioned earlier in this chapter, sampling and analysis of grave soil must look not only at the location of the body or skeletal remains, but the context within which the body was buried, so determining the movement of related organic and inorganic decompositional matter through the grave soil (Roksandic 2002 104).

1.5.6 Mass grave burials

A burial within a coffin is normally occupied by a single inhumation, placed within a grave cut or a specific layer within a grave cut, with regards to family burial plots, unless a mother was buried with her neonate infant (Cherryson *et al.* 2012 122). The latter burial, a mother with a neonate, could be referred to a mass burial, as this term is used to describe burial of two or more bodies within one grave cut that have died from a similar causes of death and are in physical contact with each other (Mant 1987 72). However, due to the context, burial of a mother and new born child within the confines of a Christian graveyard they would never be thought of in this manner.

Nevertheless, there have been certain times historically where the utilisation of mass burial has been necessary. The excavation of the 17th century grave at Braigh shore on the Isle of Lewis saw the mass burial of fully clothed bodies thought to have drowned as a result of a boat accident (Cherryson *et al.* 2012 116). The Great Plague of the 17th century saw the use of mass grave pits to dispose of the dead within areas of high urban population, as it was believed quick burial of the dead would prevent further spread of the disease (Defoe 1665 209). To prevent the spread of disease from the plague pits, it was customary where available to spread quicklime over the pit before it was backfilled, thus preventing additional spread of the disease and stemming the vapours (Tuck *et al.* 1923).

Recent human rights atrocities in countries such as Chile, Kosovo, Serbia and Croatia have seen the employment of mass graves to bury the dead from war and genocide. It is estimated that the Spanish Civil War (1936-1939) saw a large percentage of 150,000 dead interred within mass graves (Ríos *et al.* 2010). The placement of the body within a mass grave is in stark contrast to that of a single inhumation most saliently the quick burial of the body in contrast to the considered placement in the grave. Many mass grave excavations have discovered evidence of clothing still attached to parts of the corpses (Rainio *et al.* 2001).

1.6 Decomposition in the burial environment

The organic matter residues originating from burial goods and the interred body can be found in varying quantities and in varying stages of degradation in the burial soil, however, pedogenic processes are also involved and the input rate (Stolt and Lindbo 2010). It is estimated that the organic matter content of most soils, living and dead, equates to only around 5 per cent of the total mass (Dawson *et al.* 2008 295). Climatic and topographic environments are probably the most regulatory factors in the pedogenic process, affecting accumulation and decomposition rates in the soil. Minerals in the soils play an important role and are an essential constituent in the formation of humus, the final product of organic matter decomposition (Babel 1975 377). In most soils, non-decomposed organic matter accumulates in the top “O” horizon, unlike burial soil were organic matter normally accumulates in the B-Horizon. However, both soils are subject to a constant cycle of change both chemically and biologically. Organic matter in soil represents carbon based debris at varying stages of decomposition, from large plants and animals remains such as burials, on and in the soil, to humus as a by-product of decomposition and synthesis, representing the final stages of organic matter decomposition (Oades 1988). There are limiting factors affecting the synthesis of soil organic matter (SOM), with high levels of non-synthesised organic matter in soils of a low pH range or at the extremes of temperature. As discussed earlier, soils affected by environmental extremes may contain low amounts of humus and high quantities of plant debris, owing to slow decomposition rates caused by the inactivity of soil biota. Many techniques can be employed for the analysis of organic matter in soil, however such factors as sample size, time constraints and sample condition must be considered (Dawson *et al.* 2008 301). Soil properties are highly dependent on the quantity, quality and dynamics of the organic matter entering the system (Adani and Spagnol 2008). Studying the spatial distribution of organic matter in soil can lead to a greater understanding of the processes and interactions that have taken place, whilst the utilisation of thin section micromorphological analysis of organic matter can in some cases be problematic (Stoops 2003a 88).

Burial taphonomic process are related to three main factors; environmental, individual and cultural; all of which have different effects on the rate of decay (Nawrocki 1995). The excavation of human burials in an archaeological context may, in some areas of the methodology, be aligned with forensic investigation as already stated in Section 1.4 . In both study areas it is crucial to understand pre-burial influences in order to fully identify the process and time scale of decomposition (Vass 2001). It is essential that different burial practices of historic human burial are focused on, and cultural and individual factors be considered. This is particularly poignant when looking at the processes that take place during the peri-mortem/post-mortem periods and, decomposition of a human body, length of time between death and burial promoting microbial and insect attack (Vass 2001). Abundant inputs of organic matter, specific to each individual funerary practice, add to the background processes that already take place in soil decomposition. There are stark contrasts to be drawn between the sparse shrouded burials of the early Medieval period and the ornate and sometimes lavish Victorian coffined ceremonies.

The proximity of the body to soil will influence the rate of decomposition. Thus a body placed directly into the soil environment, such as a shrouded burial, will have different factors acting upon it compared to that of a coffin burial (Morton and Lord 2002 159). In many cases, however, the remains within a coffin burial may intermingle with the soil soon after deposition due to the collapse of the coffin from outside pressures and compaction (Dent *et al.* 2004). This process can lead to a depression in the soil, where the air space and compaction of the loose back fill has allowed the surface to slump either as a result of land evolution or through man-made compaction; so leading to the detection of clandestine graves (Spennemann 1999). Grave slump causes an indentation on the surface above the grave where puddling can occur, which can add to the effect of pooling and surface crusting of the soil so eventually impeding water infiltration. The initial disturbance created from digging the grave and the replacement of the soil after burial can have a dramatic effect on the grave environment. The disturbed soil, returned to the grave, will be of a looser, porous consistency (Dent *et al.* 2004).Water penetration and the increase in available soil nutrients may introduce high levels of organic matter from the top soil, with the decomposing body increasing nutrient concentrations; while disturbance of the soil will allow greater water infiltration through the created voids (Janaway 2008).

The topography and the depth of soil between the surface layers and the parental material may be markedly variable factors affecting water infiltration and holding capacity within a soil. This in turn may affect the levels of decomposition and the initial position of the grave cut (Janaway *et al.* 2002). In northern Europe and especially in Britain with its maritime climate, seasonal conditions, soil environment, and the underlying geology are often distinctly different from those in other areas of the Mediterranean and Eastern Europe. These soil forming factors, as discussed in Section 1.3 may have a considerable bearing on the rate, extent and nature of the decomposition of buried bodies. pH levels are also highly variable between different sites and an extremely important factor in the rate of decomposition due to its limiting factor on decomposer communities (Haslam and Tibbett 2009).

1.6.1 Initial stages of human decomposition

There are limited studies on the processes and influences of decomposition of a human corpse post-burial. The initial stage of human decomposition can occur immediately after death with the processes of putrification and autolysis from cellular enzymes, while internal microbes and bacteria start the process in the gut area (Dent *et al.* 2004). The process of decomposition has been categorised into two stages, pre-skeletonisation and post –skeletonisation, with no prediction of formal stages due to differing conditions of burial (Vass 2001). This is in direct contradiction to experimental piglet burials indicating five stages of decomposition, or four stages in non-soil inhumations (Payne *et al.* 1968; Campobasso *et al.* 2001). Secondary processes such as embalming, mummification, desiccation and drying, or adipocere formation (the conversion of the body fat to a waxy substance) may slow or stop decomposition (Campobasso *et al.* 2001). Adipocere can be attributed to the preservation of the body through the transformation of the soft tissue, by bacteria and microbes into an “armour-like” cream-coloured fatty substance (Fiedler and Graw 2003). The transformation process known as *saponification* hydrolyses the fatty acids in the body generally under anaerobic conditions induced by the presence of bacteria on the body (O' Brien and Kuehner 2007). Normally, fluids are released into the burial environment either directly into the soil or into the coffin. The recovery of bodies in the Spitalfields project found many examples of airtight lead coffins that retained the putrification liquids (Reeves 1993). Post-mortem processes can have an effect on the rate of decomposition or chemical preservation at reduced temperatures, ceasing microbial activity. Similarly, aerobic conditions can also reduce decomposition. As discussed in the section on soil biota, the availability of oxygen and aerobic conditions within the burial environment may play a significant role in the decomposition processes. In the Christ Church, Spitalfields burials, it was found that burials using lead coffins as a shell or liner had greater preservation, with many showing signs of adipocere (Reeves and Adams 1993). This suggests that the material used in the manufacture of the coffin can indeed be a major factor in the formation of adipocere and so reduce the decomposition rate (Fiedler and Graw 2003).

1.6.2 Bone: Post-skeletonisation.

In an archaeological context, it is the bone tissue that can be the greatest source of information as skeletonisation and the subsequent decomposition of the bones is one of the last stages in the decomposition process (Piepenbrink 1986). The preservation and decomposition or diagenesis of bone, however cannot be determined by studying any one factor (Henderson 1987 45). The changes in bone structure during degradation can occur simultaneously in two phases: mechanically; and chemically (Nielsen-Marsh and Hedges 2000). The mechanical degradation of bone occurs from the initial stages of burial, with pressures being exerted from the soil, meso-fauna mastication, microbial attack and fungal tunnelling Piepenbrink (1986) and Jans *et al*., (2004) and has also been discovered during hair degradation (Wilson *et al.* 2010). Fly larvae such as *Lucilia* have the ability to dissolve collagen, the main organic constituent in bone; while *Tineola bisselliella* - the common clothes moth can attack and liquefy keratin in hair (Janaway 1987). At the same time, products from the mechanical degradation may chemically degrade via processes of substitution, filtration or adsorption of mineral ions from the surrounding environment, in some cases complete molecule breakdown may occur (Henderson 1987). Thus, the environment immediately surrounding and enclosing bone is a preliminary factor in the damage and degradation of skeletal remains. Perhaps the most significant disadvantage of this explanation, however, is the expected presence of soil. Bone degradation levels may be notably increased in complete non-coffin burials, as the initial stages of the putrification process provide the aerobic environment required for microbes and bacteria that will later attack the bone (Jans *et al.* 2004).

In addition to environmental factors an accurate estimate of the timescale on the rate of degradation of bone is dependent on several factors within the bone such as collagen content, histology, porosity and crystallinity (Hedges 2002). Collagen content of the bone is also affected by external environmental influences. For example "temperature-sensitive collagen," experiences hydrolysis in warmer climates (Hedges 2002). The chemical degradation rate can double with every 10^{0}C of temperature, suggesting burials in areas of Northern Europe, and the North Atlantic regions would decompose at a considerably slower rate than Southern Mediterranean inhumations (Henderson 1987). Research has confirmed the preservation of bone in wet and unprocessed midden material especially in Britain and Northern European countries, decreasing decomposition due to prevailing anoxic conditions attained through climatically induced environments (Nicholson 1998). The results were drawn from experimental burials conducted on bone that had been placed in various soil types and midden materials. The results concluded that even with a high level of bioturbation in organically rich midden material, the bone deposited in soil had higher levels of degradation than bone place in a midden context, both macroscopically and microscopically due to the high soil temperatures gained by the organic matter(Nicholson 1998).Thus, temperature must also be factored in the rate of degradation in grave burials.

Fragmented bones are far more likely to be attacked by fungal hyphae, especially in areas where soil is predominantly acidic (Haslam and Tibbett 2009). Bone that has been fragmented after burial may be attacked more readily regardless of the acidity in the soil through exposure to both fungal and bacterial assault internally and externally. The pressure of the soil and compaction through surface activity can be a factor in the crushing and fragmentation of bones, especially the skull. Processes of complete skeletonisation of burials is, therefore, dependant on three main factors stated by Dent *et al*., (2004): depth of burial soil environment and burial processes .

Bone degradation in the gut area is prone to a significant level of attack from the putrification process, a high intensity of enzymatic processes and the presence of intestinal flora such as *Staphylocus proteus* (aerobic) and *Clostridium* (anaerobic) (Child 1995; Janaway 1987). Thus, structures such as hands and feet have a slower rate of decay and disarticulation, as these particular areas lack high levels of metabolising enzymes. This would suggest that decomposition of the hands and feet can therefore be affected during decomposition by their positioning during pre-burial treatment, for example with the hands placed over the pelvic areas being attacked by abdominal flora. Other factors affecting bone decomposition are shape, and age of the body prior to death and bone density, with very young children and seniors having less bone density and lower levels of collagen (Henderson 1987; Hedges 2002). This was illustrated by the archaeological excavation at Raunds, Northamptonshire, where the early medieval graveyard produced bones in varying stages of decomposition. It was hypothesised that loss of bone mass was due in part to age-related osteoporosis, a reduction in cortical thickness (Boddington 1987 35). The excavation and sampling within graves that have undergone high levels of degradation can in many cases be extremely difficult due to the friability of the material or the lack of visible evidence and so provide little archaeological evidence.

1.6.3 Decomposition of burial goods

The recovery of items from the burial environment is crucial in the process of both archaeological and forensic investigation. It is not only the human remains that can help in the reconstruction of past environments and cultures, but the furnishing can also provide information on the nature of the burial (Janaway *et al.* 2002 380). Grave goods found within a burial are usually only considered and studied when they are well preserved and in sufficient quantities to be seen by the naked eye, so that recovery of cultural artefacts may be attained (Janaway 1987 127).

1.6.3.1 *Metal*

Jewellery, swords and dress pins are some of the most common items to be recovered from furnished graves. However, the survival of the artefact is determined by the environment they are found in. There are three distinct categories for archaeological metals: non-corrosive (gold); copper and alloys that form a corrosive film reducing degradation; and rapidly corrosive (iron) (Janaway 1987). The corrosion of iron in the context of the burial environment is dependent on similar factors of degradation to those affecting human and animal bodies: moisture; porosity; and pH of the surroundings. It is known that iron grave goods may attain a protective corrosion layer in environments containing levels of increased phosphate and carbonate (Neff *et al.* 2005). It was also suggested that in soils with a high sulphate and chloride level the protective corrosion layer will tend to be degraded (Neff *et al.* 2005). Thus, in order to achieve accurate interpretations it is necessary to consider the properties of the soil before excavation for each individual grave, determining if degraded grave goods could be present and whether their fragments have been absorbed into the soil matrix.

1.6.3.2 *Textiles*

In many graves, organic materials such as textiles do not survive for long in the burial environment, with decomposition rates depending on grave location and any pre-treatments applied (Janaway 2008). The latter factor is also significant for leather goods. The surrounding environment to the textile may display conditions of dampness and organic acids formed by the decomposing body, and these can be major factors in the decay of textile, cotton being extremely susceptible to decay in an acidic grave environment. This is a result of the composition of cotton being around ninety percent cellulose-derived, thus vulnerable to hydrolysis when exposed to low soil pH levels (Janaway *et al.* 2002 287). The necessity of moisture to microorganisms and fungi may point to seasonal degradation, with dry, anoxic or freezing conditions slowing or stopping decay, and burial textiles in arid environments displaying a tendency to acquire brittleness as a result of moisture loss (Janaway 2008 166).

Silk, being protein based, is normally the strongest and least degraded of fabrics in a burial environment, as demonstrated in the Spitalfield coffins. However, here the most common fabrics seemed to be wool with a low degradation level when employed on the outside of coffins in a non-soil environment, with higher levels of wool-textile identified inside the coffin possibly as a result of putrification liquids (Janaway 1993). Small amounts of wool fibre have been found in Bronze Age burials of southern Georgia, where wool fragments were attached to acidic clay particles (Kvavadze *et al.* 2010). Wool is comprised mainly of keratin and degrades to a greater extent in alkali surroundings, with increases in temperature also a contributory factor (Janaway 2002 382). The preservation of textiles can be increased due to the presences of certain types of metals, such iron and copper, this process is known as Mineral Preserved Organics (MPOs) (Janaway 2002 396). Through the exchange of ions from the material to the metal, pseudomorphic remnants of material can survive with wool, leather and bone transferred to fly pupae and grass (Janaway 1987). It is has also been suggested that copper is related to the preservation of Bast fibres, although this is not the norm in all graves due to the underlying environmental conditions of the surrounding soil and body fluids altering pH and soil moisture (Janaway 2002 396). This can also be observed in textiles that have been dyed, especially when the dye has metal based elements with copper-based dyes being extremely significant in the preservation of burial fabrics because of its toxicity to microbes (Janaway 2002 391; Flemming and Trevors 1989). The formation of pseudo-textiles can also occur when fine soil particles envelope fibres before they degrade, thus producing an image of the weave from material (Janaway 2002 411; Sibley and Jakes 1982).

1.6.3.3 *Wood*

The degradation of wood within a burial environment depends on similar factors determining the rate of degradation observed for textiles and organic matter. The microbial and fungal decomposers require moisture, optimum temperature (≥ 4^0C), a relatively neutral soil pH and nutrients (wood being the nutrient source) for the microbial and fungal decomposers (Reeves 1993). As already stated, fungi are the main decomposing agents with regard to wood decay, with two main types of rot: white and brown. White-rot attacks all cellular structures in wood while brown-rot attacks varying forms of lignin and carbohydrates of the cellular structure, in particular hemicellulose (Pandey and Pitman 2003). It is believed that the microbial degradation process can be enhanced by increases in nitrogen and phosphorus found in soils of high organic matter content (Blanchette *et al.* 1990 168) The role of fungi in the process of degradation is to depolymerise carbohydrates and as such modify the cellular structure (Flournoy *et al.* 1991).For the degradation of wood in the grave to occur, however, the presence of a certain amount of water is necessary: desiccated wood will be present in the grave longer than wood with some moisture that may derive from the surrounding soil or the body (Griffin 1977). Much of the archaeological wood that has been excavated and found to be in a good state of preservation has been from areas of high water content, especially in the UK, Ireland and Scandinavia and this is related to the decrease in the rate of degradation in anaerobic surroundings. The lack of oxygenated conditions does not preclude degradation completely and bacteria can still compete in these conditions (Blanchette *et al.* 1990 168). Degradation levels due to fungal attack do, nevertheless, decrease as their rate of attack and decomposition is markedly slower than bacterial degradation, with fungi becoming the main decomposer (Björdal *et al.* 1999).

1.7 Comparisons with experimental burial results

Experimental archaeology may be particularly valuable when understanding the processes that take place in the burial environment, particularly when the experiment is carried out with full control of the inhumation, burial space and surrounding environment. Both the archaeological sources material and the experimental burials can be investigated with similar methods, techniques and analysis, allowing comparisons to be made and hypotheses tested. Several different experimental burials have used to this ends, with piglets buried in differing scenarios, above and below the soil, to record the varying stages, rate of decomposition and derivative (Payne *et al.* 1968; Morton and Lord 2002 157). The utilisation of pig carcasses in experiments is widely accepted as the most appropriate substitute for human remains, due to similar decompositional rates and stages (Morton and Lord 2002 157). The observations conclude that piglets buried in the soil environment have a slower decomposition rate that being place on the surface of the soil due to the lack of 'carrion' (Payne *et al.* 1968). Cold anoxic conditions observed by Payne (1968) in the soil surrounding the piglets during the Essendon Wood experiments, supports the observations that decomposition is slower as a result of the low level of microbial attack in such environmental conditions (Turner and Wiltshire 1999). Experimental burial of bone buried in two differing environments: one within soil; the other within a midden heap suggests that micro- and meso-faunal activity is the key factor in the taphonomic processes (Nicholson 1998). The compost heap experimental burial had higher levels of micro- and meso-fauna as in the soil, compared to the anoxic conditions, the meso- fauna was monitored by the movement of the bone; while degradation levels were monitored through bone diagenesis. Testing of soil burials can be of great advantage to the evaluation of protocols. However, the 'natural conditions' in experimental capacity may inhibit the 'reproductability' of the natural conditions (Turner 1972; cited in Janaway 1987)

Experimental work was also carried out on the degradation of metal material in a coffin with the burial of a rat (Janaway 1987). These results differed greatly from those of the experimental pig burial, and illustrated the influence of the coffin on degradation. Because of the confined, and in many instances, soil free environments, there was entrapment of decomposition liquids, this slowed down the translocation of organic remains from the burial to the adjacent soil. The same study also highlighted that the use of rat cadavers in the experimental context could not substitute that of a human interment and did not provide a recognised standard of investigation. This form of experimentation can, nonetheless give a clearer indication of the processes that have taken place and the factors controlling them. The key areas of research that have been addressed during the experimental burials are the rate of decay, taphonomic changes and the areas varying species of have focused on. Some forensic analysis has been undertaken on the elemental composition of the soil but the pedogenic processes and subsequent translocation/ deposition of organic matter derived from the burial has been omitted. Although forensic anthropology experiments undertaken at the University of Tennessee provide detailed information of the decomposition of bodies(Cattaneo and Gibelli 2009), they did not address the interaction between pedogenesis and the decomposition products emanating from the body, particularly as most of the bodies had been place on the surface of the soil rather than buried within it.

1.8 Summary

Early studies of the burial environment were concerned with the cultural and spatial significance of burials of a given historical period, focused on the implications of grave goods, socio-economic factors and the funeral, position of the body in the grave and its relationship regarding monument in the locale. Later, more archaeology-based multidisciplinary and micromorphological studies have been carried out on the effects of anthropogenic input into the soil, cultivation and settlement. It has been established that soil has a significant function in the decomposition of artefacts and can be employed by archaeologists on a macro- and micro-scale to establish chronological sequences whilst identifying environmental changes such as reduction of vegetation or stages in settlement evolution. However, studies of human inhumation utilising micromorphological and chemical analysis have not as yet been systematically undertaken.

1.9 Objectives of this project

The specific objectives of this project fit within the aims of my thesis and that of the *InterArChive* project (Section 1.1.2) and its remit, and are based on the background knowledge of archaeological soils and burials (discussed above in Section 1.1 to 1.7). Thus this work focuses on the development of an analytical strategy for the observation, recording, identification and interpretation of micromorphological features that are present in grave soils.

1.9.1 Objectives and summary of methodology that will be employed

The objectives of this thesis are to develop and test a protocol and criteria of analytical micromorphological investigation suitable for the recognition and interpretation of interactions between degradation and pedogenic processes that occur within the human burial environment.

1.9.1.1 *Objective 1*

To establish which micromorphological features are most diagnostic for interpretation of dispersal, transportation and distribution of degradation products.

For example:

- Investigating whether inter- and intra-pedal voids, their type, distribution and orientation in relation to the ground surface and position in the grave are related to decay product distribution.

This will be attained through the identification of the shape, size, frequency and location of the voids and their orientation to the burial plane and ground surface (Chapter 3, Section 3.4.3.3 and 3.5.3.2). This will further provided information to the relationship between pedogenic features and burial degradation products from around the burials through evaluation of the control samples unaffected by burial products.

1.9.1.2 *Objective 2*

To ascertain the location and type of pedogenic features within the burial samples which could relate to increases of organic matter and may identify increased organic decay residues.

- To investigate the frequency and location of excremental pedofeatures in the burial samples

The location and types of features relating to increased organic matter will be determined and compared to the site and grave fill control samples to evaluate the difference in frequency and distribution that would indicate increased level of organic matter.

1.9.1.3 *Objective 3*

To establish the depositional features that could relate and contain increased organic matter and may identify pooling of decay residues.

The focus will be specifically aimed at depositional pedofeatures such as:

- Analysis of redoximorphic nodules, undertaken to determine the movement of iron and possible co-precipitate (the addition of trace elements with a mineral during formation of a solid such as iron re-crystalisation) one of the most abundant minerals in the human body.
- The identification and recording of dusty clay coatings to determine their location morphology and relationship to degradation products, while ascertaining the mechanism for their development.

This will be initially be achieved by correlating the spatial distribution and causal relationships between soil characteristics such as peds, voids, and fine material, and their position with respect to their spatial distributions in burial and control samples (Chapter 5). Elemental analysis of the redoximorphic nodules will then be determined and compared to the elemental levels in the fine material that will determine the movement of phosphorus from burial degradation. Finally, statistical analysis will be applied to the inorganic elemental data to determine the correlation between the concentrations of phosphorus and iron in the fine material, redoximorphic nodules and dusty clay coatings in the burial and control samples, with its position in the grave and the actual grave. The application of statistical analysis will test the hypothesis: there is a relationship between the sampling position in the grave, the grave itself and the interaction between the sampling position and the grave to the levels of P and Fe detected in the fine material and depositional features.

1.9.1.4 *Objective 4*

It is proposed in this thesis that standard archaeological techniques such as excavation, flotation for microfossil analysis and sieving of finds may not provide a complete interpretation of burial ritual and pre-mortem/peri-mortem treatments. The final objective will be to determine artefacts of burial ritual that could no longer be identified by the naked eye, or through standard archaeological excavation techniques.

1.10 Sites investigated

The sites selected for analysis needed to provide the most comprehensive collection of burial and control samples. It was necessary to select sites that contained both control and burial samples, whilst providing samples from across the skeletal remains, so providing comparative results. Moreover, the selection of graves and samples needed to present different soil types and diverse locations as demonstrated in the urban and agricultural sites, with Syningthwaite being located next to farm building and so designated peri-urban.

Table 1 gives a summary of the sites investigated, their location, type of grave and estimated time of burial (to the nearest century).

Ultimately this thesis will look to past analytical developments, and in doing so, will be able to apply them to contemporary objectives in order to unlock the legacy of information that has developed in historical grave soils.

Table 1: The location of the sites analysed, the number of graves investigated and the period they were believed to be interred.

Site Name	Location	Location Type	Type of grave	No. of grave analysed	Time of interment
South Leith (*InterArChive* per comms)	Edinburgh, Scotland	Urban	Single inhumations	1	15-16th C
Mechelen (Van de Vijver 2011)	Belgium	Urban	Single inhumations	8	12-18th C
Syningthwaite (*InterArChive* per comms)	Yorkshire, England	Peri-urban	Single inhumations	3	14-16th C
Ridgeway (*InterArChive* per comms)	Dorset, England	Rural	Mass grave	1	10th C
Fromelles (Pollard *et al.* 2008b)	Pay de Calais, France	Rural	Mass grave	1	Early 20th C

2 Sampling, methodology and materials

This chapter highlights the field sampling strategy, micromorphological protocols, investigative techniques and data analysis employed in the examination of grave soils from pre-selected historical single and mass grave human inhumations.

2.1 Past analysis of graves and their soil/sediment

Over the last fifty years archaeological investigation has focused not only on the significance of artefacts within graves, but also their contextual significance and location in the wider landscape, the position relative to the surrounding stratigraphy and environmental influences (Cornwall 1958 13). This approach differs greatly from that adopted by antiquarians of the nineteenth century whose common goal was to obtain artefacts from excavations. Although recorded for their historical context many of these artefacts were placed in private, inaccessible collections (Ramage 1992). Most archaeological studies investigating human inhumation have focused on the successive excavation, dating and taphonomy of the human burial. It is only now, through the development of forensic investigation into inhumations, that soils have been looked at as a source of information - treated with the same interest as for a contemporary crime scene, providing a comprehensive collection of localised evidence, whilst allowing investigators to utilise their archaeological expertise and knowledge (Sigler-Eisenberg 1985). Early forensic investigative techniques were concerned with post-mortem insects that had colonised the cadaver, however, more recent investigative methods have explored microbial activity and decomposition processes, thus enhancing the understanding of soils and their function in a burial context (Hopkins *et al.* 2000; Forbes 2008a). Cross-disciplinary methods of forensics and archaeological knowledge in the areas of excavation and palynology has given rise to several investigations focused on dietary remains (Berg 2002; Reinhard and Bryant Jnr 2008). This has been further enhanced by the study of decomposition rates through experimental burial, and the subsequent analysis of decay processes over measure time periods (Janaway *et al.* 2002).Yet, although inhumation processes, and artefacts have been investigated with archaeological and forensic research no study has focussed on and thoroughly investigated the hidden archive of information unidentifiable by the naked eye and resulting from pedogenic taphanomic processes within the burial soil. Rare investigations have drawn on the pedogenic involvement during the decay processes occurring after human inhumation (Courty *et al.* 1989 49), or the resulting products that remain in the soil, although sampling of this process was alluded to by Goldberg and Macphail (2006 293).

2.2 Field sampling and recording strategy

The first stage in the analytical process was the collection of the soil samples. It was essential that samples for micromorphological and quantitative analysis were representative for the purpose of the work as unsuitable sampling strategies can bias results leading to artificial conclusions (Renfrew and Bahn 2001 76; Swift 1997 725). The development of the sampling strategy was therefore a key factor for this thesis and one of the most crucial points of the *InterArChive* project. In particular, the strategic location of Kubiena tins, utilised for the collection of systematic and selected samples within the grave environment, was necessary to capture as much information as possible for the micromorphological analysis.

Sampling was undertaken for the *InterArChive* project in varying weather conditions (noted at the time of sampling) on human inhumation excavations throughout Europe, North Africa, and the Middle East and North Atlantic region. The samples obtained varied greatly between individual sites, every excavation having its own specific characteristics, also dependant on soil properties and local forming factors (Jenny 1941). Individual climatic, environmental and excavation conditions determined that each site strategy, although following the basic layout of sampling, had to be approached according to the individual soil properties and burial orientation. Sampling of the undisturbed soil was undertaken utilising two different sizes of Kubiena tins (large: 85 x 50 mm, small: 58 x 32 mm). This was determined by the position of the skeleton, the space within the grave, and the availability of soil and sampling material around the body parts. Controls were obtained at different levels and areas in many of the sites so that local soil features and variations could be distinguished from those induced by human decay products and their effects on pedogenesis through comparison. Collection of control samples, however, was not always feasible in all archaeological settings, depending on the nature of the site excavation, its location (urban/rural) and the stage of the archaeological dig at the time of sampling. The collection of controls samples is essential in forensic investigations in order to compare evidence, regardless of the site location and disturbance that may have occurred (Goldberg and Macphail 2006 293). Such strategy of control sampling is contradictory to that of Pye (2007 186) who stipulates that the number of controls should be a minimum of three to account for the variability in soil properties and pedogenic processes which may occur across a site. The nature of the environment and its soil forming factors may be a key dynamic that could affect changes in soil properties across an excavation site. On several of the sites collection of site control samples were not possible due to excavation disturbance and spoil, construction activity or an urban location. Consequently the control sample collection did not follow the sampling protocols at all of the sites. In fact, at some of the sampling sites - such as the 11th -18th century cathedral site of Mechelen - sampling provided anomalous site controls due to the urban nature of the excavation site. As a result of the construction activity at the Ridgeway site, Dorset, there were no undisturbed areas. The collection of undisturbed grave fill control samples was not undertaken, as archaeologists had already removed the grave fill before the *InterArChive* sampling team arrived, placing it in two spoil heaps. Control samples were therefore collected for the C2 from the spoil heap and C3 controls from the edge of the burial pit in the form of soil-grab samples. Initially these samples were used for organic chemistry analysis and later provided material for micromorphological analysis.

The sampling of the human inhumations at all sites were, as previously discussed, evaluated on a grave by grave basis due to the individual complexity of sampling areas. Factors taken into consideration include soil depth and nature of the soil, position of the body and the complexity of the bones distribution. The latter point was extremely relevant with regards to the hands. Because the hand area - and also to a certain extent the feet - generally contained a high frequency of small bones, a more strategic sampling procedure was required. Field recording was utilised not only for recording specific sampling areas around the body, but also to record deviations from the subscribed set of samples or areas. To enhance recording of the micromorphological sampling points, digital photography was also used to capture tin positions, thus augmenting and establishing their exact location in relation to body parts (Figure 1b).

a)

b)

Figure 1: The collection of samples: a) sampling position around the burial of grave 6B from the South Leith excavation. Sampling had already been undertaken when the picture was taken and the impressions of the Kubiena tins and depression where the organic chemistry samples were collected can be seen; b) a Kubiena tin positioned adjacent to the skull in grave 6B, South Leith

2.3 Field sampling protocols

Undisturbed soil samples were collected near four specific areas of the body (skull, pelvis, and hand and foot region), with the collection of two grave fill samples above the body and a site control from an area of the excavation unaffected by burial decay (Figure 2).Figure 2 shows the basic sampling protocols applied to all *InterArChive* sample sites, the sample positions being modified to accommodate the specific burial difference. A field recording sheet (Appendix 2) was employed to establish the position, quantity and type of samples for micromorphological and chemical analysis. Existing methods of archaeological osteological field sampling of skeletal remains were employed and adapted to encompass standardised site recording protocol while incorporating, modifying and enhancing these methods to address the project aims and objectives (Grant *et al.* 2008 60). In the first sites excavated, only the positions of the samples with regards to the specific body parts were recorded. However, the need for consideration of the gravitational movement of decomposition materials from the inhumation within the soil became gradually apparent. Hence, a procedure was established for recording whether samples were situated above, adjacent or below specific body parts was required. This was particularly significant in locations were sampling was undertaken over several seasons (form example at Mechelen in Belgium). The skeleton sampling sheets were integrated with photographic evidence demonstrating the orientation of sample tins in relation to body part and within the context of the graves. Each of the tins was carefully and fully annotated (Figure 1) as they were sampled.

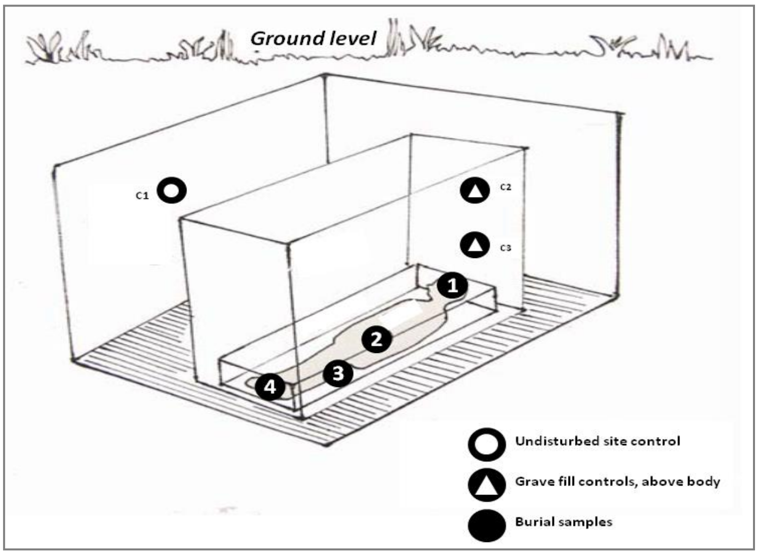

Figure 2: Basic *InterArchive* sampling protocol with the position of the samples: 1-skull; 2-pelvis/sacrum; 3-hand; 4-foot; with the C1 site control sample the C2 and C3 grave fill control samples in relation to the burial

Modification of the sampling protocols was carried out for grave fill control samples from the mass grave sites of Ridgeway in Dorset and Fromelles in France. Undisturbed control samples could not be collected at the former site (as discussed in Section 2.2).

2.4 Micromorphological sample processing

The processing and preparation of soil thin sections for micromorphological analysis must be undertaken so that the soil composition, structure and fabric remain undisturbed in order to be studied with polarizing. Two separate methods, with different resins, were employed by the *InterArChive* technical team to prepare the thin sections, as described below and in .

Table 2.

2.4.1 Thin section processing

The thin soil sections were prepared from the undisturbed and unconsolidated soil samples taken at the sampling sites. Standard procedures were initially employed by the University of York in the processing of slides (between: Sept. 2008 and Sept. 2011) according to the standards of the University of Stirling, School of Biological and Environmental Science (http://www.thin.stir.ac.uk/category/methods/. The hydrophobic properties of the polycarbonate resins required drying of the soil blocks using the acetone exchange (vapour) method. This prevented granulation or dissolution of organic matter and development of cracks due to the application of freeze drying, heat drying or acetone emersion (FitzPatrick 1993b 2). The process of acetone exchange took approx. 6 weeks depending on the level of clay in the undisturbed soil blocks, with the Fromelles samples taking approx.12 weeks.

It was initially thought that the staining of the soil blocks prior to the acetone replacement would aid in the analysis of coarse and fine organic matter. Staining techniques may in some cases give a clearer view of fungal mycelia; however, as the water is removed, so too are the dyes during acetone vapour replacement. Subsequently this process was not utilised further (FitzPatrick 1993b).

Soil blocks were initially impregnated with 17449 Crystic Resin for approximately 12 weeks and were held under 40^{0}C for the final week to remove all toxic styrene polymers from the samples while aiding in the complete polymerisation of the resin. The impregnated blocks were mounted onto glass slides using a thin layer of epoxy resin and where placed under pressure for 24 hours. The excess block was then cut from the glass slide leaving 0.5cm of impregnated sample and precisely ground to 30µm using 15 µm calcite aluminium oxides and ethylene glycol grinding medium on a precision lapping jig. A single cut of the impregnated blocks was initially undertaken in the parallel plane (Figure 3) to the sampling region of the body, as this was initially expected to provide the maximum information. However, translocation of soil nutrients through sub surface flows in soil water may result in lateral movement of decay products through the soil; consequently a second perpendicular sample was cut (Figure 3) where the size of the resin block allowed (Kleinman *et al.* 2003). The final process was polishing the samples with 3 µm and 1 µm diamond oil suspension. The slides were not cover-slipped in order to be suitable for SEM analysis. The complete process may take up to three months, with time dependent on the water retaining properties and structure of the individual soil.

Table 2: Resin utilised for the impregnation of the undisturbed soil samples from the single and mass grave sites; by grave identification name and number

		Resin Type	
Site	Grave	17449 Crystic	Polylite
South Leith	6B		
Mechelen	G26		
	G27		
	2037		
	384		
	414		
	415		
	422		
	423		
Syningthwaite	G1		
	G2		
	G3		
Ridgeway			
Fromelles			

As a result of a problem with supply of 17449 Crystic resin it was necessary to use alternative resin, thus the polycarbonate resin (.

Table 2), and Polylite 32032-00 was employed. The new processing methods were used from September 2011. The acetone replacement of the water was completed in the same manner as that of processing method one. Impregnation of the blocks, once the water had been replaced, was undertaken utilising the Polylite resin. The final part of the process was then continued in the same manner as before, with the blocks being cut, mounted, ground to 30µm and polished to provide the finished uncovered soil thin section.

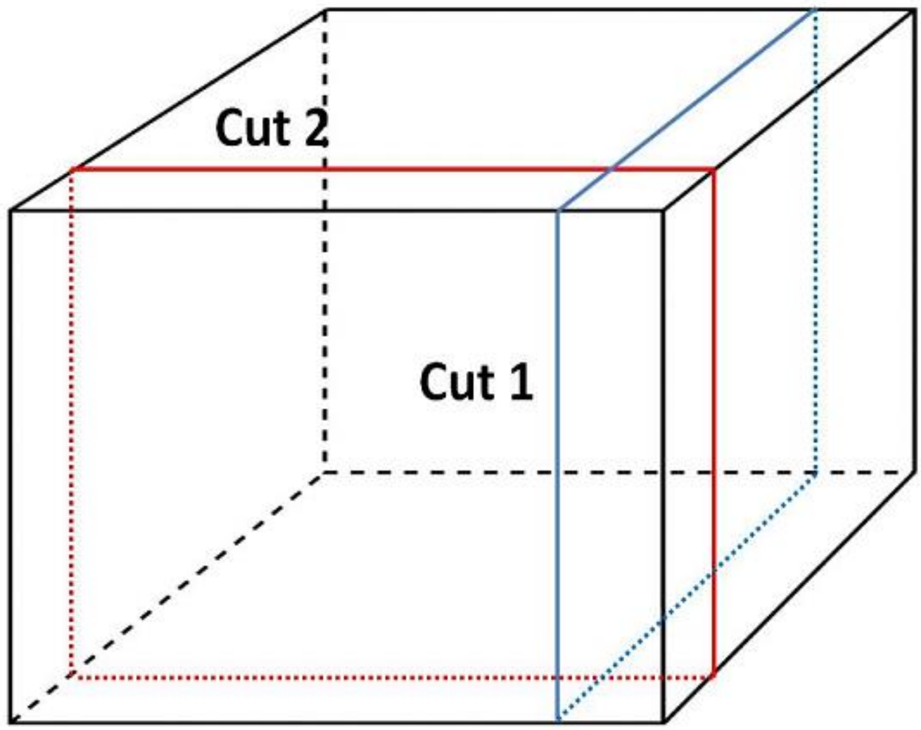

Figure 3: The cuts obtained from the undisturbed soil resin blocks. Cut 1 (parallel to the skull pelvis hand and foot) was obtained from all blocks. Cut 2 (perpendicular to the skeletal parts in each sampling region) was used in the later stages of the project

2.4.2 Soil-grab sample processing

Loose parts of some of the samples (soil-grab samples) were obtained from the *InterArChive* chemistry team, after freeze drying and homogenisation followed by sieving of the soil (sieving was completed using 1000, 400 and 200 µm sieves). The remainder of the sieved soil (~100 g), not utilised for organic chemical analysis, was air dried for 24 hours in a heat cabinet at 40^{0}C to remove any remaining moisture, placed into small plastic *Buehler* moulds (2 cm diameter) and impregnated with Epoxy resin. The processing then followed the methodology employed on the undisturbed soil samples for thin section preparation, as discussed in Sections 2.4.1. Cutting of the disturbed blocks was undertaken using a single cut, as shown in Figure 4.

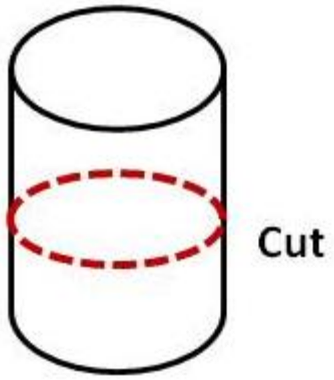

Figure 4: The single cut undertaken on the disturbed soil-grab samples once removed from the small plastic *Buehler* moulds

2.5 Micromorphological analysis

Micromorphological analysis can play a significant role in archaeological investigation (as discussed in Section 1.4) particularly when carried out with a methodical approach to observation and interpretation.

2.5.1 Protocol development

The development of the analytical protocol was formulated to encompass the maximum amount of information from each soil thin section, and in turn each burial and graveyard environment. It is believed that micromorphological analysis is not only an aid to understanding and recreating past events but can be used to unravel sequences in soil development (Stoops 2003b 5; FitzPatrick 1993b 237). No controlled micromorphological experiments and studies have been previously undertaken on soil thin sections from human inhumations. Micromorphological quantitative analytical techniques and sampling strategies for human inhumations have been suggested, but not undertaken (Goldberg and Macphail 2006 292). As such, it was necessary to develop a protocol that would ultimately capture all aspects of the information held in the burial soil. The protocol was required to determine the distribution and orientation of burial decay elements, in relation to ground level and the burial deposits. The soil thin sections were studied with plain polarized light (PPL), cross-polarized light (XPL) and dark field (DF) using a Zeiss' AxioScope. A1, binocular microscope with x/y motorised stage and AxioLab.A1, with rotary stage. Analysis was initially undertaken using existing protocols first developed by Usai (1996), and consequently adapted to collect the information required specifically to address the research questions (new protocol parameters are displayed in Appendix 1)**.** The data obtained was input into an Excel spreadsheet for analysis and the identification of spatial variation (as presented in Chapters 3 and 4 and discussed in Chapter 5).

The soil features comprised in the protocol included: coarse fraction, fine material, voids and peds, pedofeatures and the spatial patterns of distribution and orientation, their definitions, characteristics, significance and methods for their observation are described below.

2.5.1.1 *Size of coarse and fine material*

The limit selected between the coarse and fine fraction (*c/f*) was initially selected at 50 µm, within the range suggested by Bullock *et al.* (1985 18) and Stoops (2003b 46). During the analysis, such limits proved effective for a clear delineation between the two fractions in each of the samples analysed, and was adopted throughout the study to achieve comparability among all samples investigated.

2.5.1.2 *Coarse fraction*

The coarse fraction of the soil contained minerals, rocks, organic components and artefacts such as bone and anthropogenic derived detritus (Dawson *et al.* 2008 174). The coarse material in undisturbed soil thin sections can be a determining factor in the differentiation of soil variability. Variations in the type and size of coarse material may be diagnostic of differences in provenance (Bullock *et al.* 1985 50). Hence, they can give information of the source of the backfill placed on top of the grave during interment. And on whether it was different from the material removed from the grave cut before the burial was interred. The shape and nature of weathered and neo-formed minerals can be indicative of chemical and physical weathering processes, thus being representative of environmental conditions (Schaetzl and Anderson 2009 227-231). Not only does the coarse fraction of the soil incorporate minerals from the parent material, but may also contain organic fragments of charcoal, plant remains such as phytoliths, roots, seeds or even small fragments of bone, both human and animal (Bullock *et al.* 1985). Therefore, for this study, the analysis of the coarse fraction of the grave soils included minerals, rocks and coarse organic materials. The type, size, shape, arrangement and frequency (total percentage area of the slide) of the coarse fraction constituents were observed at different scales and measured with a semi-quantative observational assessment, following the recommendations of Stoops (2003b 94), to give a clear indication of coarse material composition (Courty *et al.* 1989 70). The recording format was selected to readily obtain preliminary information on patterns in the ‘degree of evolution’ the soil had undergone (Bullock *et al.* 1985 58). Transmitted and interference colours were observed for thin section thicknesses of ~30 µm in order to identify minerals, the parent soil material (MacKenzie and Adams 2011 22). The relationship between the coarse and fine fractions (*c/f*) in the thin sections was also noted with regards to the related distribution patterns within the soil. This observation allowed for the recording of coarse fabric units in relation to that of the fine material and confirmed the size classes and material in the observed soil.

2.5.1.3 *Fine material*

The fine material is ultimately the component that most reflects the pedogenic processes occurring within the soil (Bullock *et al.* 1985 50). The constituents of the fine material can indicate the level of development the soil has attained in contexts around human inhumations. The development characteristics, however, may not be defined in standard plain polarized light (PPL) microscopy alone as the thins section may vary in thickness (by a few µm) and must be combined with cross-polarized light (XPL) observation (Stoops 2003b 99). It was necessary to describe the limpidity, colour and birefringence of the fine particles of the soil under both PPL and XPL to determine the existence of discrete domains and particles. Some small particles of micro-charcoal and organic fragments or, iron/manganese nodules in the fine mass may be difficult to resolve from each other because of the level of degradation and the masking of features by dark non-isotropic amorphous material. Characterisation of the fine material can also be particularly difficult in the case of small iron/manganese nodules and the presence of micro-charcoal in the fine mass. Thus, different light sources must be employed (Courty *et al.* 1989 73). As particles may also combine to constitute the fine material, it is necessary to observe the arrangement, orientation and distribution of the fine material in domains, since single particles such as clay (<2 µm) are generally too small to define (Bullock *et al.* 1985 88).

2.5.1.4 *Distribution and orientation of clay domains*

The distribution and orientation of clay domains in the *b*-fabric may denote differences in composition and development (Kuhn *et al.* 2010 217). Clay domains were observed and recorded through the observation of interferences colours and patterns under cross polarized light (XPL) while rotating the microscope stage at different angles. This observation is particularly relevant to the soils within the grave fill, as it can give an indication of the pedogenic processes that have occurred and the degree to which the soils have developed (Stoops 2003b 99). One of the processes indicative of soil development in the fine materials is shrink/swell action from the wetting and drying of clay domains, this can play a significant role when determining soil stability and environmental interactions from soil water and translocation through the soil (Tessier *et al.* 1990; Courty *et al.* 1989 151).

2.5.1.5 *Voids and ped formation*

Voids may be recognised on both the macro- and the micro-scale, with field observations providing the first information on inter- and intra-pedal voids. Voids and peds are intrinsically linked as voids provide the boundaries required in the formation of peds. Soil macro/meso-fauna and high aggregation levels promote the development of voids between peds. Voids, filled with both air and water, account for half the volume of soil (Schaetzl and Anderson 2009 17). The study of voids and their alignment in the soil may give an understanding of the direction translocated decompositional products may flow (Bruneau *et al.* 2004). Faunal impact on peds and the development of voids can be a crucial factor in the transport of materials through the soil (Kooistra and Pulleman 2010 401). Anthropogenic activity, such as the enhancement of minerals or soil nutrients through manure application and tillage, can significantly influence the levels and activity of soil fauna. Within burial soils increased level of faunal activity may allude to human inhumation (Davidson *et al.* 2002). In contrast, areas of low anthropogenic impact, such as grassland, tend to have more developed pores due to a lack of physical disturbance and increased levels of soil fauna (Pagliai *et al.* 2004). This poses the questions: will soil around the burials demonstrate high levels of void space, and will the thin sections exhibit porosity due to biological disturbance?

Consequently, it was necessary to measure not only the width (at the largest diameter), abundance, development, accommodation and type of the voids and ped in the thin sections but also, initially, their distribution and orientation relative to ground level and, where the field observations and thin section preparation allowed, in relation to the body position. Channels, planes, vughs and packing voids were categorised following the definitions and size criteria of Stoops (2003b). Peds were classified with the terms and sizing criteria adopted by Bullock *et al.* (1985) (Table 3), recording the actual size range. It must be noted that analysis of voids in the soil thin sections only account for two dimensions of three dimensional structure, and in some instance this may skew results (FitzPatrick 1993b 115).

Table 3: Ped types and size (µm)

Size(µm)	*Crumb*	*Granular*	*Sub-Angular Blocky*	*Angular Blocky*	*Platy*	*Prismatic*
Ultra Fine	<50	<50	<100	<100	<50	N/A
Very Fine	50-1000	50-1000	1000-50000	1000-50000	50-1000	<10000
Fine	1000-2000	1000-2000	50000-10000	50000-10000	1000-2000	10000-20000
Medium	2000-5000	2000-5000	10000-20000	10000-20000	2000-5000	20000-50000
Coarse	5000-10000	5000-10000	20000-50000	20000-50000	5000-10000	50000-100000
Very Coarse	10000-20000	10000-20000	>50000	>50000	>100000	>100000

[adapted from Bullock et al (1985 42)]

2.5.1.6 *Pedofeatures*

Unlike the coarse and fine fractions of the soil, pedofeatures can be recognised by their differentiation of the matrix around them through the identification of the concentration of material and its, colour and type or with observations of their internal composition and organisation of mineral, chemical or organic material (Stoops 2003b 101; Bullock *et al.* 1985 95). Pedofeatures were sub-divided into matrix pedofeatures (on the basis of differences in the matrix) and intrusive pedofeatures, such as clay coatings or crystalline growth that do not include constituents of the surrounding matrix (Stoops 2003b 103). Due to the diversity of pedofeatures and their related development processes, it was essential that type, size, position in the thin section, orientation to related objects/voids, the body and the ground level were characterised and quantified.

The morphology of deposited illuvial clay coatings, referred to by Brewer (1976 441) as “cutans”, were some of the initial pedofeatures clearly identified in soil thin sections (Brewer 1976; FitzPatrick 1993b 169). Clay coatings are deposited onto the surface of voids, grains and aggregates after lateral and vertical translocation from the same and upper layers through the action of percolating soil water(Brewer and Sleeman 1970; Stoops 2003b 104). Not all coatings are clay based, with soil organic matter from the spodic horizons (Stolt and Lindbo 2010 387; FitzPatrick 1993b).

Dusty coatings containing large amounts of sand and silt content are referred to as textural or dusty clay coatings and have a textured, non-limpid appearance under PPL. The internal composition of the dusty coating is usually predominantly made up of the soil parent material – such as calcitic-coatings, often forming through the dissolution of soluble salts in mineral form, are identifiable under XPL (Stoops 2003b 112). In archaeological sites, however, - including human burials, dusty coatings may also include a variety of anthropogenic-related products, from agricultural land use (Usai 2001a).

The dimensions, orientation and composition of the coatings can be examined via light microscopy and SEM-EDS analysis in order to understand their origins. The observations and recording of both illuvial clay and dusty coatings was carried out employing the descriptive criteria proposed by Stoops (2003b) and Bullock (1985) to identify the nature, frequency, size, orientation and colour (under PPL and XPL) of each type of coating.

It is presumed that faunal excrement can be classed as a excremental pedofeature within thin sections because of its nature of and differentiation from the surrounding matrix (Stolt and Lindbo 2010 387). Furthermore, excrement of soil fauna can be indicative of the environment it was formed in. Excremental pedofeatures may be classified into organic matter coatings developed around the inside of void-like faunal burrows: “vermiform,” and excreta (FitzPatrick 1993b 138). The method employed for the identification and classification of excremental pedofeatures and their composition utilised interference colours, composition, frequency, orientation and morphology. Furthermore, excrement of soil fauna can be indicative of the environment it was formed in, and as such, the shape, frequency, composition and location in the soil was measured to indicate if there has been disturbance and inputs of organic matter (Bullock *et al.* 1985 133). Thus, it was of fundamental importance that the internal composition was determined in order to draw comparisons between the surrounding coarse and fine fractions.

Accumulations in the soil that are not associated with natural surfaces can be described as concretions, and are identified as ‘nodules’ pedofeatures in the adopted classification (Stoops 2003b 117). Redoximorphic nodules are concretions of translocated iron (Fe) or manganese (Mn) that are associated with reduction and oxidation processes through wetting and subsequent drying of the soil (Lindbo *et al.* 2010 129). Similar principles of recording other features such as excremental pedofeatures were applied to redoximorphic nodules (size, frequency, orientation, composition and shape). The composition was normally identified by the mineralogy, element analysis and by determining if development had occurred *in situ*, or if the features had been translocated (Stoops 2003b 117). The shape description was adapted from Fitzpatrick (1993b 197), which refers to either typic or aggregate nodules. Their relationship with other features was also recorded as it could in some cases give an indication of the stage in the formation process. For example, lining of nodules by external coatings indicates that nodule development had ceased. Colour was also a significant recording criterion in XPL, PPL and dark field (DF), as it can be crucial in determining the differences in nodule composition (Bullock *et al.* 1985 79; Kemp 1998). Recording of the location of the nodules was also important as, by definition, they should have shown no evidence of having formed in a void – in which case they could rather represent dense void infillings (Stoops 2003b 117), related to different pedogenic processes. Simple diagnostic observations of nodule composition were initially carried out to determine differentiation between Mn and charcoal under PPL and DF light source, by recognition of the lustre of the minerals (Courty *et al.* 1989 40; Stoops 2003b 23).

2.5.1.7 *Analysis of the observations*

The information gained through the application of the recording protocol was captured in Excel format spreadsheets, allowing for instant comparisons and contrasts to be made. The formatting of the spreadsheet allowed recording of information in two main areas: 1) *c/f* material and their characteristics, and 2) peds, voids and associated pedofeatures. Anomalies could be instantly highlighted from the data in the table, while patterns and trends could be identified on an individual slide, grave or site basis (Appendix 3).

2.5.2 Quantitative micromorphological analysis

2.5.2.1 *Point counting*

Semi-quantitative analysis of specific features within the thin sections was undertaken utilising point-count analysis to convey their quantity and distribution across differential fabric types. This is an established method of proportional observation that can graphically represent the distribution of pre-determined features within thin sections, thus allowing comparisons to be drawn between different areas (Eswaran 1968). Point counting of specific features such as voids may also determine the validity of image analysis through comparison studies of quantitative image analysis and point counting undertaken on the same image (Terribile and Fitzpatrick 1995). It is essential the analytical methods be used in association with each other as singularly they are extremely subjective (Terribile and Fitzpatrick 1995). The technique has been utilised in many different types of studies to rationalise data such as mineral density, excremental pedofeature concentrations and micro-charcoal analysis (Dodson *et al.* 1993; Stoltman 1989; Davidson *et al.* 2004).

In this study, point counting was carried out to establish the quantity and distribution of specific features across differential fabric types. Voids, excremental pedofeatures, coatings, redoximorphic nodules, coarse mineral and organic material were the main features identified and recorded.

Point counting was applied to each fabric type found within the thin section samples recorded during micromorphological observation, employing the Zeiss Imaging Commander Point-Count module, which utilised the X-Y motorised stage on an AxioScope.A1. The thin sections were systematically examined, employing a minimum 12 mm^2 region of interest (ROI) grid, with observations being made every 500 µm under PPL or XPL at a 5X objective, the minimum number of observations being 150, as detailed in Figure 6 and Appendix 9. Counts of less than 150 were excluded (Davidson *et al.* 2004). The ROI were determined by differences in the fabric types across the whole thin section with a maximum of three fabric types being identified in the samples analysed. Observations were made of the material directly below the central cross hairs on the image monitor (Adesodun *et al.* 2008). This semi-quantitative analysis was used to determine correlations between the relative amounts of coating, voids and redoximorphic features throughout the burial samples and grave fill controls.

2.5.2.2 *Pre-determined point count parameter*

The following table indicates the categories employed during point count analysis across the ROI in the soil thin sections.

Table 4: Definition and description of the predetermined categories employed in the point count (PC) analysis under 5x's objective on ROI within the soil thin sections

Category	*Description*
***Coarse** mineral*	Any inorganic material that measures ≥ 50µm in size. This encompasses mineral and rock material within the soil matrix. Also including man-made mineral material such as brick fragments and rubified clay.
Coarse organic	Any organic material ≥ 50µm in size, including: bone, charcoal, wood, root fragments and shell. Pollen, seeds and fungal spores.
Void	Areas not occupied by coarse or fine soil material [excluding areas without soil matrix as a result of thin section manufacture] was not classed as a void space and categorised as undifferentiated (see Undifferentiated below).
Fe staining	Areas in the coarse or fine material were there was a high level of iron staining but could not be identified as a redoximorphic nodule
Nodule	Redoximorphic nodules either typic or aggregate.
Bone	Fragments of bone ≥ 50µm where identifiable under 5X magnification under either PPL or XPL.
Dusty coating	Dusty coatings as described by Stoops (2003 109) observed on the outside of peds and within channel voids and vughs. Infillings, hypo and quasi were categorised as undifferentiated (see 'Undifferentiated' below)
Excremental pedofeatures	Excremental pedofeatures as described by Stoops (2003b 124) and which may have been coalesced (≥ 50µm).
Undifferentiated	Artefacts or thin section manufacture and fine material (≥ 50µm) were classified as undifferentiated.

2.5.2.3 *Mosaic imaging*

Mosaic imaging was undertaken employing the AxioVision software, enabling whole thin sections to be viewed as a single image (Figure 5), as detailed in Appendix 7. The software automatically acquires a multi-image mosaic of the whole thin section using the motorised stage, stitching individual images together. By employing the motorised x/y-stage, important features were precisely located and then relocated by using the x/y coordinate system. This method was applied to most micromorphological thin sections within each case study site.

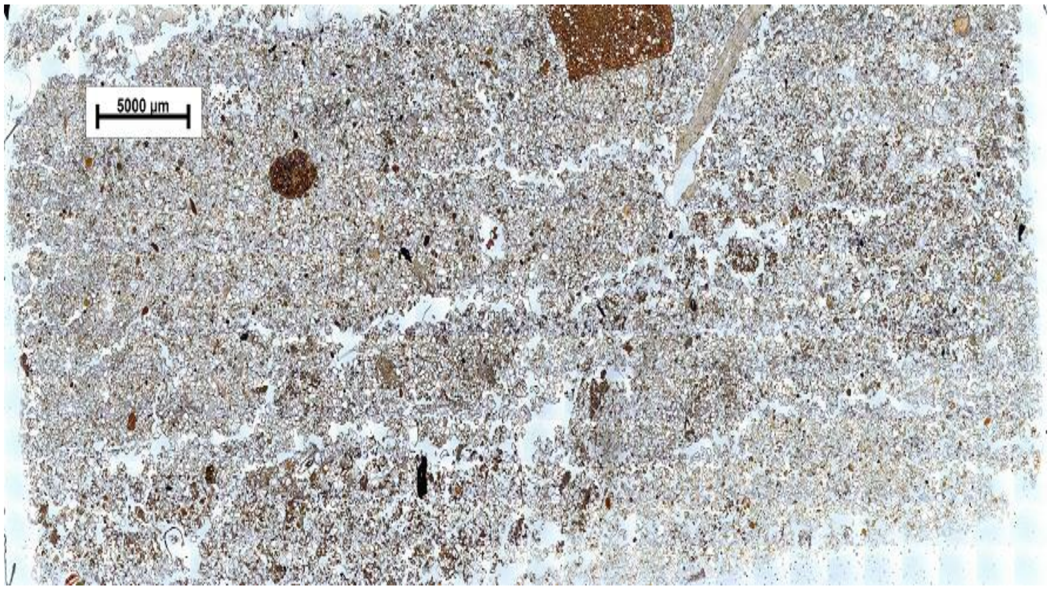

Figure 5: Mosaic image of the sample from the skull region in Grave 2037of the Mechelen site (PPL)

2.5.2.4 *Image analysis*

The use of image analysis systems can help the application of a quantitative approach to micromorphological soil thin section analysis, providing spatially detailed information (Bryant and Davidson 1996). Image analysis has been used extensively to evaluate processes such as tillage and relationships between structure and water infiltration (McBratney *et al.* 1992). With this technique, determining parameters and obtaining measurements for the areas occupied by certain features, it is essential, to keep into account images are two dimensional while relating to a three dimensional context (Elisabeth N 1991). In comparison to semi-quantitative point counting, providing quantitative measurements with image analysis can be less time consuming than obtaining semi-quantitative measurements from point counting. Even with image analysis, however, it is necessary to quantify the parameter components and ascertain the difference between void spaces and minerals, so the interactions between soil water percolation and elemental translocation can be fully understood (Ringrose-Voase 1987).

2.5.2.5 *Image analysis procedures*

Image analysis was applied to the soil thin section, in order to determine the percentage of void space within each ROI (as discussed in Section 2.5.2.1), utilising the AxioVision Release 4.8.2 and Imaging Plus, Automatic Measurement Plus and Mosaic Modules. An XPL lighting source was employed at different birefringence angles between the analyser and polarizer (90^0, 60^0 and 30^0) in order to highlight the range of extinction angles for all minerals (**Figure 6**). Colour thresholding then was applied to the three individual images through colour segmentation, to identify the individual voids from the coarse/fine fractions of the thin section. The three threshold images were then overlaid to provide a composite image of contrasting configurations obtained from the coarse mineral, coarse organic and void structures of the thin sections. The composite images were then binarized and inverted. The morphology of the pixels was determined by grey open function, with a 4-pixel edge parameter. All image processing measurements were applied using the interactive measurement of percentage μm^2 (representative of voids) across the ROI. A detailed description of the Image Analysis process is listed in

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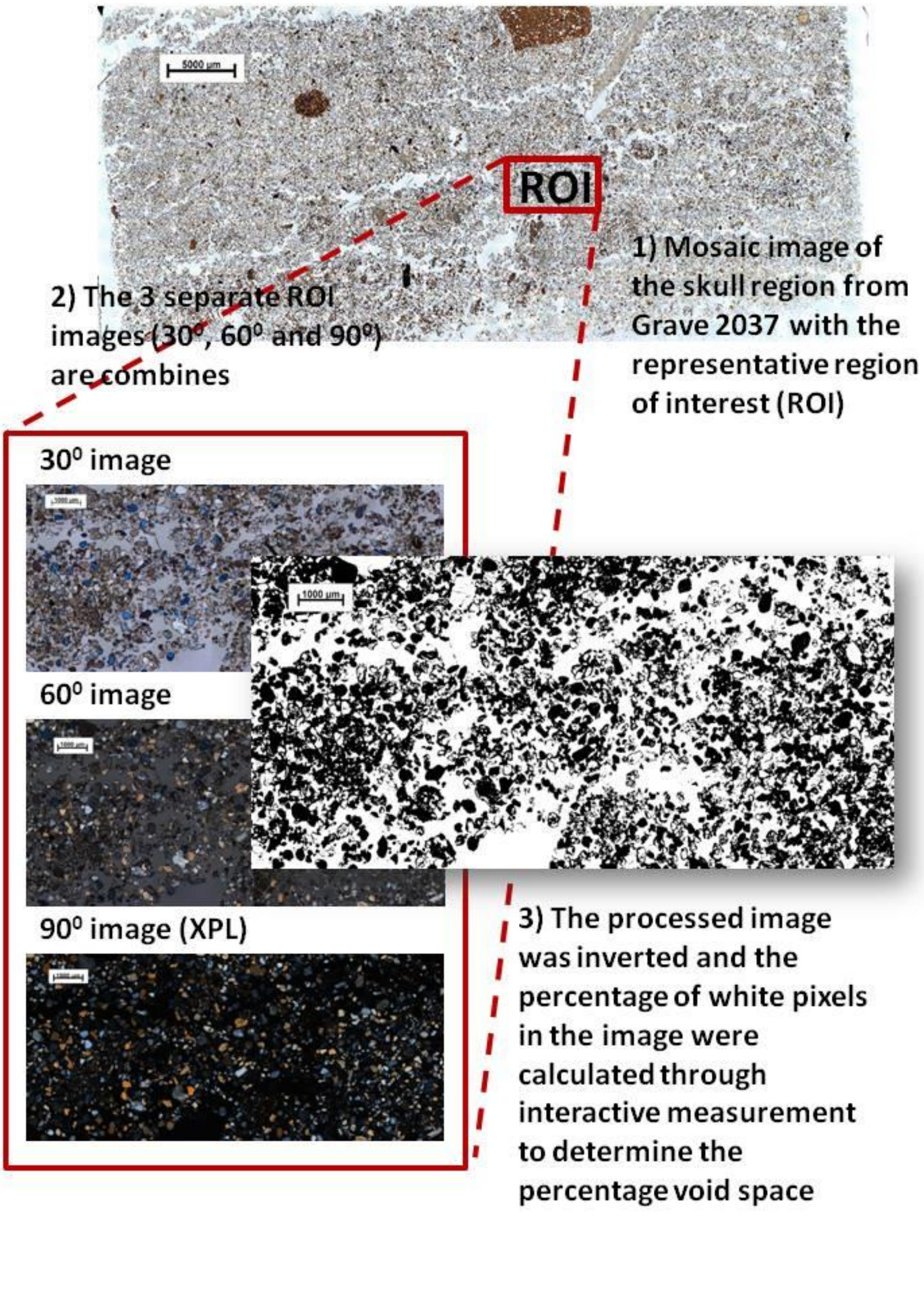


Figure 6: The 3 step methodology applied to the image analysis: 1) the mosaic image and identification of a representative RIO for the fabric type/s identified in the thin section; 2) capture of 3 mosaic images at different refraction angles from the ROI (90^0, 60^0 and 30^0), thresholding to highlight void space and combining of the images; 3) an inverted binary image was measured for the number of pixels representative of the percentage voids in the representative ROI

2.6 SEM-EDS inorganic element analysis

The analytical criteria for sampling trace element composition within thin sections were initially determined through light microscopy observations of the samples. Specific areas of interest were analysed to establish the retention of degradation products, within the soil, from the decomposition of the burials. Depositional features were identified and were analysed to determine elemental composition and patterns in the soil chemistry across the sampling positions of the burial and grave fill controls. The elemental chemistry of the depositional features was compared with the chemistry of the fine material.

Specific areas of interest were redoximorphic nodules and dusty clay coatings, with SEM-EDS macro element analysis being applied to these pedofeatures to establish whether translocation of the burial decomposition products had been deposited into the features (Kooistra and Pulleman 2010 406). Particular interest was given to elements involved in the development and synthesis of human tissue such as bone and nucleotides (phosphorus [P]) other than calcium (Ca) and clothing such as wool (sulphur [S]) (relating to the WWI mass grave at Fromelles) and its subsequent diagenesis (Mader 1998 34; Vass 2001; Tortora and Grabowski 2000a 30). The elemental levels in the redoximorphic nodules and dusty clay coatings indicated the intensity of co-precipitation between P and Fe. Fe was analysed because it is a sensitive indicator of oxidisation and water movement, whilst also co-precipitating with P (Matthews *et al.* 1987). Co-precipitation is the assimilation of trace elements into crystalline minerals such as Fe oxide when the dissolved mobile Fe^{2+} translocate with such element as P in the soil and goes into dissolution becoming immobile (Fe^{3+}) (Schlesinger 1997 98). Thus Fe nodules may be depositional features for degradation products. However, redoximorphic nodules have primarily been characterised for agricultural and archaeological soils as a diagnostic tool to determine seasonal waterlogging and the translocation of iron in the soil profile during macro-analysis (USDA-NRCS 2010).

Organic material elements of oxygen (O) and carbon (C) were also analysed within the burial and control samples. The SEM-EDS analysis was targeted using Point and ID to identify the concentrations of O and C in the fine material surrounding the voids. The levels of O to C were employed in the detection of organic burial matter, as they are the main elements in the body, and make up around 61% and 23% respectively of the composition of the human body (Wang *et al.* 1992). The detection levels of O and C were further compared to the burial indicator P.

2.6.1 SEM-EDS analytical parameters

The information was gathered by using, Point and ID analysis and relative elemental mapping to give both an accurate and pictorially representative image of the element distribution within the areas of interested (Wilson *et al.* 2008). The information from the SEM-EDS analysis augments the micromorphological evidence by providing a greater optical resolution (<2µm) than images gained through light microscopy (Goldberg and Macphail 2006 362). Samples were not coated as analysis was undertaken at variable vacuum (20kV[kilo-volts]) that prevents build-up of static, contrary to procedures recommended by Höche et al (2006). The elimination of carbon coating allowed further analysis to be undertaken through optical microscopy, as a film of carbon would interfere with optical examination.

The trace elemental analysis was undertaken on the thin sections, through complementary methods utilising SEM-EDS (Scanning Electron Microscopy - Energy Dispersive Spectroscopy) procedures at University of Stirling (FitzPatrick 1993b 32; Courty *et al.* 1989 50). Back-scatter electron microscopy was employed for imaging, using a Zeiss variable pressure EVO MA15 SEM at ~60 pa, and Oxford Instrument INCA X-Max EDS for microanalysis. Standard operating conditions of 8.5mm working distance, 20kV accelerating voltage, target size 2.6-2.7A (11cpm) and 75 second count time were used. The SEM-EDS was calibrated using a pure cobalt standard every two hours to correct for beam drift and external certified mineral standard dolomite and spinel to check the accuracy of non-normalised data (Table 5).

Table 5: The mean composition obtained for external dolomite and spinel standard during the SEM-EDS analysis. These standards were analysed to determine the accuracy of absolute, non-normalised data (Wt%).

	Dolomite			**Spinel**		
Element	Certified (Wt%)	Present (Wt%)	Error (%)	Certified (Wt%)	Present (Wt%)	Error (%)
C	12.34	30.90	3.11			
O	49.36	47.87	43.41	44.98	49.07	8.44
Mg	11.10	7.74	43.41	17.09	20.19	15.36
Ca	21.46	0.03	75.33			
Mn						
Fe	0.20	0.08	250	0.51	0.68	25.00
Sr						
Al				37.93	21.04	80.07
SI	0.07	0.00	0.00			
S	0.06	0.00	0.00			

The analysis was undertaken on areas identified initially by micromorphological observation, as discussed in Section 2.5. Three small copper triangles were added to the glass of the thin section to allow for the utilisation of the X/Y stage. A scanned image of the thin section with the areas of interest annotated was uploaded to the SEM-EDS. The copper triangles were used to triangulate the thin section with the X/Y motorised stage of the SEM-EDS system. This allowed the movement of the stage to areas of interest on the slide. A mosaic image of the thin section was also consulted during the analysis as a second reference point.

2.6.1.1 *Void analysis*

Analysis of the fine material surrounding the inter-pedal channels of the Mechelen (Section 3.4.5) and Syningthwaite (Section 3.5.5) sites was undertaken to establish the inorganic element content of the fine material and to determine if retention of carbon from decay products in the material surrounding inter-pedal channel voids had occurred.

Two different analytical methods were applied to the inter-pedal channel voids. The voids at the Mechelen site had developed parallel with the burial and the upper ground level, thus analysis was undertaken as shown in Figure 7.

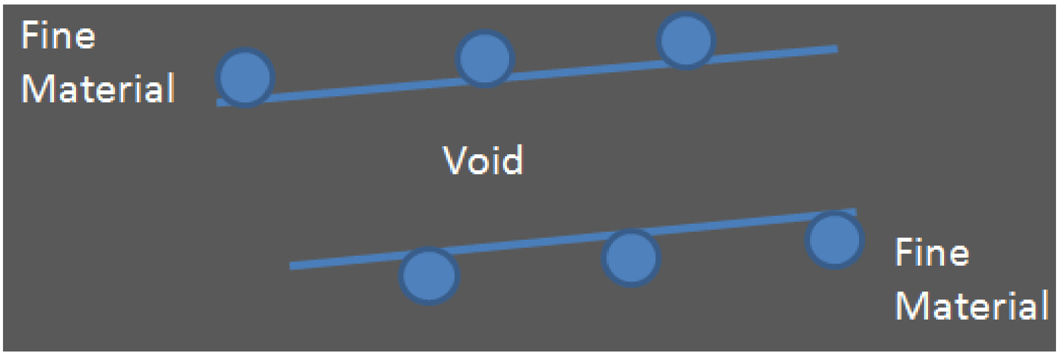


Figure 7: Diagram of SEM-ED analysis by Point and ID undertaken on the inter-pedal channel void (oriented parallel to burial and the ground surface) identified through micromorphological observation in the Mechelen grave. The Point and ID analysis of the fine material surrounding the channel being undertaken at 50 µm intervals along the length of the void edge to determine whether carbon from the burial decay had been retained in the fine material

The analysis of the Mechelen samples was undertaken using Point and ID to scan the fine material (no coarse material was scanned) every ~50 µm along the entire void and at a depth of ~20 µm from the edge of the void (~ 30 counts).

Analysis of the Syningthwaite site applied the method illustrated in Figure 8. A transect scan using Point and ID across the void from within the fine material, through the void and into the fine material at the other side. A transect was applied to the Syningthwaite site as the inter-pedal channel voids were not parallel to the burial or the ground surface but were randomly positioned in the thin sections The analysis of the voids started ~100 µm from the edge and analysis was, similar to Mechelen taken every ~50 µm dependent on the location of the coarse material (~20 counts from 4 transects). No coarse material was analysed, with only the fine material surrounding the void being utilised for further analysis.

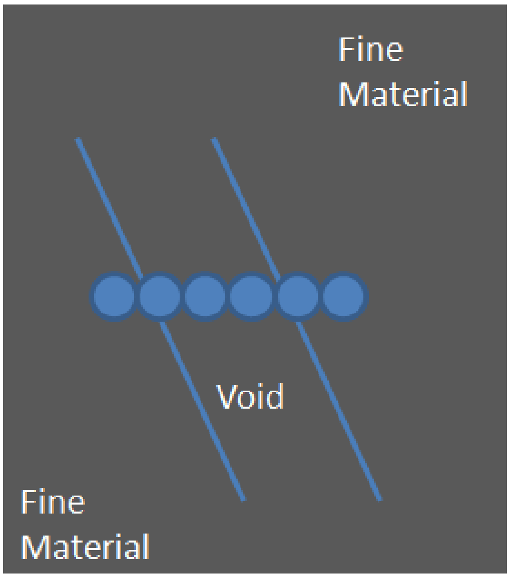


Figure 8: Diagram of the SEM-EDS sampling strategy undertaken using Point and ID across the inter-pedal channel voids of the Syningthwaite site. This was to determine whether retention of carbon from decay products derived from the human inhumation was contained within the fine material surrounding the voids

2.6.1.2 *Dusty coating analysis*

Point and ID was employed to analyse the elemental composition of the dusty clay coatings. The identified coatings were analysed every 20-50 µm, throughout the observed coatings, with a minimum of 5 points being scanned in each coating (~2 coatings per slide were applicable).

2.6.1.3 *Redoximorphic pedofeature analysis*

Similarly, Point and ID was employed to analyse the typic and aggregate redoximorphic nodules within the soil matrix, with a minimum of five scanning points in each nodule analysed at a distance of 20-50 µm (~ 3 nodules per thin section). All nodules analysed were ≥ 50 µm *c/f* limit as discussed in Section 2.5.1.

2.6.1.4 *Fine material analysis*

Analysis of the fine material was employed to provide comparisons to the elemental levels within the voids, redoximorphic nodules and dusty coatings across the burial and control samples. The analysis (Point and ID) was undertaken only within the fine material (<50 µm) - no coarse material was analysed. A minimum number of 12 counts were scanned in the fine material, depending of the *c/f* ratio and quantity of fine material, with 50 µm intervals between the analysis points.

2.6.1.5 *Textiles*

The textile-like clay inclusions from Mechelen and textiles collected at the Fromelles mass grave were analysed using Point and ID to determine the elemental composition and identify the fabric type. The samples were, in the case of Fromelles, placed on an analysis stub within the vacuum chamber of the SEM-EDS where analysis was undertaken across the textile at intervals of 50 µm, the number of analysis points was determined by the size of sample. SEM-BSE (Back scatter electron) images were also obtained from the textile-like inclusions observed in thin section, from Grave 414 at Mechelen, at varying levels of magnification (as seen in Chapter 3, Section 3.4.6).

2.7 Data analysis

A desk top survey was undertaken utilising site reports produced on completion of the site excavation and through soil/geology maps of the localised areas to the archaeological investigation.

2.7.1 Data treatment

The data gained from SEM-EDS analysis was quantitative and so provided greater evidence for comparison between different burial contexts (Adderley *et al.* 2006). The elemental data not only allowed the determination of differences between the graves but also between different sampling regions of the graves, and sample controls. Initial data for P was calculated by Microsoft Excel to determine the mean concentrations in redoximorphic nodules, dusty coatings and fine material across all burial and control samples. These results were then graphed on bar charts and displayed in tables (as seen in Chapter 3, 4 and 5) to indicate the highest elemental concentrations.

Further analysis determined the mean ratios of P:Si (fine material), P:Fe (fine material, dusty coatings and redoximorphic nodules) and S:Fe/S:Ca (fabric and fine material at Fromelles). This was employed to provide relative elemental levels (using whole numbers) so comparisons could be obtained between different sites with different soil properties, thus providing an evaluation of results across the study (Eckel *et al.* 2002; Harker and Vargas 1987). All data displayed within bar graphs had standard error of the mean applied.

2.7.1.1 *Data collection and interpretation*

The non-normalised data was employed to determine the mean ratio of P to Fe in the redoximorphic nodules and dusty coatings of the single inhumations and mass graves. This is displayed in Chapters 3, 4 and 5, and compared to the P to Fe levels in the fine material to determine movement of the degradation products through dissolution, translocation and co-precipitation across the burial and control samples. The mean levels of P:Si in the fine material across all sites was determined using the absolute data. Si being employed as the co-precipitant of P, Si being one of the most abundant minerals identified on the Earth. All data mean ratio data was displayed on Excel column graphs

Further analysis was undertaken on the mean O to C ratio in the fine material surrounding the voids in the single inhumations. The mean concentrations of O and C were calculated from the SEM-EDS elemental data using Excel spread sheets, where the mean O to C ratio was then calculated initially for graves at the Mechelen site to determine O:C levels. The ratio of O to C was then determined for the blank resins and the O:C ratio was employed as a comparison level. The data was then converted to MINITAB 16 and box diagrams were produced to identify the differences in resin to that of the mean O:C ratio within the fine material surrounding the voids. The data was used to identify areas within the graves that exhibited the highest level of mean O:C, the information was then displayed on Excel column graphs.

2.7.1.2 *Mass graves*

SEM-EDS analysis was initially undertaken on the textiles to determine the composition of the textile fibres.

The absolute mean concentration of P, S, Fe and Ca within the textile samples collected from Fromelles was calculated using Excel spreadsheets and graphed, on column graphs, to identify the levels between different sample regions were the textile was collected. Elemental data was compared to the University of York reference collection to determine the source of the fibres. Further analysis was then undertaken to determine the ratios of S to Fe (S:Fe), S to Ca (S:Ca) and P to Fe (P:Fe), thus providing information regarding the changes in element levels across the burial.

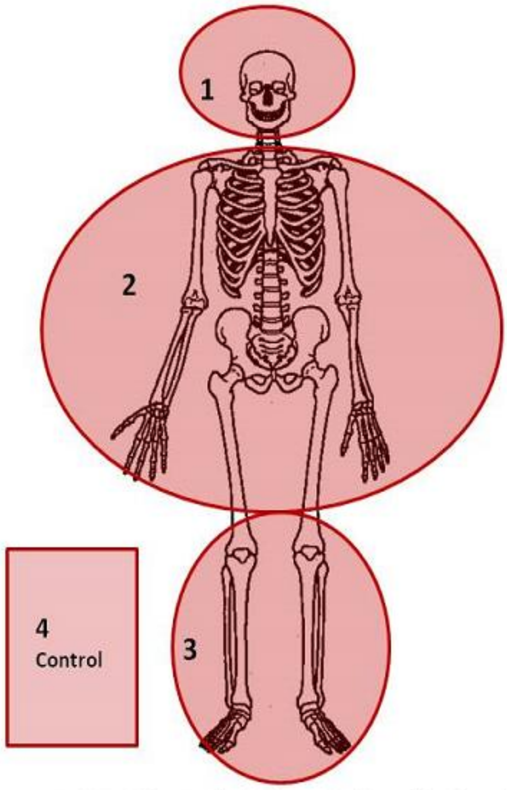
The gypsum-like crystals were analysed through SEM-EDS elemental analysis and the percentage levels of S and Ca were compared to the element concentrations expected in industrial standard gypsum (Analytic 2013).

2.7.2 Statistical analysis

Statistical analysis was undertaken on the absolute P and Fe data in the single inhumations and mass graves (Chapter 5, Section 5.2.2.2), and the P, S and Fe data in the mass graves (as seen in Chapter 4, Section 4.7). The data was collected during SEM-EDS analysis from the redoximorphic nodules, dusty coatings and fine material across all burial and control samples in all graves studied. Absolute data was initially entered into Excel spread sheets to indicate the concentrations from each Point and ID analysis. The grouping of sampling areas was necessary to perform Two-way Analysis of Variance (ANOVA) as a result of the samples collected, and the difference in sampling regions resulting from the position of the remains, thus samples were arranged into sampling regions, as seen Figure 9.

Two-way analysis of variance (ANOVA) was performed using General Linear Modelling (GLM) in MINITAB 16 software. The response factors were P, S and Fe and the analysis allowed for comparison between the source variable of *Grave*, *Sample Position* (sample regions) and the interaction between *Grave*Sample Position*. Pair-wise multiple comparisons using the Tukey method were applied to the analysis to provide p-values at 95% confidence.

Position 1*	Adjacent to and below the skull
Position 2*	Adjacent and below the pelvis, sacrum and pelvic wings, hands and elbows
Position 3*	Adjacent to and below the knees and feet
Position 4*	Site and grave fill controls



*(*Data from positions 1-4 were input into the Two-way ANOVA due to limitations in the collection of samples across the burial site)*

Figure 9: The grouping of samples for statistical analysis of raw data from the burial samples across the single and mass grave sites

3 A pilot study on the application of the *InterArChive* protocols on three historical archaeological excavations.

3.1 Introduction

Before comprehensive soil sampling and analytical protocols are routinely utilised in archaeological investigations of human burials, it is necessary to identify and test indicators that may reveal information about the burial practice, the body and its decomposition. A procedure for grave soil investigation that is both comprehensive and economical and provides pertinent and understandable information could be a powerful tool for aiding and enhancing archaeological investigations.

Due to the nature of human inhumation, especially in archaeological graves, the buried remains may no-longer be visible to the naked-eye, especially where advanced taphonomic and diagenetic processes have occurred. However, products emanating from a burial may be retained within the surrounding soil/sediment for a variable period of time, depending on the burial environments. It is therefore necessary, to devise a comprehensive, yet relevant protocol for the direct detection of decay products derived from human inhumations, whilst also identifying the indirect effects they may have on soil/sediment pedogenesis adjacent to the burial. To be useful the results obtained from applications of the protocol must enhance the archaeological analysis, and be communicated to a wider research community.

3.1.1 Aim of the case study

The aim of this pilot case study is to apply and test the new sampling and recording protocols devised by the *InterArChive* project (Usai *et al.* 2014), which was devised to investigate the effects archaeological inhumations have on the soil environment directly adjacent to interments.
The specific objectives of this chapter are to:

1. Identify pedogenic features that have developed differentially within the samples collected from the burials compared to the grave fill and site controls, recognising distinctions between sampling positions around the body
2. Observe the variability of organic particle distribution throughout the burial samples and determine the differences in bioturbation levels in the burial and control samples, in order to identify increased organic matter derived from the decay products emanating from the burial.

3. Understanding the effects of burial ritual and the environment on the deposition of decomposition products into the burial soil.

3.2 Methodology

3.2.1 Selection of primary sites

Mechelen, South Leith and Syningthwaite were selected for sampling as these samples had already been collected by the principal investigators of the *InterArChive* project. The graves contained, supine, coffined, single inhumation historical burials, interred between the 13^{th}18th centuries. The sites all contained high levels of sand but, in the case of Mechelen and Syningthwaite, field evidence and stratigraphy indicated that soil development had taken place. In each site a rescue excavation was carried out prior to building development. The three excavations provided materials for comprehensive sampling over several digging phases and stratigraphic levels.

3.2.2 Field sampling

The collection of soil samples was carried out following the field sampling protocol established for the *InterArChive* project and described in Section 2.2with undisturbed soil/sediment samples from four pre-determined regions of the skeleton (Figure 2) and site/grave controls for comparison between the site and grave fill material. Single site control samples (named C1, as indicated in Figure 2) were collected from below a sealed and paved surface at the Mechelen site during Phase 1 excavations (2009), as this was believed to be the least disturbed area. The C2 and C3 (grave fill controls) samples from Mechelen were collected, where possible, during the different excavation phases, from each individual grave. The control samples for South Leith and Syningthwaite were obtained during single phase archaeological investigations.

3.2.3 Macromorphology

Macromorphological analysis was only undertaken on bulk soil samples from the Syningthwaite site owing to lack of undisturbed soil from the Mechelen and South Leith sites. The bulk samples were collected at each control and burial point, and were stored in refrigerated conditions (*c*.4^0C) to prevent changes in the elemental, pH and microbial properties. They were analysed in the Mary Cudworth Laboratory at the University of York. Hand texturing of soil-grab samples was carried out (Thien 1979), with soil colour determined using a Munsell colour chart (Munsell 2009). pH in the soil samples was measured with a hand held *Hanna Instrument* (HI98127) pH meter displaying a 0.1pH resolution with ± 0.1pH accuracy at 0.1^0C. 50mg of soil was mixed with 50ml of distilled water, agitated and left at room temperature for 2 minutes before being analysed. Distilled water was used to clean the probe before and after analysis, whilst buffer solutions of pH 4.01 and pH 7.01 were used to calibrate the pH meter before sampling and after each soil sample was analysed.

3.2.4 Micromorphology and SEM-EDS analysis

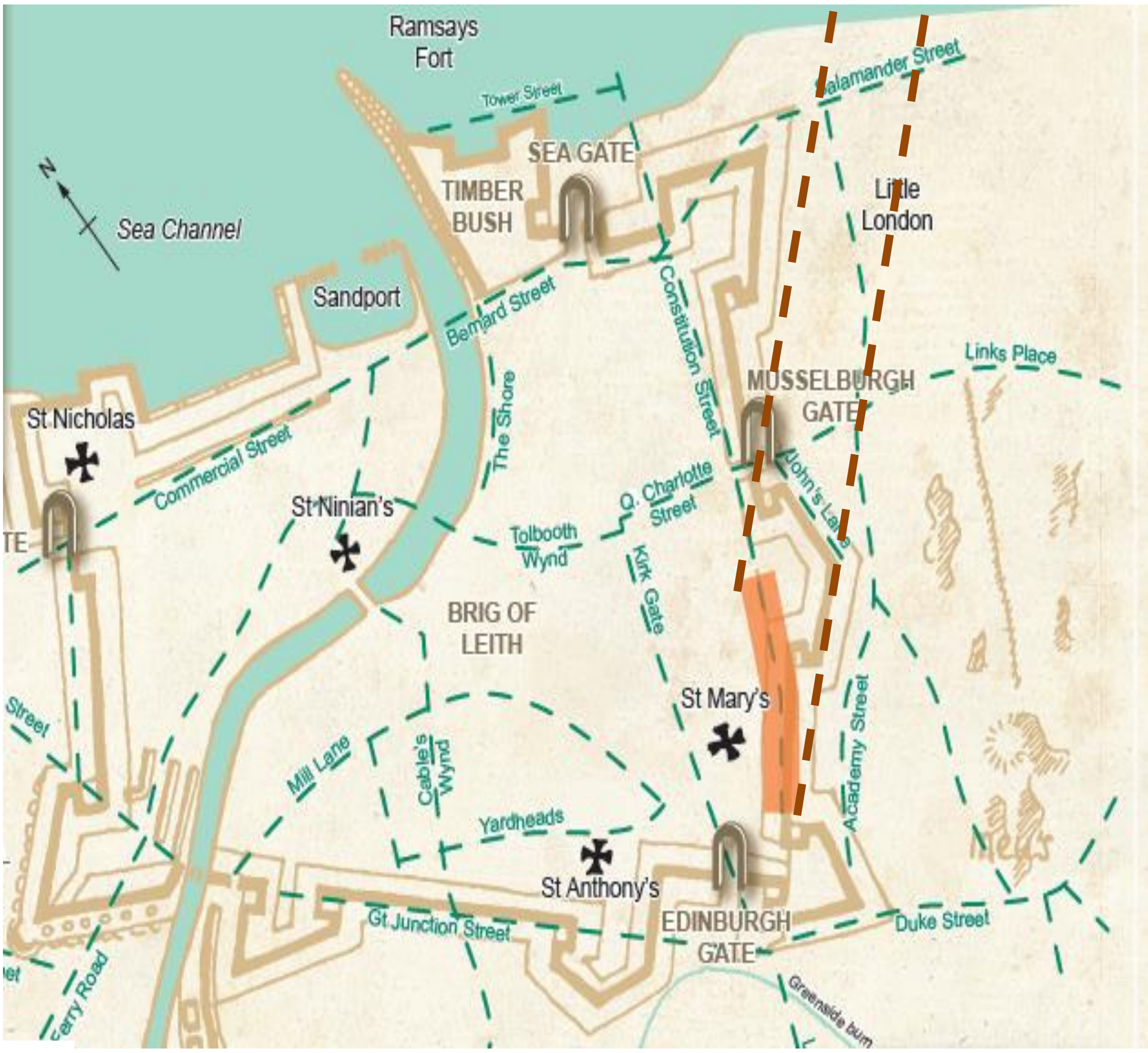
All analysis on the soil thin sections was carried out as outlined in Chapter 2.

3.3 South Leith Parish Church, Edinburgh, Scotland

The excavation at South Leith Parish, known previously as St Mary's, was commissioned by the "Edinburgh Trams" project in response to burials discovered during the construction of tram tracks along Constitution Street that runs parallel to the present day boundary wall of the graveyard. The site at South Leith Church where the excavation took place was situated under a road, beyond the present day boundary wall of the church. It is thought that the original graveyard may have been used before the building and consecration of a church on the site in the 16th century, with burials extending far beyond the boundary wall of the church, as seen in Figure 10b.

a)

b)



c)

Figure 10: a) the church and graveyard as seen today; b) the excavation undertaken on Constitution Street and; c) the location of the grave yard shown on the old plans of the city of Leith

3.3.1 Geological materials in the area of South Leith Church, Edinburgh

The parent materials within and around the South Leith excavation was mainly marine deposits, with undifferentiated Shoreface deposits overlaid Flandrian deposits of silts, clays and shell. It was Shoreface and Beach Deposits parent materials that made up the soils found at the South Leith site (Figure 11). It was evident from the geology map that many areas were classified as artificial, man-made ground as a result of the urbanisation of the site. Volcanic strata could also be identified to the south of the site (Arthur's Seat Volcanic Formation).

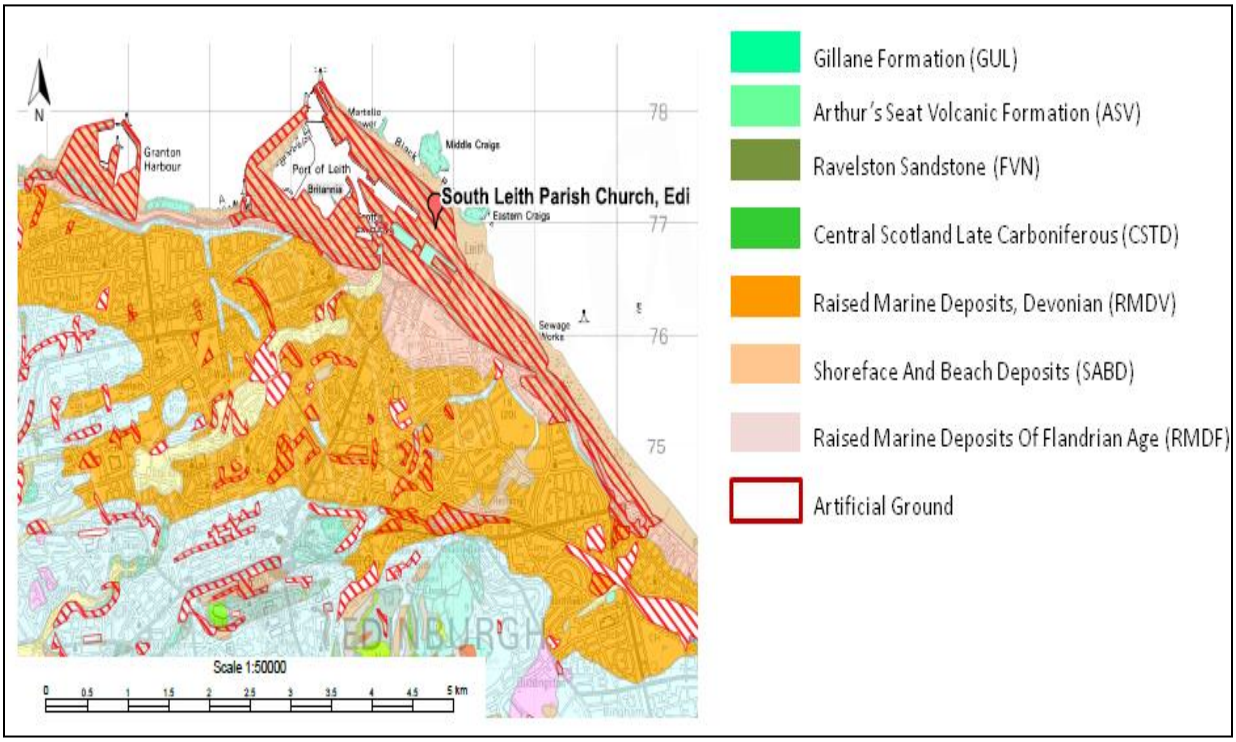


Figure 11: Geology of the excavation area and the surrounding South Leith and the city of Edinburgh (http://digimap.edina.ac.uk/geologyroam/geology)

3.3.2 Sampling of the South Leith burial

Grave 6B was one of 8, 16th century, graves sampled by the *InterArChive* team at the South Leith site, were over 100 burials were excavated as a result of construction during the Edinburgh Trams project by Edinburgh City Council .

The collection of the samples from Grave 6B of the South Leith site was undertaken following the sampling protocols as described in Chapter 2, Section 2.2. Bulk samples for macro-analysis were not obtained.

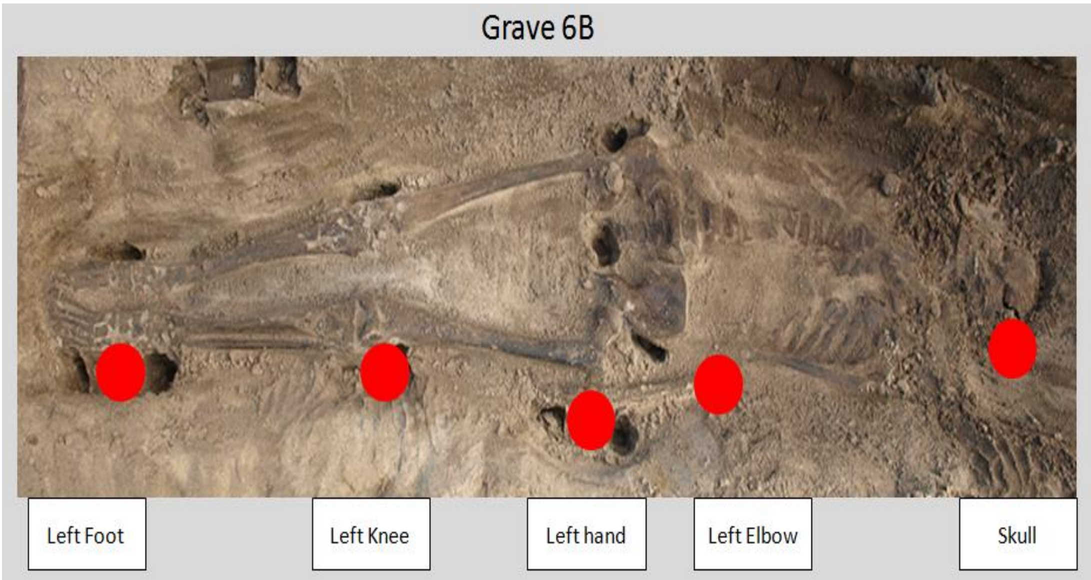


Figure 12: Sampling position around the skeletal remains of Grave 6B, South Leith. All samples were collected from the left side of the body as burials were compacted into a small space and Grave 6B had been disturbed by a later burial that removed the right shoulder and arm

Sampling regions were located along the left side of the body (Figure 12), due to the lack of skeletal remains surviving on the right side. It is believed that the density of the burials within the graveyard that grave cuts from later burials had removed the right shoulder and arms of the body (RCAHMS 2009).

A summary of the typical geology of the site soil type observed during the archaeological excavation, the position of the burial and the main micromorphological pedofeatures can be seen in Table 6

Table 6: Summary table of geology, soil type, burial position **and micromorphological features observed at South Leith**

Context (Grave No)	*Position/ type of burial*	*Geological features*	*Soil Type*	*Micromorphological Features*		
				Coarse Material	***Fine material***	***Post-depositional pedofeatures***
Grave 6B South Leith	Supine coffined burials 16th century Supine adult burial truncated by further graves removing the right shoulder and arm	Marine deposits, overlaid by Flandrian deposits of silts, clays and shell. Many areas are artificial, man-made ground. Arthur's Seat Volcanic Formation located south of site.	Well drains calcitic sand (no bulk sample obtains for macro-description)	Calcitic sands with quartz (50%) and basalt (5-10%). Micro-charcoal (<50µm)in all samples with lignified material (possible coffin wood) in the left hand and left foot region	Low levels of fine material in control and burial samples. **Speckled *b*-fabric** in C2 control, left foot and left knee **Undifferentiated** *b*-fabric in all other samples. **Limpidity**: cloudy in the C3, elbow, hand and knee Dotted in the C2 control and knee samples	**Dusty coatings** in the C3 control and left elbow **Redoximorphic** nodules in all control and burial regions

3.3.3 Micromorphology of South Leith: Results and discussion

All original micromorphological observations data from South Leith is displayed in Appendix 3.

3.3.3.1 *Coarse material*

The coarse mineral/rock fractions from the grave and control samples were only constituted by quartz and basalt fragments (Figure 13a). The frequency of quartz was *c*.50% of each thin section, whilst basalt was *c*.-5-10%, with both fractions having sub-angular, partially weathered grains. The *c/f* distribution across the controls and the grave fill samples was 80% coarse to 20% fine material (*c/f* 4:1). Coarse organic matter was particularly frequent in the hand and foot regions of the grave, where degraded lignified material and charcoal fragments were represented in the highest frequency (*c*.5-10% of the thin section area) (Figure 13b). The high occurrence of quartz in the coarse fraction is derived from the ancient dune system that runs down the east coast of Scotland (Figure 11) and on which Leith was built. The basalt in the coarse fraction was likely from the local parent material found directly to the south of the site. The high frequency of lignified material, especially around the left hand and left foot sample regions, may indicate degraded coffin wood, while the micro-charcoal (<50µm), identified throughout the site, pointed to high levels of anthropogenic burning activity in the vicinity (Adderley *et al.* 2010 580).

3.3.3.2 *Fine material*

Low levels of fine material were observed within the control and a grave sample, with the highest abundance of fine material in the burial samples was seen in the hand and foot regions, with greater frequency in the grave fill control samples C2 and C3. A speckled *b*-fabric was displayed in the C2 control, left foot and left knee under XPL with undifferentiated *b*-fabric in all other samples. The limpidity of the fine material under PPL was cloudy in the C3, elbow, hand and knee and dotted in the C2 control and knee samples.

The low frequency of fine material throughout the site corresponded to high levels of packing voids and high porosity in the sandy matrix. Localised areas of fine material around the foot, knee and C2 could suggest that increased aggregation may have occurred as a result of increased organic matter, the presence of vughs and the development of micro-aggregates (Tisdall and Oades 1982; Stoops 2003b 65). These samples also contained increased levels of lignified material possibly derived from the degradation of a coffin. However, there were low levels of root material and little evidence of bioturbation in the form of excremental pedofeatures. Based on the evidence it suggested that organic matter levels were always low. The speckled *b*-fabric suggested that the orientated clay domains had been randomly distributed through possible disturbance of the soil or low level shrinking /swelling events from the effects of wetting and drying (Dalrymple and Jim 1984).

3.3.3.3 *Ped development and void type*

Sub-angular blocky peds and inter-pedal partly accommodated channels were identified in the left foot, left knee regions and C2 sample (Figure 13c). The remainder of the sampling regions and the C3 control were characterised by complex packing voids.

The packing voids may have been attributed to the loose nature of the soil coarse fraction and the dominance of the quartz mineral in the coarse fraction. The development of sub-angular blocky peds in several of the sampling regions corresponded to higher levels of fine material and subsequent aggregation. The occurrence of inter-pedal channel voids could imply bioturbation in the regions of the left foot, left knee regions and also the C2 control; evidence of excremental pedofeatures however, was too little to substantiate the presence of macro-fauna. The ped development was possibly the result of compaction and formation of inter-pedal channels at the weakest points within the microstructure. It is possible that the development of the sub-angular blocky peds cannot be absolutely attributed to isotropic stresses that occurred through shrinking /swelling caused by wetting and drying as suggested by the *b*-fabric evidence (Section 3.3.3.2).The locality of the burials being enclosed within modern urban sprawl, sealed by road layers. Rather, their development could attributed to the pressures exerted in the site from the construction of the road surface, with the inter-pedal channel voids developing in areas of weakness (Schaetzl and Anderson 2009 264).

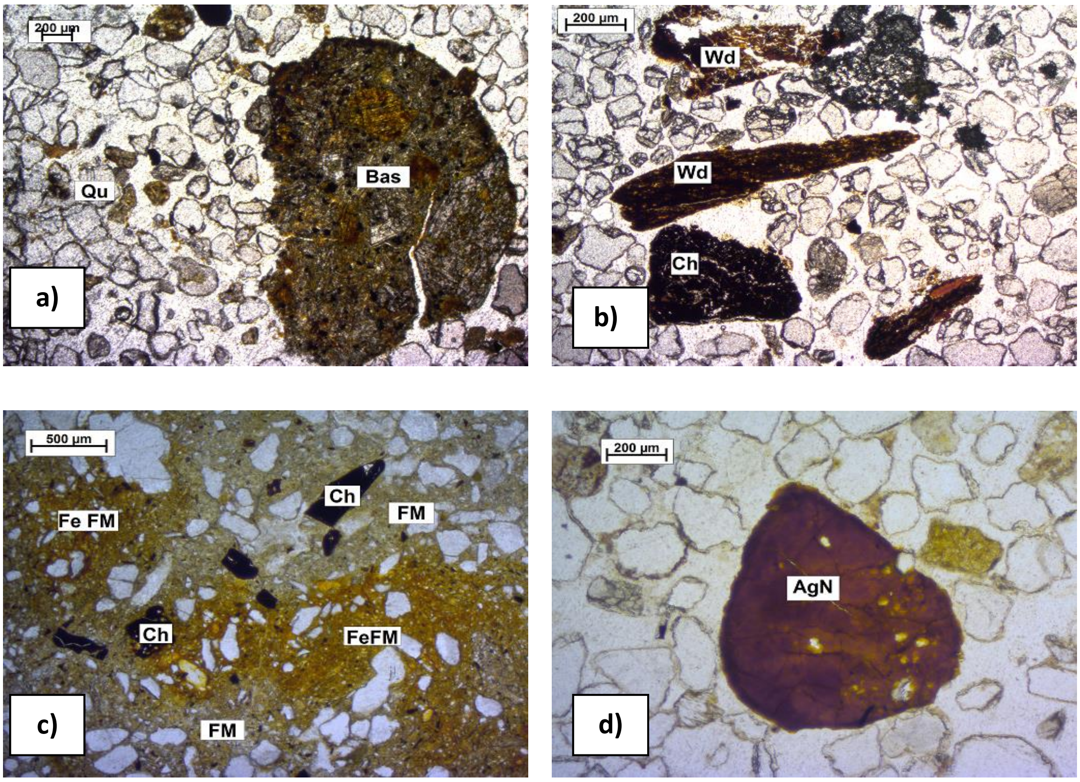


Figure 13: a) Basalt (BaS) and quartz (Qu) coarse material in the burial regions and the C2 grave fill control (PPL); b) Wood-like fragments (WD) and charcoal (Ch) from the left knee sample (PPL); c) Fine material (FM), Fe-stained fine material (FeFM) and charcoal (Ch) from the C2 grave fill control above the body in the grave fill (PPL); d) Anorthic aggregate nodule (AgN) from the left knee sample (PPL)

3.3.3.4 *Pedofeatures*

Dusty coatings around the coarse mineral material (quartz) of the C3 control and samples from the region near the elbow region were observed in low frequencies (Table 7). The frequency of redoximorphic nodules was moderate in all samples (Table 7), with the highest in the region of the knee. Excremental pedofeatures were not identified in either the control or burial samples.

The low level of dusty coatings across the burial and control samples would suggest there has been little surface disturbance. However, the barrier formed by the 18th century road surface would prevent surface movement. The frequency of redoximorphic nodules across all burial samples suggests that there were variable conditions of reduction and oxidation, elevated levels of organic matter, optimum pH and temperature have been present in the grave soils (Lindbo *et al.* 2010 138). The highest concentration of redoximorphic nodules in the left knee region could suggest that redoximorphic processes had been prolonged or more intense in this area. The absence of excremental pedofeatures in the burial and control samples could either suggest that there had not been faunal activity, normally associated with increased levels of soil organic matter. This implies that there was little or no organic matter available in the samples or that excremental pedofeatures had been washed away, in which case bioturbation can be discounted.

3.3.4 Quantitative micromorphological analysis

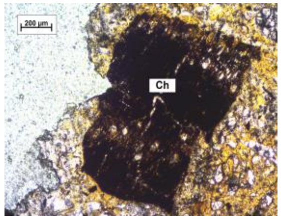
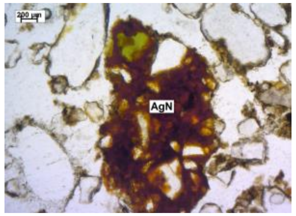
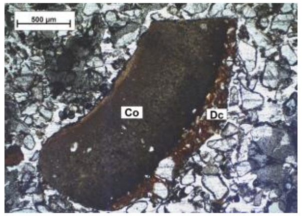
Quantitative micromorphological analysis was undertaken on regions of interest (ROI) identified during observation of the thin sections (as described in Chapter 2, Section 2.5.2).

3.3.4.1 *Point counting analysis*

Table 7: Point counting of predetermined features (Chapter 2, Section 2.5.2.1 and Appendix 9), in the control and grave samples from the South Leith site

		% of total counts									
	Sample region	**Voids**	**Nodules**	**Coatings**	**Bone**	**Excremental**	**Pedofeature**	**Coarse Material**	**Coarse Organic**	**Fe Staining**	**Undifferentiated**
	C2	**26**	**2**	**1**	**0**		**0**	**65**	**2**	**0**	**4**
	C3	**26**	**0**	**1**	**0**		**0**	**65**	**2**	**1**	**5**
Grave 6B	**Skull**	**31**	**0**	**1**	**0**		**0**	**67**	**2**	**0**	**0**
	Left Elbow	**38**	**0**	**0**	**0**		**0**	**60**	**0**	**0**	**1**
	Left Hand	**23**	**0**	**1**	**0**		**0**	**66**	**10**	**0**	**1**
	Left Knee	**24**	**1**	**0**	**0**		**0**	**65**	**7**	**0**	**4**
	Left Foot	**30**	**0**	**0**	**0**		**0**	**63**	**3**	**0**	**4**

Table 8: **Distribution of selected coarse fractions and pedofeatures identified through micromorphological observation from Grave 6B, South Leith**

	Feature	*C2*	*C3*	*Skull*	*Left Elbow*	*Left Hand*	*Left Knee*	*Left Foot*
Charcoal(Ch) *(>50 µm)*		****	***	*	**	***	****	**
Fe Nodules (AgN)		**	**	**	**	**	***	**
Dusty Coatings(Cc)			*		*			

Frequency of the features in each thin section: * 0-2% low; ** 3-5%moderate; *** 6-10% high; * >10% very high, percentages represent the feature area as a proportion of the whole thin section area***

The results of point count analysis for Grave 6B are indicated in Table 7. Coarse mineral material was the main component of the soil matrix (60-67%). The highest area of porosity (38%) was around the left elbow region, whilst the left hand region demonstrated the lowest level of porosity (23%). Redoximorphic nodules were infrequent, only being counted in the C2 control and left knee region.

The varying levels of porosity across the sample regions mirrored the levels of fine material and sub-angular peds observed during micromorphological analysis, with a lower frequency of void space in the left hand region. Similarly, the increase in fine material could also be correlated to the lower levels of coarse fraction in the left foot. The results from the left elbow, left hand and skull regions points to increased disaggregation of the fine material, possibly as a result of increased porosity occurring due to high frequency of coarse mineral material (Jongmans 2003).

3.3.4.2 *Image analysis*

Image analysis of the South Leith site indicated that the C2 control had the greatest percentage of void spaces, with the regions near the foot and hand regions as well as the C3 control displaying the lowest % void space (Figure 14).

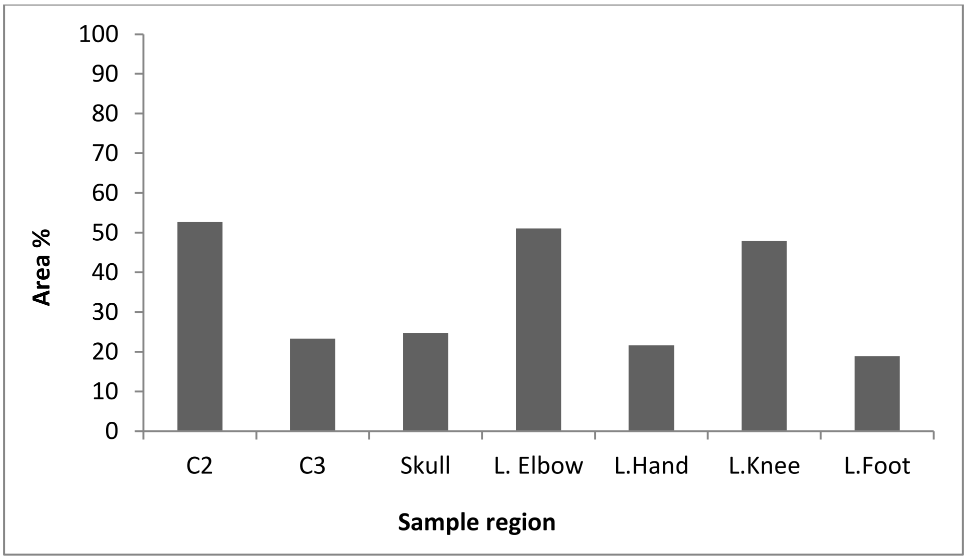


Figure 14: Percentage void spaces established by image analysis of the controls and grave sample regions of South Leith, Grave 6B

The image analysis results for the control samples (C2 and C3) indicated that the void space was reduced in the grave fill nearer to the burial. This suggests that there was compaction of the soil lower down the profile due possibly to the weight of the upper soil layers. A lower amount of void space in the regions near the hand and foot regions correlated with increased levels of fine material and, the increase in ped development as identified in the micromorphology (Section 0). The higher percentage of void space in the C2 control correlates to a greater occurrence of packing voids.

3.3.5 SEM-EDS multi-elemental analysis of South Leith

3.3.5.1 *Pedofeature analysis*

The graph (Figure 15) of normalised data indicates ratios of P to Fe are higher in the nodules than the fine material.

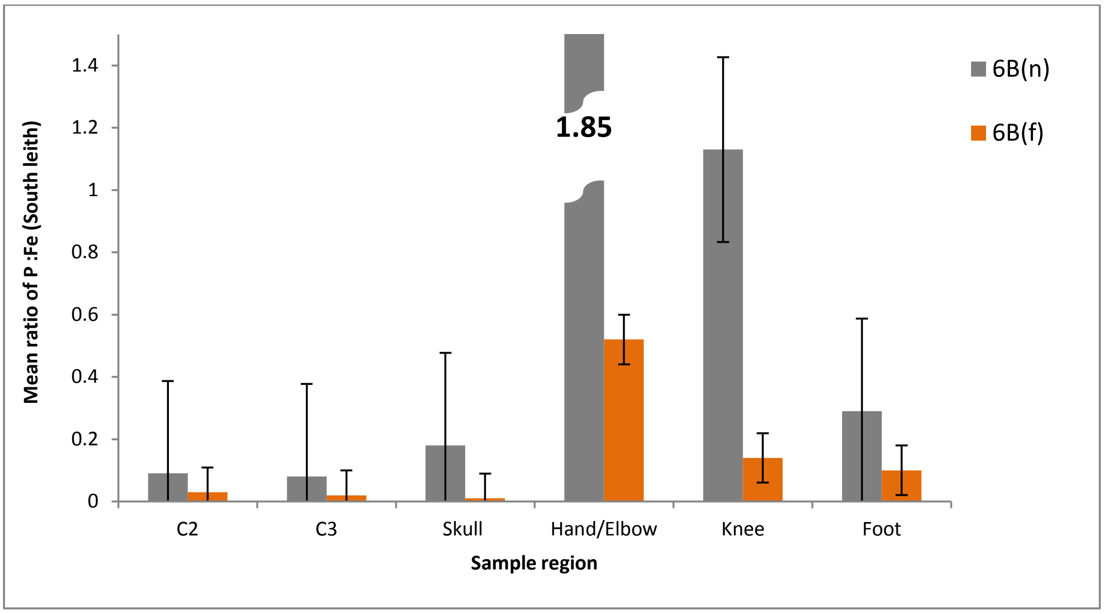


Figure 15: The mean elemental levels displayed as ratios of P:Fe in the redoximorphic nodules (n) and fine material (f) within the controls and the grave samples of the South Leith site. The error bars represents 1 standard error of the mean

Nodules were present in all sampling positions. P is shown to have the highest relative concentrations in both the nodules and fine material of the hand/elbow region. The relative concentrations of P in the fine material and nodules of the C2 and C3 control are lower than the hand/elbow, knee and foot region and, the nodules of the skull regions, with the lowest ratio of P:Fe detected in the fine material from the region of the skull.

The results of the mean ratio of P: Fe in Figure 15 would suggest higher levels of P are available for co-precipitation with Fe into the redoximorphic nodules of the hand/elbow regions. In contrast, the skull region displays low levels of P:Fe in the fine material, whilst exhibiting the lowest relative level of P in the nodules, when compared to the other burial samples and the C2 and C3 controls. All the burial samples and grave fill controls indicate there is a greater ratio of P:Fe in the nodules, when compared to the fine material, suggesting the P may have been precipitated in into the nodules with Fe. The micromorphological analysis suggests this had occurred, with the frequency of nodules being similar in all the grave and control samples (**Table 7**), except the left knee region that displayed an increase in development. It is evident the ratio of P:Fe in the redoximorphic nodules and the fine material of the control sample are lower than in several of the burial samples, with only the nodules in the skull region the exception. As a result of the site's urban location, inputs of urban waste material are likely. However, the increased levels of P in the burial samples when compared to the controls suggest it originated from the degradation material derived from the burial rather than surface inputs. The increase in P to Fe levels in the fine material and the redoximorphic nodules around the hand/elbow regions of the burial indicates pooling of degradation fluids in this particular area of the coffin. The levels of Fe possibly being a limiting factor in the frequency of nodules that had developed in this sample region, with only the left knee region exhibiting increased frequency and therefore suggest increased level of Fe were available.

3.3.6 Summary and discussion: South Leith

The graveyard at South Leith Church in Edinburgh on an ancient calcareous dune provided medieval burials from an urbanised location.

3.3.6.1 *Site conditions*

Capping of the site by the road surface has formed a protective layer, although it is possible that initial construction in the 18th century could have provided a high level of disturbance. The analytical results from Grave 6B confirmed that after burial there had been a high level of anthropogenic activity at the site probably resulting from the intense usage and the truncation of the skeletal remains in Grave 6B around the right shoulder and arm regions, by a later 17th century burial. The compact nature of the individual grave cuts, the location of the site within the urban surroundings of the inner-city of Edinburgh, and the excavation work undertaken by the archaeology team, prevented the collection of undisturbed site control samples and bulk soil grab samples (Figure 10 and Figure 12). However, the depth of the grave cut allowed for the collection of grave fill controls (C2 and C3), providing materials indicative of background pedogenesis and elemental composition.

3.3.6.2 *Pedogenesis and preservation*

The coarse mineral fraction of the control and burial samples was dominated by quartz, with a high frequency of basalt, this likely reflects the site location; at the end of a chain of extinct volcanoes and next to an ancient calcareous dune system, and not the localised building material of sandstone (Figure 11). The coarse mineral components of the control and burial soils were separated by packing voids with little fine material. Moderate quantities of fine material were limited to the hand and foot areas, where an increased frequency of degraded lignified material and charcoal was also present. The increased levels of lignified organic matter may have been related to the increase in fine material. Organic colloids together with clay particles providing multivariate cation soil stability, whilst the decomposition products from the organic material may have attracted mucus forming bacteria to provide aggregation of the soil particles (Oades 1984). The hand and knee regions were positioned adjacent to or touching the organic material of the coffin and this could, therefore, have been a contributory factor in slowing the translocation of fine material. The development of sub-angular peds separated by inter-pedal channels and voids was observed in the regions with a higher abundance of fine material, possibly due to the increased levels of organic matter; these peds were also present in the C2 control where fine material was also present. The presence of fine material in the C2 control above the burial plane and coffin suggests aggregation from increased organic matter was derived not from Grave 6B but adjacent burials as a result of the compact nature of burial in the graveyard.

The quantitative data collated through both point counting and image analysis validated much of the qualitative data obtained from the micromorphological observations. Void space analysis of the control and burial samples indicated decreased levels in the C2 control, elbow and knee, where a higher frequency of fine material was observed. The results of the image analysis suggested higher levels of fine material had been washed through the skull, hand and elbow regions to a greater degree and this was confirmed by the point count analysis and micromorphological observations.

The results of the void point counting suggested there was a degree of discrepancy, when compared to the image analysis results for the total percentage area of void. The image analysis and point counting data indicated there was a lower percentage void space across the sample regions

Table 14). Increased levels of fine material (Figure 13c) were identified through micromorphological observation and point counting not only in the left knee and foot regions, but also in the C2 and C3 controls. Thus, both image analysis and point counting were effective in validating the semi-quantitative micromorphological observations.

Grave 6B samples contained no excremental pedofeatures, confirmed through quantitative data analysis. The results propose there are two hypotheses for their absence: 1) disaggregation and translocation of these features had already occurred; 2) the level of organic matter in the soil was of such low levels that soil fauna were not attracted to the site. The initial hypothesis is based on the lack of fine material observed within the burial samples, with the presence of dusty coatings indicating translocation of fine material through the soil. The complete absence of excremental pedofeatures in all control and burial samples would correspond with both hypotheses. Organic matter may have been washed through the profile providing little nutrient value to the meso- and micro-fauna or the excremental pedofeatures had been translocated through the soil, within soil water. It is evident coarse organic matter was still present in the burial soil from lignified fragments which could have derived from the coffin (Figure 13b). The evidence, therefore, supports the hypothesis that disaggregation of excremental pedofeatures had occurred due to the porosity of the sandy soil, with the larger lignified coarse organic matter being unable to translocate through the soil matrix.

3.3.6.3 *Analytical performance*

Dusty coatings were identified in low frequency and limited to the C3 control and samples from the elbow region (Table 13). Lack of laying and lamination in the dusty coatings indicated that their development was likely to have occurred through a single disturbance event. However, since both the development of the road and the subsequent excavation of the site provided adequate bioturbation scenarios for dusty coating formation it is unclear when they formed. Redoximorphic nodules were observed throughout all the samples, with increased frequency in the left knee region. This region displayed higher levels of fine material and coarse organic matter (Figure 13c); likewise increased frequency of fine material was observed in the C2 control. The redoximorphic nodule development in all regions would require several factors such as the increase in organic matter, the presence of Fe, and alternating reduction and oxidation conditions and to develop the necessary redox conditions, with increased frequency in the left knee region suggested a greater presence of these factors. Increased levels of fine material also in the left knee region could suggest that the greater aggregation was possibly through increased organic matter, whilst the proximity of the sampling position to the sides of the coffin would have allow greater entrapment and pooling of soil water or even degradation products.

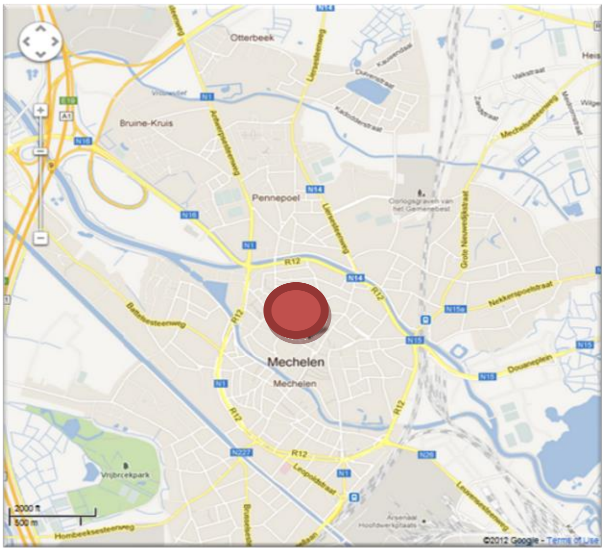
Evidence from the micromorphological investigation of Grave 6B, South Leith highlighted the presence of redoximorphic features, hence that there had been a movement of Fe, across the burial context. The highest relative level of P in the nodules, one of the main elements within the body, was identified in the hand/elbow sample region, where the highest relative levels of P was also detected in the fine material (Figure 15). The mean ratio of P:Fe in the control samples, pointed to low background levels, whilst the remaining burial samples displayed increased P in the fine material. It is suggested here that the coffin may have been integral in the retention and development of redoximorphic nodules, whilst allowing a flux of P to enter the fine material surrounding the burial, as proposed by Janaway (2002 352). The level of P produced by human faecal matter may represent some of the P present in the hand/elbow region, which is adjacent to the pelvis. However, micro-nutrients produced by the body will normally be excreted in urine which leaves the body immediately after death, before being laid in a coffin and certainly before interment (Lee *et al.* 2014; Vass 2001). This consequently suggests the higher relative levels of P in the hand/elbow sample region may have originated from the degradation of the burial, particularly the fleshier parts of the body around the pelvis.

3.4 St. Rombout’s Cathedral, Mechelen, Belgium.

An excavation of a graveyard adjacent to St Rombouts Cathedral in Mechelen, Belgium (Figure 16a) was carried out by the local council archaeological services, ahead of the development of an underground car park. The city is situated on the south bank of the River Dijle, and today has a population of approximately 320, 000.

Christianity was introduced to Mechelen and the surrounding areas by the Irish missionary St. Rombout. The cathedral was founded between 972 and 1008 AD, but the building seen today, dates back to the 12th century (Figure 16b). The grave yard was adjacent to the cathedral and was in use from around the 11th century until the 18th century (Van de Vijver 2011).

a)



b)

Location of St. Rombout’s Cathedral and excavation in relation to the city

Figure 16: St. Rombout’s Cathedral: a) Location of the cathedral and excavation site in the centre of Mechelen. The site was situated on an island of land between two water courses; b) the main tower of the cathedral

3.4.1 Local soil and stratigraphy

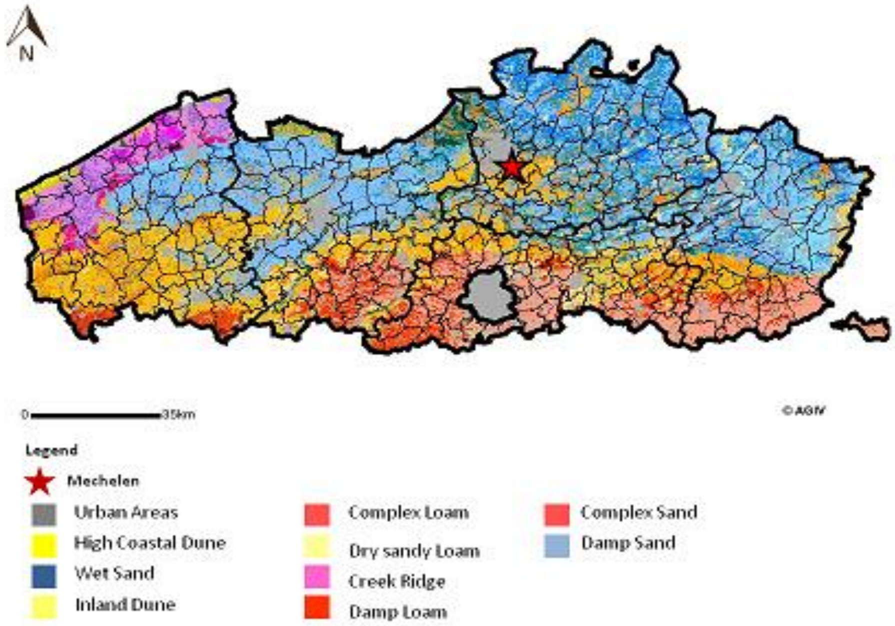


Figure 17: Soil map of the Flanders region of Belgium with Mechelen highlighted (adapted from:http://gevlaanderen.agiv.be/geovlaanderen/bodemkaart/?startup=ze(154199.967099609,188781.498955078,161598.498349609,192943.172783203))

The soil map of the Flanders region, Belgium (Figure 17) indicated that the predominant soil type across the region was sandy.

Mechelen is located on an ancient inland dune system consisting of high coastal dunes and inland dunes. The soil map concurred with the archaeologist's excavation description of the site (Van de Vijver 2011) and the underlying sandstone geology.

The diagram of stratigraphy (Figure 18) shows the upper layers to be highly disturbed due to the location of the graveyard within the central part of a built up urban area. The lower layers also indicate disturbance with high levels of fragmented bone and pottery recorded by the archaeologists during excavation. The soil type was identified as dark brown loamy sand in the upper layers (Van de Vijver 2011), which may indicate increased levels of organic matter in the upper soil layers. The lowest layer, where Graves 384, 414, 415, 422 and 423 were located has a grey/brown colour, which may point to some gleying of the soil due to water table fluctuations.

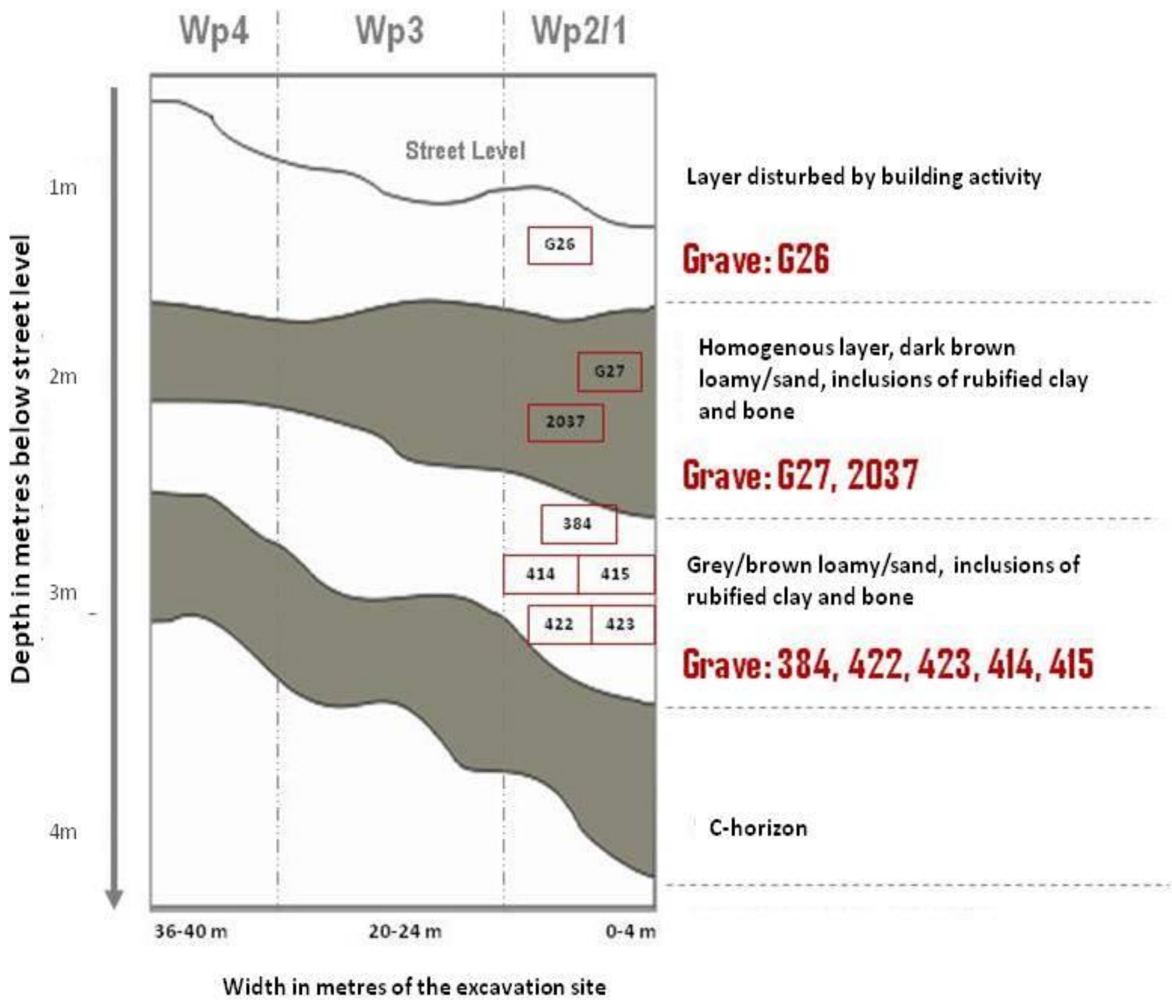


Figure 18: The archaeological context observed from north to south across the Mechelen excavation site with positions of the graves. The y-axis indicates the depth below street level, the x-axis the width of the excavation site and Wp4, Wp3 and Wp2/1 refer to the trench numbers (as adapted from Van de Vijver, 2011)

3.4.2 Site location and environmental context of the Mechelen excavation

The graveyard was located on a sandy ridge to the north of the River Dijle with up to 2m deep sandy soils below the level of the modern street (Figure 18), and podzol along the slopes dipping to the NE part of the excavation area (Figure 19) (Van de Vijver 2011). Throughout the different horizons, high levels of fragmented human bone and inclusions of fired pottery sherds were discovered (Figure 18).

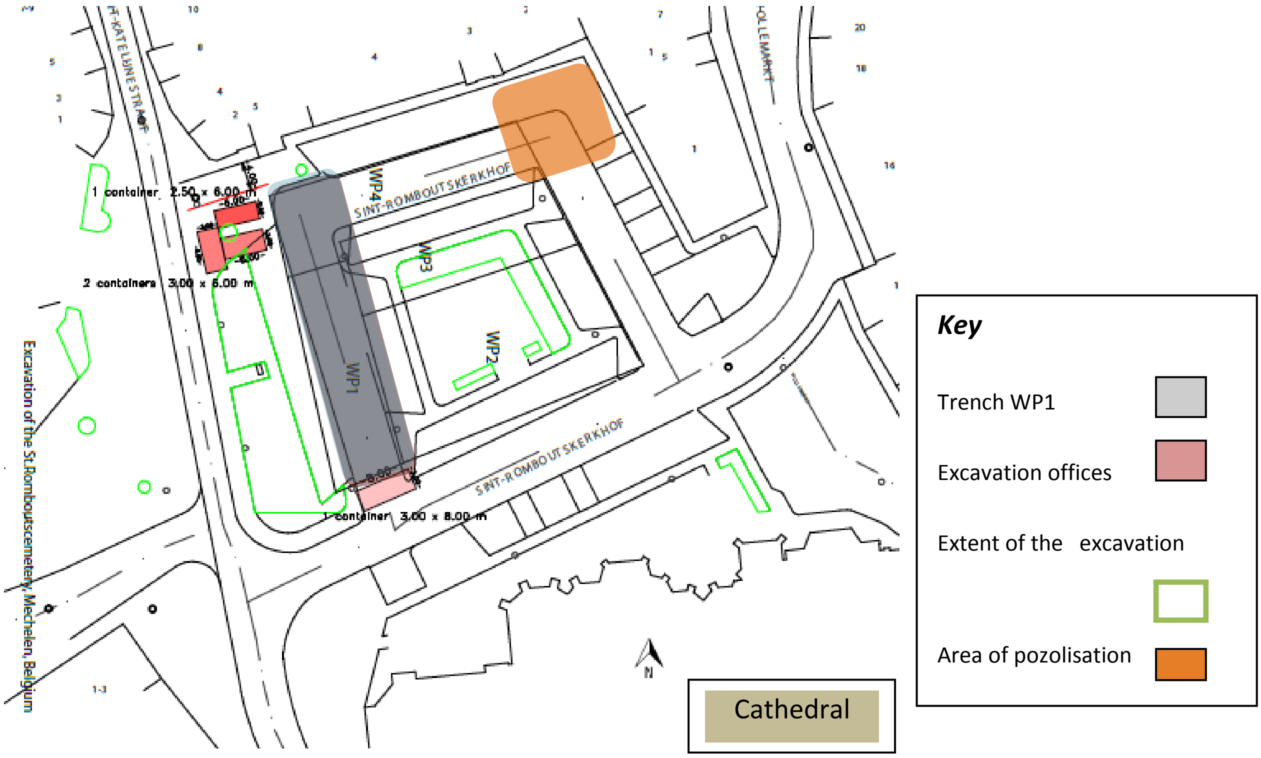
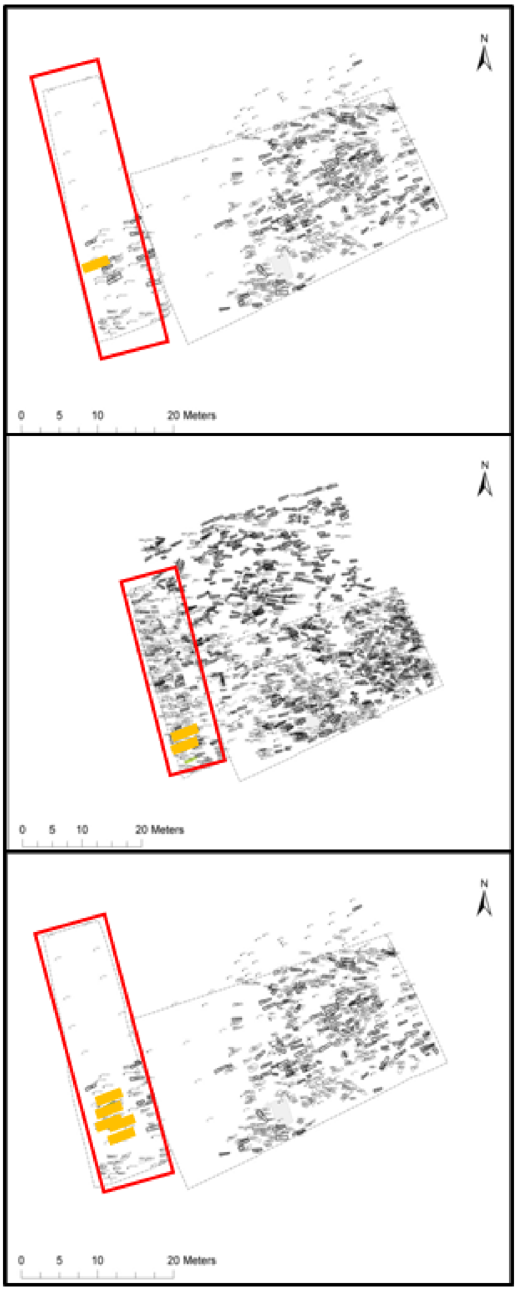


Figure 19: Schematic representation of the Mechelen excavation site and the trench where the eight pilot graves were sampled

The study area was situated to the north of the cathedral in a locale used as a car park (Figure 19). The graves were excavated over two phases (spring/summer 2009 and 2010) from four distinct layers (L1-L4) containing eight pilot study graves. Layer 1(L1) were the most recent graves and layer 4 (L4) the oldest, the site dating from the 12th to 18th century (Figure 20).



Layer 1: Trench WP1

Phase 1 Excavation (2008)

Graves excavated: G26

Layer 2: Trench WP1

Phase 1 Excavation (2008)

Graves excavated: G27 and 2037

Layer 4: Trench WP1

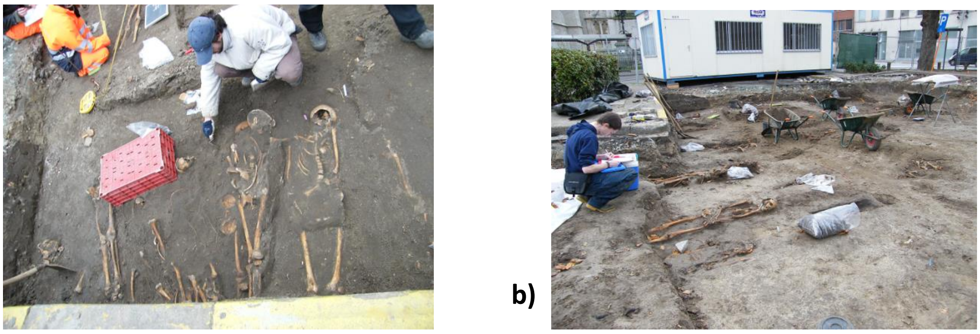
Phase 3 Excavations (2009)

Graves excavated: 422, 423, 414, 415 and 384

Grave	G26	G27	G2037	G384-4	G414	G422	G415	G423
Layer	L1	L2	L3	L4	L4	L4	L4	L4
Approx. date (Century)	17^{th}-18^{th}	17^{th}	14- 15^{th}	13^{th}-14^{th}	12^{th}-13^{th}	12^{th} -14^{th}	12^{th} -14^{th}	12^{th}-14^{th}

Figure 20: Excavation plan indicating the position of the grave trenches in WP1 (highlighted in red, with graves highlighted in yellow). The diagram indicates the position of the graves and excavation layers

High levels of anthropogenic activity were identified from the close proximity of buildings in the foreground surrounding the site and in proximity of the Cathedral at the centre of urban development in the city and in close vicinity to the traditional market place (Figure 21).



a) b)

Figure 21: Images of the high density of urbanisation around the graveyard and the compaction nature of the graves: a) across the site and; b) in proximity of the urban buildings

The initial samples were collected from areas adjacent to each body (Figure 22), with the positions of the bodies in the graves determining the sampling configuration. In the older burials (12^{th}- 16^{th} century) the hands had been placed at the side of the body, allowing the collection of samples in the hand region. In the later 17-18^{th} century burials, hands were often placed across the pelvic region, thus not enough soil was present to sample without disturbing the configuration of the hand bones needed for archaeological investigation (Figure 22). During each excavation phase, different C1 site control samples were obtained with one from Phase 1 (2009) collected from beneath a pavement because of a lack of undisturbed areas on the excavation site. Since the site controls were from highly disturbed building material, their suitability for comparison with the grave samples was limited.
A summary of the burial type, basic geology, soil type and primary observed micromorphological features are displayed in Table 9

Figure 22: Graves G26, G27, 2037 and 422 and the position of the bodies in the grave cut in relation to the surrounding graves

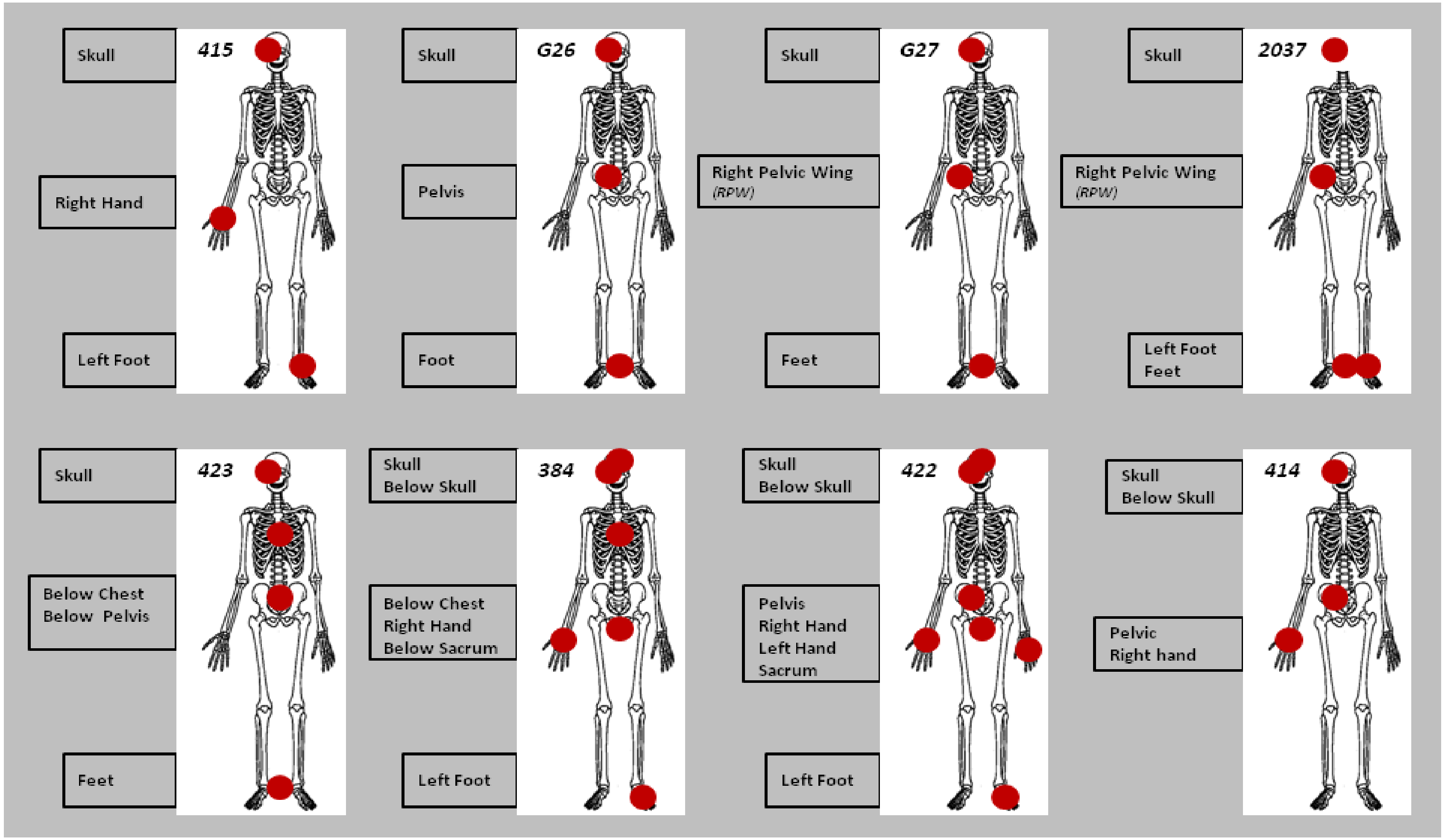


Figure 23: Sampling positions adjacent to and below the skeletal remains in the eight graves sampled at Mechelen and investigated through micromorphology and SEM-EDS

Table 9: Summary table of geology, soil type, burials and main micromorphological features observed at Mechelen

Context (Grave No)	*Approx. date of burial (century) and type of burial*	*Geology*	*Soil Type*	*Micromorphological Summary*		
				Coarse material	*Fine Material*	*Post-deposition pedofeatures*
G26	17^{th}-18^{th} century Single adult, supine, coffined burial	Ancient dune system forming the underlying sandstone geology of Mechelen	Brown loamy sand with visible root fragments and rubified clay	Sub-angular quartz (40%) rounded glauconite (5%)	Undifferentiated *b*-fabric, possible masked by amorphous organic matter	Channel voids parallel to ground surface from compaction. **Redoximorphic nodules** particularly in the foot region
G27	17^{th}-18^{th} century Single adult, supine, coffined burial		Dark brown loamy sand with visible rubified clay fragments (20%).	Sub-angular quartz (40%) rounded glauconite (5%) Channel voids parallel to ground surface from compaction	Speckled *b*-fabric	Dusty coatings in the skull region, with redoximorphic nodules in pelvis and feet. Bioturbation visible in all burial samples
2037	14^{th}-15^{th} century Single adult, supine, coffined burial, Truncated at the right knee			Sub-angular quartz (50%) rounded glauconite (10%)	Undifferentiated *b*-fabric, possible masked by amorphous organic matter	**Redoximorphic nodules** were predominant in the feet and sacrum regions of the burial. There were no visible dusty coatings
384	13^{th}-14^{th} century Single adult, supine, coffined burial			Sub-angular quartz (40%) rounded glauconite (10%) with mollusc shell and bone (%5)	Poro- and grano-striations in right hand and left foot region. Speckled in all other samples	**Root bioturbation** in the hand and foot region. Redoximorphic nodules in the skull and sacrum, with C3 displaying dusty coatings
414	12^{th}-13^{th} century Single adult, supine, coffined burial		Grey/brown sandy loam with visible rubified clay (10%) and shell (5%) fragments.	Sub-angular quartz (40%) rounded glauconite (10%) with mollusc shell and bone (5%)	Poro- and grano-striations in pelvis and right hand region. Speckled in all other samples	**Dusty coatings** in the skull and the hand region, with redoximorphic nodules in the pelvis and hand
415	12^{th}-14^{th} century Single adult, supine, coffined burial			Sub-angular quartz (40%) rounded glauconite (10%) with mollusc shell and bone (%5%)	Speckled *b*-fabric	Dusty coatings in the hand and feet regions, with no visible nodules
422	12^{th}-14^{th} century Single adult, supine, coffined burial			Sub-angular quartz (40%) rounded glauconite (20%) with mollusc shell and bone (5%)	Undifferentiated *b*-fabric, possible masked by amorphous organic matter	**Dusty coating** observed in all samples, with redoximorphic nodules only in the below skull sample
423	12^{th}-14^{th} century Single adult, supine, coffined burial			Sub-angular quartz (40%) rounded glauconite (20%) with mollusc shell 5% and vivianite (10%)	Speckled *b*-fabric	Redoximorphic nodules in the skull region

3.4.3 Micromorphological analysis for Mechelen: results and discussion

All original micromorphological observations data from Mechelen are displayed in Appendix 3.

3.4.3.1 *Coarse material*

Weathered quartz was the predominant constituent (*c.*40%) of the unsorted coarse material in all eight graves and control samples. Significant amounts (*c.*20 %) of weathered green/brown (PPL) glauconite were observed in all samples. Large amounts of rubified clay (Figure 24and Figure 32c), identified under dark field illumination (DF), were scattered throughout the control and grave samples. A low frequency (*c*. 2%) of partially degraded shell (mollusc) was found in the lower (12^{th}-14^{th} century) graves 384, 422, 423, 414 and 415. Several fragments of rubified clay had a white coloured coating the fragments (Figure 24a), identified using scanning electron microscopy (SEM-EDS) as lead-based.

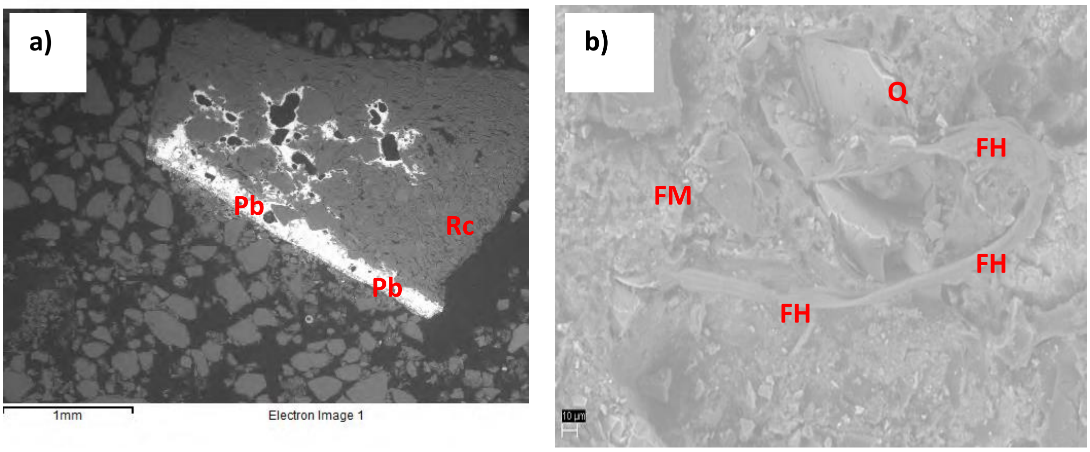


Figure 24: SEM –EDS back scatter electron image of a) rubified clay (Rc) fragment from the upper layer of the excavation in Grave G27 displaying lead (Pb) glaze and b) Quartz fraction (Q) and fungal hyphae (FH) scanned from the impregnated unpolished block from Grave 414, and samples from under the skull region

The concentrations of coarse biological matter varied between graves, with the upper layer Graves G26, G27 and 2037 not displaying any shell fragments. Figure 25a illustrates the relationship between the distribution of bone fragments and the samples collected near the skull, pelvis and feet (Figure 25b and c). The frequency of bone across the upper layer graves (Graves G26 and G27) was spread more evenly across all regions, with Grave 422 displaying an increased frequency of bone in region 3 (foot area). Fungal hyphae were identified by their size, frequency and morphology throughout the unpolished block samples by Dr Allan Hall using scanning electron microscopy backscatter electron imaging (SEM-BSE) (Figure 24b). Charcoal, identified in DF and ferruginised root remnants, occurred across the upper layers in Graves G26 and G27, with increased concentrations in the pelvis and skull regions of Grave G27. Enhanced degradation of root fragments, characterised by a decrease in visible cellular structure as indicated by low levels of birefringence under cross polarized light (XPL) (Babel 1975 458), were observed in graves from Layer 4 (Graves 384, 422 423, 414 and 415). Iron impregnated root material was also evident (Figure 26a). Blue/white tabular crystals of vivianite were observed in Grave 423 below both the pelvis and chest.

a)

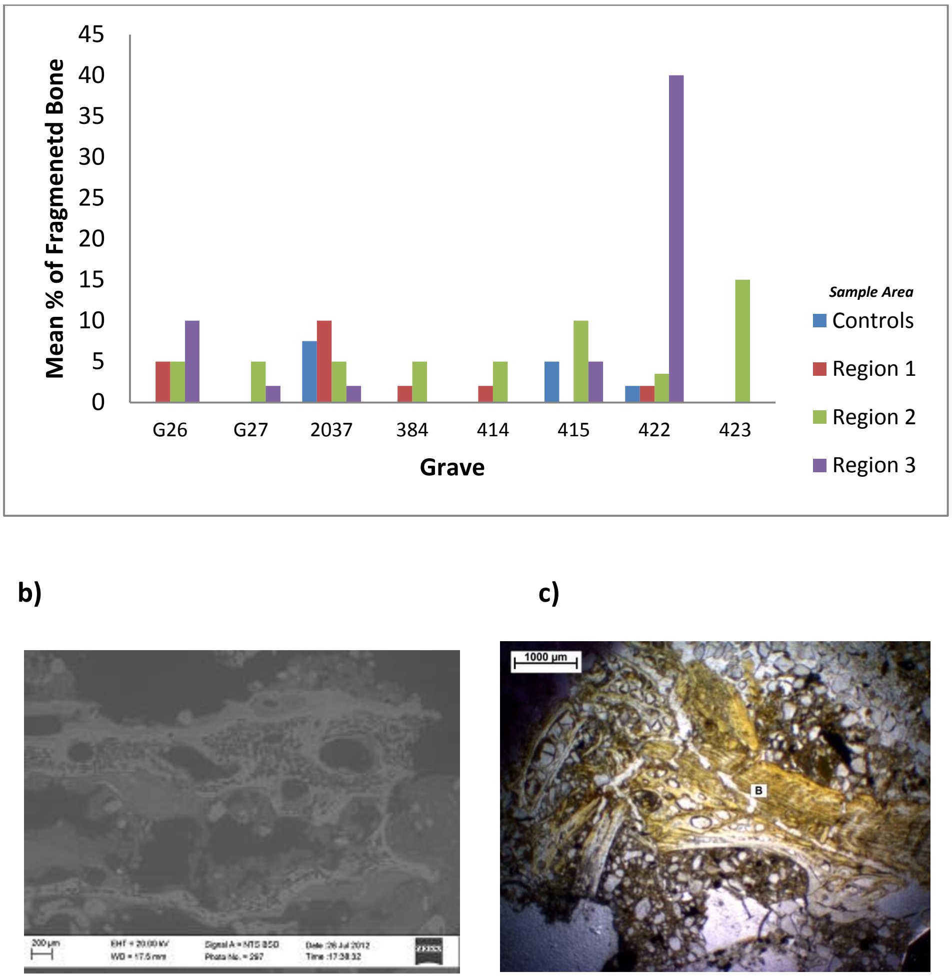


Figure 25: a) Mean percentage distribution of fragmented bone observed within the control and each sample region and of all graves at the Mechelen site [Region 1-head area, Region 2-pelvis/hands area and Region 3-foot area]; b) SEM back scatter electron image of a large section of fragmented bone with a dusty coating from sample Region 3 of Grave 422; c) Fragment of bone (B) from Region 1, of Grave 422 (PPL)

Fragmentation of the bone was identified in all layers through micromorphological observations. It was evident from the distribution of fragmented bone across the Mechelen site that Grave 422 had the highest frequency of bone fragments in Region 3 (foot area). Grave 423 had a high frequency of fragmented bone in Region 2 (pelvis/hands area) (Figure 25a). There was a low frequency of fragmented bone recognised in some of the control samples, but none were observed in Region 1 (around the skull) in Graves G27, 415 and 423.

The presence of fragmented bone across the site implied that there had been a high level of disturbance in all graves, with fragmented bone also observed in the grave fill control samples (C2 and C3).The position of the bone fragments across not only the burial samples but also the control samples may point to inherited disturbance even in the lower level graves such as Graves 415 and 422. The presence of ferruginised root across the burial and control samples suggested there had been root penetration, possibly from the localised trees around the parking area (Figure 26). Turbation by roots may also be a factor in the dispersal of fragmented bone. Identification of rubified clay across all graves and controls indicates disturbance may not only have been the result of bioturbation, but anthropogenic activity. The rubified clay provides an indication of building work, signalling disturbance of the surrounding environment likely from the construction of the cathedral or the many shops and dwellings within the urban centre.

3.4.3.2 *Fine material*

The groundmass has a speckled *b*-fabric in all samples except those from Graves G26 and 2037, where undifferentiated. Graves situated in the lowest excavation layers showed striated *b*-fabric within certain sample regions: Grave 384 has striated *b*-fabric in the material from the right hand and left foot regions ad also the C3 control, whilst Grave 414 had a striated *b*-fabric in the fine material of the pelvis and right hand region. The fine material in the areas of the pelvis and skull region within Grave 422 (lower layer) was masked by brown amorphous organic matter (Figure 26b).

a) b)

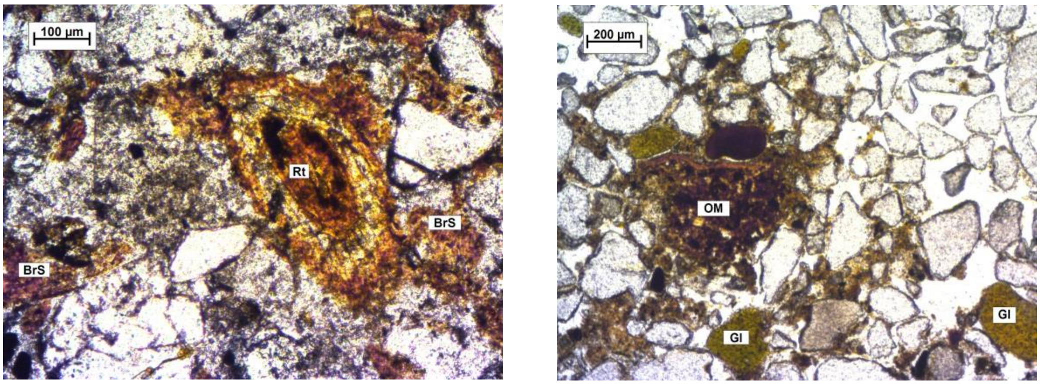


Figure 26: a) Degraded, ferruginised root (DR) and brown staining (BrS) masking the birefringence of clay and plant remains (Rt) in the lower layer, Grave 422 (feet region) (PPL); b) amorphous brown organic matter (OM), with rounded/weathered green glauconite (Gl), Grave 422 (pelvis region) (PPL)

The development of a striated *b*-fabric in Grave 414 is in contrast with Grave 415, which was only speckled (XPL). Similarly, the sample from Grave 422 was characterised by a masked *b*-fabric probably due to the frequency of amorphous organic matter distributed throughout the grave, whilst the adjacent Grave 423, with a predominantly speckled *b*-fabric.

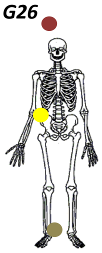
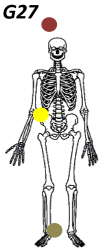
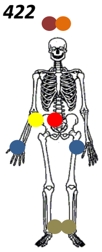
The speckled *b*-fabric in most of the grave samples and controls suggested several hypotheses: 1) disturbance in the grave, through bioturbation may have randomly redistributed the previously oriented clay; or 2) there has been little shrink/swell of the soil through the mechanism of wetting and drying of the clay particles, thus not providing alignment of clay domains (Dalrymple and Jim 1984). In contrast, the striated *b*-fabric observed around the pelvis and the right hand region of Grave 414, and the right hand, left foot region and C3 control of Grave 384 suggested low levels of disturbance and the occurrence of wetting and drying allowing shrinking and swelling to align clay particles to form linear striations within the fine material.

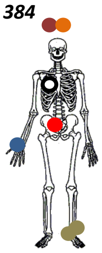
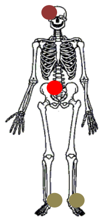
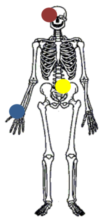
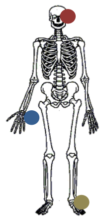
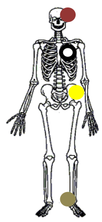
3.4.3.3 *Voids and peds*

Inter-pedal channel voids were present throughout all graves and controls with the exception of Grave 422, which displayed a high frequency of apedal sample regions (Table 10). Apedality could also be observed in the C2 and C3 controls collected in the backfill of Grave 422. The inter-pedal channel voids are parallel to both the body and ground surface in many of the samples and controls.

The channel voids, particularly in the upper graves (Graves: G26, G27 and 2037), were accommodated or partly accommodated in comparison to the lower levels (Graves 414, 415, 423 and 384) where non-accommodated void walls were present (Table 11). Intra-pedal vughs displayed a random pattern of distribution throughout the graves and control samples, with none identified in Graves 2037 and G27.

Table 10: Ped and void types and their frequency in all Mechelen graves (*indicates that the resin block had been cut in 2 orientations; parallel to the ground surface and perpendicular to the body [Chapter 2])

Grave Number	Sample Region *(Near)*	Ped Shape Orientation/ Distribution	Development *(Apedal-A, Weak-M, Moderate-M,Strong-S)*	% of Slide *(Void)*	Dominant Void Type Orientation/ Distribution
G26 	*Skull* *Pelvis* *Foot*	SA-B (Platy)(Parallel) Apedal SA-B(Random)	*S* *A* *S*	*90%* *100%* *100%*	*Channels(Random)* *Vughs(Random)* *Channels/Cracks(Linear/Parallel)*
G27 	*Skull* *Pelvis* *Feet*	SA-B(Platy) (Linear/Parallel) SA-B(Platy) (Linear/Parallel) SA-B(Platy) (Linear/Parallel)	*M* *S* *S*	*100%* *70%* *100%*	*Channels (Linear/Parallel)* *Channels (Linear/Parallel)* *Planes/Channels*
422 	*C2* *C3* *Below Skull* *Skull* *Pelvis* *Sacrum* *Right Hand* *Left Hand* *Left Foot* *Below Feet*	Apedal Apedal SA-B(Random) Apedal Apedal SA-B(Platy) SA-B(Random) Apedal Apedal SA-B(Random)	*A* *A* *M* *A* *A* *M* *M* *A* *A* *M*	*20%* *30%* *100%* *30%* *60%* *50%* *60%*	*Vughs (Random)* *Vughs (Random)* *Channels (Banded/Parallel)* *Vughs (Random)* ***No Voids*** *Channels (Linear/Parallel)* *Channels (Random)* ***No Voids*** ***No Voids*** *Channels (Random)*

384 	C3	SA-B (Linear/parallel)	M	70%	*Channels (Linear/Parallel)*
	Skull	SA-B (Linear/parallel)	M	100%	*Channels/Vughs (Linear/Parallel)*
	Below Skull	SA-B (Random)	S	100%	*Channels/Vughs (Linear/Parallel)*
	Below Chest	SA-B (Parallel/Oblique)	S	100%	*Channels/Vughs (Random)*
	Below Sacrum	SA-B (Random)	S	70%	*Channels/Vughs (Random)*
	Right Hand	SA-B (Random)	M	60%	*Channels (Random)*
	Left Foot	SA-B (Random)	M	80%	*Channels (Random)*
	Left Heel	SA-B (Random)	M	90%	*Channels (Random)*
SK2037 	C2	SA-B (20cm above L .shoulder)	S	100%	*Channels (Linear/Parallel)*
	C3	SA-B (10cm above pelvis)	M	70%	*Channels (Linear/Parallel)*
	Skull	SA-B (Platy)(Linear/Parallel)	S	100%	*Channels (Linear/Parallel)*
	Sacrum	SA-B (Random)	M	100%	*Channels (Random)*
	Left Foot	SA-B (Random)	M	90%	*Channels (Linear/Parallel)*
	Feet	SA-B (Random)	W	100%	*Channels (Random)*
414 	C2	SA-B(Linear Parallel)	S	100%	*Channels (Random)*
	Skull	SA-B(Linear/Parallel)	M	100%	*Channels (Linear/Parallel)*
	Pelvis	SA-B (Linear/Parallel)	M	70%	*Channels (Linear/Parallel)*
	Right Hand	SA-B (Random)	W	90%	*Channels/Vughs (Random)*
415 	C3	SA-B (Random)	W	70%	*Channel(Linear)/Packing(Random)*
	Skull	SA-B (Random)	M	100%	*Channels (Random)*
	Right Hand	SA-B (Random)	M	60%	*Channel(Linear)/Packing(Random)*
	*Right Hand**	SA-B (Random)	M	60%	*Channel(Linear)/Packing(Random)*
	Left Foot	SA-B(Random)	W	100%	*Channel (Linear)*
423 	C3	SA-B (Random)	S	100%	*Channels (Random)*
	Skull	SA-B (Linear/Parallel)	M	50%	*Channels (Linear)*
	*Skull**	SA-B (Linear/Parallel)	M	50%	*Channels (Linear)*
	Below Chest	SA-B (Random)	M	50%	*Channels (Random)*
	Below Pelvis	Granular/SA-B (Random)	S	70%	*Channel(Linear)/Packing(Random)*
	*Below Pelvis**	Granular/SA-B (Random)	S	70%	*Channel(Linear)/Packing(Random)*
	Feet	SA-B (Linear/Parallel)	S	25%	*Channels(Linear)/Vughs (Random)*
	*Feet**	SA-B (Linear/Parallel)	S	20%	*Channels(Linear)/Vughs (Random)*
	Coffin Wood	Apedal/SA-B (Linear/Parallel)	S	50%	*Channels (Linear)*

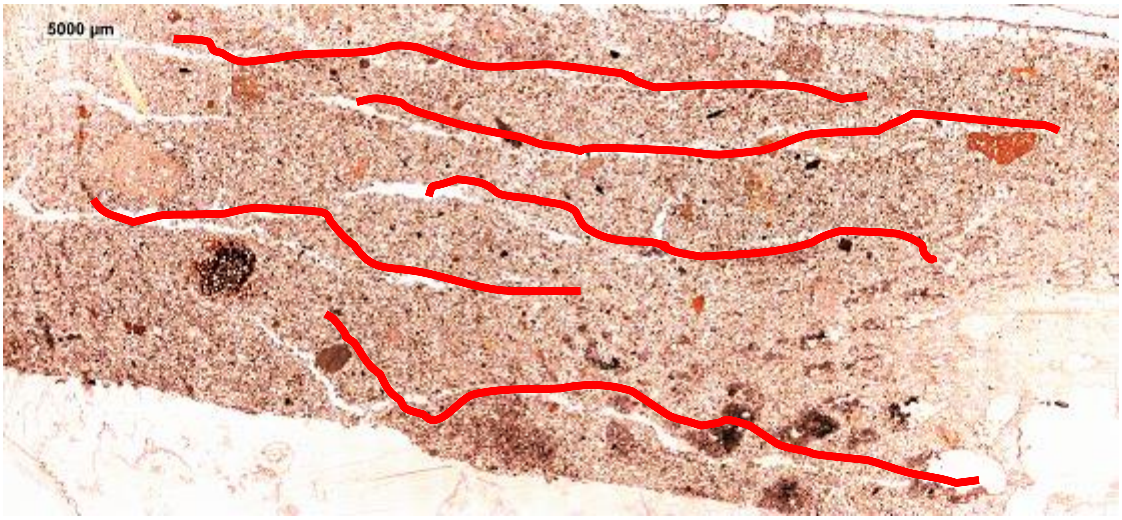


Figure 27: Mosaic image of the sample from the skull region of Grave G26 with the red lines highlighting the parallel orientation of the strongly developed channel voids

Lower levels of pedality were observed in the lower layers, as in Grave 422, particularly in the left hand, foot and pelvic region samples. Two different types of peds were observed in the graves (Table 10). Sub-angular blocky peds delineated predominantly by strongly developed parallel orientation channel voids were identified in all graves except Grave 422. Graves G26, G27 and 2037 were the only graves to exhibit strongly developed platy peds (Figure 27).

Table 11: Degree of void accommodation in the grave and control samples (0 =no sample, *=not accommodated, **=partially accommodated and *=accommodated)**

	G26	*G27*	*2037*	*384*	*414*	*415*	*422*	*423*
C2	0	0	**	0	**	0	**	0
C3	0	0	0	**	**	**	0	**
Skull	**	**	***	***	**	**	*	**
Below Skull	0	0	0	0	**	0	**	0
Pelvis	0	*	0	0	**	0	0	*
Sacrum	0	0	**	**	0	0	**	0
Left Hand	0	0	0	0	**	0	0	0
Right Hand	0		0	0	0	**	*	0
Feet	***	**	0	0	0	**	0	**
Below Feet	0	0	0	0	0	0	*	0

The level of accommodation of the inter-pedal channels can be observed in Table 11, showing the highest level of accommodated voids is in the skull regions, particularly in Graves 2037 and 384. The majority were partially accommodated (Table 11), with only the sample below feet region of Grave 422 and from the pelvis regions of Graves G27 and 423 displaying non-accommodated voids.

The apedality identified in Grave 422 was replicated in the pelvic region of Grave G26. Apedal areas were exhibited in the C3 control, skull, left foot, left hand and pelvic region of Grave 422. The sample location of the apedality suggest three possible hypotheses: 1) settling of the soil around these areas of the body had occurred, 2) high aggregation levels had resulted in the development of large peds not identified through micromorphology, or 3) there had been disturbance during the excavation and sampling of these particular sample regions.

The pelvis and hands regions, which were placed alongside the pelvis, would have initially been rich in organic matter from degradation of the fleshy parts of the body. This could have allowed aggregation to arise. However, the increase in organic matter would have attracted high levels of bioturbation and the subsequent development of peds separated by inter-pedal channel voids. Settling of soil could have occurred from the collapse of the coffin and ingress of soil from the grave fill. The bones may have been de-fleshed and the organic matter from putrification may have translocated, thus apedality had taken place. The amorphous organic matters identified throughout Grave 422, indicated the dispersal of degradation products may not have taken place (Section 3.4.3.2). The final hypothesis is the most likely; with the disturbance of the burial taking place either prior to sampling or during sampling. Apedality was identified in the left side of Grave 422, in the C3 control and around the skull region. This suggests the samples had been taken repeatedly from the same areas. The development of apedality in the pelvic regions of Graves 422 and G26 would also point to sampling disturbance with excremental pedofeatures being identified in the pelvis region samples from Grave G26, as described in the later Section 3.4.3.4.

The development of the platy peds and linear inter-pedal channel voids across the site may indicate compaction events had occurred. The level of accommodation (predominantly partially accommodated) identified in the voids could suggest there has been a moderate level of ped development in the soil. There are several factors that may have been significant in the development of platy peds such as surface movement and trampling from the archaeological excavation. High levels of anthropogenic activity were identified on the site (Van de Vijver 2011), this may also have been a factor in the development of the platy peds and partially accommodated inter-pedal voids.

3.4.3.4 *Pedofeatures*

Dusty continuous and discontinuous (fragmented) coatings were observed on coarse grains, within vughs and channels and within fractures in charcoal fragments (Table 13), across all graves and controls. Dusty coatings in most graves and controls were speckled, displaying random orientations of clay particles, with laminated dusty coatings below the skull and feet regions in Grave 422. The fragmentation of the dusty coatings was identified through their composition and morphology. The samples below the skull region from Graves 384 and 422 displayed a low frequency of dusty coatings. Aggregate and typic iron redoximorphic nodules were found in all grave and control samples with a maximum frequency of *c*. 5% (measurement of total thin section) in the skull, pelvis and feet region sample regions (Figure 28g and Table 13).

Table 12: Excremental pedofeatures observed in thin section across the Mechelen site

	Excremental Pedofeatures	*Skull*	*Below Skull*	*Below Chest*	*Pelvis*	*Sacrum*	*Hands*	*Feet*	*C2*	*C3*
G26	*Calcitic (worm)*	5			5					
	Organic							5		
G27	*Calcitic (worm)*	2			2			2		
	Organic									
2037	*Calcitic (worm)*									
	Organic	5				2			2	5
384	*Calcitic (worm)*					2	2			5
	Organic									
414	*Calcitic (worm)*									
	Organic				2		2			
422	*Calcitic (worm)*	2	2			2				
	Organic									
415	*Calcitic (worm)*									
	Organic						2			
423	*Calcitic (worm)*									
	Organic			10	20					

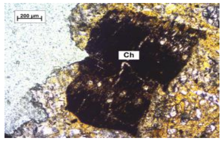
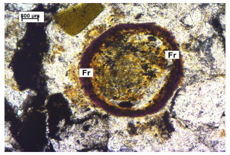
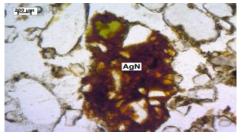
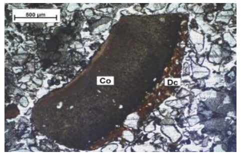
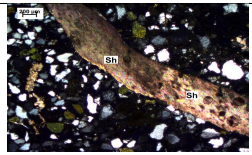
Numerical values indicate the percentage of the total thin section sample area

Faunal activity was evidenced by the presence of excremental pedofeatures, which in many burial samples were adjacent to degraded roots and organic (lignified) material. A high frequency of excremental pedofeatures were identified in Grave 423, with the below pelvis region sample displaying granular pedality owing to the frequency of coalesced and non-coalesced excremental material. Bioturbation was also expressed through the observation of calcitic earthworm excrement (Figure 28h) in ll pelvic, skull and feet regions. It was apparent, however, that Graves 415 and 423 did not contain mammillae excrement. Calcitic pedofeatures were observed in the right hand regions of Grave 422 and Grave 415, and around the left foot of Grave 2037 and Grave 415; while the below-skull samples from Grave 384 contained calcium phosphate nodules, identified under PPL, XPL and SEM-EDS elemental analysis (Table 12).

Dusty discontinuous coatings are indicative of disturbance and can provide generational evidence of at least two separate events; the development of the coating and their fragmentation. The initial development of the dusty coatings may have resulted from surface disturbance either through the removal of the covering layer, in this instance the removal of the urban sealing, or due to preparation of the ground for burial in the overlying graves. Rain splash on the exposed surface may loosen clays and silts particles and allow them to wash down the soil profile (Kuhn *et al.* 2010 220; Usai 2001b).

The distribution of excremental pedofeatures across the site suggested there had been differing level of bioturbation, with the highest levels displayed in Grave 423 below the pelvis region. The composition of the excremental pedofeatures suggested that there could have been different meso-faunal species or the activity had occurred over a period of time resulting in coalesced and non-coalesced shapes, however, this cannot be confirmed (Stoops 2003b 124). The presence of calcitic worm granules and organic excremental pedofeatures were observed in most graves and suggested that there had been high levels of bioturbation in graves, again precisely when the activity had taken place was not established.

Table 13: Distribution of selective coarse factions and pedofeatures through all investigated graves at Mechelen

	Feature	*C2*	*C3*	*Skull*	*Below Skull*	*Below Chest*	*Below Sacrum*	*Sacrum*	*Pelvis*	*Hand*	*Feet*
Charcoal(Ch) *(>50 µm)*		422 384** 2037** 414*	384** 2037** 423** 415**	G26* G27** 384** 414** 2037* 423**	384** 422*	384** 423*	384****	384* 2037**	G26* G27* 414** 423*** 422*	384** 414**** 415**	384*** 2037* 423****
Roots(Rt)		414* 422*	2037**	G27**** 384* 414* 2037** 423* 415** 422*	384*	384* 423*		422*** 2037*	G26* G27**** 414*** 423**	415* 384****	G27** 384**** 423*** 422**
Fe Nodules (AgN)		414* 2037*	2037* 415*	414** 423* 415*	422 ** 384**	384*	384**	2037**	G27** 414*	384* 414*	G26* G27** 2037**
Dusty Coatings(Cc)		422*	415** 384**	422** G26* G27*** 423** 414***	422* 384*			422**	422* 414****	415** 414*** 384* 422*	423** 415** 422**
Shell(Sh)		422*	423* 384*	414*	384* 422*	384*	384*			415** 384*	423**

Frequency of the features in each thin section: * 0-2% low; ** 3-5%moderate; *** 6-10% high; * >10% very high, as representative of the percentage in the whole thin section sample***

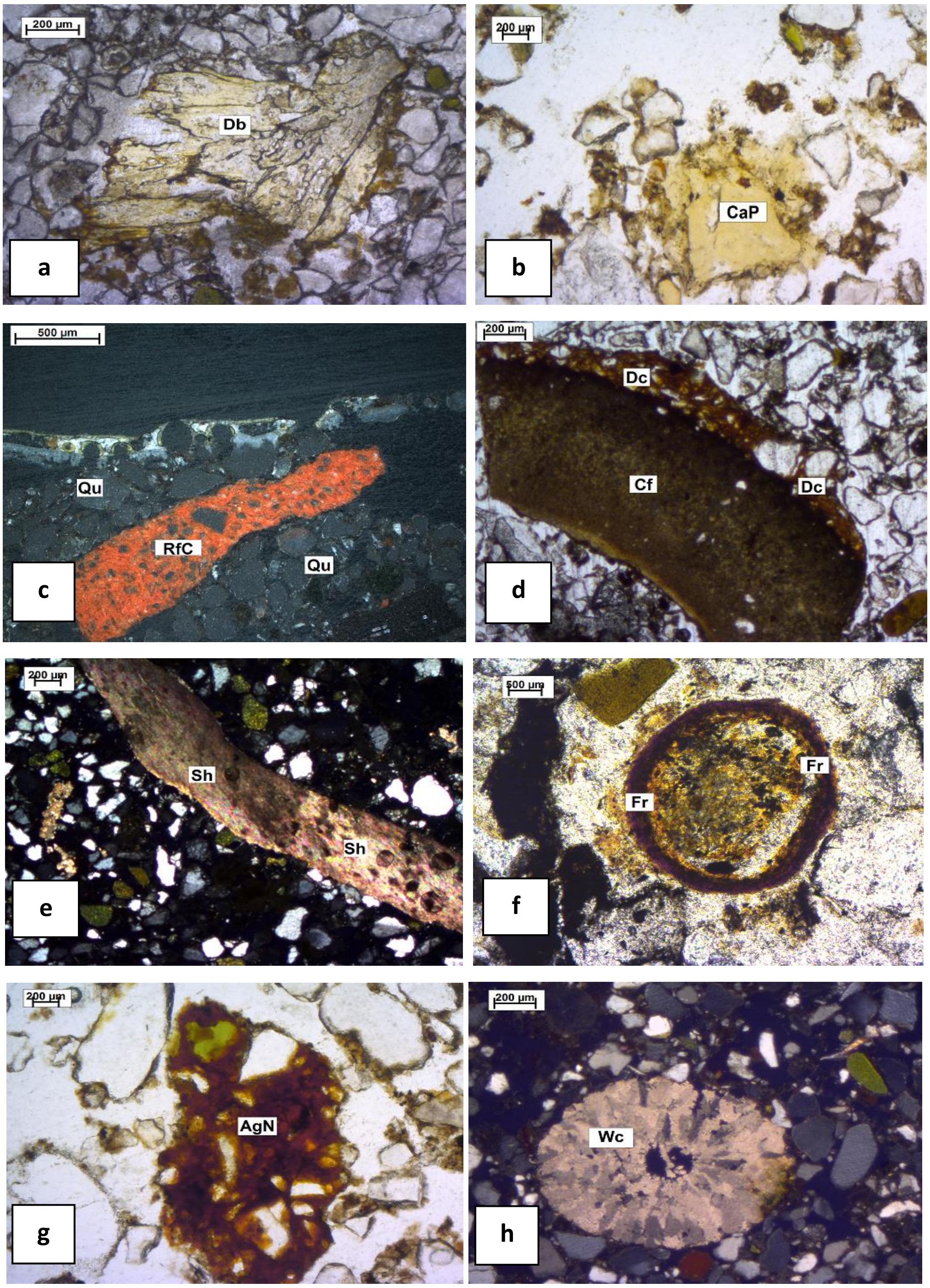


Figure 28: Coarse mineral and organic material and pedofeatures observed in the Mechelen graves: a) Degraded bone (Db) fragment from Grave G26 pelvis region, PPL; b) Calcium phosphate nodule {analysed by SEM-EDS](Cp) from Grave G27 skull region, PPL; c) Rubified clay (Rc) from the C1 site control, DF; d) Chert (Cf) displaying a thick dusty coating (Dc) from the C1 site control (PPL); e) Degraded mollusc shell (Sh) observed in the lower layer graves (Grave 422, C2 grave fill control) (XPL); f) Fe/Mn (Fr) impregnated root (as determined by SEM-EDS) from lower layer Grave 422, below the feet region (PPL). g) Aggregate redoximorphic nodule (AgN) from the Grave G27 feet region (PPL); h) Calcitic earthworm excremental (Wc) pedofeatures (Ex) Grave G26 skull region, (XPL)

3.4.4 Quantitative micromorphological analysis

3.4.4.1 *Point counting analysis*

The point counting results are shown in

Table 14. This indicated similarities in the percentage void space counted and the coarse mineral material between the different orientation cuts of the resin blocks {Chapter 2, Section 2.4). High levels of excremental pedofeatures were counted in the regions below the chest and below the pelvis regions in Grave 423, and in the C3 control of Grave 2037. Fragmented bone was counted in the highest percentage (>4%) in two graves (Graves 423 and G26) with other samples having a markedly lower frequency (<2%). There was a clear difference in the percentage of void space and percentage of coarse material between ROI1 and ROI2 across most graves. This was particularly evident for the voids of Grave 422. The coarse material in ROI1 and ROI2 around the foot region of Grave G27 also displayed a considerable difference.

In

Table 14 there was evidence to suggest that higher levels of disturbance had occurred in Graves 423 and G26 due to the frequency of fragmented bone. The presence of excremental pedofeatures identified in Grave 423 also implied an increase in organic matter within the sample regions below the chest and pelvis regions. This could correlate with the high frequency of fragmented bone in these areas.

Table 14: Results of the point count analysis on orientations 1 and 2 from all graves and controls from Mechelen.

		Region of Interest *(ROI)*	Voids	Nodules	Coatings	Bone	Excremental Pedofeature	Coarse Material	Coarse Organic	Fe Staining	Undifferentiated
	C1		4	1	0	0	0	69	2	0	24
	Skull		27	0	1	0	1	57	2	2	10
G26	Pelvis		9	0	0	1	0	72	2	2	15
	Foot	*ROI1*	17	1	1	1	1	70	1	1	7
		ROI2	61	0	2	13	0	10	1	0	13
G27	Skull		26	2	1	0	0	53	3	0	15
	RPW		20	0	0	1	0	55	3	2	19

	Feet	*ROI1*	27	0	0	0	0	60	1	1	11
		ROI2	27	0	1	0	0	60	1	1	10
	C2		10	1	2	1	1	61	4	3	1
	C3		5	1	1	0	0	73	4	2	7
	B.Skull		23	0	2	0	0	72			14
	Skull*		15	2	3	1	0	55	4	2	3
	Pelvis	*ROI1*	23	0	0	0	0	68	2	2	18
		ROI2	26	1	1	0	0	61	1	1	5
	Sacrum	*ROI1*	28	1	1	0	1	46	2	4	9
		ROI2	10	1	1	0	2	54	3	2	17
422	R.Hand	*ROI1*	10	4	1	0	0	48	4	7	27
		ROI2	24	2	0	0	0	43	9	1	26
		ROI3	26	1	2	0	0	57	3	2	21
	L.Hand		33					51	1	2	9
	L.Foot		27	1	0	0	0	53	3	1	13
	B.Feet	*ROI1*	17	1	2	0	0	49	4	4	15
		ROI2	13	1	1	0	0	46	3	5	23
	C3		26	1	1	0	1	56	0	1	14
	B.Skull		18	0	0	0	0	63	2	1	16
	Skull		23	0	0	0	0	64	1	1	11
	B.Chest		13	1	0	0	0	70	1		12
	B.Sacrum	*ROI1*	11	0	1	0	0	68	1	3	16
		ROI2	18	0	0	0	0	64	3	1	14
	R.Hand	*ROI1*	22	0	0	0	0	65	2	1	10
384		*ROI2*	25	1	0	0	1	60	1	1	11
	R.Hand**	*ROI1*	16	3	2	0	0	63		0	16
		ROI2	27	0	0	0	0	63	1	0	9
	L.Foot		31	0	0	0	0	61	1	0	7
	L.Heel										
		ROI1	24	0	0	0	0	62	10	0	4
		ROI2	30	0	1	0	0	56	0	2	11
	C2	*ROI1*	36	0	0	0	0	46	1	0	17
	C3	*ROI2*	25	0	1	1	0	61	2	0	10
	Skull		38	0	1	0	11	43	1	0	6
2037	Skull**		28	0	1	1	0	56	2	1	11
	Skull**		33	0	1	0	0	56	1	1	8

	Sacrum		**45**	**0**	**1**	**0**	**0**	**45**	**1**	**1**	**7**
	L.Foot		**34**	**0**	**1**	**0**	**2**	**47**	**7**	**0**	**9**
	L.Foot**	***ROI1***	**33**	**1**	**1**	**0**	**0**	**56**	**2**	**0**	**8**
		ROI2	**21**	**2**	**1**	**0**	**0**	**60**	**3**	**3**	**10**
	B.Skull	***ROI1***	**20**	**1**	**2**	**8**	**0**	**55**	**5**	**34**	**6**
		ROI2	**25**	**2**	**2**	**0**	**0**	**66**	**1**	**4**	**0**
	Skull		**17**	**0**	**1**	**0**	**0**	**69**	**1**	**1**	**11**
	Skull**		**28**	**10**	**2**	**0**	**0**	**48**	**1**	**1**	**10**
414	**Pelvis**		**19**	**0**	**1**	**1**	**0**	**57**	**5**	**2**	**15**
	Pelvis**		**13**	**0**	**3**	**0**	**0**	**69**	**1**	**2**	**12**
	R.Hand		**17**	**0**	**0**	**1**	**0**	**66**	**4**	**1**	**11**
	C3		**29**	**0**	**0**	**0**	**0**	**36**	**0**	**1**	**34**
	C3**		**27**	**1**	**2**	**0**	**0**	**64**	**1**	**1**	**4**
415	**Skull**		**34**	**1**	**1**	**0**	**0**	**49**	**0**	**0**	**15**
	R.hand		**19**	**2**	**0**	**2**	**0**	**58**	**1**	**0**	**18**
	R.hand**		**14**	**1**	**0**	**0**	**0**	**60**	**1**	**0**	**24**
	L.Foot		**26**	**0**	**0**	**0**	**0**	**63**	**2**	**0**	**9**
	C3		**28**	**1**	**0**	**0**	**0**	**55**	**2**	**1**	**13**
	Skull		**29**	**0**	**0**	**0**	**0**	**57**	**2**	**0**	**11**
	Skull**		**27**	**0**	**0**	**0**	**0**	**55**	**3**	**0**	**15**
	B.Chest		**23**	**0**	**0**	**0**	**0**	**66**	**1**	**1**	**9**
423	**B.Pelvis**		**30**	**1**	**0**	**1**	**2**	**48**	**6**	**3**	**9**
			43	**0**	**0**	**4**	**13**	**17**	**12**	**0**	**11**
	B.Pelvis**		**59**	**0**	**0**	**2**	**19**	**14**	**5**	**0**	**1**
	Feet		**16**	**1**	**0**	**0**	**0**	**59**	**5**	**2**	**17**
	Feet**		**29**	**1**	**1**	**7**	**0**	**48**	**6**	**2**	**8**

** identifies thin sections were ROI are less than stated in Chapter 2 Section 2.5.2.1 ** identifies the secondary [parallel] cut to the resin block as stated in Chapter 2.*

3.4.4.2 *Image analysis of the void space*

The results of the image analysis are displayed in Figure 29.

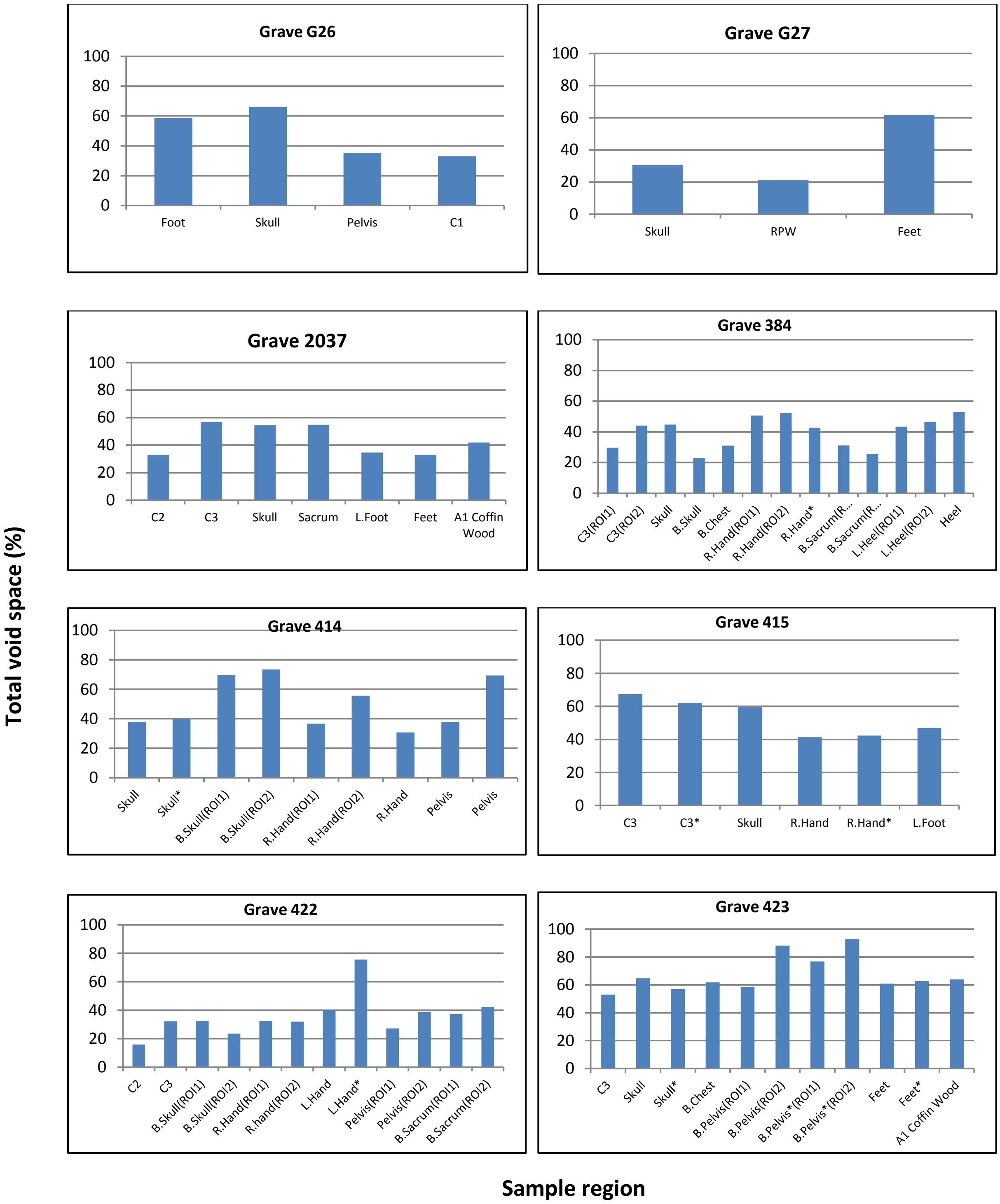


Figure 29: Total void space, as a percentage of total area of the sample, identified through the application of image analysis to soil thin sections from the burial sampling regions and control samples of each Mechelen grave (* indicates the second parallel cut taken from the resin block sample; B: Prefixing a sample region denotes a sample collected below the body)

The lowest frequency of voids was in the burial samples below the skull region, particularly in Graves 384 and 422, with the C2 control from Grave 422 also displaying a low percentage of void space (Figure 29). The greatest frequency of void space was in Grave 423 in the pelvic region, with the parallel burial sample having *c.*90% void space. There was a greater frequency of void space in the burial samples from all graves except Grave 415, than in C2 and C3 control samples. The perpendicular and parallel cuts have a similar percentage void area, with the left hand sample of Grave 422 being the only area that displayed a notable difference in void frequency (an increase of 50%).

The increased amount of void area in the burial samples compared to the control samples, suggested greater bioturbation. This could have resulted from increased organic matter emanating from the burial. The parallel and perpendicular cuts from the same block did not provide a difference in the percentage void area except for Grave 414, the only one with a significant difference. The identification of several regions of interest (ROI) within samples indicated there had been movement with the presence of different soil fabric type. This was measured particularly across the hand and pelvic region from Graves 384, 414, 422 and 423, the lower layer of the excavation.

3.4.5 SEM-EDS multi-elemental analysis

3.4.5.1 *Void analysis of the oxygen to carbon ratio (O:C)*

The O:C ratios were analysed, as discussed in Chapter 2, Section 2.6.1.1, to determine C distribution in the fine material surrounding the channel void and within the peds. An elevation in C may suggest residual organic matter from the decomposition process had been retained (Forbes *et al.* 1953; Sollins *et al.* 1988). The identification of increased C may address one of the main objectives, to identify decomposition products derived from the burial in the burial soils.

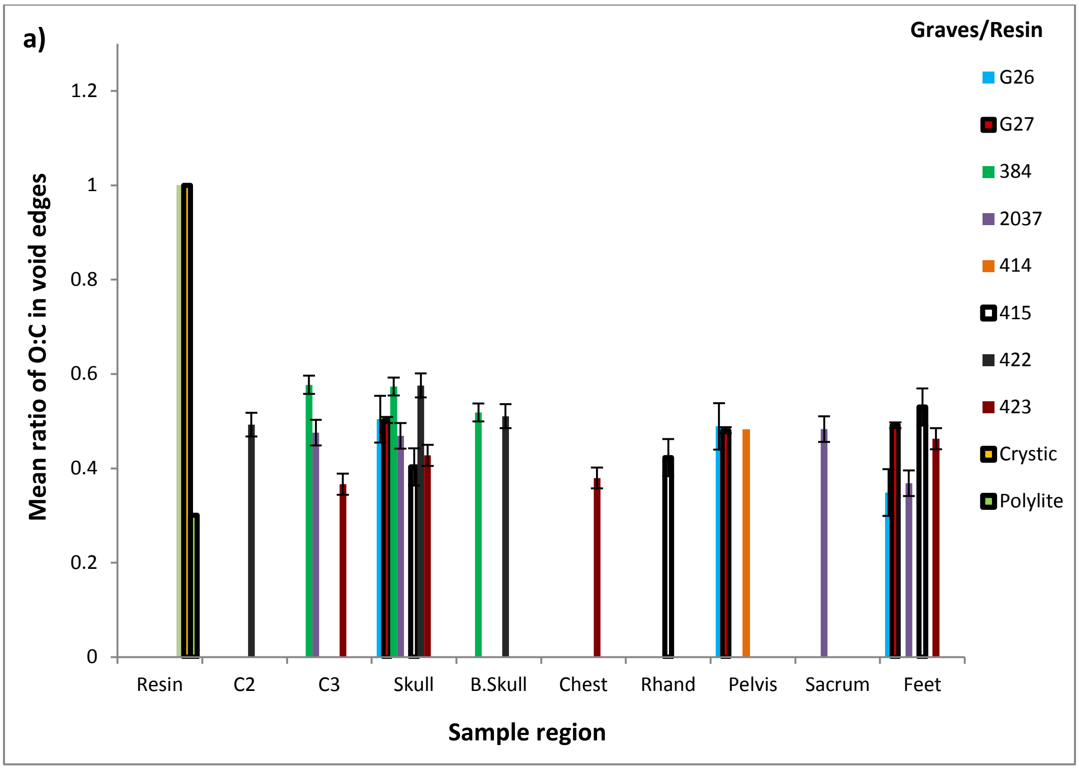
The mean O:C ratio in the fine material of the inter-pedal channel void edges, identified in the Mechelen graves, and the mean O:C in the fine material within the peds is displayed in Figure 30. The lower the mean ratio of O:C displayed the greater the level of carbon within the sample region of the grave.

Figure 30a shows the data obtained from the fine material surrounding the inter-pedal channel voids, with the lowest O:C ratio (the highest levels of C) in the C3 control from Grave 423 in the lower layer at Mechelen, with the lowest levels of C (high O:C ratio) in skull region of Graves 422 and 384 and the C3 control sample from Grave 384. Grave 423 exhibits the highest levels of

C in the void edges of the C3 control, chest and skull regions. The highest C (low O:C) levels in the foot region is displayed in Grave 2037.

Figure 30b displays the level of O:C in the fine material within the peds away from the channel voids. The lowest relative levels of C can be observed in the skull sample region of Grave G26, with the highest relative levels of C being exhibited in the feet sample region of Grave G26 and the chest region of Grave 423.

The analysis of the O:C ratio of the fine material at the void edges suggested that the highest levels of C were identified in both the fine material of the voids and peds of Grave 423, located in the lower layer of the excavation. Grave 422 also in the lower layer of the excavation displayed the lowest level of C at the void edges. In comparison, the level of C within the fine material in the centre of the peds was of Grave G26 suggested that the upper layer grave contained a greater level of carbon. The highest level of C was found in the foot region and correlates to the higher frequency of redoximorphic nodules observed in this region and the higher concentrations of P. The results of the O:C ratio pointed to the retention of C in the voids of the lower layers graves and the translocation of C away from the voids edge into the peds in the upper layer graves, with only Grave 423 being the exception, having similar levels of carbon in both areas.



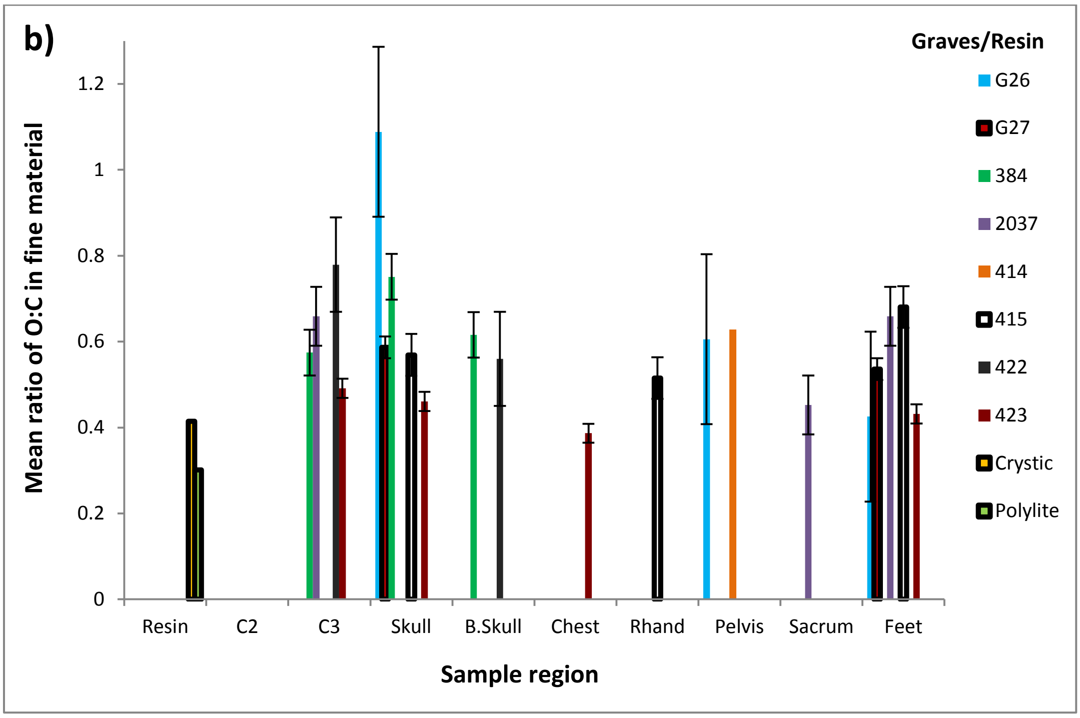


Figure 30*:* Mean ratio of O:C in the crystic/polylite resin and in the graves and controls from sampling points across the Mechelen site: a) Channel voids; b) Ped fine material. The error bars represent 1 standard error of the mean

3.4.5.2 *Redoximorphic nodules and fine material: Phosphorus to Iron ratio (P:Fe)*

The concentration of P, which is the second most abundant mineral in the human body, after calcium (Tortora and Grabowski 2000b), was analysed in the fine material and redoximorphic nodules across the burial and control samples. The aim was to identify the distribution of degradation product from human inhumations and determine whether the decay products remained in the fine material or translocated away through co-precipitation with Fe in nodules.

Figure 31 displays the mean P levels in the fine material across the control and burial samples from the Mechelen graves. The highest level of P can be seen in the hand region of Grave 384, whist the below skull region also in Grave 384 displayed high levels. The C2 and C3 control samples were lower in P than that of the burial samples, with most skull and foot regions across the site displaying increased levels. Grave 422 presented a significantly higher concentration of P.

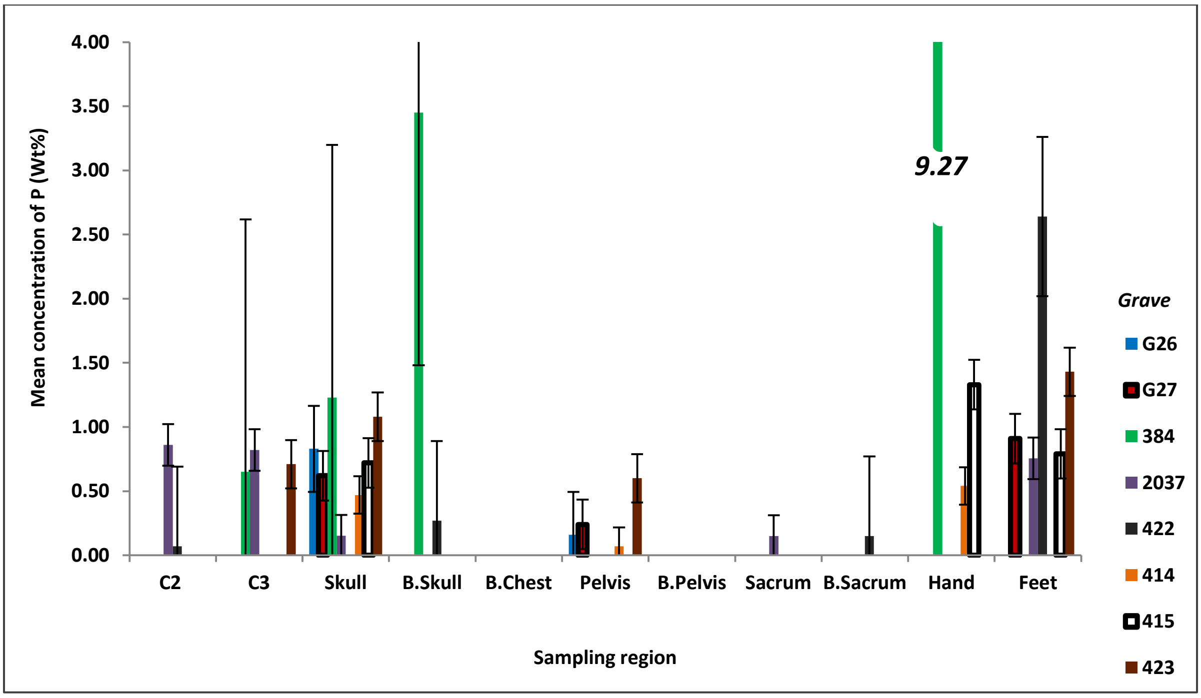


Figure 31: The mean concentration of P in the fine material across the control and burial samples from the Mechelen site. The error bars represent the mean of all data displayed to 1 standard error

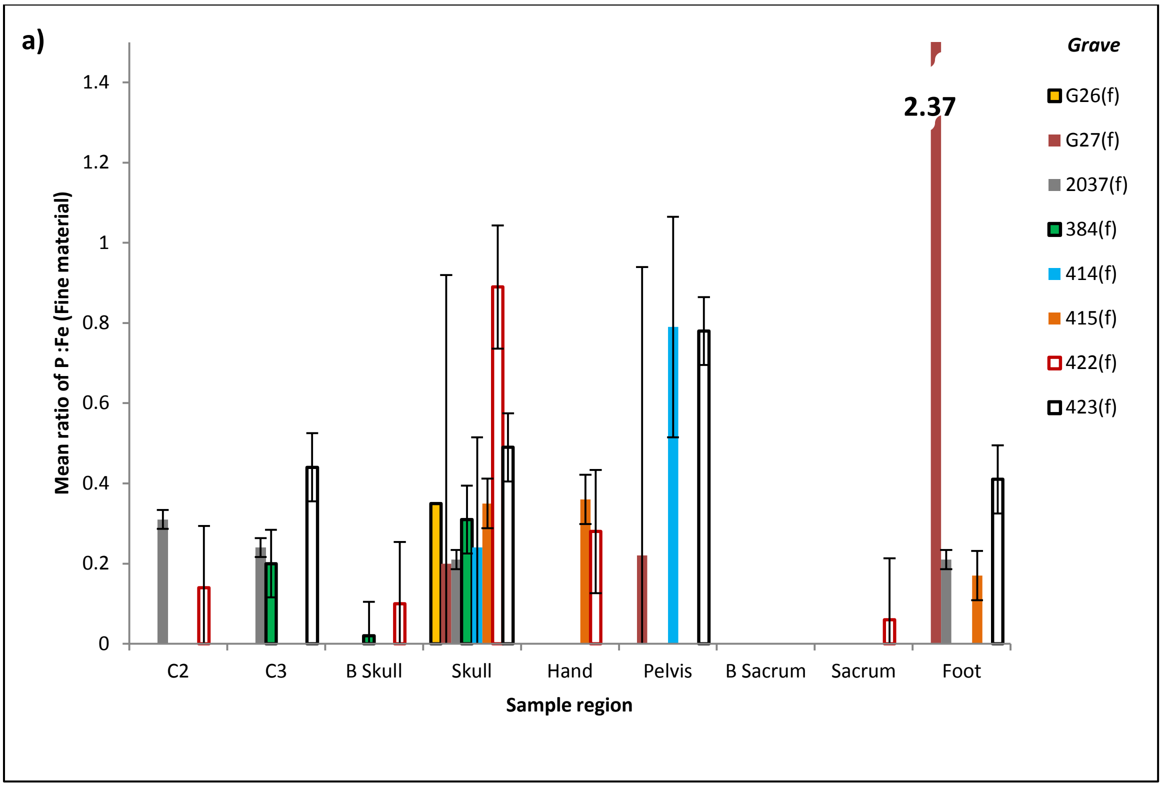
Nodules and fine material throughout the graves and control samples at the Mechelen site were analysed employing the mean ratio of phosphorus to iron (P:Fe). Figure 32a and 32b displays the P:Fe mean ratios in the fine material and redoximorphic nodules across the control and burial samples from the Mechelen site. The fine material below the skull region in Grave 384 and below the feet region in Grave 422 display the highest P:Fe ratios (Figure 32a). Graves G26 and G27 in the upper layers of the site have little similarity with the lower graves (Graves 414, 422 and 384), displaying a higher ratio of P:Fe.

Figure 32a displayed the P:Fe mean ratios in the fine material and redoximorphic nodules across the control and burial samples from the Mechelen site. The mean ratio of P:Fe displayed in Figure 32b showed increased levels in the redoximorphic nodules of the sacrum region the highest ratio was in the hand region, with C2 controls in Grave 2037 displaying similar ratios to the skull region samples. Grave G27 demonstrates the highest ratio in the pelvis region.

A significantly high ratio of P:Fe was displayed the fine material of the hand region in Grave 384 (Figure 32a). The P: Fe was similar in the control, skull and pelvis regions of Grave 423, whilst Grave 422 also showed similar ratios in the skull, hand and feet regions. The below pelvis and below chest sample regions indicate a P:Fe ration of zero in all graves.

The development of redoximorphic nodules across the burial and control samples indicates there has been reduction and oxidation condition occurring. This is particularly noted in the sacrum region and especially the foot region of Grave 2037. The increased P:Fe mean ratios in these regions of the burials could suggest these conditions have occurred, with the relative levels of P in the regions being elevated as a result of pooling from degradation products, which have emanated from the body. The significantly increased levels in the foot region of Grave 2037 would point to pooling of putrification fluids and an increase in microbial activity in the coffin, whilst redox conditions occurred, thus this could have provided the factors required in the translocation and co-precipitation of P with available Fe (Janaway 2002 352; Haglund *et al.* 2001).

Error! Reference source not found.a indicated there was an increased in the ratio of P:Fe in the ine material of the hand region in Grave 384, this could suggest redox conditions had not occurred as intensely as in other graves; the P from the degradation of the body being released into the fine material surrounding the hand region. This may in turn, through anion absorption have been retained on the surface of the soil minerals such as Fe in non-occluded forms (Schlesinger 1997 98).



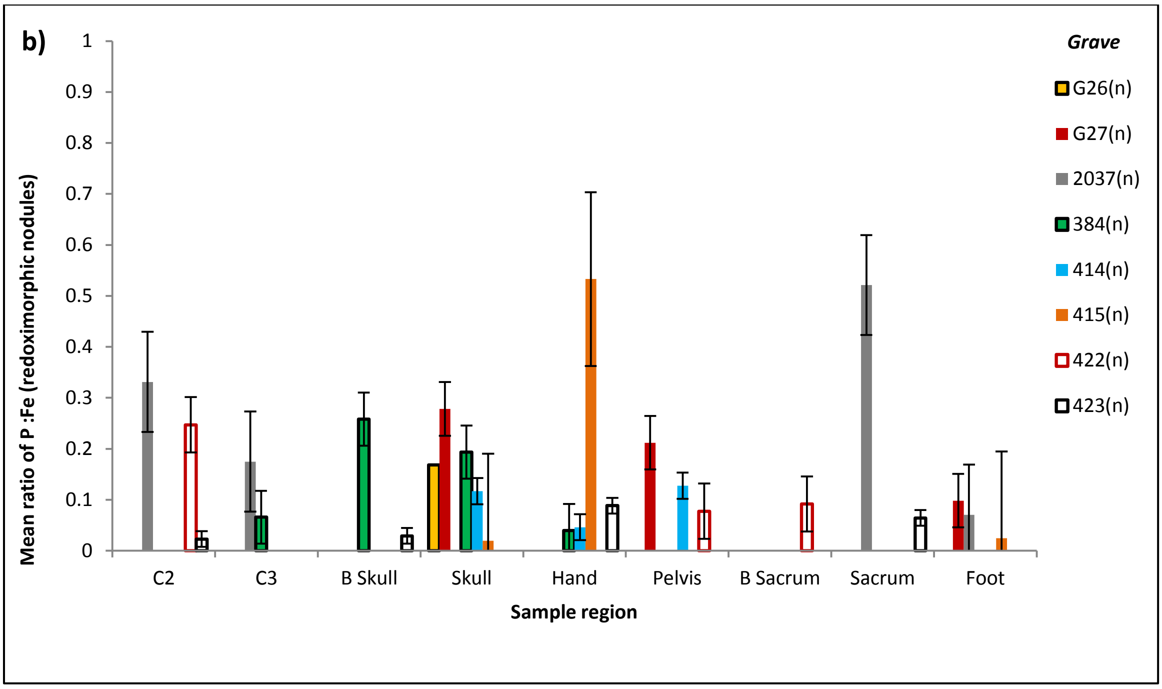
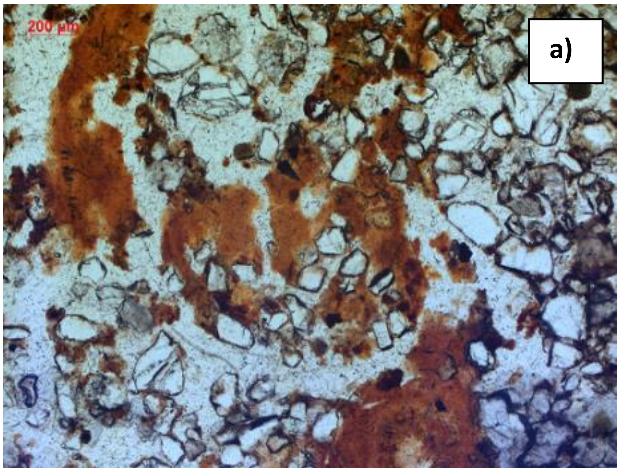


Figure 32: The mean ratio of P:Fe in the: a) fine material (f) and; b) redoximorphic nodules (n) of all burial and control samples from the Mechelen site. The error bars represent 1 standard error of the mean

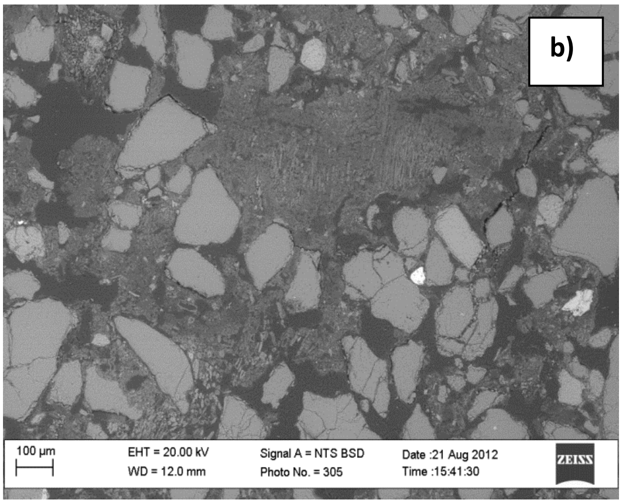
3.4.6 Artefacts



a) Micromorphological Image

Fabric impregnation by poorly ordered clay, as observed under PPL. The sample was from under skull samples from Grave 414.

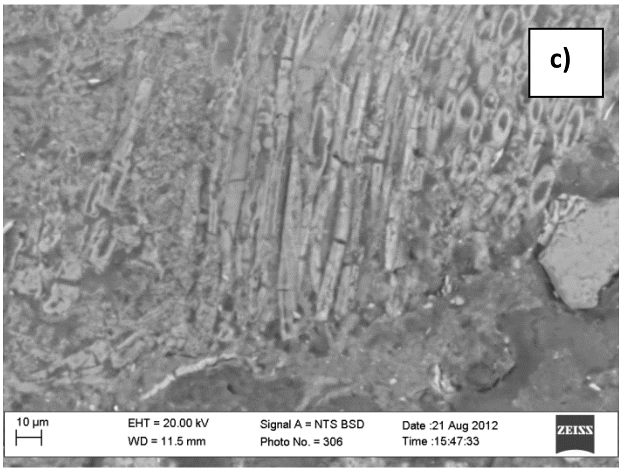
In XPL clay domains appeared aligned to the structure unseen in PPL, following a cross-hatch pattern



b) SEM-EDS Image

Image of the same feature

Cross hatching was detected at this magnification.



c) SEM-EDS Image

Higher magnification of the same feature of images ***(a)*** and ***(b)***. Phytoliths appeared aligned parallel with each other.

Figure 33*:* Micromorphological image (a) Poorly ordered of clay impregnation (PPL) from Grave 414 (below the skull), (b) SEM-EDS back scatter electron image of the same area and (c) SEM-EDS back scatter image of same area at higher magnification demonstrating alignment of phytoliths

SEM-EDS analysis initially identified the object seen in Figure 33b in the groundmass of the sample, found under the skull of Grave 414. The image in Figure 33c at high magnification showed the alignment of inter-woven, cylindrical, phytolithic-like remains of <10 µm in diameter, indicating that they were initially from stems of leafy flora (Thwaite 2006). Further examination of the thin section under PPL initially suggested the inclusion was seemingly poorly ordered clay material, but with the application of XPL showed that the clay domains were arranged in a cross-hatch pattern and not cross-striated. The region of interest was compared to several textile sources in the University of York reference collection: hemp, cotton, flax and wool. Elemental signatures pertaining to these textiles were not detected. There was no increase in elemental signatures of carbon and oxygen with only elevated levels of Fe being detected, whilst silica (Si) was present in all samples because of the high frequency of quartz. The images and elemental analysis of the textile-like material could not conclusively determine the remains to be phytolithic; the textile could have been pseudomorphic. The development of a pseudomorphic textiles occurs when the textile is enveloped by soil minerals, Fe_2O_3 and $Fe(OH)_2$, as identified in the Figure 33 (Janaway 2002 411; Sibley and Jakes 1982).The encasing of the textile in soil minerals would allow degradation of the organic matter; thus only the mineral signature of the soil could be detected during elemental analysis. Although, the evidence points to the possible utilisation of textiles below the skull during burial, the origin of the artefact, whether phytolith or pseudomorphic, could not be conclusively ascertained.

3.4.7 Summary and discussion: Mechelen

The general location of the Mechelen excavation was marked by a localised calcareous sand dune in an otherwise wet and sandy area.

3.4.7.1 *Site conditions*

The Mechelen site, within a centre of high urban population and located below the capped surface of a car park was characterised by high levels of anthropogenic indicators, such as charcoal and building material, these were observed in all control and burial samples across the site (Figure 28c and e) (Table 13). The proximity of the graves and intensity of burials over three layers suggested the interments had incurred disturbance, not only through the removal of upper covering layers but within the grave fill. This was confirmed through macro-analysis undertaken on the site, with fragmented bone and rubified clay mixed throughout the stratigraphic layers (Van de Vijver 2011).

Excavation activity had occurred on the site over several seasons with the redistribution of over-burden preventing the collection of undisturbed soil control samples, resulting in the C1 site control samples being collected beyond the boundary of the graveyard and from highly disturbed building material and road rubble, thus it did not offer a suitable comparison with grave samples. The sample was collected and catalogued to comply with the list of control samples that had to be obtained during sampling and was believed to have contained suitable information to compare the burials to. However, as a result of the urban location high levels of contemporary construction had brought foreign regolith into the area, whilst sealing in homogenising locally developed soil.

General patterns between site control (C1) samples in comparison to the grave fill controls (C2 and C3) and the burial samples in the upper and mid (Graves G26, G27 and 2037) and the lowermost (Graves 384, 422, 423, 414 and 415) layers indicated that the local soil parent material identified differed to that of the C1 site control. Sedimentary rock fragments were observed equally in both C1 site control samples but not in the grave fill controls or sample regions around the burials, where quartz, chert and glauconite predominated.

This suggests that although the C1 site control samples could not be used as valid comparison material in the investigation, soils sealed under the construction layers, within the grave fill, closer to the graves, could be employed as valid grave fill control material. The prolonged use of the site further justified the use of grave fill controls (C2 and C3) as functional comparisons. Pedogenesis had occurred in the grave fill controls concurrently with the actual burial samples. Thus comparisons could be drawn between soil affected by burial decay and soil that had not been affected.

3.4.7.2 *Pedogenesis and preservation*

The coarse mineral and rock material within the grave fill controls and the burial samples reflected the composition of the parent material. Micromorphological observation identified different pedogenic features along with coarse organic fragments: platy and sub-angular peds, dusty coatings, redoximorphic nodules and speckle *b*-fabric (Appendix 3). A high degree of soil development, as characterised by sub-angular blocky peds delineated by inter-pedal channels parallel to the ground surface, were observed in most graves. Further ped development was indicated by elongated platy peds (Figure 27), typically associated with compaction (Milnes and Farmer 1987). They were observed in Grave 384, a lower layer grave, but were more commonly found in the upper-and mid-layers (Grave G26, G27, and

2037). Development of the peds in the upper-and mid-layer graves may correlate with anthropogenic interaction, and could relate to high levels of compaction (Oades 1984) during the development of parks and car parking around the cathedral area.

Most grave fill controls (C2 and C3 controls) and burials across the site displayed degraded ferruginised root and amorphous organic material in preferential areas of graves , particularly around the pelvis and skull regions, where inter-pedal channel voids were present and ped development was moderate to strong (Table 10a). The pedogenesis in the pelvis and skull regions suggested the possibility that root penetration had favoured zones with high organic residue. There was a greater development of void space in the C2 and C3 control samples in Layer 3 and 4 than observed in the upper grave fill control samples from the Layer 1 graves. This could indicate that there has been greater levels of bioturbation within the lower grave fill control samples. The increased nutrient availability as a result of translocated decay products, from graves in the upper layers, may have allowed for increased root and meso-faunal activity, forming channels in planes of weakness in the aggregates (Phillips and FitzPatrick 1999). Conversely, the degree of ped development in Grave 422 was low, with apedality in the skull, pelvis, hand and feet regions, areas where degraded amorphous organic matter was observed. The apedality in this grave initially suggested low levels of organic matter, although observed during micromorphological investigation, thus pointing to increased aggregation associated with its retention (Oades 1984). Ped development within these particular samples regions may simply encompass a large area (i.e. the complete thin section), thus planes of weakness would have been absent in these particular sample regions. On the other hand the size of the aggregate would suggest greater planes of weakness would be present (Oades 1993). It was evident that organic matter had been present in these particular sample regions (Grave 422: skull, pelvis, hands and feet regions; Grave 423: pelvis region), with the skull region sample displaying calcitic worm excrement. This evidence indicates that there had been bioturbation but this is not supported by the evidence for inter-pedal channels and ped development. The only possible explanation, as a result of the considerable evidence is; apedality in these particular sample regions could be associated with the fracturing of peds through sampling, transportation and manufacture of the thin sections.

The speckled *b*-fabric observed in the Mechelen graves indicates the random arrangement of clay domains, this may have occurred through the re-arrangement of previously aligned clay particles, either through bioturbation or external reworking of the soil, possibly during grave digging activity, as identified in the truncation of Grave 2037 (Figure 22), however this cannot be confirmed. Alignment of clay domains may not have taken place prior to the disturbance event: the processes of shrinking/swelling from wetting and drying a factor in the development of the fine material and its resulting striated appearance under XPL (Dalrymple and Jim 1984). However, these processes may have been prevented by the sealing of the site, through urban development.

The development of dusty coatings suggested localised levels of surface disturbance, as a result of their development in different sample regions of the graves and in different layers of the site (Table 13). The removal of surface layers during burial activity in adjacent graves or construction activity in the surrounding area may have been the mechanism for a vertical translocation of fine clay and silt particles, in soil water, through the profile. It can be hypothesised the development of the coatings, although providing evidence of disturbance, cannot be characterised by one singular event. The location of the coatings within different burial layers across the site would point to different disturbance events, with coatings being observed in the upper, middle and lower layers of the site a difference in depth of around 2-3 m. The movement of fine particles from a single disturbance in the upper/surface layers of the site would have required a high level of soil water to transport the fine material through the soil to the lower graves. The capping of the site through the development of a car park could have reduced the translocation potential of the fine soil particles within soil water. Furthermore, the development of coatings could be derived from internal collapse of the coffins or soil infill around the particular sampling regions, providing movement within the grave itself. The soil particles being translocated through the proceeding rainfall events once the soil surface directly above the grave had been exposed allowing soil water to percolated through to the sample region.

Noticeable differences in the degree of organic matter degradation between the upper and lower layer graves were identified, with areas of highly degraded amorphous organic matter in the lower layers, whilst Fe and manganese (Mn) ferruginised root material in the lower Layer 4 graves (as confirmed by SEM-EDS analysis), demonstrated little birefringence. The ferruginisation of the root material may have masked the cellular birefringence in lower layer graves, to a greater degree than that of the upper layers, which has not allowed degradation levels within root fragments to be determined (Babel 1975 454). This was particularly evident in the upper layers, which still displayed high levels of birefringent cellulose under XPL, especially in Graves G26 and G27, indicating the low levels of degradation within the root fragments, whilst displaying little ferruginisation. The presence of both Fe and Mn in the roots suggested that there could have been prolonged periods on waterlogging (Lindbo *et al.* 2010 138) in several areas of the lower levels graves. This could have provided the reduction and oxidation environment in the burials for the dissolution and precipitation of Fe, with prolonged waterlogging providing conditions for the precipitation of Mn.

The increased levels of root material within the grave samples, particularly in the pelvis and foot regions may have been the cause of localised disturbance and the high frequency of fragmented bone observed across the control and burial samples. It was suspected there could have been increased levels of organic matter particularly in Region 2 around the fleshy parts of the burials; derived from burial decay, thus movement of the bone through bioturbation (Canti 2003). High levels of organic matter from decay within the burial may provide a nutrient-rich environment that could favour root development (Forbes 2008a 206). The increase in fragmented bone around Region 3 of the burials may also be related to the increased number of bones that comprise a human foot (Mader 1998 217).

3.4.7.3 *Analytical performance*

The characteristics of the fine material surrounding the large channel voids parallel to the ground surface, as denoted in Section 3.4.5.1 above, suggested that decay material had been transported within soil water through the inter-pedal voids leaving residual decay products in the surrounding fine material (Figure 30). Increased carbon (C) residues, measured through the O :C ratio, were distinguishable across several sample regions, with levels in the upper layer Grave G26 concentrated in the fine material surrounding the foot region.

The C in the fine material within the internal fine fabric of the peds showed overall similar ratios to those identified in the fine material of the voids. The increase was, however, particularly noted in the C3 control, chest and skull regions of Grave 423, although it was also observed the skull, pelvis and foot regions of Graves 422 and 384, and all graves in the lower layers.

The levels principally increased in the fine material of the voids in C3 control of Grave 423. This could be a result of decay product that had translocated from another grave or through possible analysis of some micro-charcoal fragments, identified during micromorphological observations, throughout the controls and burial samples. Each explanation for the elevated C levels in Grave 423 can be justified, with the most likely explanation being the latter: micro-charcoal residue.

The uniformity in the level of C residue between the fine material of the peds and the material surrounding the voids suggested there had been a similar level of C deposition and translocation through the fine material and the voids.

Depositional patterns of decay may be seen in all the burial samples through the co-precipitation of P in relation to the presence of Fe in redoximorphic nodules and compared to P:Fe in the control samples (Figure 32). The presence of redoximorphic nodules suggested that seasonal wetting and drying had occurred for some time across the lower and older levels of the site (Schaetzl and Anderson 2009 499). With the development of redoximorphic features in the upper layer, younger graves could also be linked to the incidence of platy peds in the upper layers, with parallel channels possibly slowing the drainage of surface water through the soil, encouraging the development of alternating reducing and oxidizing conditions (Schaetzl and Anderson 2009 20). On the other hand, increases in redoximorphic nodules were observed around the skull and foot regions of several burials with no correlation to depth or ped shape (Table 13). The development of nodules can be the result of reduction, translocation and oxidisation of Fe through seasonal wetting of the soil and the fluctuation of the localised water table and has been utilised for the determination of hydraulic potential (USDA-NRCS 2010). Further to this, the increased levels of organic matter may have encouraged microbial activity, which can also be a factor in the development of redoximorphic features as; decompositional microorganisms may catalyse electron transport from Fe^{3+} to the more soluble Fe^{2+}, thus Fe goes into dissolution with subsequent precipitation more likely. The burial environment around the inhumations could have provided increased levels of organic material in the grave, but especially around the areas of the pelvis and skull regions where there was a correlation to increased levels of Fe. The feet region and C2 control samples from Grave 2037 also display an abundance of redoximorphic nodules. The increased levels of redoximorphic features in the C2 control may be affected by surrounding burial decomposition, due to the compact nature of the burials in the graveyard, particularly in the later graves and the truncation of this particular grave (Grave 2037) (Figure 22). The increase in nodules in the feet region of Grave 2037, similar to that of Graves G26 and G27, may have indicated that the base of the grave had not been excavated on a flat plane, prior to the interment of the burial, thus allowing the decompositional organic fluids to flow away from the skull and pelvis regions and pool in the foot region. The redox conditions may have developed to a greater degree in the foot region of coffin before it lost integrity and the decay products flux into the surrounding soil (Janaway 2002 353). The mean P concentration in the fine material (Figure 31) across the burials was higher than in the control samples, with Grave 384 displaying significantly higher concentrations of P to the rest of the graves. This suggests there has been greater levels of P in this particular burial, thus translocation of P into the nodule would have been determined by the levels of Fe in the soil. The levels of P in the fine material suggests that was Fe levels of absorption onto the surface of surrounding soil minerals through anion exchange; and held in clay minerals and Fe/Al oxides (Schlesinger 1997 98).

3.4.7.4 *Artefacts*

The retention of burial artefacts at the micro-level was minimal, with low levels of wood-like fragments, possibly derived from coffin-wood. However, the wood like material was observed in both grave fill control and burial samples. The large majority of wood-like material was identified under dark field light as charcoal.

The artefact identified in Grave 414 (Figure 33) was shown to consist of aligned phytolith-like remains. Elemental analysis could not detect comparisons with the University of York reference collection suggesting the remains may have been pseudomorphic of the original material, from which they had taken their shape. The formation of pseudomorphic textile-like material, from the initial phytolith composition of cellulose based textiles such as cotton, linen and wode would require the fabric to be encased in iron oxides, leaving an external caste of the textile. This process would have been determined by the degradation of the body and, on the basis of the information from Janaway (2002 413) is believed to have occurred within the first initial years of decomposition. This suggested decay of the burial may have been fairly rapid, with the encasement of the textile possibly resulting from soil entering the coffined burial within this time scale.

3.5 The Cistercian priory, near Syningthwaite, Yorkshire

The excavation at Syningthwaite Priory was undertaken by the *InterArChive* project in 2009 following a previous large scale excavation during which *c*.100 bodies were located and removed from the site (undertaken by Dr Malin Holst, *pers. comms*). During the 2009 excavation the remains of an infant and two adult burials, and a fourth burial only yielding lower limbs, were exposed (Figure 34).

The site was located in a peri-urban location eight miles to the west of York and east of Wetherby, North Yorkshire. The priory had been established in the 12th century as a Cistercian monastery that housed around 12 nuns until the Reformation of the 16th century. After extensive building work in the 18th century, the priory was utilised as a family farm.

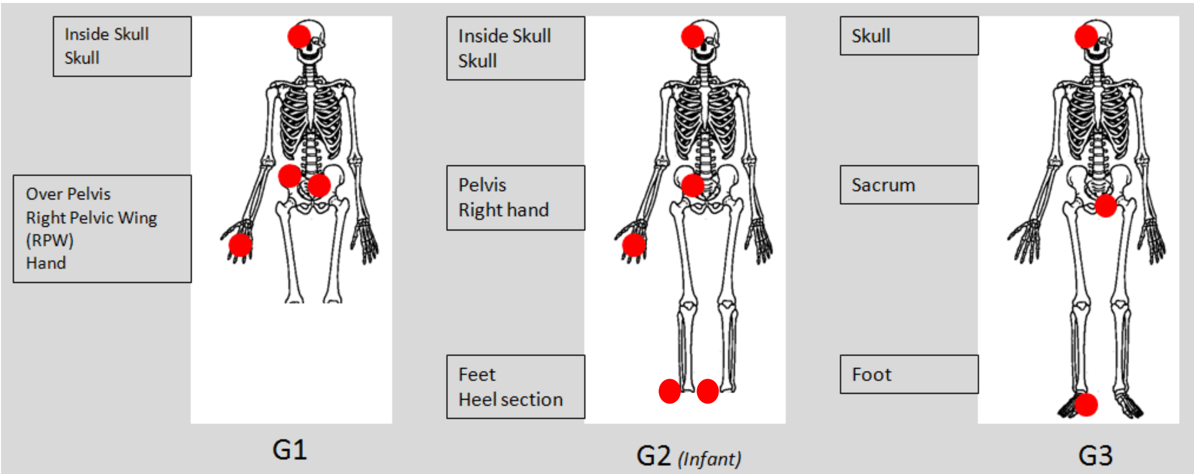


Figure 34: The internal configuration and sampling positions in the 3 graves: Graves G1 (bone missing below the knee) and G3 (both adult burials) and Grave G2 (foot bones missing) of an infant. The sampling points indicate the areas were undisturbed soil blocks were collected following the *InterArChive* sampling protocol

3.5.1 Sampling

Sampling was undertaken by a team from the *InterArChive* project, and included comprehensive control samples. The excavation provided the opportunity to broaden the sampling strategy with samples from within the skull cavity of two graves (Graves G1 and G2) (Figure 34).

3.5.2 Geology and macromorphology: Description and discussion

The site of Syningthwaite priory was located on the solid deposits of Sherwood Sandstone Group, and Glaciofluvial till comprising of sandstone, pebble sandstone and conglomerate, with small quantities of mudstone and siltstone (Haynes and Naidu 1998).The solid geology of Brotherton and Cadeby Formations were located to the west of the site and included the dolomitic limestone utilised in the building of the priory (Figure 35) (British-Geological-Survey 2012).

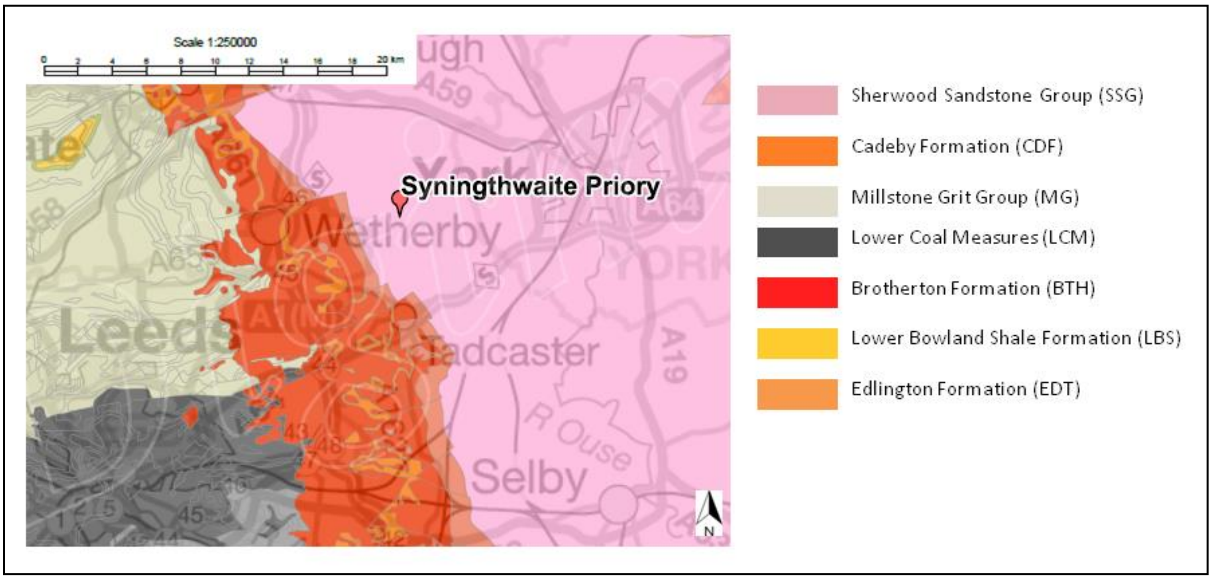


Figure 35: Geological map of the area of the Syningthwaite priory site (http://digimap.edina.ac.uk/geologyroam/geology).

Figure 36: The soil profile of the excavation pit with identifiable soil horizons, which have been described by employing Munsell colour (wet) and hand texturing (Munsell 2009)

Analysis of the pH from the bulk soil samples indicated a neutral pH range of 6-8 in all areas of the stratigraphy, control samples and grave samples. It is evident from

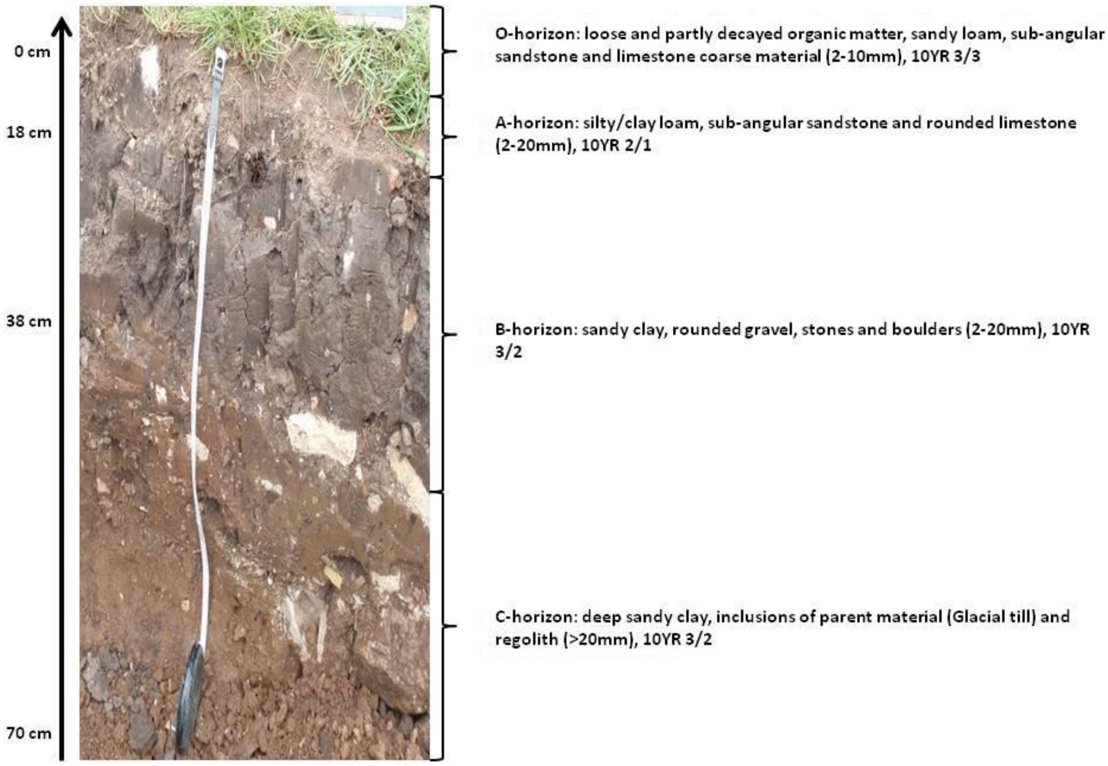


Figure 36 the colour of the soil changed between the horizons and structure and composition changed from granular with high levels of root litter in the organic O and A-horizon to blocky peds with high levels of parent material in the B and C horizons

The sandy texture of the soil may be linked to the Sherwood Sandstone Formation (

Figure 36) underlying the site, whilst the pebbly sandstone and conglomerate of the same formation was identified through hand texturing. The neutrality of the soil pH across the site could be indicative of the length of time the samples had been refrigerated, with the dispersal of CO_2 produced by microorganisms in the soil have resulted in a lower pH. The moderate degree of preservation of the skeletal remains, however, suggested soil neutrality to low alkalinity had been within the 6-8 pH range, with some bone friability during the excavation of the remains (Hedges 2002).

A summary of the main geological features, soil type and a summary of the micromorphological observations are displayed in Table 15.

Table 15: Summary table of geology, soil type, burials and micromorphological features observed at Syningthwaite

Context (Grave No)	*Position/type of burial*	*Geological features*	*Soil Type*	*Micromorphological Features*		
				Coarse Material	*Fine material*	*Post-depositional pedofeatures*
G1	14^{th}-15^{th} century Supine, adult coffined burial	Situated on the Sherwood sandstone Group with the Edlington formation to the west	Burials in the B-horizon were in a brown sandy/clay soil with rounded stone and gravel coarse material	Quartz (50%), calcite (20%) and chert (5%), all samples displayed bone, and charcoal (5%), with shell (2%)	Speckled *b*-fabric with striations in the C3 control, skull pelvis and inside skull	Redoximorphic nodules highest in the skull region, with dusty coatings highest in the hand region
G2	14^{th}-15^{th} century Supine, infant coffined burial			Quartz (40%) and vivianite (2%), bone, root and charcoal (2%) in all samples	Speckled/striated *b*-fabric throughout the control and burial samples	Dusty coatings in all control and burial samples but particularly in the skull region, with redoximorphic nodules in a high frequency around the skull region
G3	S14^{th}-15^{th} century supine adult burial with lower leg bones below the knee missing			Quartz (50%), calcite (5%) and chert (5%),with charcoal (5%) and shell (5%)in the control and burial samples	Speckled/striated *b*-fabric throughout the control and burial samples	Dusty coatings in the skull, with redoximorphic nodules in all areas control and burial samples, low in the foot region

3.5.3 Micromorphological analysis: results and discussion

All original micromorphological observations data from Syningthwaite are displayed in Appendix 3. Coarse material

Figure 37 presents the mean percentage frequency of the different coarse mineral and rock fractions of the soil in the thin sections from across the burial and control samples. Micromorphological analysis revealed unsorted, partially weathered quartz was the principal constituent of the coarse fraction (*c*.40%) in the control and grave samples. Sandstone and natural cement fragments were present in all control and grave samples, with small fractions of feldspar and limestone also observed throughout the graves and control samples. The $c/f^{50\mu m}$ distribution of the soil matrix was 60% coarse to 40% fine material (*c/f* 3:2). The nature of the coarse organic matter was different throughout the graves and control samples. The degradation levels of the fragmented bone were tentatively identified by considering the birefringence of the bone fragments under XPL, displaying bone suggesting varying levels of bone diagenesis across the control and grave samples (Entwistle *et al.* 2000). Moderate mollusc shell fragments (Table 18) and frequent micro-charcoal fragments (<50 µm) were in several control and the skull region of Graves

G1 and G2. The samples collected from inside the skull region demonstrated low levels of calcium phosphate-like features (identified through SEM-DS analysis) in Grave G1 (d), whilst secondary blue/green phosphate minerals identified as vivianite (PPL), were observed in the C2 control, but not in the grave samples. Degraded root fragments were recorded in the channel voids of all grave and control samples, with fungal spores identified in the right hand region of Grave G2. Calcite was most frequent in the C2 control (*c*. 20%) and skull region of grave G3 but was not visible in any of the C3 controls. Sandstone was not observed in the samples from inside the skull region of both Graves G1 and G2.

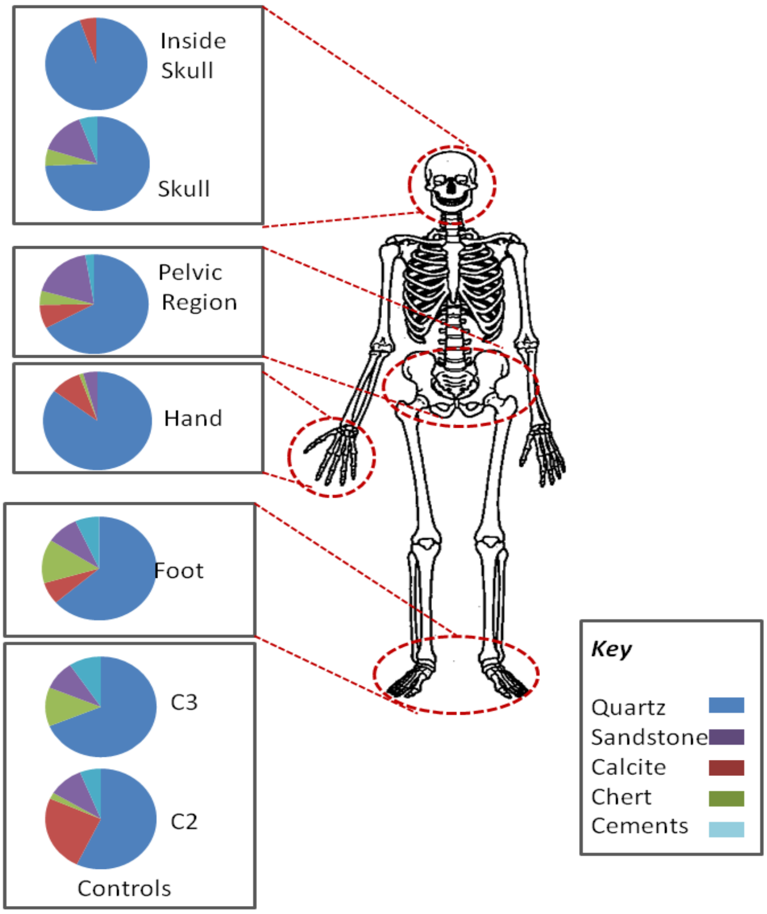


Figure 37: The mean distribution of mineral material throughout the three Syningthwaite burials and control samples

The high levels of quartz in the coarse material suggested the sand in the soil matrix was derived from the parent material. The fragments of limestone and feldspar were possibly derived from the Cadeby and Brotherton Formations, located to the west of Syningthwaite. Fragmented bone within the graves, with the highest levels identified in the foot region of Grave G2 indicated that there had been disturbance across the site. Although evidence of skeletal remains was not visible during normal excavation procedures, small fragments of bone were still present in the grave region. Increased levels of bioturbation may have been one of the factors that caused increased disturbance levels. The presence of vivianite (Appendix 3) could point to saturation with water and hydrological movement in the C2 control of Grave G1 together with a source of phosphate from the degrade bone. The frequency of shell fragments in the grave fill control and skull region samples of Graves G2 and G3 could have derived from several sources: 1) the result of domestic midden material as fertiliser on the agricultural land and the proximity of the burials to the priory buildings; 2) it may have been from limestone employed in the building of the priory; of 3) it was derived from the geological till material. The location of shell material (Table 18), only observed in the C2 and C3 grave fill controls and skull regions of Graves G2 and G3 suggested localised deposition of the midden material. The use of midden material as grave backfill may, therefore be unlikely as fragments of shell should have been broadcast across the graves and controls to a greater degree and as such have may derive from fragmentation of parent material. The derivation of the shell from fragments of limestone employed in the building of the priory could be a possibility, but it is likely the provenance of the shell was from the geological till.

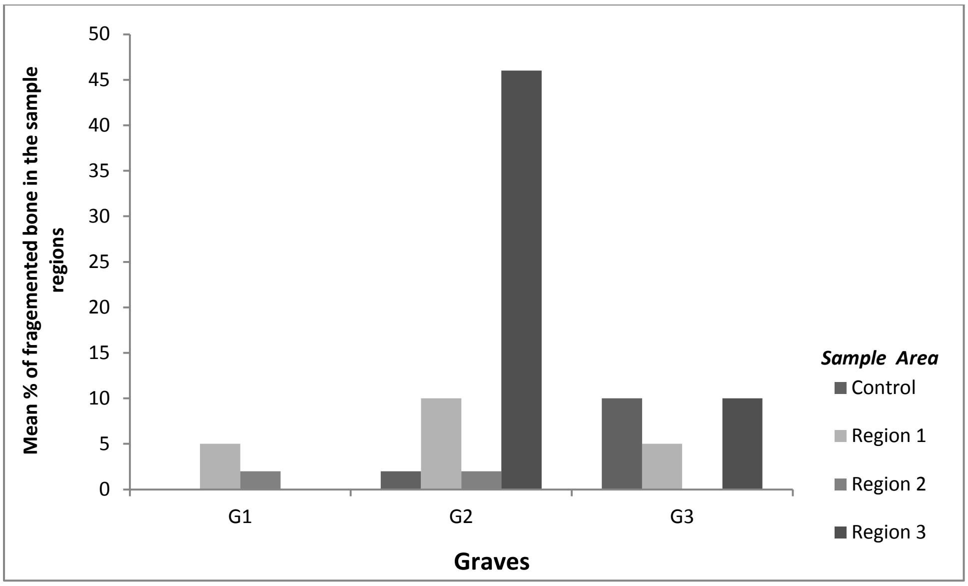


Figure 38: Frequency of fragmented bone in the control and burial samples across the Syningthwaite site (the burial samples have been categorised into regions as used in statistical analysis described in Chapter 2, Section 2.7.2 (Region 1 –skull, Region 2 –pelvis/hand and Region 3 -foot).

3.5.3.1 *Fine material*

The groundmass was characterised by areas of mono-striated and speckled *b*-fabric throughout the controls and the skeletal samples. Mono-striated *b*-fabric was particularly prevalent in grave G3 around the skull region. Poro-striations and grano-striations were present in the skull and pelvic regions of all graves with interlaced striations particularly dominant in the sample inside the skull region of Grave G2. The fine material throughout the controls and grave samples appeared dotted in PPL and thus displayed a dotted limpidity. The right hand and skull region of Grave G2 contained high levels of dark brown humified organic material with no isotropic properties.

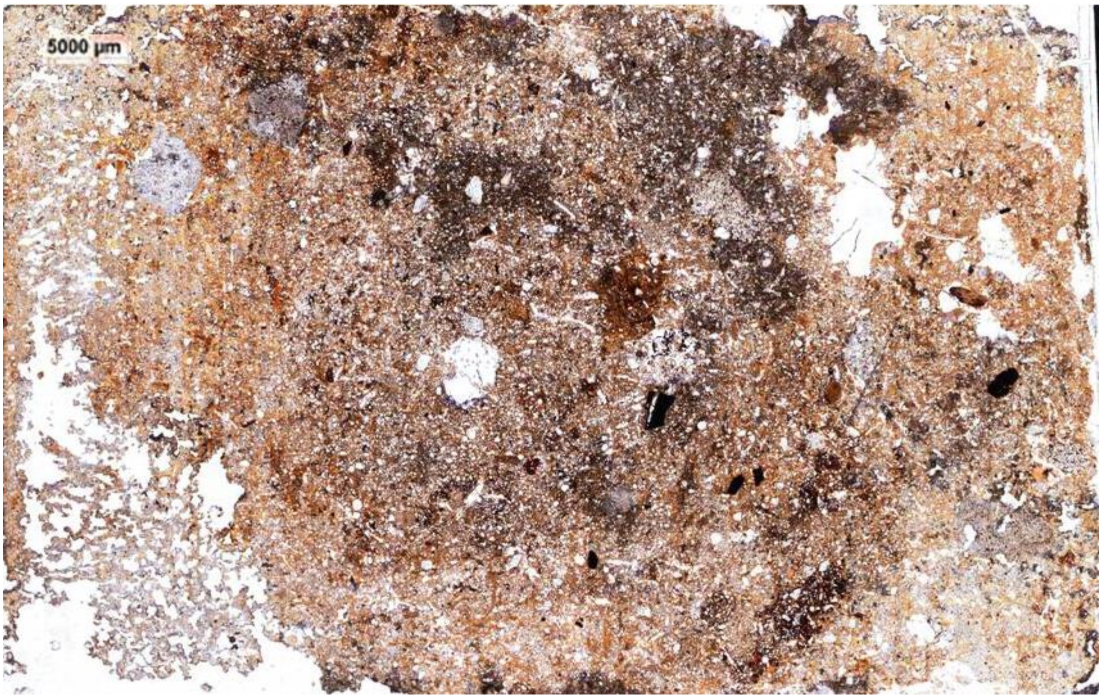


Figure 39: Mosaic image of the C3 control from Grave G1 with micro-charcoal identifiable throughout the sample

The different characteristics of the *b*-fabric suggest two different processes occurring in the fine material. The striated *b*-fabric (Figure 40a) across all the graves and controls could have been caused by shrinking/swelling processes, linked to the occurrence of wetting and drying, and clay domain alignment caused by the isotropic stresses within the fine material and surrounding the coarse material (Dalrymple and Jim 1984; Stoops 2003b 96). In contrast, the speckled nature of the *b*-fabric suggests that the clay domains were randomly oriented. The dotted appearance of the fine material under PPL could be attributed to the presence of dark amorphous organic fractions or of micro-charcoal (<50 µm), possibly associated with domestic activity with the location of the graves being adjacent to the main priory buildings.

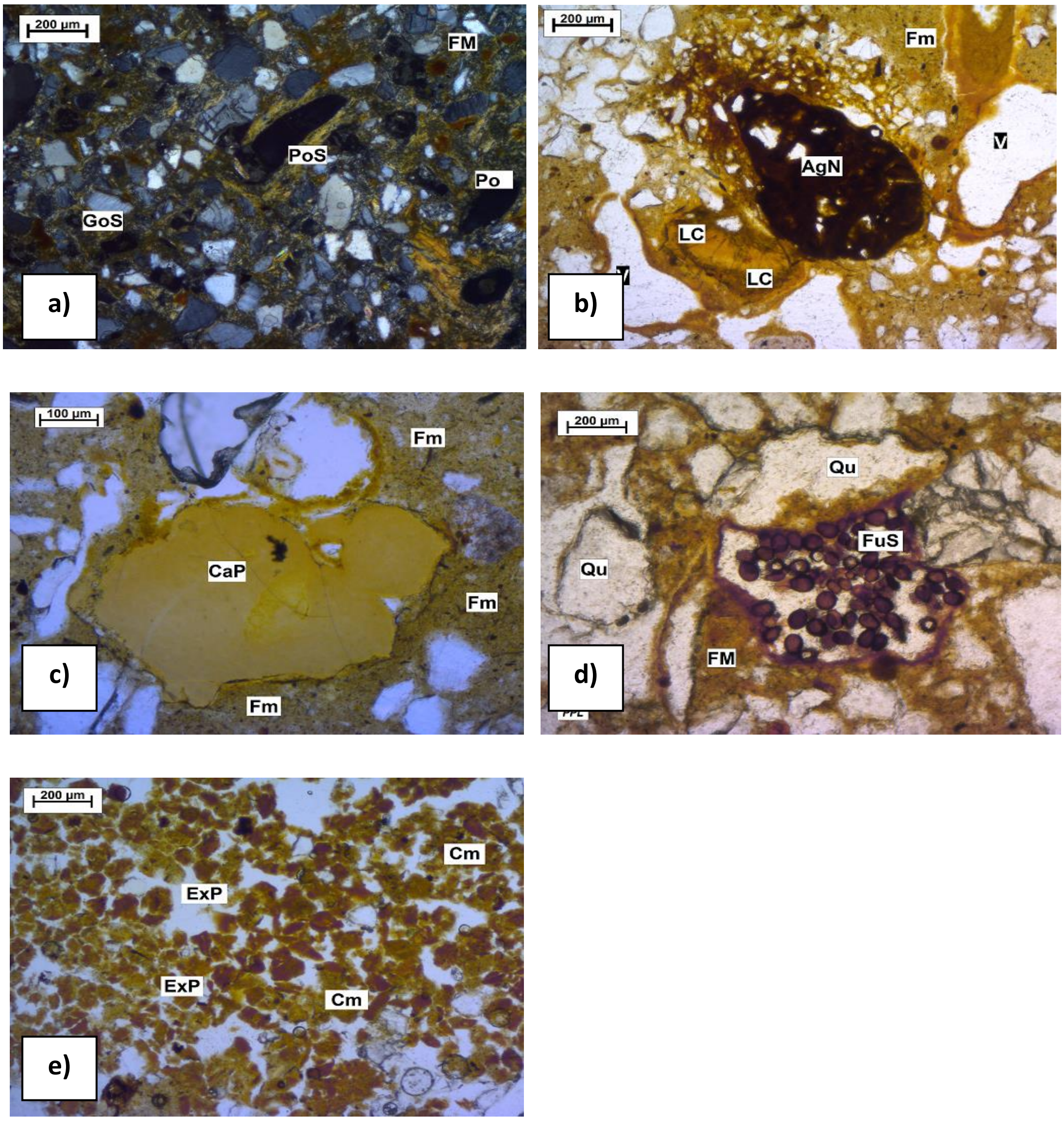


Figure 40: Features observed in thin sections from Syningthwaite; with a) Quartz-rich coarse fractions surrounded by grano- (GoS) and poro-striations (PoS) in the fine material (FM) of the hand sample region from Grave G3 (XPL); b) Aggregate nodule (AgN) surrounded by laminated coatings (LC) and Fe-stained fine material (FM) from the sacrum sample of Grave G3 (PPL); c) Calcium phosphate nodule (CaP) [as identified by SEM-EDS analysis] surrounded by fine material (Fm) in the sample inside the skull in Grave G1 (PPL); d) Fungal spore (FuS) surrounded by quartz (Qu) and fine material (FM) near the right hand of the skeleton in Grave G2, PPL; e) Coalesced excremental pedofeatures from the inside the skull sample of Grave G1, (PPL).

3.5.3.2 *Ped development and void type*

Ped development was determined by micromorphological observations and the mosaic imaging (Figure 41).

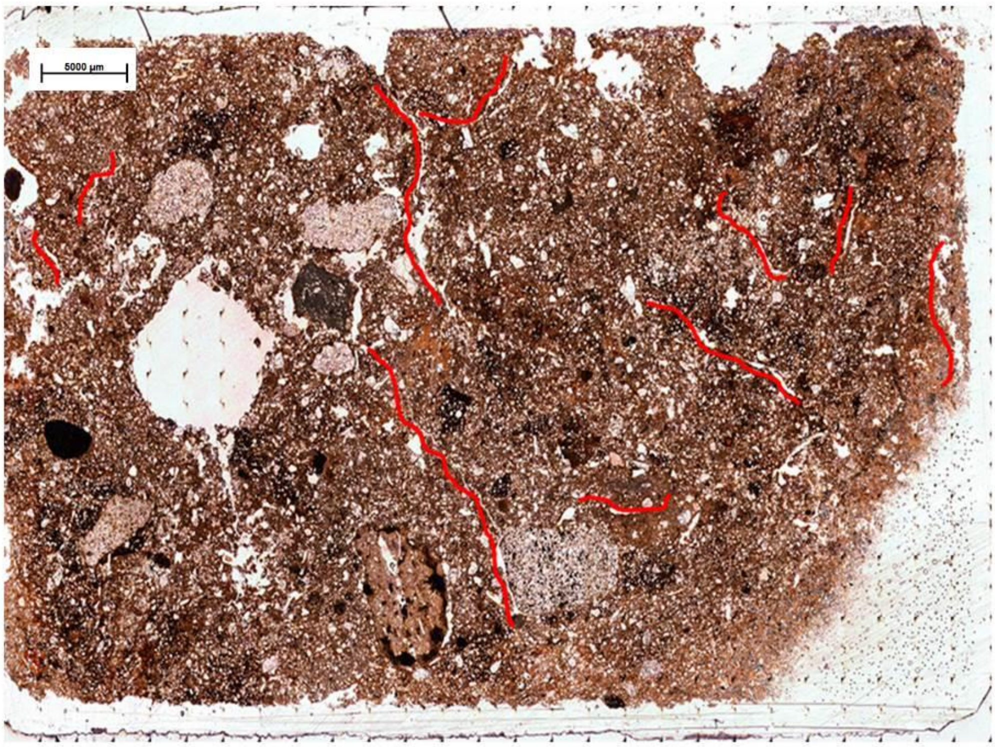


Figure 41: Mosaic image of the pelvic sample from Grave G2 illustrating weak/moderate, sub-angular blocky peds in the grave and control samples

From the mosaic image from the pelvic region in Grave G2 it is evident that ped development was weak, with sub-angular blocky peds separated by partially and unaccommodated inter-pedal channel voids and intra-pedal vughs. This pattern was observed throughout the control and burial sampling regions (Table 16).

Table 16: The degree of ped development identified through micromorphological observation across control and burial samples of Grave G1, G2 and G2 at the Syningthwaite site

Grave	Skull	Inside Skull	Pelvis	Sacrum	RPW	Hand	Foot/ Feet	C2	C3
G1	S	S	M			W		W	W
G2	W	M	W			W	M	W	M
(Infant)									
G3	W			S			S	W	W

S=strong; M=Moderate; W=Weak to denote the development of the peds

Ped development as a whole was weak across the site, with Grave G1 being an exception: the soil from around and inside the skull region was characterised by strong ped development, with granular peds separated by complex packing voids. In contrast, both the infant Grave G2 and the adult Grave G3 grave exhibited weak ped development in the skull region, with moderate granular ped development inside the skull region sample of G2.

The development of strongly defined sub-angular and granular peds around and inside the skull region of Grave G1 indicate high levels of aggregation between clay particles and organic minerals (Oades 1988), possibly pointing to increased organic matter in this region. Grave G3 samples also displayed higher levels of aggregation in the sacrum and feet regions. The development of partially and unacommodated channel voids suggested that the peds were developed through bioturbation rather than as a result of samples drying during processing.

3.5.3.3 *Pedofeatures*

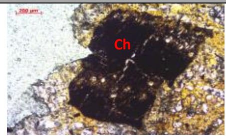
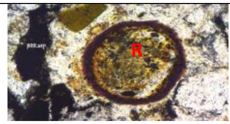
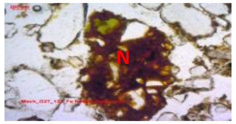
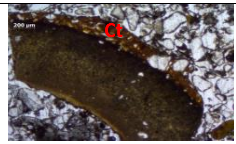
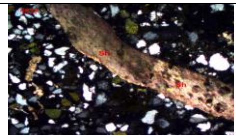
The coatings observed at Syningthwaite were dusty coatings, as defined by Stoops (2003b 106), and laminations were also displayed in many dusty coatings (Table 18). Excremental pedofeatures, with the highest frequency (*c*. 40%) were noted in the samples from inside the skull region (Figure 40e), where coalescence (merging) of the features had occurred to form larger more dense units (Stoops 2003b 124). Calcitic worm excrement was also observed in the pelvic regions of the Grave G2 and Grave G3 (Table 17). The skull and pelvic regions exhibited both orthic aggregates and typic redoximorphic nodules, which were also visible in the C2 and C3 control samples (Table 18).

Table 17: Frequency of excremental pedofeatures and calcitic worm excrement observed during micromorphological analysis for the Syningthwaite site and expressed in percentage of the thin section area

	Excremental Pedofeatures	*Skull*	*Inside Skull*	*Below Chest*	*Pelvis*	*Sacrum*	*Hands*	*Feet*	*C2*	*C3*
G1	*Calcitic (worm)*				**5**					
	Organic		10							
G2	*Calcitic (worm)*	**5**					**2**	**5**	**2**	
	Organic	30	5		5			5	2	
G3	*Calcitic (worm)*								**2**	
	Organic									

The development of dusty coatings in the Syningthwaite samples suggested that disturbance had occurred at the surface, above the graves, thus providing a mechanism for fine silts and clays to be washed down the soil profile during precipitation events. The laminations observed could have indicated the development of the dusty coatings may not have been a singular event and the deposition of the clay material forming the coatings may have been deposited over a period of time, or alternatively, via distinctly different episodic illuviation/eluviation within the same event (Kuhn *et al.* 2010 229). Excremental pedofeatures observed in the samples inside the skull region of Graves G1 and G2 may have indicated that this region of the burial had retained high levels of organic matter. This was also observed in the skull region sample of Grave G2, where a high frequency (*c*.30%) of excremental pedofeatures was recorded (Table 17). Coalescence of the excremental pedofeatures pointed to the occurrence of degradation. However this was not conclusive as a high frequency of bioturbation may also have resulted in the aggregation of the features. Redoximorphic nodule development suggested reducing and oxidising conditions had occurred, particularly in the C2 and C3 controls and the skull and pelvic regions. The development of such features may have pointed to two causal factors: localised water-logging or; increased organic material and degradation fluids emanating from the body (Lindbo *et al.* 2010 138). Conditions of waterlogging could have been the result of the presence of clays in some level of the soil profile, slowing down soil water percolation; whilst increases in putrification fluids from the burial could have provided the waterlogging and increased organic material.

Table 18:The distribution of selection of coarse fraction constituents and pedofeatures through all investigated graves at the Syningthwaite site

	Feature	*C2*	*C3*	*Skull*	*Inside Skull*	*Sacrum*	*Pelvis*	*Hand*	*Feet*
Charcoal(Ch) *(>50 µm)*		G1* G2* G3**	G1**	G1** G2** G3*			G1**	G2**	
Fe- and Mn-Stained Roots(R)		G2*	G3*				G1*	G1*	
Fe Nodules		G1** G2** G3**	G1** G2**	G1*** G2** G3**	G1** G2**	G3**	G1** G2**	G1** G2**	G2** G3*
Dusty Coatings(Ct)		G1*** G2** G3**	G1**** G2***	G1** G2**** G3****	G2***	G3*	G1* G2**	G1*** G2**	G2**
Shell		G3*	G2*	G3**					

Frequency of the features in each thin section: * 0-2% low; ** 3-5%moderate; *** 6-10% high; * >10% very high, as preventative of the percentage in the whole thin section sample***

3.5.4 Quantitative micromorphological analysis

3.5.4.1 *Point counting*

From the results of the point counting, bone and excremental pedofeatures were not detected with this method in the samples from the three Syningthwaite graves. As shown in Table 19, the lowest levels of coarse material in the grave and control samples from all graves was identified in ROI 2 from the sacrum region of Grave G3 (3%), whilst the over pelvis region sample from Grave G1 had the highest percentage (56%). The void space within the sacrum region of rave G3 presented the highest density (46%) within ROI 2. Coarse organic material was at higher levels (12%) in the C3 control in comparison with the other sample regions.

It was evident there was a difference between the point counting results and micromorphological observations. This may have been a result of the intervals set for the movement of the stage in the point counting (500 µm).The size of the excremental pedofeatures, ranging from 50- 300µm, suggested that the method had not identified them, as they were below the 500µm steps, whilst their infrequency across the graves may have also been a factor in their absence from the results. On the other hand, the high level of coarse organic material identified in the control sample could have come not from the degradation of the burials, but from material used in the backfill of the grave cut. The sacrum region from Grave G3 displayed a high percentage of void space in comparison to the other graves, possibly because of the higher levels of pedoturbation linked to the increases in organic matter derived from degradation products.

Table 19: Point counting from the different regions of interest (ROI) in the control and grave samples of graves G1, G2 and G3 from the Syningthwaite site. ***Units are expressed as a percentage (%) of the point counting total undertaken within different fabric types (Regions of Interest: ROI)***

	ROI (*Regions of Interest*)		Voids	Nodules	Coatings	Bone	Excremental Pedofeature	Coarse Material	Coarse Organic	Fe Staining	Undifferentiated
Grave G1	C2		3	3	0	0	0	55	1	2	37
	C3		10	3	0	0	0	40	1	4	42
	Skull		5	2	2	0	0	34	1	6	50
	Hand	*ROI 1*	8	4	2	0	0	45	1	2	38
		ROI 2	23	0	20	0	0	0	0	8	48
	Over Pelvis		3	2	4	0	0	56	2	3	31
	Pelvis		5	5	3	0	0	44	0	4	39
Grave G2	C2		13	1	1	0	0	49	0	1	35
	C3		29	1	1	0	0	28	12	0	28
	Skull										
	Inside Skull		12	1	1	0	0	47	0	0	40
	Hand										
	Pelvis		5	8	3	0	0	48	0	3	33
	Foot		10	0	2	0	0	46	0	4	38
Grave G3	C2	*ROI 1*	8	1	3	0	0	45	2	2	40
		ROI 2	6	3	1	0	0	53	1	3	33
	C3	*ROI 1*	2	2	4	0	0	51	2	3	36
		ROI 2	5	2	1	0	0	42	1	8	41
	Skull	*ROI 1*	8	1	0	0	0	50	3	1	38
		ROI 2	26	0	4	0	0	33	3	2	32
	Sacrum	*ROI 1*	46	1	4	0	0	30	0	1	18

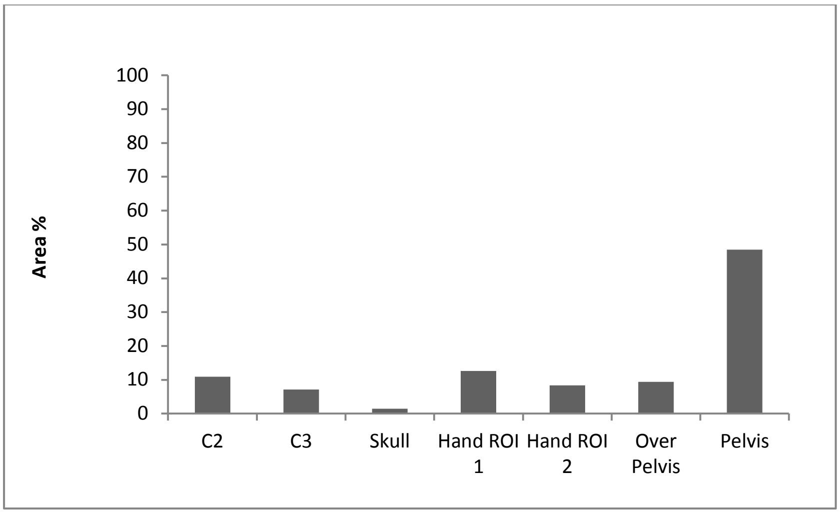
	ROI 2	26	0	4	0	0	3	3	2	32
Foot	*ROI 1*	10	0	2	0	0	51	2	2	33
	ROI 3	5	2	0	0	0	22	2	0	19

3.5.4.2 *Image analysis and the determination of the void space*

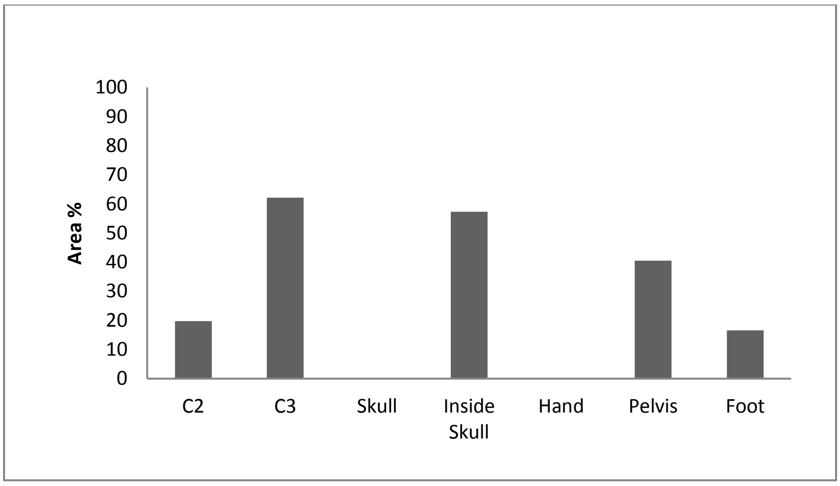
The percentage of void space within the Syningthwaite graves is shown in Table 19. The percentage of void space in the three graves was observed in Grave G3, especially in the foot and sacrum regions. Grave G2 burial samples displayed the greater percentage void space in the inside the skull region, with the overall highest percentage in the C3 control. Grave G1 had the lowest percentage void space of all three graves, with <5% in the skull region. The C2 and C3 grave fill control samples from Graves G1 and G2 displayed similar patterns with the C2 exhibiting less void space in comparison to the C3.

Differences in void space across the graves could have been caused by different factors. The C3 control samples from Graves G1 and G2 displayed a higher percentage void space when compared to the C2 control within the same graves. This could indicate that there had been collapse or compaction in the upper layers of the grave fill that had not occurred in the lower C3 control. Collapse was particularly relevant to the sample from inside the skull region, this area would have been protected from infilling and soil compaction. Only bioturbation and some soil ingress could provide pedogenic material. Soil fauna could, therefore, have been a factor in the development of the void space in the inside the skull region.

G1



G2



G3

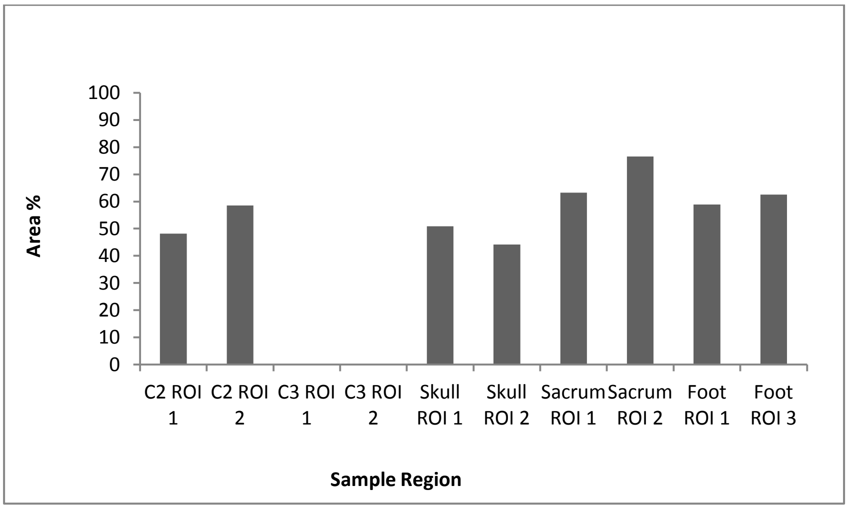


Figure 42: Percentage of void space shown by image analysis for the controls and sample regions of Graves G1, G2 and G3

3.5.5 SEM-EDS multi-elemental analysis

The results of elemental analysis for the samples from Syningthwaite are indicated in Figure 43.

3.5.5.1 *Analysis of trench stratigraphy*

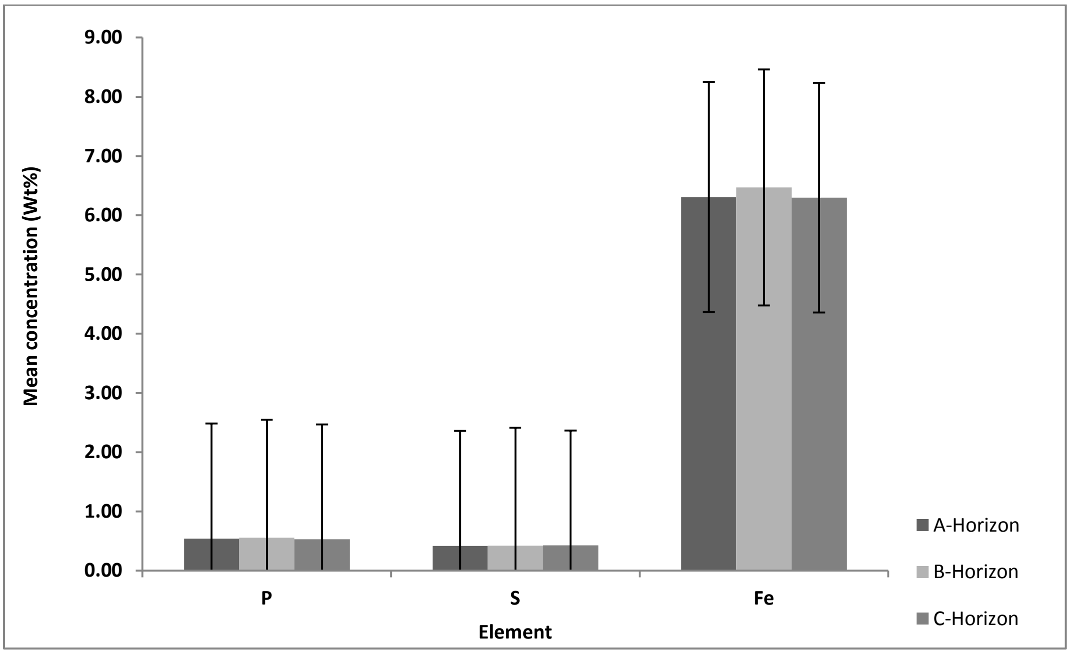


Figure 43: The mean concentrations of P (phosphorus), S (sulphur) and Fe (iron) in the fine material across of the soil horizons of the excavation pit. The error bars represent 1 standard error of the mean

Figure 43 shows high concentrations of Fe in all horizons. The concentration of P and S were also similar across all three horizons, although there was a slight (non-significant) increase in S in the C-Horizon

None of the differences were significant as a result of the high variability.

Void Analysis

Figure 44 shows the mean ratio of O:C in the fine material in the peds and fine material surrounding the voids of Graves G1, G2 and G3; where comparisons could be obtained.

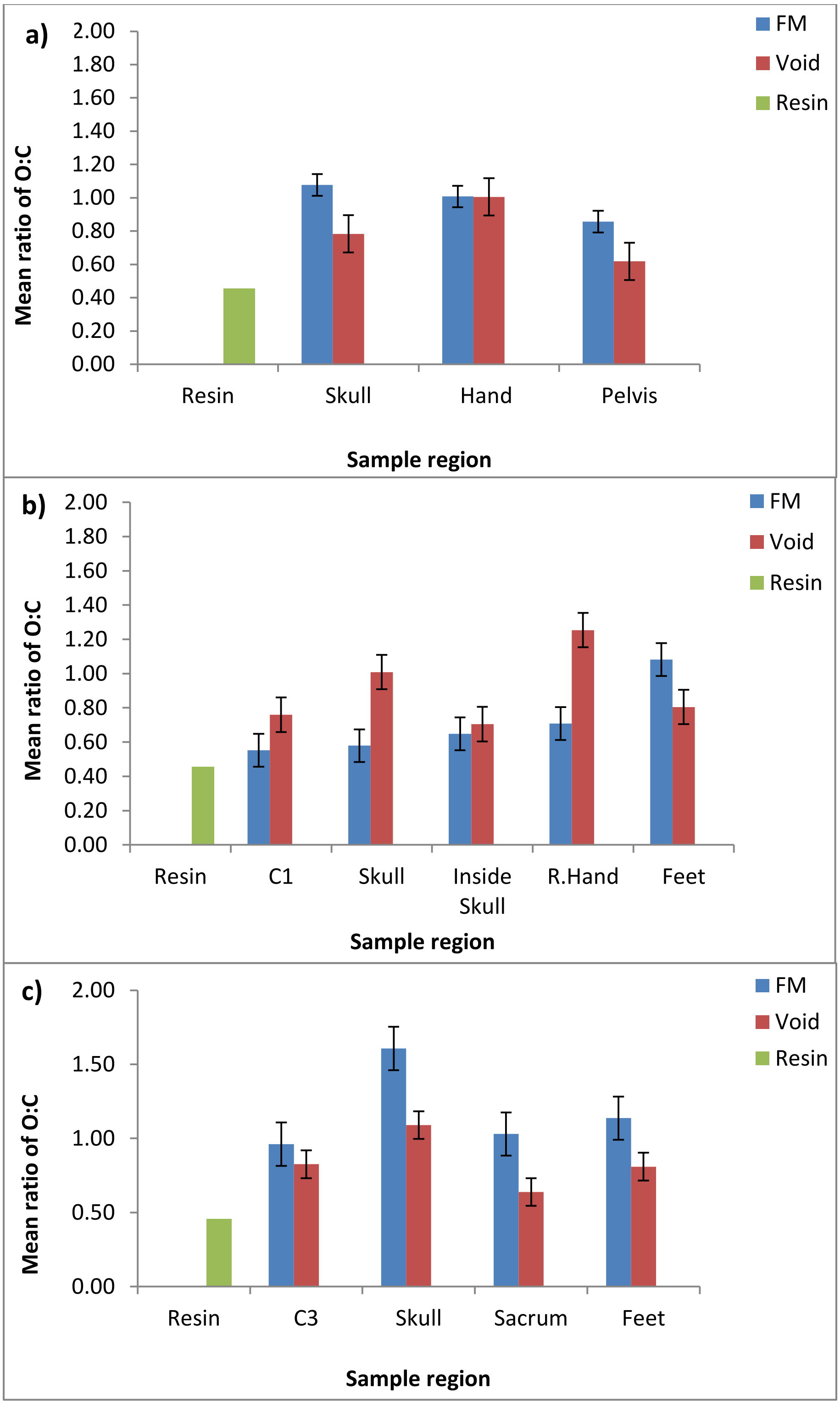


Figure 44: The identification of carbon residues through mean O:C in the fine material surrounding inter-pedal channel voids and the fine material in peds from Graves G1(a), G2(b) and G3 (c) Syningthwaite. The error bars represent 1 standard error of the mean *(FM=fine material)*

The O:C ratios in the graves were compared to the level of O:C in the crystic resin. The lower ratio in the resin was representative of a greater concentration of C. The highest relative C levels are exhibited in the fine material within the ped in Graves G1 and G3, with the highest level of C in Grave G2 being in the fine material surrounding the voids, the feet region being the exception. The highest relative carbon levels were in the fine material of the peds from the pelvis region of Grave G1 and the void edges of the sacrum region of Grave G3.

The increased level of C in the pelvis/sacrum region within Graves G1 and G3 suggests that there is a higher level of C possibly from degradation products entering the voids in these sample regions, the fleshier parts of the body. The increased level of C in the voids area, when compared to the inner ped fine material suggests there could may have been little translocation of C in Graves G1 and G3. However, translocation seems to have occurred in Grave G2, with higher C levels in the fine material of the peds. This could suggest that there may have been an increased resin filled microporosity that was not visible optically. However, this could not be determined employing the analytical methods used.

3.5.5.2 *Analysis of depositional features: Redoximorphic nodules and coatings*

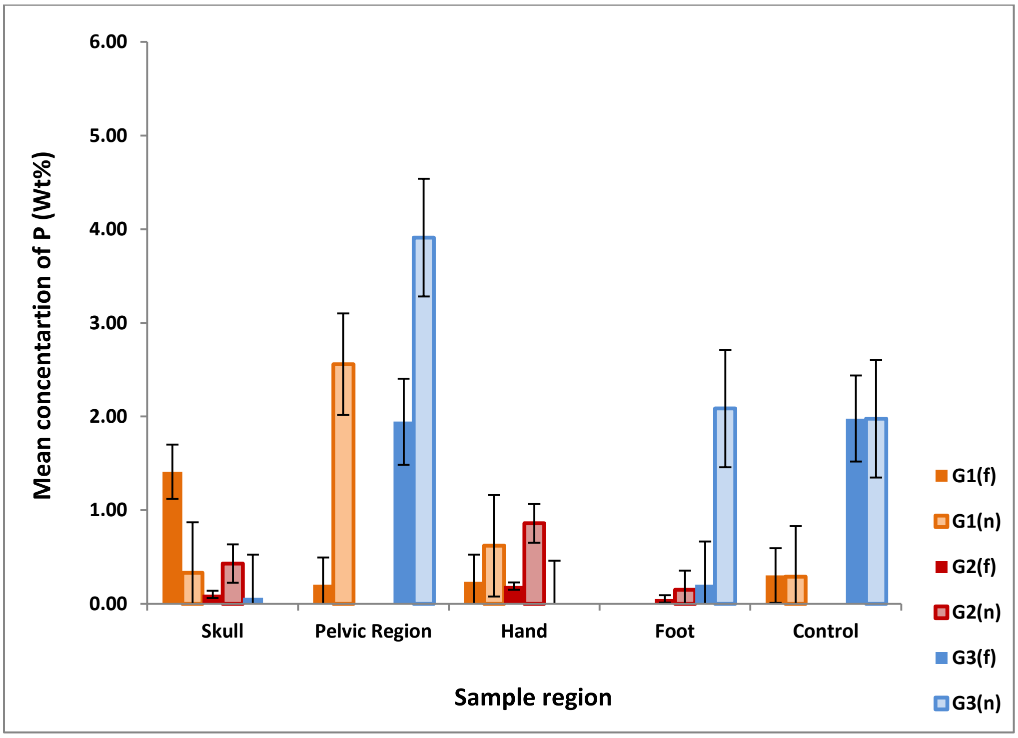


Figure 45: The mean concentrations of P in the redoximorphic nodules (n) compared to P in the fine material (f) of the Syningthwaite graves. The error bars represent 1 standard error of the mean

The mean concentration of P in the fine material and redoximorphic nodules in all three graves from the Syningthwaite site (Graves G1, G2 and G3) are displayed in Figure 45. The graph indicates the highest concentrations of P were in the nodules of the pelvic region of Grave G3. The lowest overall levels of P are in the hand region of all the graves. The nodules from Grave G3 displayed the highest overall level of P. The fine material of Grave G1 has the highest levels of P in the skull region sample.

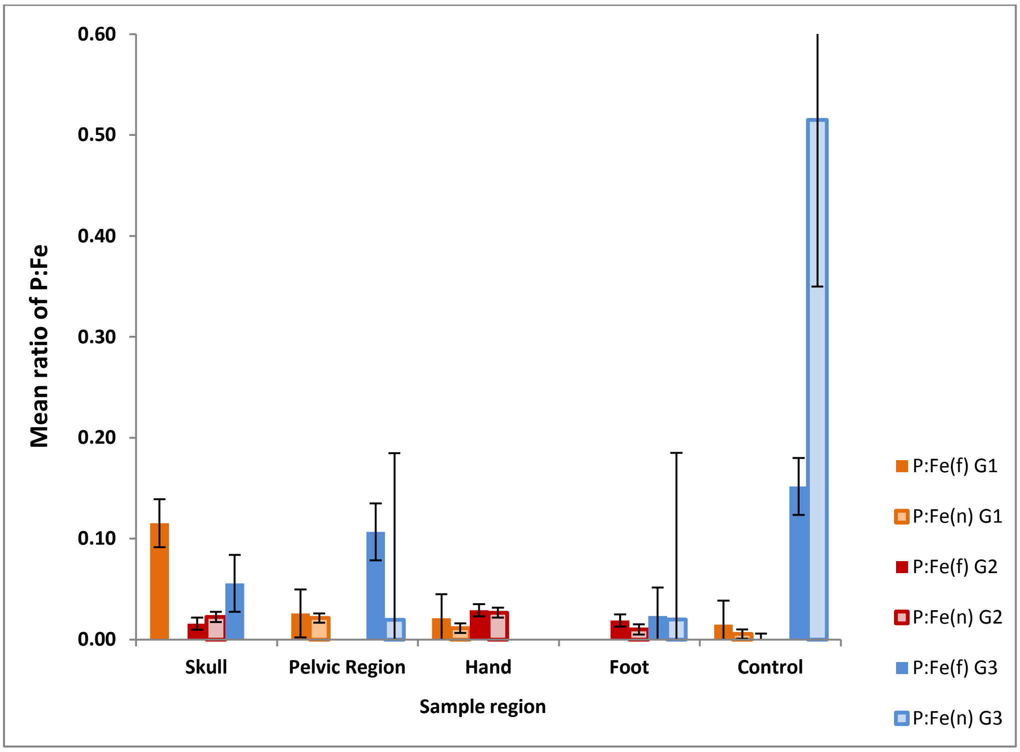


Figure 46: The mean ratio of P:Fe in nodules (n) and fine material (f) observed in graves G1, G2 and G3 of the Syningthwaite site. The error bars represent 1 standard error of the mean

Figure 46 shows the mean ratio of P:Fe in the fine material and redoximorphic nodules in the control and burial samples. The levels of P:Fe across the burial and control samples are highest in the nodules of the control from Grave G3. The lowest levels of P:Fe are displayed in the nodules in Grave G1, particularly in the skull region and control. The fine material of the burial samples in all graves presented the highest P:Fe levels, with the exception of the control from Grave G3.

The mean absolute concentration of P (Figure 47) showed that Grave G3 contains the highest levels in the nodules of the pelvis region, foot region and control. Grave G1 also contained high levels of P in the nodules of the pelvic region. Grave G3 displayed high levels of P , whilst the P:Fe ratio was low, suggesting the levels of Fe are higher than in the other graves (Graves G1 and G2). Neither the mean P levels nor the ratio of P:Fe in the fine material and nodules of the Syningthwaite graves provide conclusive evidence of decomposition products being retained in the soil; however they do indicate areas where levels of P are concentrated, which correlate with fleshier areas of the burial.

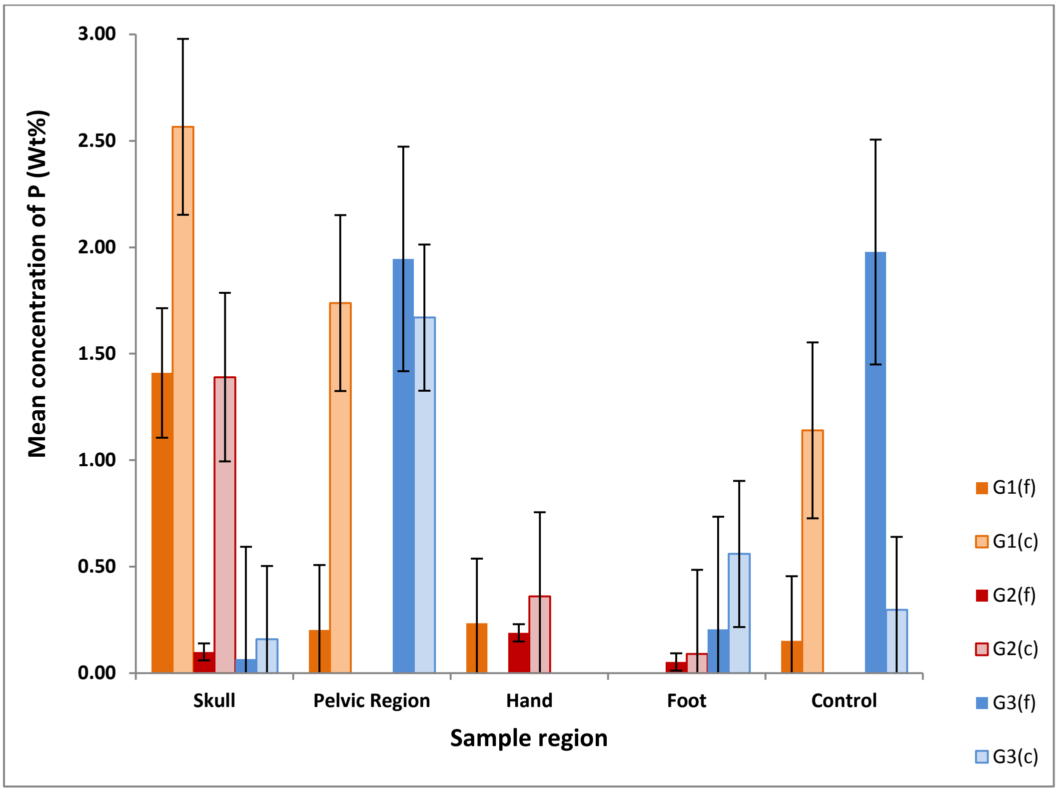


Figure 47: The mean concentrations of P in the dusty coatings (c) compared with the P levels in the fine material (f) of the Syningthwaite graves. The error bars represent 1 standard error of the mean

The mean concentrations of P in coatings and fine material are displayed in Figure 47, where it can be seen the highest level of P was in the dusty coatings of the skull region in Grave G1. The dusty coatings in the pelvic region of Grave G1 also show high levels of P, whilst in Grave G3 the fine material in the control and pelvis regions displayed the highest levels. The concentration of P in the dusty coatings is generally greater than in the fine material; except in Grave G2 where the fine material in the skull and pelvis region and control displayed higher levels.

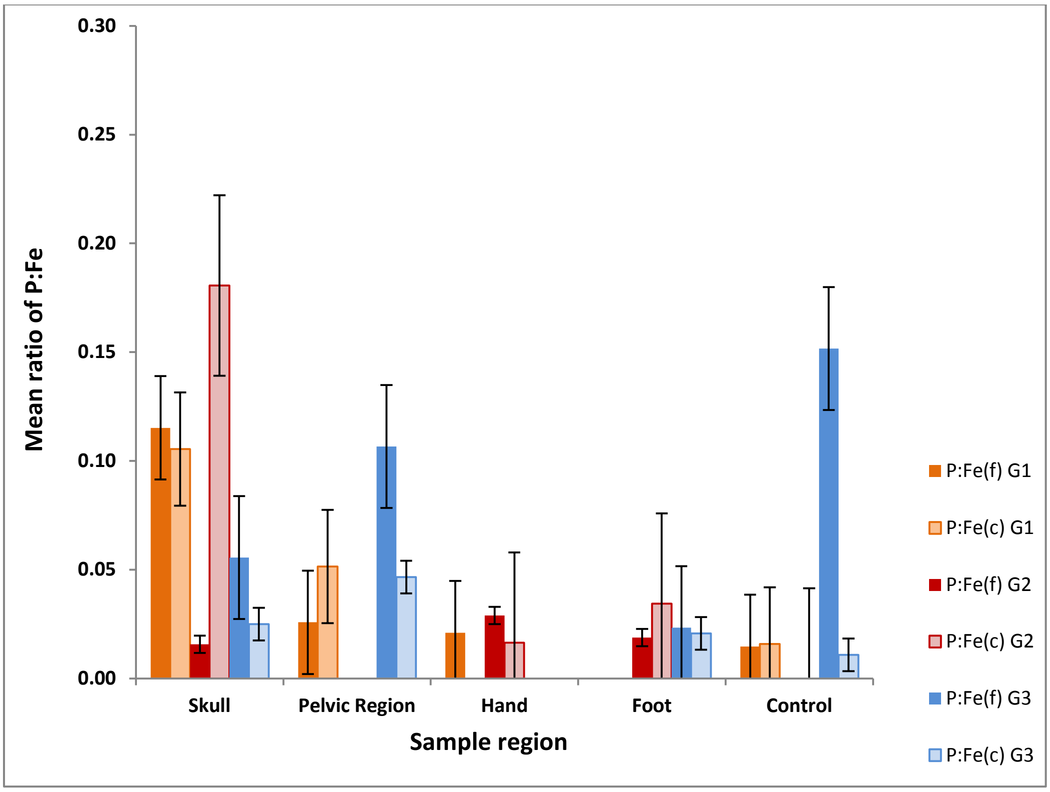


Figure 48: The mean ratios of P:Fe in coatings (c) and fine material (f) observed in Graves G1, G2 and G3 at the Syningthwaite site. The error bars represent 1 standard error off the mean

The ratio of P:Fe (Figure 48) is highest in the coatings of the skull region in Grave G2, whilst it is the control samples from Grave G3 that contained the highest P:Fe in the fine material. There is a higher ratio of P:Fe in the fine material across the Grave G3 when compared to the coatings, whilst Grave G2 has a greater ratio of P:Fe in the coatings of the skull and foot region compared to the fine material in the same sample regions. The overall ratios of P:Fe are lowest in the hand and foot regions in all graves from the site.

The mean P concentrations were highest in the coatings compared to the fine material of Grave G1 across both the burial and control samples. The P:Fe in the coatings of Grave G1, when compared to the fine material, are nevertheless lower (Figure 48). This suggests there had been little co-precipitation or adsorption of P with Fe in the coatings and instead it is being adsorbed to clay particles, thus accounting for the concentration of P in the dusty coatings. Across the whole site it was the skull region of Grave G1 that displayed the highest ratio of P:Fe in the fine material and suggests there had been a greater adsorbtion of P to Fe, clay particles and Al (Schlesinger 1997 98). The higher levels of P in the fine material in Grave G2 in both Figure 45 and Figure 47 implied P had remained adsorbed in the fine material. The difference in the level of P between the fine material compared to the localised coatings suggests the particles in the coatings from this sample region had been translocated from another part of the grave containing lower P (Kuhn *et al.* 2010 219).

3.5.6 Summary of results and discussion: Syningthwaite

The excavation planned and undertaken by the *InterArChive* project achieved a full set of control samples through the stratigraphy, and undisturbed C2 and C3 grave fill controls. Skeletal remains were not visible in the foot region during excavation of Grave G2, with samples still collected from the region. Micromorphological observations identified a substantial amount of bone (>45% of the thin sections area) still present in the foot region, although this was not visible to the naked eye (Figure 38), probably because the skeletal remains were significantly friable and fragmented. Thus, the microscopic identification of bone indicated the effectiveness of the analytical and sampling methods even when bone was not macroscopically visible.

Macro-analysis of the stratigraphy indicated the development of four discrete horizons, all with neutral to alkaline pH (6-8).The relative uniformity of pH across the sampling positions and soil horizons could have been a result of homogeneity of the bulk soil-grab samples once collected and stored. Hand texturing showed differences in the composition of the soil in the horizons, with greater reddening, clay content and higher levels of stone from the regolith in the lower horizons. Elemental analysis confirmed the differences, with evidence for eluviation/illuviation through the movement of Fe suggested by the low difference in the levels of Fe deposition.

The components of the coarse mineral material indicated that it was derived from the local geological till, with shell coming from the limestone in the till. Small fragments of bone throughout the samples pointed to disturbance of the graves, with the bone pieces showing different levels of diagenesis, characterised by diverse degrees of birefringence (Entwistle *et al.* 2000) in the control and grave samples (Figure 40). Significant differences in the composition of the coarse mineral and organic material were observed between the grave and control samples, with less quartz and considerable less fragmented bone in the controls.

Poro-, grano- and inter-laced striations were observed throughout the fine material in the burial and control samples, indicating that wetting and drying processes had occurred. This was particularly evident in the samples from inside the skull region of Grave G2 and from the region near the skull in Grave G3 with low levels of disturbance in these areas in comparison to the rest of the control and grave samples. Excremental pedofeatures were observed with micromorphological analysis throughout the burial samples, especially in the skull and pelvic regions. Point counting, however, did not register these features (Table 19).

Moderate to low development of sub-angular blocky peds were observed across all grave fill controls (C2 and C3 control) and grave samples. The peds were separated by partially accommodated and unaccommodated inter-pedal channels and also displayed intra-pedal vughs across the skull region and inside the skull region of Grave G1 and the sacrum and foot regions of Grave G3. However, peds were more strongly developed in sacrum and foot regions of Grave G3. It is evident from Table 16 that the development and percentage of voids in the sacrum and foot regions of Grave G3 exhibited a correlation with stronger ped development. Again, such patterns were not observed in the point counting; hence, care is needed in interpreting point counting data in the absence of other supporting evidence.

Evidence for bioturbation throughout the Syningthwaite site was indicated by micromorphological analysis but not by point counting as this did not detect excremental pedofeatures because density of the counts were not sufficient to highlight such features in either the grave or control samples, this result being similar to that of the void analysis. The application of point count analysis in this study must, therefore, only be seen as supporting evidence for the estimates of the soil composition and structure displayed by the full micromorphological analysis.

Elemental analysis of the fine material at void edges and in the peds at Syningthwaite was applied to determine the level of organic matter that may have been derived from burial decay and retained around the void. The ratio of O:C surrounding the voids was determined as an indicator of carbon to denote organic matter retention, as employed by Glaser (1989) when determining organo-mineral associations. Increased levels of C were detected in the voids of the pelvis/sacrum regions of Grave G1 and G3, however, Grave G2 displayed a greater level of C in the peds. This would suggest there is differential translocation of C across the site.

Analysis of redoximorphic nodules and dusty coatings was undertaken in order to further identify the remains of degradation products from the burials. The coatings had formed on the inside of intra-pedal vughs and inter-pedal channels, whilst the redoximorphic nodules were located in the matrix, particularly in the skull and pelvic regions. The dusty coatings identified could either have formed through the removal of surface protection such as grass, or owing to recent activity within the area prior to excavation, as such surface trampling, leaving clay colloids and silt free to be washed through the soil profile (Usai 2001b). Disturbance of the area through archaeological investigation had occurred prior to the *InterArChive* excavation. Alternatively, disturbance may have occurred within the grave, through the collapse of the coffin and the soil surrounding the burial during decomposition.

Laminated dusty coatings identified in control and grave samples suggested different phases of development within the coatings, with the percolation of silt and clay particles down the soil profile during different water regimes, thus providing limpid fine clay and dusty clay silt and micro-charcoal impregnated layers within the same coating (Stoops 2003b 109).

The elemental analysis of the coatings compared to the fine material suggested there had been localised disturbance in the foot region of the graves as they displayed similar levels of P. This was identified particularly in the foot region of all three graves. The development of dusty coatings throughout the burial and control samples and their similar elemental composition to the localised fine material, whilst displaying little pattern to their development suggested localised disturbance may provide the movement of soil particles, in available soil water, or even decay fluids. The fine material deposited in inter-and intra-pedal channels and on coarse material within the same region (Kuhn *et al.* 2010 221). In contrast, there were varying levels of P between the fine material and burial samples in the pelvis, and skull regions; with Grave G1 showing differences in the P level (Figure 45). This difference in P and also P:Fe recognised in Figure 46 and Figure 47 could point to the silt and clay particles, which make up the dusty coatings within these regions, to have translocated from other areas of the grave.

3.6 Summary of the case studies and interpretations

The purpose of this study was to determine the validity and effectiveness of the analytical methods employed in the newly developed *InterArChive* protocol through the application and evaluation of results gained from comprehensively sampling sites of South Leith, Mechelen and Syningthwaite. The main aim of the *InterArChive* research was to determine the degradation and translocation of decayed materials, from human inhumation, through the grave soil, by applying recording and analytical protocols to produce a comprehensive set of results. The results would distinguish the differences in soil pedogenesis associated with the burial environment, burial ritual and burial degradation products, to that of general soil variation.

3.6.1 Burial environment

The excavation and sampling of the sites and the application of the new protocol confirmed that analysis of the burial soil may enable recognition and interpretation of the interactions between degradation and pedogenic processes. It was established that the parental material of the burial infilling from all three sites was likely to have derived from the local geology, through identification of comparable coarse mineral/rock composition in the grave fill control and burial samples. Modern urbanisation, however, across the Mechelen site resulted in the accumulation of contrasting materials between grave fills and the control samples as a consequence of foreign construction materials being deposited. The occurrence of ferruginised Fe and Mn root fragments was identified across the Mechelen, with Mn only observed in the lower layer 12th to 13th century graves. The presence of Mn indicated there had been occurring for prolonged periods of waterlogging as Mn has a low redox potential going into dissolution before Fe and remains there for a longer period of time (Lindbo *et al.* 2010 138; Schlesinger 1997 232). The location of the graveyard investigated in Mechelen, near the River Dijle, suggested seasonal, prolonged waterlogging of the earlier graves, providing anoxic conditions where degradation processes, could have been slower, this is highlighted by the presence of vivianite in the lower burials (particularly Grave 423) (Kristensen *et al.* 1995).

In contrast to Mechelen, the South Leith excavation was located in fast draining calcareous sand. Here, the dry and calcareous nature of the sediments corresponded to good preservation levels in the skeletal remains, although the coarse composition of the sandy soil allowed soil water to remove high levels of fine material that may have contained degradation products and organic material from the burials. Small fragments of wood-like organic matter, believed to be coffin wood, was retained around the edge of the burial but its degradation level was such that determination of wood species was not possible. The sample regions containing the coffin wood provided good retention of the fine material, suggesting that the coffin had slowed the wash-through of the fine material by soil water.

High levels of human occupational debris have been mixed throughout the sites with shell fragments observed at Mechelen and Syningthwaite. Rubified clay was also present at the Mechelen site and micromorphological investigation points to the material being present prior to the consecration of the burial ground, whilst the inclusion of mollusc shell in the control and burial samples only identified in the older 12-14th century graves, this suggested that after the 14th century, monastic waste may have been discarded in other locations away from the land adjacent to the cathedral and grave yard.

Remnants of domestic activity were also identified in the control and burial samples from both the South Leith and Syningthwaite sites, with high levels of micro-charcoal identified in the fine material, and shell fragments through the possible incorporation of midden material at Syningthwaite. However, the difference between the composition of parent materials and the identification of shell could point to their provenance being from the localised geology and not through anthropogenic incorporation of material (British-Geological-Survey 2012).

The highly urban location at South Leith and Mechelen had provided a covering layer to both sites, with the graveyards being sealed under road surfaces. This seems to have impeded strong percolation of water through the soil although translocation processes may have occurred. The development of coatings within the graves at both the Mechelen and South Leith sites suggested there had been a disturbance event, providing the mechanisms for the percolation of silt/clay particles, in soil water, to be deposited onto coarse grains and within inter-pedal and intra-pedal void spaces (Kuhn *et al.* 2010 221; Usai 2001b). The limited development of dusty coatings at South Leith were limited to the C3 control and left elbow regions, both with some fine material present in the soil matrix. This could indicate the dusty coatings had developed through internal disturbance in the grave, collapse of the coffin or of the actual burial. The morphology of the dusty coatings indicated a single event as lamination was not observed. The construction processes required to build a road surface above the grave, however, could point to a second event although no evidence emerged to confirm this.

The coatings at the Mechelen site were similar to those from South Leith: both indicating singular disturbance events which could have caused the deposition of fine silts and clays, particularly in upper layer Mechelen graves. Dusty coatings were located in the skull, hand and feet regions, whilst dusty coatings in the control samples were limited to the Layer 4 graves from Mechelen. The upper layer of the Mechelen site and the South Leith graves were both pointing to the causal factor, in their development of dusty coatings, as disturbance by construction, with the lower developing through destabilisation of the fine soil particles during successive excavation.

The development and morphology of dusty coatings at the Syningthwaite would indicate several disturbance events, or a singular events with varying intensity as shown in the within coatings (Kuhn *et al.* 2010 229). The earlier theory suggesting collapse within the burial may have produced a disturbance event, although surface activity was prevalent at the site whilst there was a high incidence of surface covering removal during earlier excavation .The discovery of several lamina within the coatings, both in the control and burial samples, could have suggested the grave fill and burial samples were affected by the development of coating at similar times. The internal collapse of the coffin and soil surrounding the burial could have affected the grave fill controls. Nevertheless, the question remains: would the grave fill control samples display the same effects as the burial samples? The dusty coatings within the grave fill controls are positioned above the burial samples thus collapse around the coffin may not have affected the control samples to the same degree as and the burial samples. SEM-EDS analysis of the levels of P and P to Fe in the grave fill control and burial coatings, when compared to the fine material within the same samples, suggested differences in elemental composition in the controls of grave G3 and the burial samples in grave G1 and G3. This implies the coatings and the fine material did not derive from the same source, thus suggesting that the coatings had developed from material percolating into area. The skull and foot region of Grave G2, however, displayed similar elemental composition between the fine material and coatings, suggesting they had developed from disturbance within the sample region. The most logical theory is: all grave fill controls and most burial samples formed their dusty coatings at the same time through disturbance from surface activity, with the exception of the skull and foot sample in grave G2 where internal disturbance and the development of coatings had occurred.

3.6.2 Burial ritual and the detection of burial degradation

The burials at the sites were all single coffined burials, with bodies placed in their coffins in a supine position, with variation in the positioning hands, either to the side of the body or across the pelvic cavity. The position of the hands within the burials determined the sampling strategy around the pelvic area, with no sampling undertaken in the South Leith grave and for Grave 415 at the Mechelen site as a result of disarticulation and the position of finger bones. The level of decomposition identified in several graves (the lower layer at Mechelen and Grave 6B from the South Leith site) provided no evidence of coffins, although the positions of the burials within the graves suggested such, with arms closely placed next to the body, thus, the body was possibly shrouded. The positioning of the feet suggested they had been bound together, with the ankles still closely positioned together. The fragments of wood-like material identified in micromorphological observations across the sites established evidence of coffins in these graves, although binding material from the region of the feet could not be observed. Bioturbation through meso-faunal activity was identified particularly around the skull, pelvic and feet regions, with only low levels identified in controls of the Mechelen and Syningthwaite sites; whilst increased bioturbation identified though fragments of root and the development of inter-pedal channel voids. Carbon residues were identified in the fine material surrounding the channel voids. Grave G2 at Syningthwaite where displayed an increased level at the void edge and not in fine material within the ped; this was contrary to Grave G1 and G3 in Syningthwaite and Mechelen graves. The increase in carbon residue in the fine material at the Mechelen site and Grave G1 and G3 of the Syningthwaite site were identified in the central part of the ped and not the edge of the voids. These results would point to C residue being easily translocated from the edge of the void at the Mechelen site. The South Leith site provided no evidence of bioturbation, although organic matter was identified, in the form of wood-like fragments. Increased levels of C residue were particularly noted in the foot region of Grave G26 of the Mechelen site, were the upper layer grave also displayed an increase in redoximorphic nodule frequency and increased concentrations of P. This suggested there was a correlation between the C levels, nodules and P, and suggested increased burial decay products.

Artefact identification of burial ritual was detected combining micromorphology and SEM-EDS analysis (Figure 33). A 12-13th century (Grave 414), from the lower layer of the Mechelen site displayed poorly ordered clay domains (PPL). Further examination of birefringence suggested ordering of the clay minerals in a cross-hatched and not cross-striated manner. The SEM-EDS images provided greater detail of the textile-like inclusion; however the element analysis provided no evidence of textile when compared to reference materials (University of York reference collection). The evidence suggests the artefact is a pseudomorphic textile, the organic material being enveloped by soil minerals, Fe_2O_3 and $Fe(OH)_2$ prior to decomposition, as observed in XPL illumination and SEM-EDS analysis indicating increased level of Fe (Janaway 2002 411). The location of the burial could have favoured a slow decomposition, as the grave was in a position to be affected by prolonged periods of waterlogging, thus providing the conditions favouring the encasement of the textile by soil minerals.

In fact, waterlogging and slower decomposition rates in the lower graves of Mechelen also provided reduction and oxidation conditions, which saw the development of redoximorphic nodules. The nodules were not localised in only waterlogged areas, with particularly increased levels identified in the skull and foot regions within the Mechelen graves in all layers, whilst low levels were observed in the grave fill control samples in the lower layers. Similarly, the same nodules were found at South Leith, a freely drained site, and Syningthwaite, particularly in the skull regions but also in the C2 and C3 grave fill controls. Elemental analysis of P in the nodules, when compared to concentrations in fine material using SEM-EDS, indicated differences and pointed to variations in redox conditions across all the burial. Levels of P in the fine material were higher than in the nodules, indicating that there may have been lower level of Fe. The levels of P in the fine material, therefore, indicated that there had been retention by the clay minerals or occlusion by the Fe/Al oxides (Schlesinger 1997 98). Increases in the deposition of P into the fine material could suggest that the coffin had not retained the putrefaction fluids and redox conditions may not have occurred. The low levels of putrification fluid retention allowed P to flux into the soil before reduction and oxidation processes had taken place. The increased frequency of redoximorphic nodules and raised levels of alternating reducing and oxidising conditions within specific areas of the burial, but particularly in the skull and foot region, may have been provided through the retention of decay fluids. The pooling of fluids in the coffin corresponding to increased levels of organic matter, and alternating reducing and oxidising conditions, could all provide optimum conditions for the formation of nodules - thus an increase in their frequency (Janaway 2002 352; Lindbo *et al.* 2010 132). The development of redoximorphic nodules identified in the control samples from the lower graves may have resulted from increased organic matter percolating down the soil profile from the upper layer graves, providing small pockets of reducing and oxidising conditions as the soil water moves down the soil profile. The differences in the level of P and P:Fe in the redoximorphic nodules and fine material, suggests that they were determined by the integrity of the coffin at the South Leith and Mechelen site. Thus burial ritual is integral in the retention of decay products in sandy soil and the form in which they are retained.

Redoximorphic nodules at the Syningthwaite site were represented in high frequency in the skull region of Graves G2 and G3 and the grave fill controls from Grave G1. The SEM-EDS analysis of P levels and the ratio of P to Fe suggest there has been localised development of nodules across the site, with the control regions of the grave displaying increased levels of P:Fe whilst P levels were actually higher in the fine material of the pelvic region. The co-precipitation of P with Fe could suggest that there have been increased reduction and oxidation conditions in the control regions of the graves. This may have been a result of decreased void space compared to the burial samples, thus providing localised water logging.

Although this study was a pilot application of the micromorphology recording protocol and SEM-EDS methods, preliminary results indicate that causal and spatial correlations may potentially be inferred within grave soils. In particular, thin section and inorganic elemental analysis have provided an insight into the potential of the protocol to identify the effects of burial ritual, environment and degradation products on soil pedogenesis. The protocol has displayed a comprehensive ability to determine correlations within and between graves.

4 An investigation of two mass grave burials; Ridgeway and Fromelles

4.1 Introduction

In order to expand on the sampling strategy and soil analysis from historical inhumations, mass graves are considered here. Unlike the traditional singular burials seen at the Mechelen, South Leith and Syningthwaite (described in Chapter 3), mass graves contain more than one body, are generally not in the consecrated ground of a church yard and are often buried swiftly in a non-coffined manner. This can directly impact the research as the burials are not contained in a supine position and have not been placed into the grave with religious reverence.

4.1.1 Determinacy of a mass grave

Several distinctions can be identified between the traditional mortuary practice observed in spiritual and culturally determined interments, or graveyard burials, and that of mass burials (Jessee and Skinner 2005). The term mass grave has different connotations but, in general terms, they are graves containing more than one individual buried at the same time, often associated by a similar cause of death, whether through natural disaster, conflict or mass extermination. The term has in some instances been employed for as little as two skeletal remains, where the remains were “in physical contact with each other”, especially in relation to war graves (Mant 1987 72), and many such burials have been discovered during investigations undertaken after World War II (WW2). Such a definition, however, was later disputed in the 20th century, when internationally recognised criminal atrocities were investigated in countries such as Vietnam, Chile, and latterly, Spain. In these cases, a mass grave was defined as a single burial cut, that contained no fewer than six bodies arranged randomly together, all having suffered similar causes of death (Jessee and Skinner 2005; Ríos *et al.* 2010; Skinner 1987).

4.1.2 The employment of mass graves as a method of burial

As a result of parochial and investigative documentation, the utilisation of a mass grave in historical terms has been attributed to several different causal events such as natural disaster, fatal epidemics, war and genocide (Skinner 1987). The disposal of bodies in mass graves, especially in centres of high population, was widely documented in England during the Great Plague, which ravaged Europe during the 17th century. At that time it was impossible to inter the bodies following “normal patterns of burial” due to the exponential increase in mortality (Harding 1993). The disposal of plague victims within large pits around London was documented as the easiest way to dispose of the dead safely, thus preventing rotting corpses remaining in buildings and thoroughfares (Defoe 1665 209). In many cases, slaked lime [$Ca(OH)_2$] was employed to sterilise large areas and prevent the spread of disease (Tuck *et al.* 1923). In the 20th century, the discovery and exhumation of mass graves from the First and Second World Wars and politically motivated genocides has provided evidence of bodies buried in mass graves and treated with quicklime (CaO) to prevent and reduce diseases and odours (Hatch and Rastall 1969; Digimap 2012).

4.1.3 Aim of the investigation

As a result of differences between the configurations of skeletal remains in mass graves and those of singular human inhumations, it was necessary to also test on mass graves the new *InterArChive* sampling protocol that had already been applied to the three site pilot investigation (see Chapter 3). Two sites at Ridgeway, England and Fromelles, France provided the samples. The aims of the investigation were to:

1. To ascertain the practicality of following the *InterArChive* sampling protocols (as described in Chapter 2, Section 2.3 and employed Chapter 3, Section 2.3), whilst determining the burials areas that would provide the most comprehensive information.
2. To establish the pedogenic differences between the control and burial samples.
3. To discover the validity of grab-soil samples as comparison controls for undisturbed soil samples
4. To determine the significance burial practise had on the degradation processes within the burials.

4.2 Methods of sampling and analysis

4.2.1 Sites selected

For the purposes of this study, the term "mass grave" will describe a burial containing more than two individual bodies touching each other, which have suffered similar causes of death. Two sites: Ridgeway in Dorset, England and Fromelles, Pas de Calais, France were selected for this investigation.

4.2.2 Ridgeway

The site of Ridgeway was discovered during the construction of the new A354 relief road, north of Weymouth, Dorset. The initial investigation carried out by Oxford Archaeology in 2009 found 51 skulls which were believed to be the associated with decapitated human skeletons excavated adjacent to the skulls. Results from radiocarbon dating, undertaken by the Oxford C^{14} Laboratory, indicated the interment to be *c.* AD 890-1030 {Boyle}. Isotopic investigation of tooth enamel by the British Geological Survey Isotope Laboratory, Nottingham, determined that the bodies could not have originated from the area of an Anglo-Saxon held territory but from a region of much colder climate, possibly Scandinavia

(Boyle 2009). Two hypotheses were suggested regarding the origins of the skeletal remains: 1) the group were mercenary Vikings fighting for the English; 2) the group were a raiding party that were captured and executed as prisoners of war. The latter hypothesis was believed to be the most likely.

4.2.3 Fromelles

The burials in Fromelles, in contrast to the one in Ridgeway, contained bodies which, in most cases, had not been completely skeletonised, possibly because of the relatively short time (*c*.105 years) that had elapsed since burial and the anoxic environmental that had included possible 'pH neutralising substances' during burial (Szibor *et al.* 1998).

In the summer of 2007, a trial excavation was undertaken within a farmer's field known as Pheasant Wood and located in the NE area of the village of Fromelles, in the Pas de Calais region of northern France. The trial excavation was carried out as it was believed there was a yet undiscovered WW1 grave containing both Australian and British soldiers. Historical aerial photography taken by the Royal Flying Corp. (RFC) at the end of WW1, showing eight formally arranged pits, was utilised in locating the site in relation to recent agricultural topography. The Glasgow University Archaeology Research Division (GUARD) exploratory excavations were undertaken on five pits, where remains and personal belongings pertaining to soldiers from the battle of Fromelles were discovered (Whitford and Pollard 2009).

Following the initial discoveries, a full excavation commenced in the summer of 2009, headed by Oxford Forensic Archaeology. The excavation and subsequent investigation aimed to exhume what was believed to be the remains of both British 61st Division and Australian 5th Infantry Division from the WW1 Battle of Fromelles and, through DNA analysis, identify the bodies that were interred. In total there were remains from 250 combatants, of which, 82 were British soldiers and the remainder Australian.

4.2.4 History of Fromelles

The *Attack of Fromelles* was planned as a diversionary tactic by the British and Commonwealth troops in the summer of 1916 to prevent the delivery of provisions, ammunition and troops to the main battle at the Somme (Cobb 2010 9). Between the 19th and 20th July 1916 the area around Fromelles had seen some of the worst fighting and sustained some of the highest casualties and fatalities ever encountered by the Australian military (Whitford and Pollard 2009; CWGC 2012). During the two day attack there were 7080 known casualties sustained by the newly deployed 61st Division and 5th Infantry Division. 5500 of these casualties were sustained by the Australian 5th Infantry (Cobb

2010). The remains of the fatalities from the battle had to be disposed of quickly because of the high seasonal temperatures. Degradation of the bodies was rapid and burial was undertaken by the German troops, orders being dispatched by Major von Braun of the 21st Bavarian Reserve Infantry Regiment (Whitford and Pollard 2009). Boots were, in many instances, removed from the corpses (Figure 49) before transportation; the bodies were interred in eight large pits and covered in a lime-type material that was thought to aid in degradation, reducing smells and sterilising the area of pathogens (Hochrein 2002 48).

Figure 49: The utilisation of a rail car by the German troops to remove the Australian and British dead. The dead were still clothed but it is evident that boots had been removed from the corpses revealing sock-covered and bare feet

4.2.5 Sampling strategy

Sampling of the mass graves was significantly more problematic in comparison to that of single interments. The co-mingling of bones within the burial pit made determining and sampling strategic points around the body difficult, not only for the identification of an individual skeleton's body parts but also for the low volumes of soil surrounding the sampling regions as a result of the high quantity of bones (Figure 50). The collection of undisturbed soil samples was carried out by the *InterArChive* team using two Kubiena tin sizes (large: 85 x 50 mm and small: 58 x 32 mm), with the smallest being employed most frequently.

Figure 50: The intensity of co-mingled bone discovered within the burial pit when sampling at the Ridgeway site. The skulls can be seen piled together in the upper part of the picture

4.2.5.1 *Sampling of the Ridgeway grave*

Soil samples were collected near two torsos, adjacent to the pelvis and heel regions. The skull samples were collected adjacent to three different skulls and were therefore differentiated as Skull, Skull (A) Skull (A1) and Skull (B).

Undisturbed soil samples could not be collected as grave fill controls, owing to the grave fill having been removed before the *InterArChive* sampling team arrived on site, with much of the grave fill placed in mounds around the site (Figure 51). It was, therefore, necessary to utilise bulk loose disturbed soil-grab samples that had initially been collected for organic chemical analysis from the spoil heap (C2) and edge of the pit area (C3), as grave fill controls. As a result of soil disturbance local to the site were available for collection of a C1 site control. The skulls and torsos had been buried in different areas of the pit with peri-mortem marks on the vertebra indicating that the skulls had been removed using sharp heavy cutting implements.

Figure 51: Images a) and b) display the extent of the overburden from the excavation and construction of the Weymouth A354 relief road surrounding the Ridgeway excavation

4.2.5.2 *Sampling of the Fromelles grave*

The excavation was carried out by Oxford Archaeology in conjunction with several government agencies from Australia, France and the UK, and the exhumation of the bodies took around 12 weeks. Due to the sensitive nature of the Fromelles excavation, sampling of the site by the *InterArChive* project had been achieved within the brief time given by the agencies. The micromorphological samples collected was undertaken from one of eight burial pits (Grave 4) discovered on the site. Sampling was carried out using Kubiena tins to collect the soil in the regions adjacent to two skulls and a foot, whilst grave fill controls were obtained at 7.5cm (Control C2) and 30cm (Control C3) below the ground surface from the vertical face of the trench (as seen in Figure 52) above the burial pit. In total six undisturbed micromorphological samples were obtained.

Figure 52: West end of Grave 4 exposed in Trench 4 showing soil changes and well defined pit edges, with the collection of the C2 and C3 control samples collected on the vertical face of the trench (Pollard *et al.* 2008a)

4.2.5.3 *Samples collected from Ridgeway and Fromelles*

The nomenclature and location of the samples collected at Ridgeway and Fromelles is indicated in Table 20.

Table 20: The sampling positions, type of sample collected and nomenclature of the mass grave sites of Ridgeway and Fromelles

		Sample type and location	
Grave No.	*Sample*	*Ridgeway*	*Fromelles*
	C2	From spoil heap	7.5 cm depth from surface
	C2	From beyond edge of pit	30 cm depth from surface
Fromelles: Grave 4	SK1525		Skull
	SK1527		Skull (A)
			Skull(B)
			Foot
Ridgeway: Pit	SK3738	Skull	
	SK3755	*Skull (A)	
		*Skull (A1)	
		Skull (B)	
	SK3756	Heel	
		Pelvis (A)	
		Pelvis (B)	

* *Same skull had been sampled twice*

4.2.6 Micromorphological analysis

Thin section preparation was undertaken on the undisturbed soil/sediment blocks utilising the same methods applied to the pilot study (described in Chapter 3). The disturbed C2 and C3 soil-grab control samples, were freeze-dried and homogenised for chemical analysis through sieving (at 1000, 400 and 200 µm). The remainder of the sieved soil (>5µm), not utilised for organic chemical analysis, was air-dried for 24 hours at 40^0C, placed into small plastic *Buehler* moulds (2 cm diameter) and impregnated with Epoxy resin. The resin blocks were mounted onto glass lapped to a 30 µm thickness and polished using the same method as for the undisturbed thin sections.

Micromorphological analysis was carried out as described in Chapter 2, Section 2.5

4.2.6.1 *Quantitative micromorphological analysis*

To enhance the semi-quantitative analysis undertaken through micromorphological observations, both point counting and image analysis were applied to all the undisturbed thin sections from Ridgeway and Fromelles (as described in Chapter 2, Section 2.5.2). The soil-grab samples from Ridgeway, as a result of their homogeneity, were not analysed quantitatively.

4.2.7 Element and data analysis

Elemental analysis was undertaken at the University of Stirling using SEM-EDS as described in Chapter 2, Section 2.6.

All raw data (weight %) derived from the elemental analysis was converted from the INCA format to Excel spreadsheets. The mean absolute elemental concentrations in nodules, coatings and fine material, as initially identified through the micromorphological observation, were calculated to provide an overall indication of the elemental concentrations in the thin section burial samples and controls. MINITAB 16 statistical analysis packages was then utilised to perform cross tabulation of the data was first employed to establish a contingency table, providing information of cells in the data where no information had been input. Two-way ANOVA was then applied to the data to test for significant difference in Fe, P and S concentrations in dusty coatings, redoximorphic nodules and fine material. The sampling positions within the graves were grouped into three regions due to the variation in sampling strategies at the two sites (as described in Chapter 2, Section2.7.2).

4.3 Ridgeway

4.3.1 Geology of Ridgeway

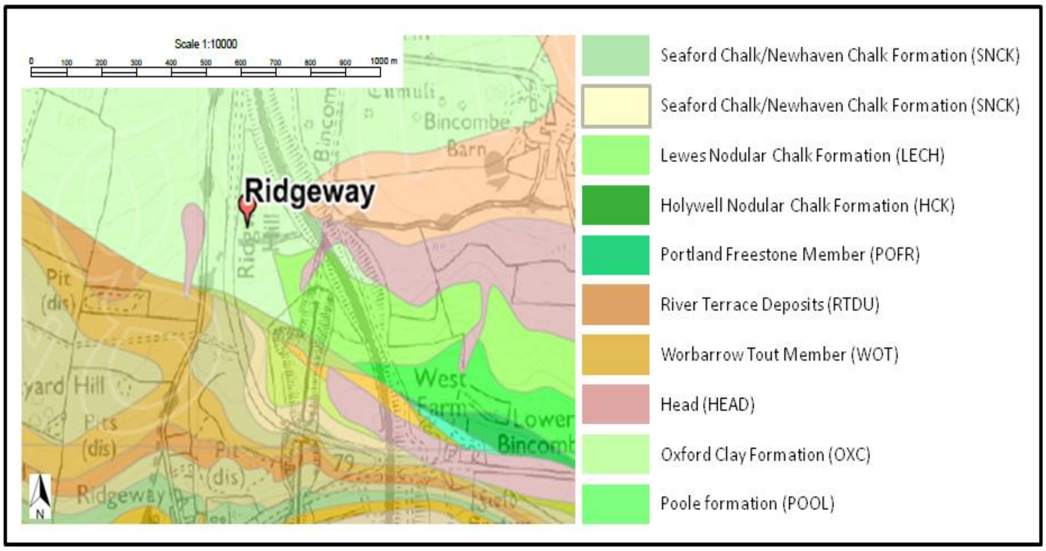


Figure 53: Geological formations in and surrounding the Ridgeway archaeological excavation (http://digimap.edina.ac.uk/geologyroam/geology)

The local geology of the site at Ridgeway was composed of Seaford Chalk/Newhaven Chalk Formations and bordered by Lewes Nodular Chalk to the south and west, with Head to the east. The site was located in the western side of the Ridgeway summit, located between a Roman road and the A354 main road (main road at time of excavation) south to Weymouth. The excavation was undertaken on what was grass pasture with a silty/loam soil

A summary of the burial context, geological features, soil type and main micromorphological features are displayed in Table 21.

Table 21: Summary table of geology, soil type, burials and micromorphological features observed at Ridgeway

Context	*Position/type of burial*	*Geological features*	*Soil Type*	*Micromorphological Features*		
				Coarse Material	*Fine material*	*Post-depositional pedofeatures*
Ridgeway	10th century Mass grave burial with heads decapitated from torsos and place in separate areas of an Iron Age quarry cut	Seaford Chalk/Newhaven Chalk Formations bordered by Lewes Nodular Chalk to the south and west and Head to the east	Silty/loam, with the soil containing a high level of organic matter from the grass covering.	Quartz (20%), calcite (10%) and flint (5%). With coarse organic matter of root (2%) charcoal (2%), shell (5%) and bone (2%)	Speckled *b*-fabric was observed in all samples	Dusty clay coatings in the grab samples and in skull, pelvis and foot samples Redoximorphic nodules in the granular peds of the skull Sk3738 sample

4.3.2 Micromorphological analysis

All original micromorphological observations data from Fromelles are displayed in Appendix 3.

4.3.2.1 *Coarse material*

The thin sections from Ridgeway displayed partially weathered sub-angular quartz (c.20%), with weathered Fe-stained calcite (c.10%) throughout the grave samples. Coarse organic material was unsorted and evident in most samples, with high levels of mollusc shell (Figure 54b) clearly identified in all but the heel region of SK3755. Fragmented, weathered bone with little birefringence under XPL was observed in the skull region sample of SK1525. Bioturbation was apparent around the pelvic region samples of SK3755 (Figure 54d) with ferruginised roots (*c*.2%) presenting high levels of lignin under XPL.

The calcite fraction of the coarse material suggested that it could have derived from the adjacent Lewes Nodular Chalk Formation. The surrounding geology was however derived from chalk (Figure 53). Mollusc shell (**Error! Reference source not found.**b) observed hroughout the burial samples could provide evidence of dry grassland. However, the chalky parent material may well have been the origin of many fragments (Canti *et al.* 2004). The low birefringence of the fragmented bone implied that weathering and the diagenesis of collagen had occurred in the skull region sample of SK3738 through the diagenesis of collagen (Oakley *et al.* 2004). Bioturbation through worm activity in the samples was identified by the deposition of calcitic worm castes, with worm trails through the fine material clearly identified (Figure 54d). The high frequency of partially degraded ferruginised root may be indicative of the pastoral grass area, where the grave was discovered (British-Geological-Survey 2012; Canti 2003).

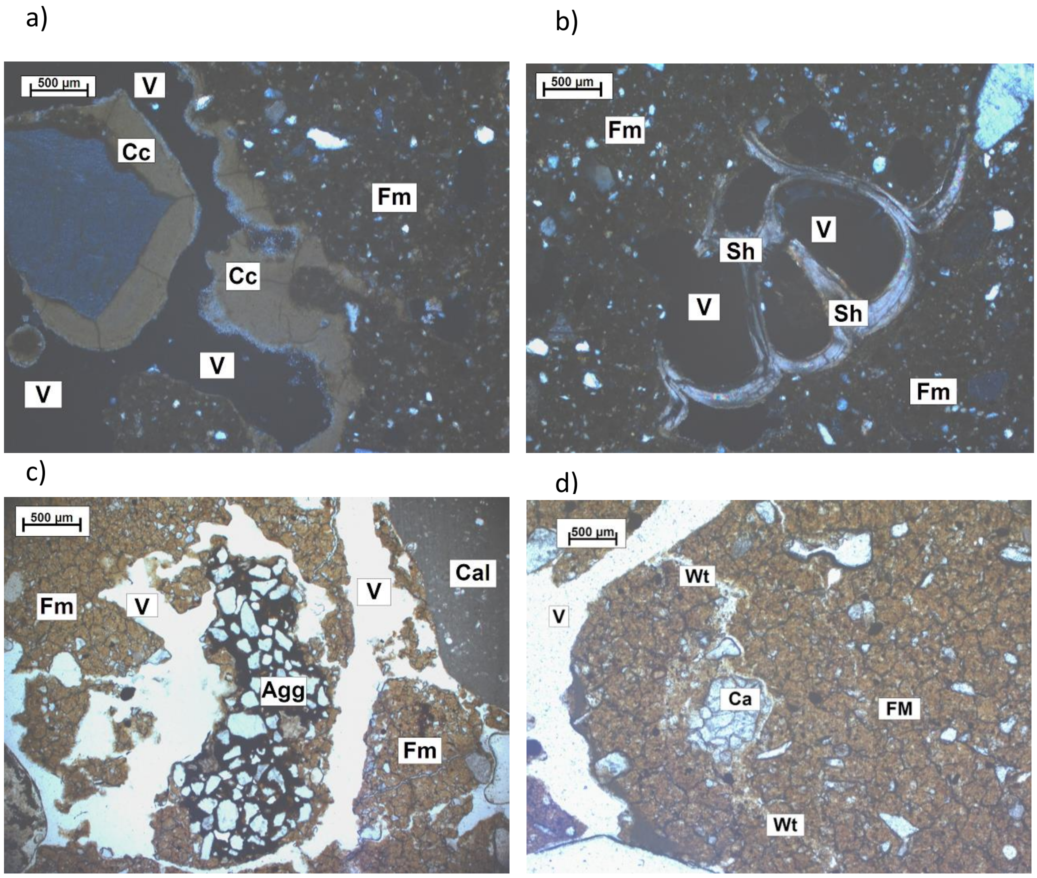


Figure 54: Features from the Ridgeway site. a) Dusty coatings (Cc) formed on the fine material in the peds (Fm) and coarse material with inter-pedal non accommodated voids (V) of the pelvis (B) region of SK3755, (XPL); b) Mollusc shell (Ms) deposited within the fine material (Fm) of the skull (B) region of SK371, (XPL); c) Redoximorphic aggregate nodule (An) in the fine material (Fm) of Skull (B) region (SK3751) also demonstrating the coarse calcite fraction (Cal) and partially accommodated voids (V), (PPL); d) Partially accommodated channels (V) adjacent to fine material (Fm) containing a worm trail (Wt) and calcitic worm caste (Wc); in the pelvis (B) region (SK3755), (PPL)

4.3.2.2 *Fine material*

There was a high ratio of coarse to fine material (*c/f*) of 3/7 in the burial and control samples. The fine material had a speckled *b*-fabric with 1st order interference, whilst in PPL the material was dotted.

The speckled *b*-fabric , with randomly arranged clay domains, suggests little overall pedogenic development of the fine material in the burial (Stoops 2003b 99). However, the random orientation of the domains could also point to recent disturbance of the soil by bioturbation (Figure 54d). The dotted appearance in PPL suggested that possible remnants (<50 µm) of micro-charcoal fragments, plant fragments and coarse micro-minerals had been incorporated (Stoops 2003b 86).

4.3.2.3 *Pedality and void development*

Granular peds were observed in the C2 and C3 control samples. Moderate to strong peds were recorded across most sampling regions (Table 22), the sub-angular blocky separated by partially accommodated and non-accommodated inter-pedal channels. Intra-pedal vughs and chambers were present in all samples. A strong abundance of granular peds separated by complex packing voids was exhibited in thin sections from the skull (A) region (SK3751). Smaller accommodated planar voids, intersecting the inter-pedal channels, were identified from thin sections in the pelvis (A) and pelvis (B) regions (SK3755).

Table 22: Ped development across the Ridgeway site

Skeleton No.	Skull	Skull (A)	Skull (A1)	Skull (B)	Pelvis (A)	Pelvis (B)	Heel
SK3738	M						
SK3851		S	S/M	M			
SK3755					M	M	M

S: strong, M: moderate and W: weak

The control sample method of collection and processes would indicate there has been a disaggregation of sub-angular blocky peds that may have formed prior to sampling, thus only granular peds were observed. The development of inter-pedal channels separating the sub-angular blocky peds in the undisturbed burial samples, could point to high levels of bioturbation forming areas of weakness in the soil, suggesting the presence of organic matter (Table 22). The identification of vughs within the peds may also point to aggregation of the soil colloids or, alternatively, disruption of the microstructure through bioturbation, again implying high levels of organic matter (Stoops 2003b 65). The granular peds developed around the region of the skull (A) (SK3751) may have been derived from a higher level of organic matter in the region linked to a raised frequency of bioturbation. The formation of planar voids displayed in pelvis (A) and pelvis (B) regions of SK375 are subsequent to the development of the channel voids, as shown by their intersection with the latter. The features may be the result of shrinkage during sampling or drying processes; however, this cannot be confirmed.

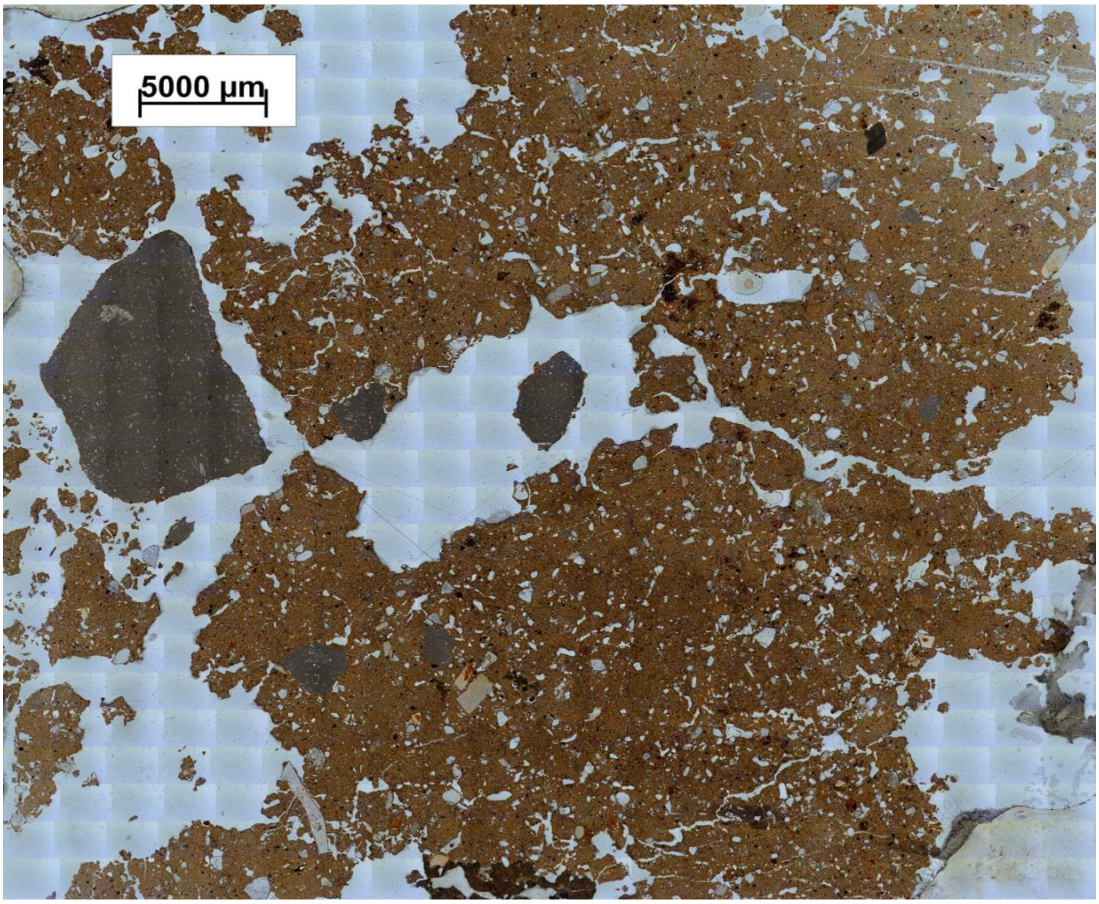


Figure 55: Mosaic image from the heel region of SK3755, Ridgeway, with strongly developed sub-angular blocky peds, inter-pedal channels and intra-pedal vughs (PPL)

4.3.2.4 *Pedofeatures*

Well-developed textural pedofeatures were observed throughout the burial thin sections and were dominant in the skull regions (SK3738 and SK3751), whilst their increased frequency was observed in the heel region. The samples from the pelvis (A) and pelvis (B) region (SK375) also exhibit, dusty coatings with iron staining. Fragmented dusty coatings on coarse mineral material were observed in the C2 and C3 control grab-samples. Typic and aggregate nodules were observed specifically within the granular peds of the skull region samples from Sk3738, whilst there was a high frequency of dusty coatings. The pelvic region also displayed a high frequency of excremental pedofeatures (*c*.10% of the whole soil thin section) but a lower frequency was observed in all other sample regions.

The increase in dusty coatings around the areas of the skull region samples may indicate there had been a higher level of disturbance above this area. Vertical translocation of clay particles suspended in soil water from the upper horizons could have been the basis for their development (Kuhn *et al.* 2010 223). Surface disturbance through the removal of grass and increased movement from construction traffic could have been the causal factor for the development of dusty coatings through the translocation of soil particles in soil water. Loosening of the soil particles and further precipitation events could have allowed percolation of soil particles into the soil profile. The morphology of the dusty coatings displayed no laminations, which suggests that a singular flow of soil particles, containing silt/clay within soil water, had percolated through the soil profile. The presence of dusty coatings on peds and within the channel voids indicated that the coatings developed after ped development. The identification of fragmented dusty coatings in the grab-sample controls, similar in morphology to the dusty coating identified in the burial samples, suggests that their development could have occurred during the same disturbance and illuviation process. The fragmentation of the coatings, however, could have occurred from the processing of the grab-soil samples for chemical analysis. The relative abundance of typic and aggregate nodules suggests there had been an increase in redoximorphic conditions and the reduction, translocation and precipitation of Fe to areas of greater organic matter content (Haglund *et al.* 2001), particularly in the skull region of SK3738 and near skull (A) and skull (B) regions of SK3751. Increased organic matter within the skull region samples was also suggested by the development of granular peds (as discussed in Section 4.3.2.3).

4.3.3 Quantitative micromorphological analysis: Ridgeway

4.3.3.1 *Point counting*

The results of the point count analysis are displayed in Table 23.

Table 23: Occurrence of pedofeatures, void space and coarse fraction from the sample regions expressed as a percentage of all counts from each region of interest (see Section 2.2.1 for ROI definition)

		Occurrence of pedofeatures, voids and coarse fractions							*(% of total counts)*	
		Coarse Minerals	Coarse Organic	Voids	Bone	Excremental Pedofeature	Nodule	Iron impregnated	Coatings	Undifferentiated
Skull	*SK3738*	15.13	0.42	14.29	0	0	2.10	0.42	3.78	63.87
Skull(A1)	*SK3751*	26.67	0.56	9.44	0	0	0.56	2.78	7.22	52.78
Skull(A)	*SK3751*									
	ROI 1	15.48	1.19	13.09	0	0	0.59		0.59	69.05
	ROI 2	9.69	0.51	43.37	0	0	3.06	0.51	1.02	41.84
Skull(B)	*SK3751*	8.73	0.40	40.08	0	0		0.40		42.46
Pelvis(A)	*SK3755*	13.09	0.40	21.43	0	0	0.40		2.78	61.90
Pelvis(B)	*SK3755*	17.78		17.78	0	0	2.78	2.77	10.56	48.33
Heel	*SK3755*	16.96	0.44	13.48	0	0	3.48	1.30	4.78	59.5

The abundance of coarse material within the skull (A) region was lower than that of skull (A1) region, with both regions of interest (ROI) in skull (A) region sample having a lower percentage occurrence of coarse material. The skull (A) region had the greatest amount of void space, whilst the skull (B) region also contained high levels. The heel region sample from SK3755 has the highest occurrence of nodules, while coatings were identified in higher levels in the pelvis (B) region of SK3755 and skull (A1) region of SK3751. Bone and excremental pedofeatures were not identified during the point counting analysis.

The identification of increased void space in the skull (A) region suggested there had been an increase in aggregation (as already identified with the micromorphological observation of granular peds) and possibly higher levels of bioturbation. Identification of bioturbation within the skull (A) region sample through micromorphological observations was not confirmed, with null results for the identification of excremental pedofeatures in all samples, as shown in Table 23. It was also evident there was a null result for bone, with none being identified during the point counting. Although fragmented bone was identified through micromorphological observation, the results suggested the point counting parameters were not close enough together to detect these features in the soil,. The point counting also indicated the undetected features were smaller in size than the 500 µm step taken between every count. The development of dusty coatings, especially in the skull (A1) and heel regions could point to a greater degree of soil particle movement and illuviation within these sample regions, compared to the rest of the samples. Nodule frequency was higher in the pelvis (B) region and heel sample region both from SK3755, and was comparable to the levels in C2 control. This may indicate that higher levels of reduction and oxidation had occurred during decomposition of the burials, which may have been the result of increased organic matter (Lindbo *et al.* 2010).

4.3.3.2 *Image analysis*

The greatest percentage of void space was observed in the skull (B) region (SK3851), for over 30% of the representative area of the thin section Figure 56. In contrast, the lowest level of void space was observed in the skull region samples from SK3728 (~10%). Pelvis (A) and pelvis (B) region samples both from SK3755 differed from one another, with the pelvis (A) region having around 19% void space in comparison to that of pelvis (B) where voids were around 27%.

The pattern of voids seen in the image analysis suggests higher levels of bioturbation had occurred in those areas with a high percentage void space (skull (B) region and pelvis (B) region) owing to increased organic matter. In comparison, the low levels of void space in skull region sample of SK3738 indicated that bioturbation could have been very low suggested by the low levels of soil aggregation, ped development and organic matter in this region (Oades 1993), and the absence of excremental pedofeatures.

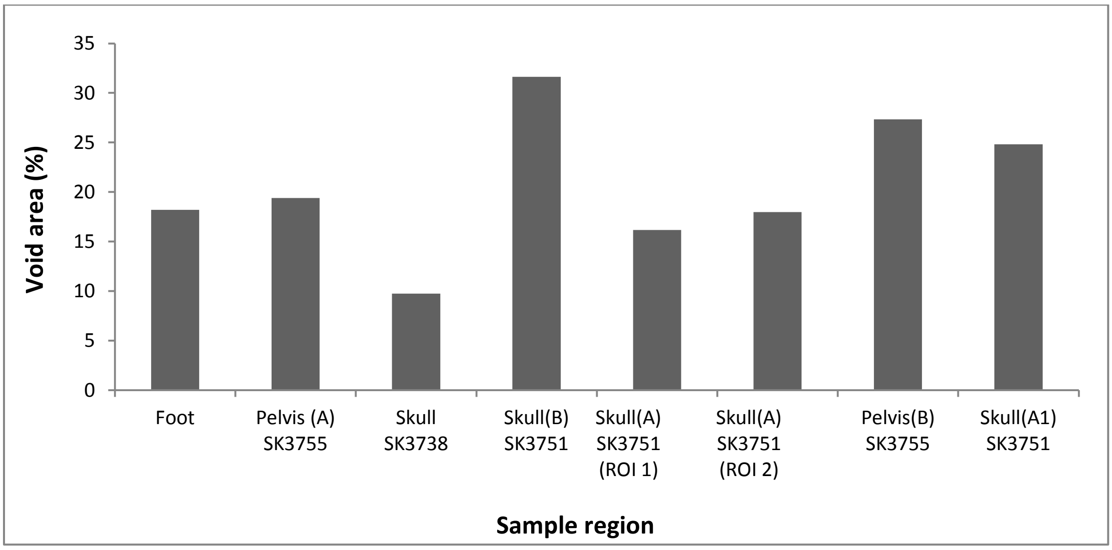


Figure 56: Total percentage of void space as determined by image analysis, from selected regions of interest (ROI) in the thin sections from Ridgeway

4.3.4 SEM-EDS analysis

4.3.4.1 *Redoximorphic nodules*

Figure 57 indicates there were high levels of P relative to Fe in the nodules from the skull (A1) region samples, compared to the ratios in the fine material of the same sample.

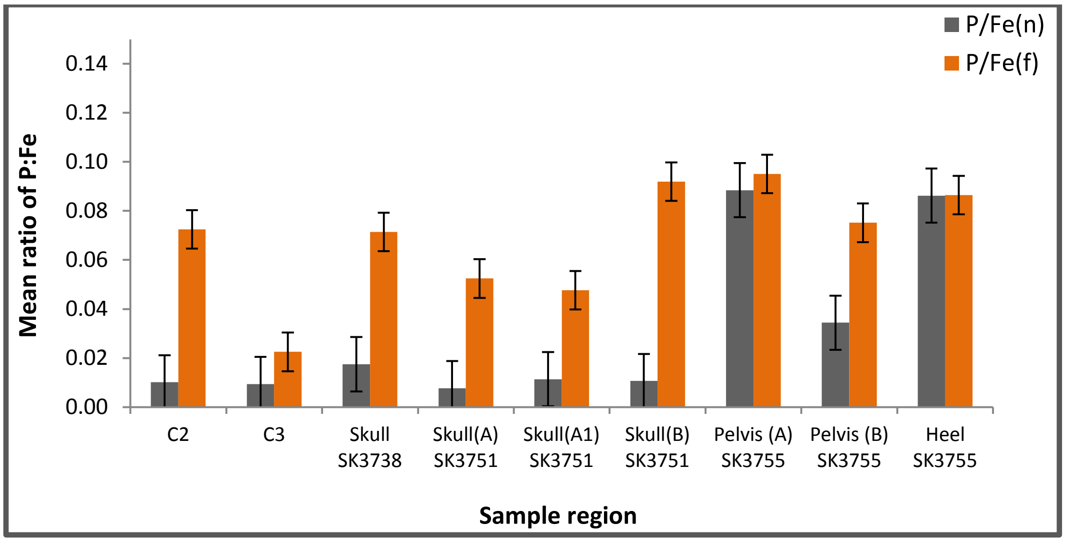


Figure 57: Mean ratio of P:Fe in the fine material (f) and redoximorphic nodules (n) across all burial and control samples from the Ridgeway site. The error bars represent 1 standard of the mean

In contrast the C3 control showed low ratios of P:Fe in both the fine material and nodules. The nodules across most samples had higher ratios of P:Fe in the nodules when compared to the fine material in the same sample, only the pelvis (B) and heel region samples and the C3 control showed higher levels of P in the fine material compared to the nodules.

The mean ratio of P:Fe is highest in the fine material of the pelvis (B) sample of SK3755, with high levels also seen in the nodules of this sample (Figure 57). The P:Fe levels are similar in the fine material and the nodules of the heel (SK3755) sample (0.09). The levels of P:Fe across all samples indicate there are higher levels in the fine material compared to the nodules, with the C3 control displaying the lowest levels (nodules: 0.01; fine material: 0.02).

The mean concentration of P was displayed in Figure 58 where the highest concentration of P can be observed in the nodules of the skull (A1) region. In all samples except the skull (A) region there nodules exhibit higher concentrations of P in the nodules. The lowest concentrations of P are seen in the C3 control both in the fine material and the nodules.

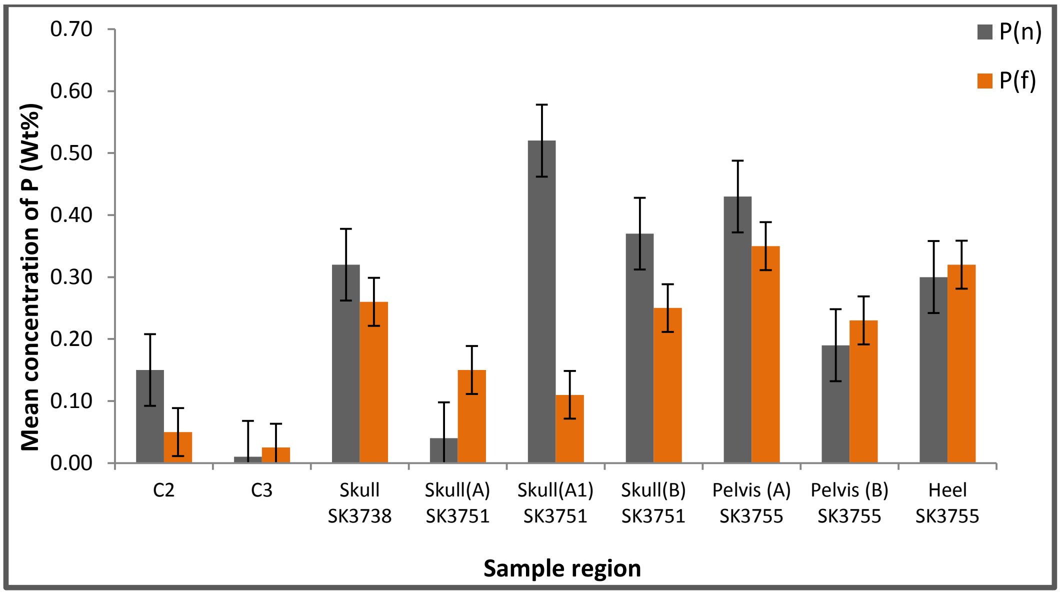


Figure 58: The mean concentration of P in the redoximorphic nodules (n) and fine material (f) in the burial and control sample from the Ridgeway site. Error bars represent 1 standard error of the mean

From Figure 57 and Figure 58 it is evident that the C3 control had the lowest levels of P in both the fine material and the nodules. The level of P in the nodules of the skull (A1) region sample from SK3751 was high, yet the level of P:Fe was less when compared to the fine material in the same sample. This suggested there were higher levels of P co-precipitating with relatively low levels of Fe. This pattern of co-precipitation has occurred throughout the site, with high P levels in the nodules and relatively low levels of P in the fine material, whilst the P:Fe levels are higher in the fine material and lower in the nodules. This implies the P may have been adsorbed by the clay minerals and Fe/Al oxides in the fine material (Kittrick and Jackson 1956).

4.3.4.2 *Dusty coatings*

The ratio of P:Fe in coatings can be identified in Figure 59, with the highest ratio of P:Fe seen in the coatings in the C2 and C3 controls. The ratio of P:Fe is higher in the coatings compared to the fine material in the skull ts8 and skull (A) region. The skull (B) region sample (SK3751), the pelvis (A) and pelvis (B) region samples, and the heel region sample of SK3755 displayed increased levels of P:Fe in the fine material, whilst the skull (A1) sample from SK3751 contained no detectable P.

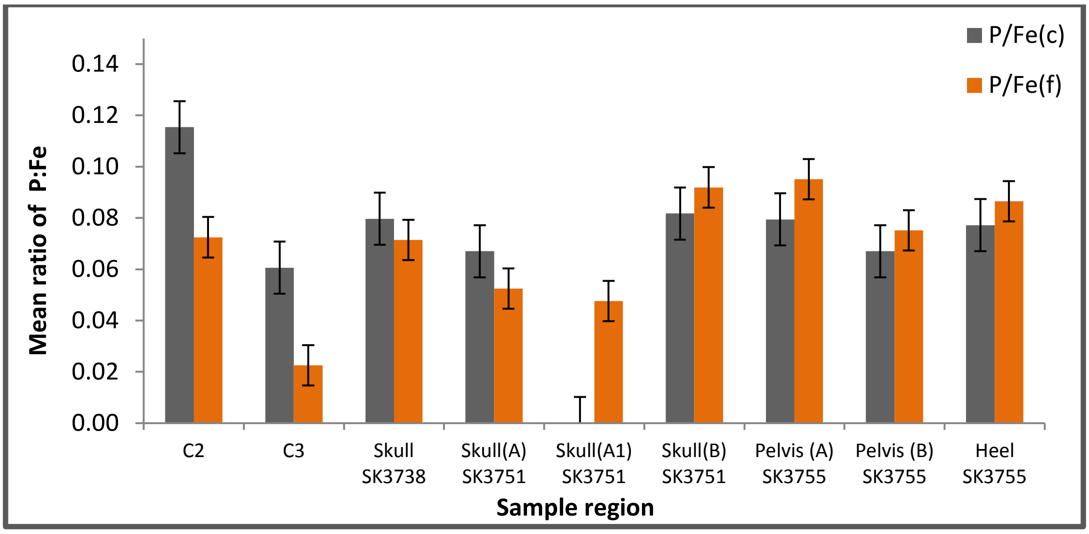


Figure 59: Mean ratio of P:Fe in the fine material (f) and dusty coatings (c) across all burial and control samples from the Ridgeway site. Error bars represent 1 standard error of the mean

The coatings of skull (A1) region sample of SK3751 exhibited a P:Fe ratio of zero, whilst the C3 control had the lowest levels of P:Fe in the fine material (0.2). The C2 and C3 control samples the skull region sample from SK3738 and the skull (A) region sample (SK3751) all display higher P:Fe ratios in the coatings compared to the fine material, with the C2 control having the highest ratio (0.12). The other burial samples all have higher P:Fe in the fine fraction.

The coatings in the skull (A1) region exhibited no detectable P (Figure 60). The mean concentration of P was greatest in the fine material compared to the dusty coatings across the burial and control samples, the pelvis (A) region sample from SK3755 displayed the highest concentration of P(0.35 Wt%). The C2 and C3 controls had the lowest levels of P across the site, both in the coatings and fine material. However both control samples still showed higher levels of P in fine material compared to the coatings.

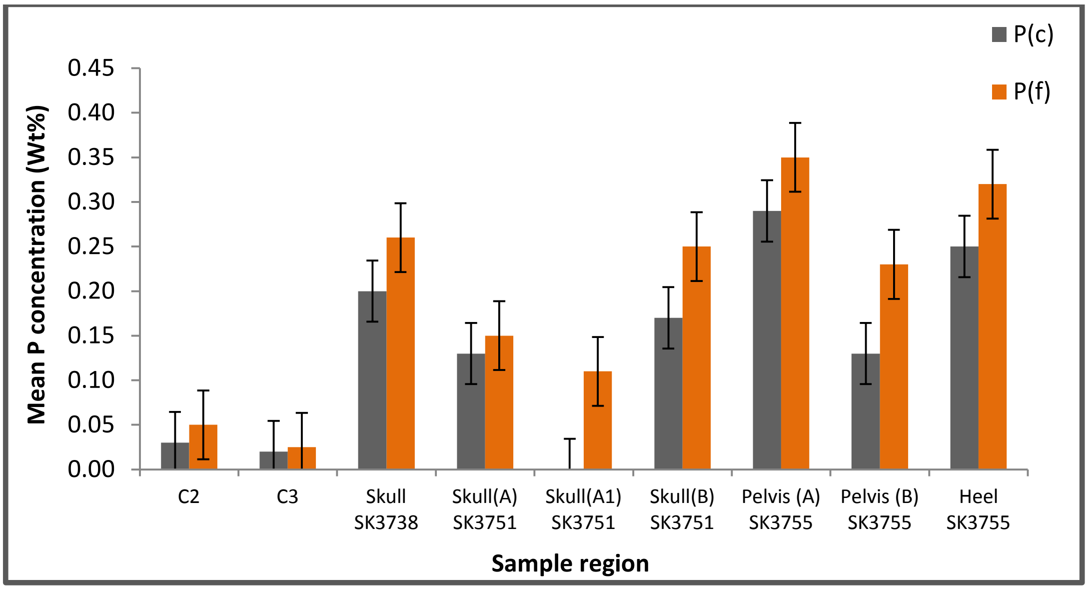


Figure 60: The mean concentration of P in the dusty coatings (c) and fine material (f) in the burial and control sample from the Ridgeway site. Error bars represent 1 standard error of the mean

The mean concentrations of P in both the coatings and the fine material of the control samples were low compared to the levels in the burial samples. P in the burial samples especially in the pelvis (A) region sample and heel region both from SK3755 were high when compared to the C3 control and skull (A) region samples, however, the coatings had less P than the fine material within the burial samples. These patterns were comparable with the P:Fe ratios in the coatings and the fine material, suggesting the co-precipitation of P:Fe mirrors the absolute concentrations (Figure 58). This pattern also suggests P had been retained in the fine material by the clay minerals and Fe/Al oxides and not co-precipitated with Fe into the coatings of the skull (A1), skull (B), pelvis (A), pelvis (B) and the heel regions. The ratios of P:Fe in the coatings of the C2 and C3 control samples and the skull (SK3738) and skull (A) (SK3751) region samples were greater than those in the other sample regions, thus also showing either increased co-precipitation into the coatings or adsorption of Fe/Al oxides and clays. This leads to two hypotheses: 1) as co-precipitation could only take place in areas were reduction and oxidation occurred, the areas with increased co-precipitation had developed redox conditions on a greater number of occasions or for a prolonged period of time; 2) the P had been retained by clay minerals and the crystal Fe/Al oxide formations in the coatings.

The initial hypothesis suggests there had been localised anaerobism in the control and the skull (SK3738) and skull (A) region sample (SK3751). The calcareous free-draining soil implies waterlogging could have been low, with the control samples collected in the upper part of the burial pit above the burials, whilst the skull (A) region sample was collected next to the skull (A1) and skull (B) region samples that showed lower oxidising conditions. This may have been caused by decomposing microbes depleting localised soil oxygen levels. In contrast, the second hypothesis, involves clay minerals and Fe/Al oxides retaining P, reducing the amount that could have been co-precipitated with Fe. The observed levels of P and P:Fe ratios could be derived from either explanation.

4.4 Summary: Ridgeway

4.4.1 Sampling

The employment of a watching brief during construction of a relief road to the north of Weymouth in Dorset resulted in the discovery of the Anglo-Saxon (*c.* 89-1030AD) burial pit, containing the decapitated remains of 51 bodies. Because of the position of the torsos in the pit, the *InterArChive* sampling strategy was only employed as a guide during the collection of undisturbed soil samples from around the burial. Sampling of the skull regions was not as difficult, as a result of their position away from the torso and adequate quantities of soil being available for collection of Kubiena samples.

Collection of undisturbed control samples, from the site and grave fill regions was not carried out in line with the initial *InterArChive* micromorphological sampling protocols. This was as a result of over-burden deposited around the excavation and the prior removal of the grave fill before the sampling team arrived on site. Thus, control samples were collected from the edge of the burial pit and over-burden spoil heap (from the grave fill) using a grab-sampling method. Analysis of grab samples was only undertaken through micromorphological observation and SEM-EDS analysis as it was evident that owing to the nature of sampling and the initial soil preparation that pedogenic features and spatial relationships may have been eliminated.

4.4.2 Burial environment

Partially weathered quartz and calcite were the dominant components of the unsorted coarse mineral material, with fragments of weathered bone in the burial samples and speckled *b*-fabric identified in all burial and control samples, suggesting disturbance in the grave. High levels of root organic material and excremental pedofeatures indicated that bioturbation had occurred in all burial samples. This was possibly a causal factor in the disturbance. Thus the formation of the speckled *b*-fabric and movement of fragmented bone throughout the remains (Canti 2001). Organic matter and fragments of bone or excremental pedofeatures related to bioturbation were not observed in the control samples, probably owing to their sieving and homogenisation. The components of the coarse mineral fractions were, however, similar in composition in the control and burial samples, suggesting similar origins. The high frequency of bioturbation in the burial samples not only suggested disturbance, but could have been a contributory aspect to the genesis of inter-pedal channel voids between the sub-angular peds. The granular peds localised around the skull regions indicated increased bioturbation, and could also have pointed to increases in organic matter around the skull region through greater root and soil faunal activity (Reatto *et al.* 2009). Granular peds, however, had not developed around the pelvic region samples [pelvis (A) and Pelvis (B) of SK3755]. Instead, strongly developed sub-angular peds were present, with increased levels of excremental pedofeatures (Table 22). Redoximorphic nodules were also identified in increased frequency around the areas of higher aggregation, with both typic and aggregate nodules with a greater incidence in skull (A) region (SK3751) and pelvis (B) region (SK3755) samples, as identified by image analysis.

The development of dusty coatings in all samples, including the controls, suggested a singular soil disturbance event, affecting the whole site. The singularity of the disturbance was determined by the absence of laminations in the clay components of the dusty coatings (Stoops 2003b 109). The C3 control sample collected from the edge of the pit contained fragmented, non-laminated dusty coatings around coarse mineral material. Two hypotheses can be proposed for the development of dusty coatings in the control and burial samples : (1) Development was due to disturbance of the soil at the ground surface from the removal of the sealing layer or high levels of activity on the soil surface, with successive illuviation of soil particles in water suspension during precipitation events. The disturbance may also have arisen from trampling/movement of machinery during construction followed by a precipitation event providing transport of fine material through the profile; and (2) Disturbance had occurred from a single collapse event of the soil around the skeletal remains in the pit, once degradation of the flesh had taken place. The latter hypothesis suggests that the disturbance event could have occurred below the ground surface, with the possible collapse of the soil surrounding the burial at some point during the decay of the flesh on the bones and possible disarticulation of remains. This would have provided the disturbance required for the disaggregation of loose silts and clays to be moved, within the burial pit, after a subsequent flush of soil water through the channels and voids (Kuhn *et al.* 2010 229). However, the dusty coatings were not confined to the burial samples and the grave fill from the pit but were also identified in the material collected at the side of the pit in the soil-grab samples. If collapse was the causal factor it suggests that the deposited silt/clay had translocated laterally through the soil. The initial hypothesis of a single ground layer disturbance is more feasible because of the lack of laminations, which in turn could have occurred, if the collapse had been the causal factor. However, the presence of dusty coatings with similar morphology in the disturbed grab- soil sample controls and the burial samples pointed to surface activity being the mechanism for their formation.

4.4.3 Detection of burial degradation products

The mean absolute P levels in the fine material of the C3 control and skull (A) region sample from SK3751 are higher than detected in the nodules. However, these levels were the lowest detected in any of control and burial samples. In all other samples the level of P in the nodules was higher than in the fine material. Conversely, the P:Fe ratio was lower in the nodules compared to the fine material. These deposition patterns in the fine material and the nodules suggested the level of Fe in the grave is low, thus lowering co-precipitation potential of P:Fe, except for the skull (A) region and C3 control were P:Fe ratios are increased above the fine material ratios. The frequency of nodules within the control and burial samples seemed to support this hypothesis. The results suggest the P may have been retained by the clay particles in the fine material (Kittrick and Jackson 1956).

The concentrations of P identified in the control samples were low when compared to the burial samples, in both the coatings and the fine material. This suggests P in the burial samples remained in the fine material, possibly on the clay minerals and within the Fe/Al oxide crystals, while the P in the control samples has co-precipitated out with the Fe into the coatings. Thus, the degradation products from the burial would seem to have been retained in the fine material, this is supported by the comparatively lower levels of P in the fine material of the control samples.

The investigation of the Ridgeway mass grave has identified pedogenic features within the undisturbed burial samples. The analysis of disturbed soil grab samples in conjunction with that of undisturbed soil samples has provided confirmation of dusty coatings and redoximorphic nodules, thus similar pedogenic processes were occurring in all areas of the site. This also indicated that the grave fill and the soil from around the burials were derived from the same parent material. The nature of the events which led to the development of the dusty coating cannot be conclusively identified, but the resulting pattern of formation in the control and burial samples has allowed two hypotheses to be posed; as to their development. Evidence of the development of redoximorphic nodules across the site could indicate that they were most frequent in areas of higher bioturbation and void space within the fleshier parts of the burial samples such as the skull and pelvis regions. This further implied that their formation was linked to an increase in organic matter in certain regions and confirmed by the higher levels of P in the nodules, possibly derived from the degradation products.

4.5 Fromelles

All micromorphological observations from the Fromelles site are displayed on a summary sheet in Appendix 3

4.5.1 Geology of the area

The geology within the areas of Pheasant Wood and Fromelles comprised of Flanders Clay a sedimentary formation. Beyond the wood, the region was characterised by superficial glacial silt deposits (Figure 61).

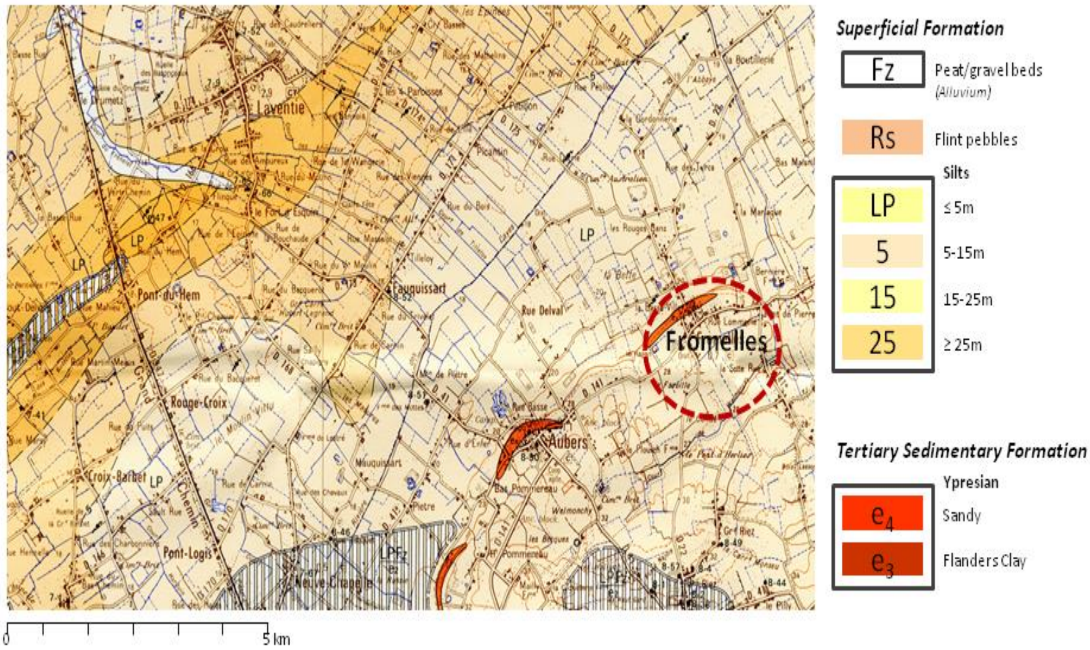


Figure 61: Geology map of Fromelles and the surrounding region, highlighting the soil parent material and sedimentary deposition layers. (*Carté géologique de la France, Région: Haezebrouck, 1/50 000, www.brgm.fr*)

The sedimentary formations of the region with the underlying Flanders Clay at the base was identified during the initial dig of the site in 2008 by the GUARD, with a heavy wet clay being observed during the excavation (Szibor *et al.* 1998).

A summary of the burial context, geology, soil type and main micromorphological features are displayed in Table 24.

Table 24: Summary table of geology, soil type, burial and micromorphological features observed at Fromelles

Context	*Position/type of burial*	*Geological features*	*Soil Type*	*Micromorphological Features*		
				Coarse Material	*Fine material*	*Post-depositional pedofeatures*
Fromelle	20th century Pre-dug pit for a mass burial of co-mingled, clothed WW1 soldiers.	Flanders clays over drift deposited gravel beds	Grey/black clay (clay content of approx. 90%)	Quartz (10%) in the controls (C2&C3). Gypsum (20%) and quartz (2%) in the burial samples. Bone(10%), textile (5%) and wood (2%) in the burial samples	Speckle *b*-fabric in the controls with a speckled/striated *b*-fabric in the burial samples	Dusty clay coatings observed in the inter-pedal channel voids of the C2 control and burial samples. Redoximorphic nodules observed in the skull and C3 control

4.5.2 Micromorphological analysis

All original micromorphological observations data from Fromelles are displayed in Appendix 3.

4.5.2.1 *Coarse material*

The control samples obtained from above the inhumations, within the backfill of the burial pit, had a *c/f* ratio of 2/3. A low incidence of partially weathered, sub-angular quartz (*c*.10%) and a low frequency of partially weathered, sub-angular flint fragments were identified in C3 control (*c*.2%). No quartz was identified in the skull (A) region sample SK1527, although it was observed in a low frequency (<2%) with a *c/f* ratio of 1/4. Tabular shaped crystals of gypsum-like minerals (Figure 62a) (Stoops 2003b), were observed in the matrix and channel voids of most burial samples, with the greatest in the foot region sample(SK1527). Fragments of bone (*c*.10%) displayed low birefringence and were identified around the skull region (SK1525). Amorphous wood-like fragments and areas of amorphous organic matter were noted in the foot region (SK1527), whilst a high incidence of textile -like structures were recognised around the skull (B) and foot regions of SK1527.

a) b)

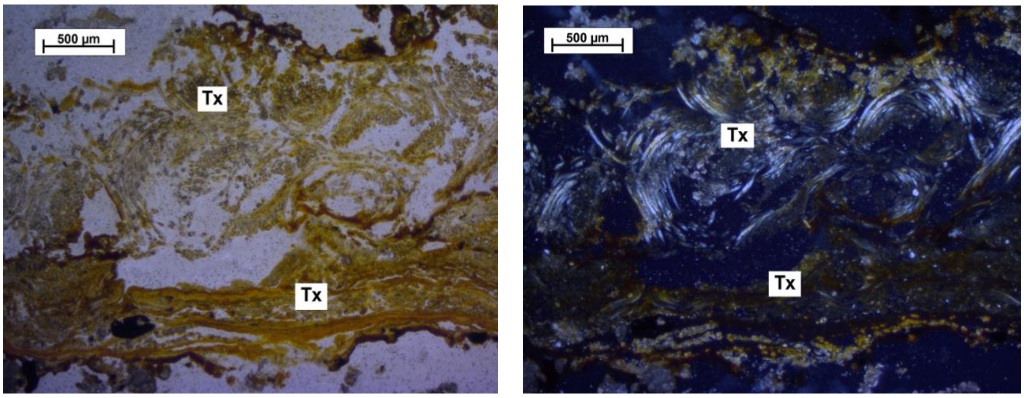


Figure 62: Textile-like (Tx) features in the foot region of SK1527 shown in a) PPL and b) XPL

A significant difference in coarse material and the *c/f* ratio was observed between the control samples obtained from the back fill of the burial pit and those of the burials. Micromorphological observations provided poor evidence for translocation of coarse mineral fragments from the upper control layers of the backfill into the soil around the burials. The identification of well preserved, textile-like structures around the skull (B) and foot regions of SK1527 were derived initially from the identification of textile-like material adjacent to the Kubiena tin when the undisturbed soil was collected (Figure 62). In contrast, the low levels of birefringence identified in the fragmented bone and the amorphous wood-like organic matter, could indicate an increased level of degradation (Babel 1975 458; Oakley *et al.* 2004). The difference in the degradation levels between the textile and the wood-like fragments suggested two hypotheses: 1) there were localised changes in soil pH, providing soil micro-environments where preservation and decay were dissimilar; 2) different degradation factors were present.

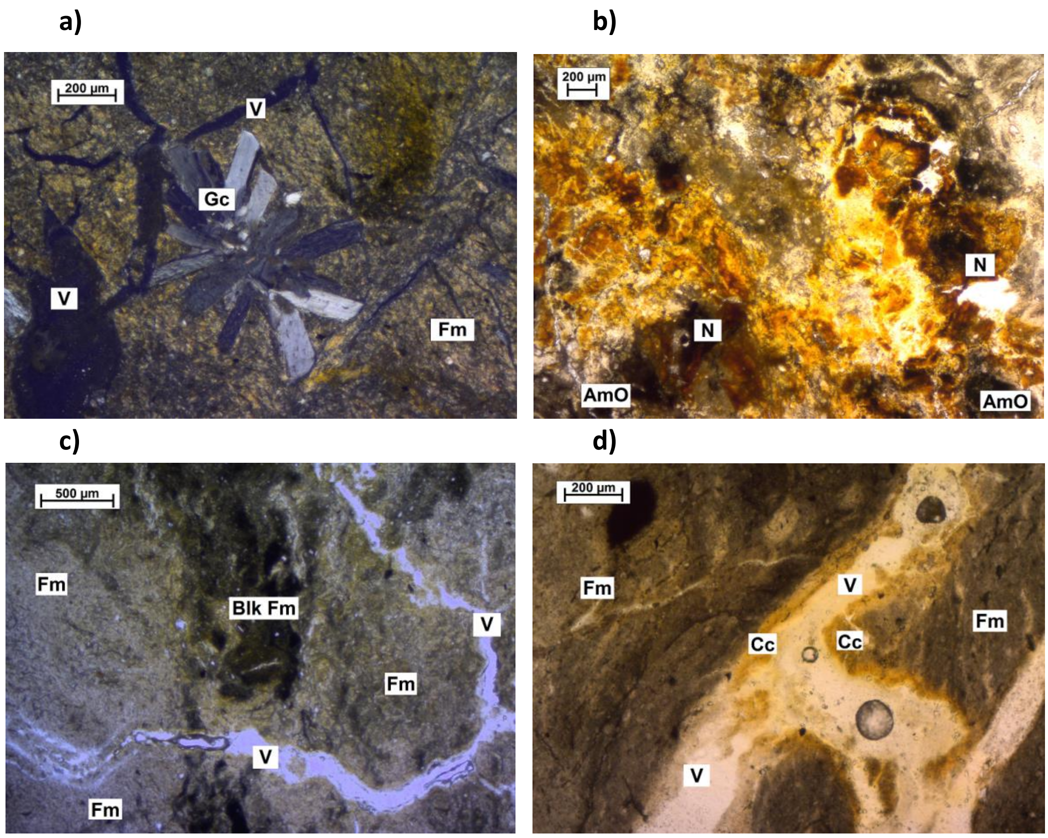


Figure 63: Features identified in the Fromelles samples through micromorphological observation: a) Gypsum crystals (Gc) in the fine material (Fm) of the foot region (SK1527) (XPL); b) Redoximorphic nodules (N) and amorphous organic matter (AmO) in the fine material around the skull of SK1525 (PPL); c) Partially accommodated void (V) with fine material (Fm) and black amorphous organic matter (Blk Fm) in the skull (B) region of SK1527 (PPL); d) Development of dusty coatings (Cc) around the edge of partially accommodated channels (V), and grey fine material (Fm), skull(B) region of SK1527 (PPL)

The initial hypothesis suggested that soil properties changed significantly across the same sample area, in particular near the feet region. This may have been a result of the increased levels of gypsum-like minerals in this region of SK1527. The excavation of the burials identified white dust attached to the bones and the remains, within the graves, the evidence suggested there had been a powdery pre-burial treatment added to the grave (Szibor *et al.* 1998). If quicklime (CaO) was added to the grave, the water present in the Flanders clay could have provided an exothermic reaction and the slaking of the CaO would have formed calcium hydroxide ($Ca(OH)_2$) raising the pH of the soil to neutral or alkaline state (Estrela *et al.* 1995; Gabrisova *et al.* 1991) The presence of neutral to alkaline pH would have allowed the preservation of bone and cellulose based organic matter through ; however a higher pH environment could degrade protein-based keratin within wool products, which contain strong disulphide bonds (Janaway 2002 353). The formation of gypsum-like minerals further suggests a reaction with weak hydro sulphuric acid

($H_2S_{[aq]}/H_2SO_4$) (Janaway 2002 353), derived from the dilution of cellulose based sulphuric acid (H_2SO_4) from the hydrolysis of carbon based organic matter in anaerobic conditions (Mabey and Mill 1978), and the degradation products from protein based keratin in wool textiles. The dilution of sulphuric acid would come from the heavy wet clay environment, whilst the latter degradation of wool from the alkaline conditions provided by $Ca(OH)_2$ and putrification products from the burial (Costanza *et al.* 2007). The last processes could have supplied the compounds required for the seeding of gypsum crystals: ($Ca(OH)_2$ and $H_2S_{[aq]}$ (Sutton 1984 p.313). The presence of the gypsum crystals throughout the burial may indicate that dissolution and translocation had taken place, as gypsum enters into dissolution at a lower more acidic pH. The result of gypsum translocation and crystallisation suggests there was fluctuations in the pH of the soil (Gabrisová *et al.* 1991).

The evidence suggests, therefore, that both hypotheses are important, with changes in pH providing degradation of cellulose and protein based materials and microenvironments, within the soil samples, with changes in pH and mineral content.

4.5.2.2 *Fine material*

The control samples of Fromelles displayed mono-striated and circular-striated *b*-fabrics (XPL) and cloudy limpidity (PPL). The burial samples also displayed a partially cloudy and masked limpidity (PPL), but had both speckled and mono-striated *b*-fabrics (XPL), the latter particularly in the skull region (SK1525) sample. Large areas of dark brown/black amorphous organic matter were noted in the burial samples, and were particularly prominent in samples collected from the skull regions (Figure 63c).

The high level of circular and mono-striated *b*-fabric in the C2 and C3 control samples suggested several formation processes. Wetting and drying episodes may have occurred causing the clay minerals within the soil to shrink and swell, aligning parallel to each other and displaying isotropic stresses (Dalrymple and Jim 1984).The high levels of amorphous organic matter may have masked the striations in the burial sample, with only the presence of mono-striated *b*-fabric, especially around in the skull samples. The difference in the level of striation observed in the *b*-fabric between the burial samples and the control samples could, however, be through the effects of prolonged wetting and drying periods in the burial samples. The control samples showed evidence of being affected by surface precipitation, whilst little interaction has occurred between the different levels (burial samples below the controls). The burial samples may have been affected by the retention of water in the heavy clay soil and possibly from the water table below. The black amorphous organic matter could have derived from the putrification stages of human decomposition along with butyric fermentation (Sagara *et al.* 2008 75).

4.5.2.3 *Pedality and void development*

Weak to moderate development of sub-angular blocky peds separated by partially accommodated, inter-pedal planes and channels was observed in the control samples (Figure 64a). Randomly distributed inter- and intra-pedal voids were identified in the C2 sample, whilst parallel orientation of peds (relative to the burial and ground surface) was observed in the C3 control sample. In contrast, the samples from the burial displayed strongly developed, randomly orientated, angular blocky peds separated by accommodated inter-pedal channels and planes (Figure 64b).

The development of peds in the control samples cannot be confidently attributed to bioturbation as the pedofeatures and the coarse organic material were characterised by little evidence of faunal activity. Ped development in the controls was more likely due to the aggregation of soil particles and clay domains, whilst organic matter from modern agriculture could also have provided aggregation material (Oades 1984; Szibor *et al.* 1998). The C3 control displayed parallel channels and compressed sub-angular blocky peds Figure 54a); this suggested there had been some surface activity in the region. It is evident, from post excavation reports, that there had been harvesting activity in the area of the graves, possibly causing compaction of the peds in the control samples (Szibor *et al.* 1998). The ped development surrounding the burials was possibly the result of aggregation of clay particles with high levels of organic matter. The shrinking/swelling mechanism of clay-rich soil particles can help to form aggregates (Figure 63b) (Brady and Weil, 2008 139). Voids within the soil are formed in areas of weakness, thus ped development in the burial soils may be the result of aggregation alone (Oades 1993). The planar voids in the burial regions, truncated the channel voids and so may be shrinkage features from the drying of the undisturbed block owing to high organic matter and clay levels.

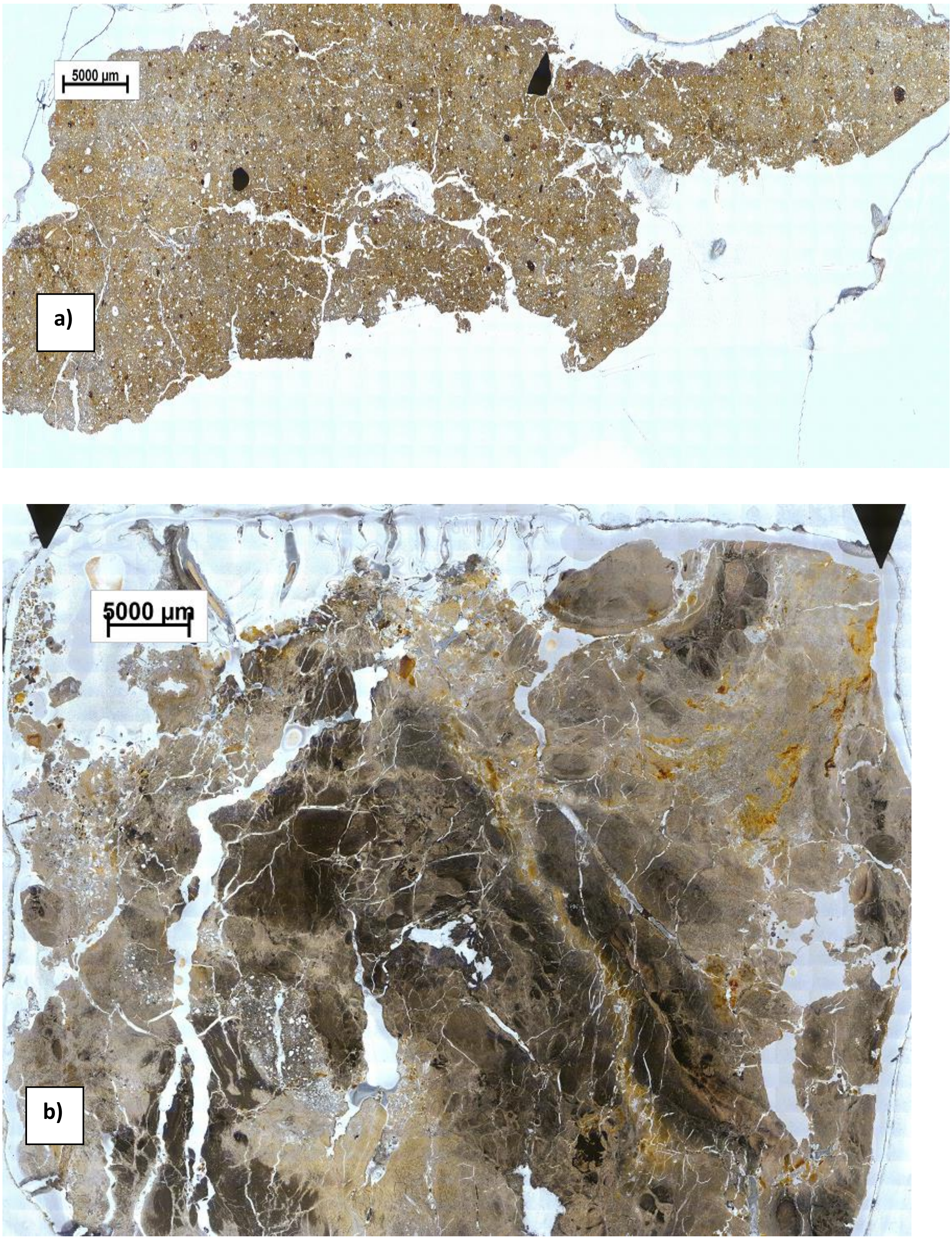


Figure 64: Mosaic images of the ped development: a) Fromelles C3 control sample displaying moderately developed sub-angular block peds; (PPL); b) foot region sample with moderately developed angular peds, inter-pedal channels and black amorphous organic matter; (PPL)

4.5.2.4 *Pedofeatures*

Continuous, non-laminated dusty coatings were observed around channel walls in both the foot (SK1527) and skull (SK1525) regions. The dusty coatings were also observed in the C2 control. Evidence of faunal activity was limited to the skull (A) region sample (SK1527), where randomly distributed excremental pedofeatures could be identified within the fine material. The C2 and C3 controls showed evidence of redoximorphic nodules, also recognised in the foot region of SK1527.

Dusty coatings were only identified in the burial samples and C2 control and were not observed in the C3 control sample. This evidence could propose that the dusty clay coatings had formed in two stages, and were not absent as a result of sampling bias: the first with the upper soil layers being disturbed when the grass was removed from the excavation site, and a secondary disturbance event occurring once the upper control layers had been removed from the burial. The clay components in the dusty coatings displayed no laminations in both the control and burial samples, this suggested that only one event may have occurred providing translocation of soil silt and clay particles down into the channel voids (Kuhn *et al.* 2010 219). Evidence of faunal activity was limited to the areas within the burial pit, only being recorded in the skull region of a single sample. The low levels of faunal activity may have been the result of changes in pH across the soil, waterlogging and anaerobic conditions (Voroney 2007 43). In contrast, redoximorphic nodules were identified in the control and burial samples, with higher frequency around the foot region sample

4.5.3 Quantitative micromorphological analysis

4.5.3.1 *Point count*

Results of quantative point counting analysis are shown in Table 25, with the count parameters as described in Chapter 2, Section 2.5.2.1.

Table 25: Occurrence of pedofeatures, void space and coarse fraction expressed as a percentage of all counts from each region of interest (ROI)

		Occurrence of pedofeatures, voids and coarse fractions (% of total counts)								
		Coarse Mineral/Rock	Coarse Organic material	Voids space	Bone fragments	Excremental Pedofeature	Nodule	Fe Staining	Coatings	Undifferentiated
C2		3.18	0	16.27	0	0	0.40	2.37	4.37	73.41
C3		25.36	0	17.50	0	0	5.36	0.35	0.36	51.07
Skull										
	SK1525	0	0	14.03	0	0	2.10	0.42	3.78	63.87
Skull(A)										
	SK1527	2.22	0.56	1.67	0	0	0	0	0.55	95
Skull(B)										
	SK1527	5.65	0	8.26	0	0	0	0	1.30	84.35
Foot	***SK152***									
	ROI 1	1.02	0	6.12	0	0	0	1.70	3.74	87.42
	ROI 2	6.12	0	8.16	0	0	5.78	7.82	2.04	70.07

ROI are denoted by different fabric types across a thin section as discussed in Section 2.2.1

Point counting within the sample regions and controls (Table 25) did not detect the bone and excremental pedofeatures identified micromorphologically. The level of coarse material identified in the C3 control (25.36%) were significantly greater than that of the C2 (3.18%) and burial samples (~3.75%). The lowest level of coarse material across the burial samples was observed in the skull (ts593) region, with the highest level of undifferentiated material and lowest percentage of void space. The percentage abundance of redoximorphic nodules in the C3 control was comparable to that of the foot (ROI2) region. Coatings were counted with similar frequency throughout the control and burial samples, with the skull (ts561) and foot (ROI2) regions presenting similar percentage frequency.

Point counting identified dusty coatings throughout the control and burial samples, with increased levels in the foot and skull (A) region samples of SK1527. This could suggest similar levels of disturbance in and above these samples. The results in Table 25 also suggested little disturbance from bioturbation, as already indicated in Section 4.5.2.4. This may have been the result of changes in pH across the samples regions. The results exhibited by the point counting of the coarse material corroborated the micromorphological observations, with lower levels detected in the burial samples in comparison to the C2 and C3 controls. Contrary to the micromorphological investigation, the point counting analysis showed a lower level of coarse material in the C2 control, in comparison to that of the C3 control.

4.5.3.2 *Image analysis*

Image analysis was undertaken under three different angles of XPL illumination (as described in Chapter 2, Section 2.5.2.4) to highlight the characteristics of the voids and aggregates.

The analysis revealed that the highest percentage of void space (around 10%) was in skull (A) region (SK1527) (Figure 65). Similarly, skull (B) region (SK1527) showed void space of just below 10%; in comparison to the skull region of SK1525 with <1%. ROI 1 and 2 in the foot region sample. This indicated a difference in void frequency between the different fabric fine materials and gypsum mineral fabric types. Void space in the control samples was around 8-9%.

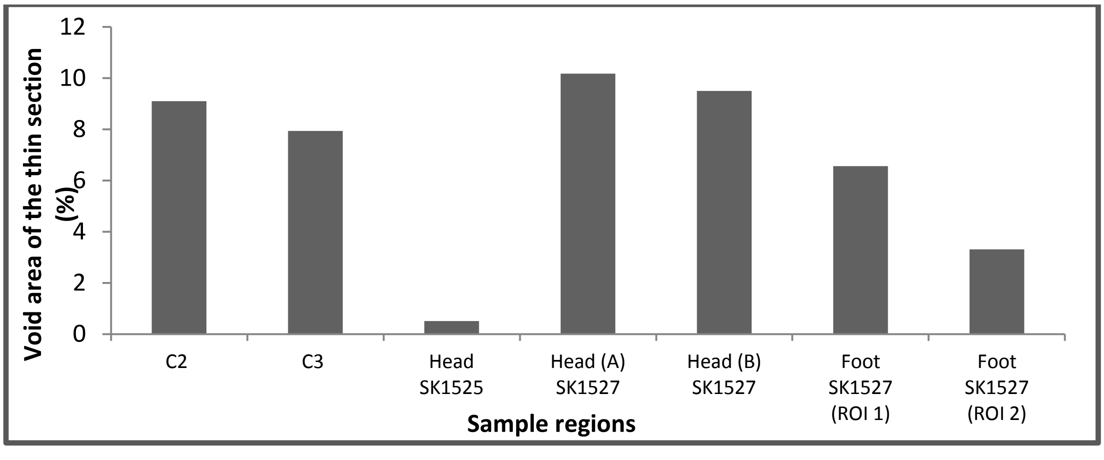


Figure 65: Total percentage of void space, as determined by image analysis, from representative areas in the Fromelles burial and control sample

4.5.4 SEM and SEM-EDS analysis

4.5.4.1 *Textile analysis*

Textile fragments recovered from the burial pit were observed using the SEM-BSE (Scanning electron microscopy backscatter electron) and analysed using SEM-EDS for their elemental composition

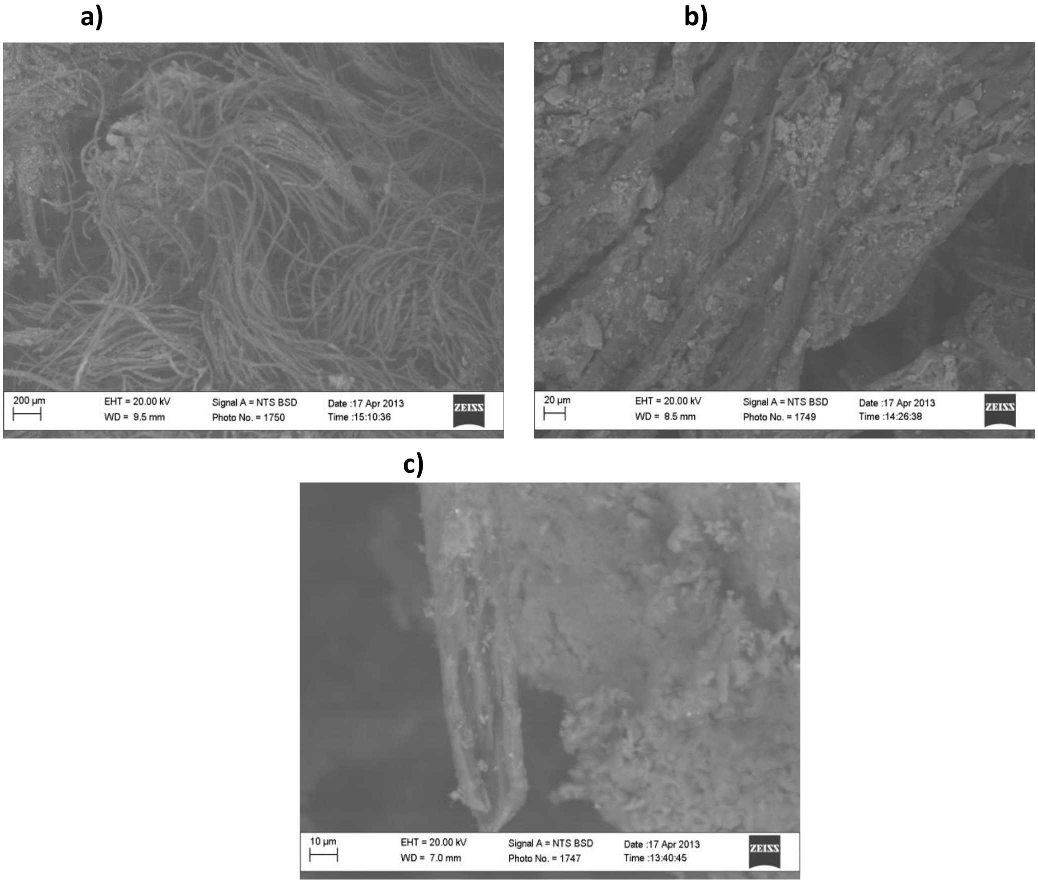


Figure 66: SEM-BSE imagery of the fibres from the textiles recovered at the Fromelles excavation: a) overview of the entangled fibres, which looked relatively well preserved; b) higher magnification image of the same item displaying soil micelle attached to the fibres of the textile; c) the hollow nature of the fibres as seen in a degraded section

Image (a) in Figure 66 clearly shows the jumble of surviving fibres that make up the textile, while image (b) provides a higher magnification image of the soil particles adhered to the fibres. It is evident the textile fibres are hollow, as seen at higher magnification (Figure 66c).

The absolute mean concentrations of P, S, Fe and Ca in the textiles (**Error! Reference source ot found.**) show the highest element levels to be Fe (2.38 Wt%) in the pelvis textile from SK1527. The lowest levels are seen of P with the pelvis textile from SK1525 showing the highest concentration (0.06 Wt%). The pelvis sample from SK1525 also showed levels of S higher than that of Fe, whilst the pelvis sample from SK1527 displayed the highest concentrations of S, Fe and Ca.

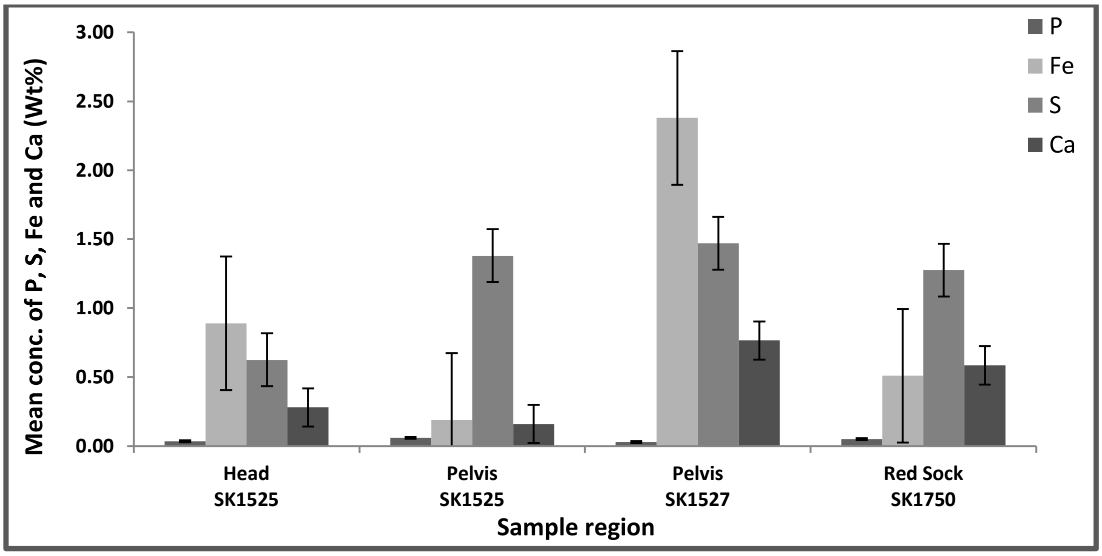


Figure 67: The absolute mean concentration of phosphorus (P), sulphur (S), iron (Fe) and calcium (Ca) in the textiles from the sample regions of the mass grave at the Fromelles. Error bars represent 1 standard error of the mean

The highest concentrations of P are seen within the textiles of the pelvis region. The low concentration of P in the textiles is evident (Figure 67) when compared to the concentrations of Fe, Ca and S. The Ca concentrations are variable, with the pelvis (SK1525) region displaying the lowest concentrations, whilst the pelvis (SK1527) region sample has the highest.

The absolute Fe levels are lower than S levels (Figure 67). The presence of Fe in the textiles suggests natural dye may have been employed in colouring the fibres, with red sock still identifiable during exaction, this could point to goethite or haematite based pigments (Froment *et al.* 2008). However, the levels of Fe are lower in the red sock sample than in the two pelvis samples, this could also suggest there was pigmentation in these samples. The levels of S in the Red sock and also the textile from the pelvis sample of SK1525, when compared to the other textile samples, pointed to the presence of wool based fibres (Ward *et al.* 1993).

4.5.5 Depositional features

The following section discusses the mean concentrations of P and the mean ratios of P:Fe in redoximorphic nodules and dusty clay coatings.

4.5.5.1 *Redoximorphic nodules*

The greatest concentration of P was in the nodules of the skull region sample (SK1525) (1.08 Wt%) (Figure 68), with P concentrations also high in the fine material. The C2 control and the skull (A) region samples (SK1527) indicate P concentrations where below detectable levels. The concentration of P was highest in the nodules in all samples except skull (B) region (SK1527), where the fine material indicated it contained more P than the nodules. The foot region (SK1527) and the C3 control had similar concentrations of P (0.16 Wt% and 0.14 Wt% respectively).

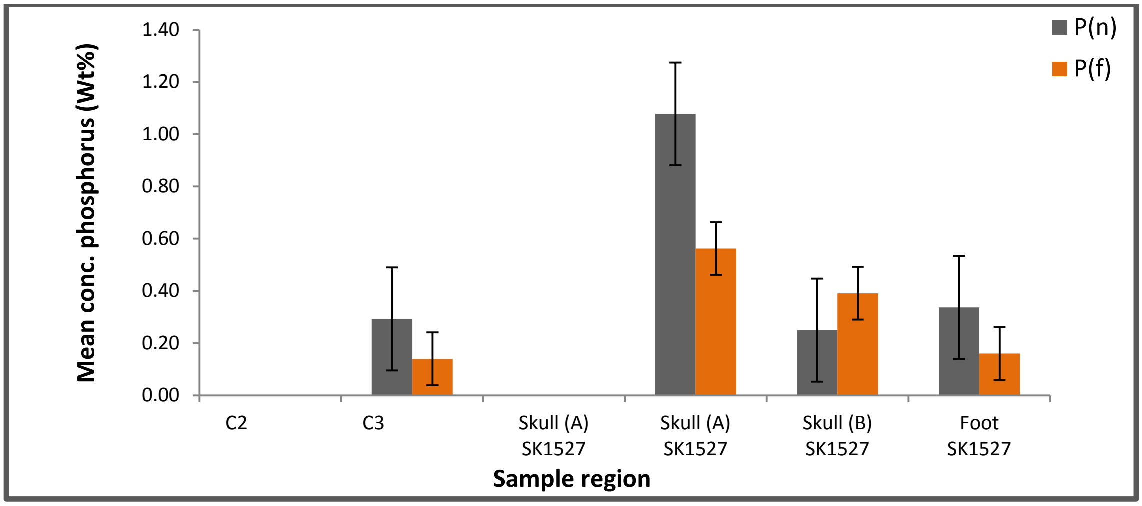


Figure 68: Mean concentration of P in the redoximorphic nodules (n) and fine material (f) in the Fromelles samples. Error bars represent 1 standard error of the mean

The ratio of P:Fe, as shown in Figure 69, is higher in the fine material compared to the ratio in the nodules in all samples. The skull (SK1525) region displayed the highest ratio of P:Fe in the fine material (0.44), with the skull (B) (SK1527) region also showing high ratios (0.26). The lowest P:Fe ratios were seen in the C3 control and the foot region (SK1527).

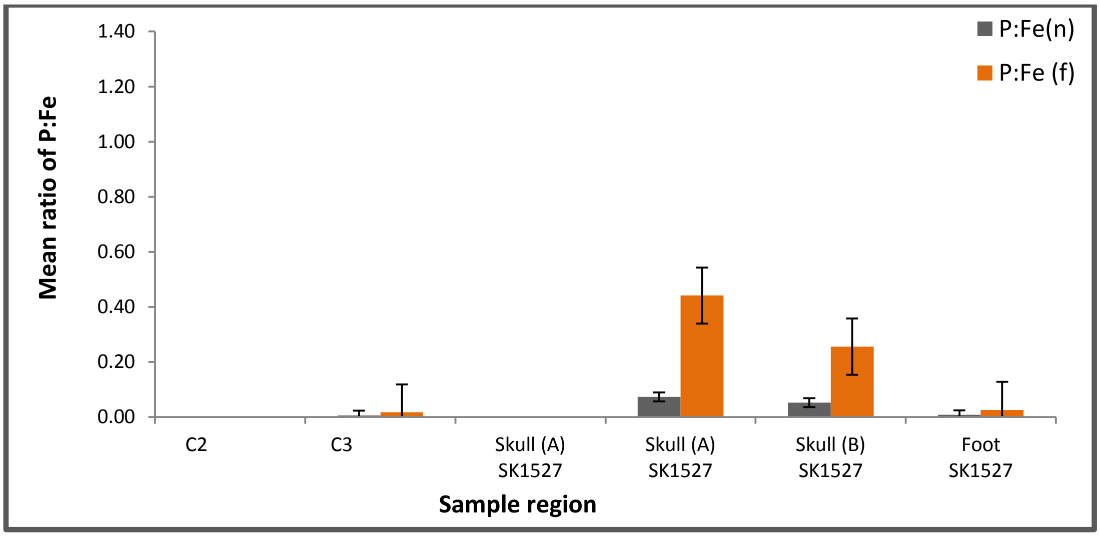


Figure 69: Mean ration of P:Fe in the redoximorphic nodules (n) and fine material (f) in the control and burial samples from the Fromelles grave. Error bars represent 1 standard error of the mean

It is evident there had been a low level of co-precipitation into the nodules of the skull (A) and skull (B) region. The level of co-precipitation was possibly determined by the available Fe, with the concentration of P in the nodules higher than that of the fine material. This pattern has occurred throughout the burial and control samples, with higher concentration of P in the nodules and higher relative P:Fe in the fine material. The patterns suggest two possible hypotheses: 1) the levels of Fe required for co-precipitation is low; 2) there has been preferential retention of P in the nodules and not in the fine material by the clay minerals and in Fe/Al oxide crystals.

Higher levels of Fe were identified in the fine material during micromorphological observations; the relatively high concentration of P suggested preferential precipitation into the nodules. The evidence also pointed to the relative timing of the nodule formation and P input into the soil from deposition of the burials. This pattern had occurred throughout the burial and control samples, with higher concentration of P in the nodules and higher P:Fe in the fine material. The formation of the nodules, therefore, there is greater precipitation of P into the nodules and lower levels of Fe/Al oxide adsorbtion in the fine material presenting a higher ratio of P:Fe.

4.5.5.2 *Dusty clay coatings*

The fine material in the skull (SK1525), skull (B) and foot (SK1527) regions displayed the highest concentrations of P, whilst the skull (A) region from SK1527 and the C3 control had the highest P concentrations in the coatings (Figure 70). The C2 control, the fine material of skull (A) region (SK1527) and the coatings in the skull region of SK1525 all indicated P concentrations below detection levels. The lower concentrations of P were seen in the coatings, compared to the fine material, in most samples with only the foot region having a low P concentration in the fine material.

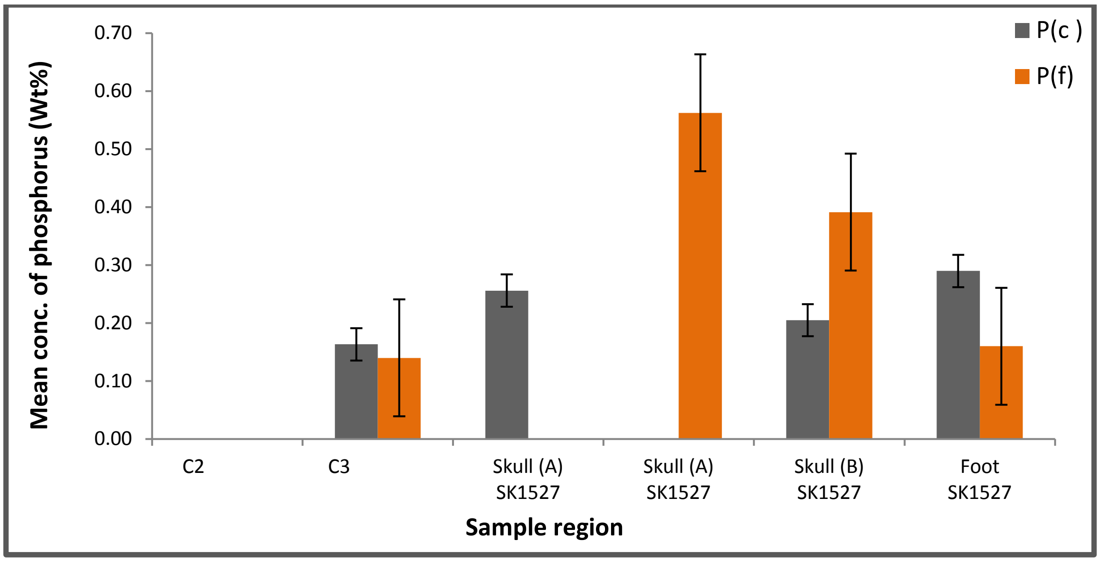


Figure 70: The mean concentration of P in the dusty coatings (c) at the Fromelles grave. Error bars represent 1 standard error of the mean

The mean ratio of P :Fe is highest in the coatings of the skull (B) region (SK1527) (0.39) (Figure 71). The highest ratios of P:Fe are seen in the coatings across the sample regions, with only the C3 control sample containing a significant P:Fe ratio in the fine material (0.03).

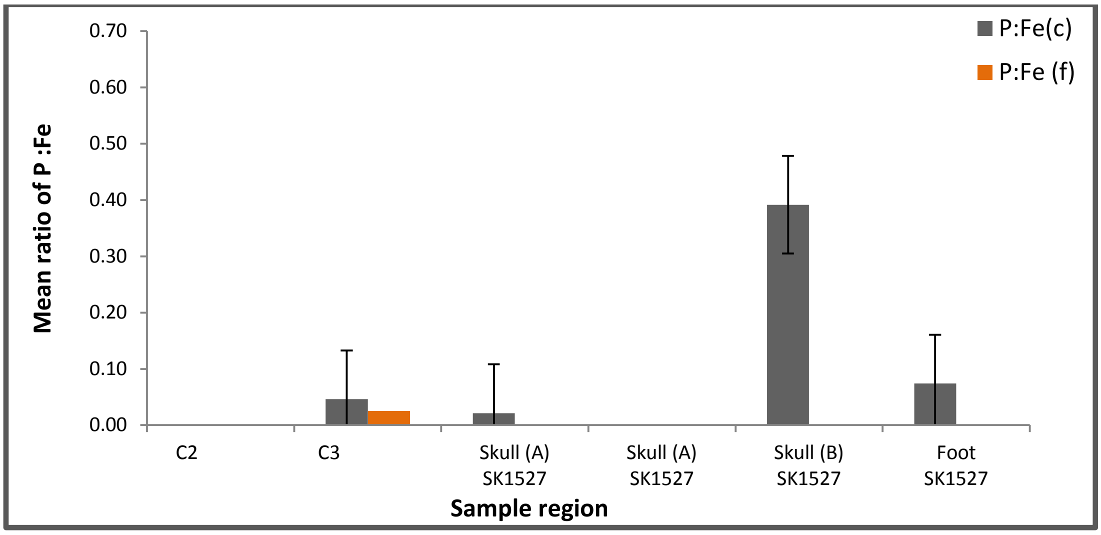


Figure 71: The mean ratio of P:Fe in the dusty coatings (c) and fine material (f) in al samples from the Fromelles grave. Error bars represent 1 standard error of the mean

The level of P shown in Figure 71 indicated that the fine material in the skull (SK1525) region contained the highest concentration across the control and burial samples. A P:Fe ratio of zero in Figure 71 suggested that there had been little adsorbtion of P to Fe/Al oxides in the fine material. Similarly, this has been identified in the fine material of the foot and skull (B) (SK1527) region samples. This could again indicate there has been no co-precipitation of P to Fe and that P had also not been retained by the clay particles and adsorbed by Fe/Al oxide crystals in the fine material. By contrast, the higher ratios of P:Fe in the skull (B) region and foot region suggested that adsorption of P to the clay minerals and Fe/Al oxides in the coatings had occurred. Although the foot region displayed higher P levels (Figure 70), the skull (B) region displayed higher ratios of P:Fe, this suggested that there may be a higher availability of Fe in the skull (B) sample region.

The patterns of P:Fe in the coatings of the skull (B) and foot (SK1527) regions may further suggest the fine material (silts/clays) in the coatings were derived from a different region of the burial. The difference in the P:Fe ratio in the coatings and the fine material suggested there had been preferential translocation of fine soil particles. This may be corroborated by the skull region (SK1525), in which the fine material displayed high P concentrations but the ratio of P:Fe was zero.

4.6 Summary: Fromelles

The micromorphological observations and SEM-EDS inorganic elemental analysis of the mass grave at the Fromelles site show clear differences in soil pedogenesis between the burial and control samples as evidenced by the development of features such as redoximorphic nodules (burials and controls) and coatings (burials). There are also differences in elemental composition of the fine materials between the burial and control samples.

4.6.1 Sampling

The location of the site, the age of the grave and sensitive nature of the excavation all had to be considered when applying the *InterArChive* sampling strategy, with the archaeologist working quickly to remove burial remains for identification. The co-mingled remains in the burial pit determined where and which samples could be collected. Many of the skeletal remains still had high levels of identifiable clothing, whilst the quantity of soil surrounding sampling regions was low. The collection of pelvis samples was especially problematic, as a result of the clothing and the low quantities of soil in the pelvic regions, hence only the skull and heel regions of the burials were sampled. Control samples were obtained at the edges of the excavation, as burial pits had been excavated vertically on a stratigraphic basis, thus providing contextual information for the C2 and C3 controls.

4.6.2 Burial environment

The mineral/rock components of the coarse material identified in the C2 and C3 control samples were indicative of terrestrial sediment formations of sand and fine clays containing flint and quartz pebbles (Figure 61). In contrast, the burial samples displayed low frequencies of coarse material, made up of small sized quartz fractions (50-200µm) and high levels of silts and clay throughout. The fine material of the burial samples was made up of Fe stained and grey clays/silts, with black amorphous organic material observed in most burial sampling regions. The low levels of coarse mineral/rock material in the burial samples suggested that only the finer soil particles (silts and clays) had eluviated down the soil profile. The movement of fine material down the soil profile could be identified not only in the soil matrix of the burial but also in the dusty coatings, observed in the inter-pedal channels of the burial samples. The translocation of coarse mineral/rock material down the profile was limited and may have occurred once degradation processes were more advanced as many of the bodies still retained clothing that could have inhibited downward movement of the coarse material.

Striations were noted in the fine material of all control and burial sample regions suggesting an alignment of clay domains, possibly from wetting and drying processes occurring around the burials. The upper control sample may have been affected by wetting and drying from surface percolation, whilst the lower soil levels could have been affected by putrification fluids and water table fluctuation (Szibor *et al.* 1998). The difference in the types of striations, circular and mono-striated may be related to the levels of coarse material in the control and burial samples. Dusty coatings were observed in the channel voids from the burial samples; however, these were not seen in the planar voids that truncated the channels voids. The formation of the channel voids and dusty coatings suggested they had been formed before the development of the planar voids. The planar voids were a possible result of the undisturbed samples drying out and cracking once they had been collected, as a result of their clay (Stoops 2003b 65).

4.6.3 Burial ritual

The textile sampled in the skull, pelvis and heel regions was identified as woven wool (Figure 62). Excellent preservation of the textiles was observed in all sample regions during the collection of the undisturbed soil, with identification of red coloration remaining in the textile around the heel region. The preservation of the wool suggested that the pH of the burial pit had, in some regions, been acidic as wool degradation primarily occurs in neutral to high pH conditions (Janaway 2002 397). The acidity derived from the decomposition of the burial could have provided optimal conditions for the degradation of all other organic material, relating to the body and artefacts such as plant based textiles. The remains of leather from boots were not detected, possibly owing to the removal of the boots before burial (Figure 49). The conditions of the soil pH may also have prevented bioturbation by macro-fauna and meso-fauna across the burial pit, with indications of excremental pedofeatures being absent from most burial samples. However, there was also little evidence, of bioturbation in the C2 and C3 controls. This suggests either low organic matter content in the soil or that the waterlogged anaerobic soil conditions were a causal factor in the low level of soil faunal activity.

The most significant difference between the control samples and the burial samples was the presence of tabular crystal gypsum formations. These formations were not observed in the control samples and were not components of the parent material in the area. Gypsum was observed in both voids and the soil matrix of the burial samples, with an increased frequency in the foot region. There are two hypotheses to explain the presence gypsum in the grave: 1) white powdery gypsum had been added to the burial environment after being mistaken for white powdery quicklime; or 2) the gypsum had formed as a secondary mineral. The initial hypothesis suggested there was availability of white powdery gypsum in the locality that may have been used an additive to prevent smells and diseased originating from the corpses. This was common practise to prevent the spread of disease and reduce the smell of putrification, the latter as a result of decay process occurring rapidly in the summer heat (Digimap 2012; Tuck *et al.* 1923) .

The second hypothesis required quicklime (CaO) to have been incorporated into the grave during the burial of the bodies, with the water present in the heavy clay soil providing an environment for the quicklime to slake during an exothermic reaction forming calcium hydroxide ($Ca(OH)_2$). This in turn might have reacted with weak H_2S/H_2SO_4 derived from the breakdown off organic matter in the grave (Costanza *et al.* 2007). The last reaction could have provided the compounds required in seeding of gypsum crystals (Sutton 1984 313). The reaction of slaked lime with weak sulphuric acid provided a relatively neutral pH and allowed the formation of gypsum crystals. The formation of gypsum would have relied on the pH of the soil remaining alkali to neutral. However, putrification fluids retained by high clay levels could have lowered the pH in the burial. This lower pH would have seen the gypsum go into solution, eventually being translocated into the channel voids and pH neutral areas of the burial, such as the foot region of SK1527, again crystallising. In summary the second hypothesis: the gypsum had formed as a secondary mineral, has the greatest probability, however the gypsum could have been unwittingly added, ultimately the source of the gypsum is inconclusive.

4.6.4 Detection of burial degradation products

The wool textiles detected across the burial (Figure 62 and Figure 66), may have provided significant amounts of S, thus providing the formation of H_2S/H_2SO_4 (Cuthbertson and Phillips 1945). H_2S/H_2SO_4 may also have derived from the breakdown of organic matter within the burial samples. A high frequency of black amorphous organic matter was observed in the burial samples during the micromorphological investigation, although, it was absent in the control samples. This suggested the black amorphous organic matter was derived from the decomposing remains in the burial pit. The colour of the organic matter may have been from the production of butyric acid and lactic acids produced during the putrification processes through the breakdown of sugars in anaerobic conditions. Anaerobic conditions are likely to have been present in the Fromelles burials as a result of localised waterlogging, thus both aerobic and anaerobic degradation could have occurred (Dent *et al.* 2004 ; Szibor *et al.* 1998).

The coatings identified in the channel voids across the control and burial samples indicated little P had been adsorbed by Fe/AL oxides and clays, with only the foot and skull (B) regions (SK1527) and C3 controls displaying some movement, with coatings being derived from other regions of the burial/control regions . In contrast the P concentration in the fine material suggested P had been retained by the clay minerals and Fe/Al oxides(Kittrick and Jackson 1956). Low ratios of P:Fe were detected in the redoximorphic nodules, possibly indicating there was a high level of Fe and that P had been preferentially retained in the nodules. The concentration of P in the burial samples was greater than that found in the controls, with undetectable levels of P in the C2 control, collected above the C3 control. This suggested there had been a fluctuation of water from the water table affecting the level of P in the lower C3 control with capillary action forcing the P derived from the decomposition of the burial into the C3 immediately above the burial; whilst not affecting the upper control. If the P had derived from recent agricultural activity there should have been some indication in the C2, with P levels percolating down the profile, rather the levels are seen to increase from the burial to the controls.

4.7 Statistical analysis of Ridgeway and Fromelles

The following section discusses the statistical analysis performed on the elemental data from the fine material, dusty coatings and redoximorphic nodules from both mass grave sites using analysis of variance to determine the significance of the site, position of the sample in the grave and a combination of site*position.

4.7.1 Two-way ANOVA

The sampling strategy determined the parameters of the analysis undertaken. Sampling positions were identified by the three predefined regions: the skull, trunk and foot (as identified in Chapter 2, Section 2.7.2). P, Fe and S concentrations were analysed to determine the effects of site (Ridgeway and Fromelles), body region (position) and their interaction, on elemental concentrations.

Table 26: The p-values obtained through two-way ANOVA when testing the effects of site, position and site*position interactions on the concentration of P, S and Fe in the redoximorphic nodules, dusty coatings and fine material (*significant p-values of <0.05 are highlighted*)

	p-value								
	Redoximorphic nodules			*Dusty Coatings*			*Fine material*		
Source	P	S	Fe	P	S	Fe	P	S	Fe
Site	0.399	0.206	0.814	0.092	0.312	0.091	0.000	0.049	0.001
Position	0.000	0.356	0.160	0.001	0.011	0.010	0.000	0.000	0.000
Site*Position	0.498	0.360	0.000	0.000	0.011	0.138	0.038	0.000	0.000

Table 26 displays the p-values for P, S and Fe concentrations and that of 'site', 'position' and the interaction between the factors of 'site*position' in the Ridgeway and Fromelles mass graves. The analysis of the fine material suggests a correlation between P, S and Fe concentrations in the fine material and the factors of 'site', 'position' and 'site*position' with all p-values <0.05 indicating a >95% confidence level. The correlation between the response (P, S and Fe) and the source factors indicates there is only a significant correlation between the P concentration in the redoximorphic nodules and position within the grave (p-value of 0.000). S and Fe are not statistically significant, with any source factors their p-values being >0.05. The P, S and Fe coatings do not have a significant interaction with the 'site', while Fe does not have interaction with 'site*position'. S and P do have interaction with the 'site*position', whilst all response factors (P, S and Fe) display a significant association to the 'position' of the sample.

The two-way analysis of variance indicates with 95% confidence that 'position' is the most significant factor for the concentration of P in the burial and control samples at Ridgeway and Fromelles, in terms of redoximorphic nodules, dusty coatings and fine material. This suggests that the concentration of P within the control and burials may be determined by the degradation process, the levels of P derived from the sampling positions being decided by the degree of decay from the different areas of the remains, such as skull, feet and pelvis regions.

In contrast, site did not affect the levels of P, S and Fe in the redoximorphic nodules and coatings, but did affect their concentration in the fine material. This may be a result of the clay mineral levels in the fine material, with P and S being retained by the clay minerals. The level of Fe/Al oxide-rich coarse soil minerals could also be a causal factor.

The interaction factor of 'site*position' was significant in determining the concentration of Fe in the redoximorphic nodules. The development of the redoximorphic nodules could be indicated by the correlation between 'site*position', with levels of organic matter and of reduction and oxidation conditions, based on micromorphological data, were seen particularly in the waterlogged burial samples from the Fromelles site. It is evident that the combined factor of 'site*position' did not affect the concentration of P and S in the coatings but does not affect the concentration of Fe in the coatings.

4.8 Discussion and summary

The Ridgeway burials are believed to have resulted from ritual executions buried in a pit, the pit being formed from quarrying of the calcareous bedrock during the Iron Age to early Roman occupation of the area, *c.* 900years prior to the dating of the burial (Boyle 2009). In contrast, the burial pits at Fromelles were dug specifically for the burial of fatalities from the battle that took place there in the summer of 1916 during some of the heaviest fighting allied troops encountered in WW1 (Cobb 2010 9). The results suggested considerable differences in micromorphological features and chemical signatures between the two mass grave sites.

The collection of samples from the mass graves was determined by the position of the bodies and the quantity of soil surrounding the sampling positions. When compared to single inhumations, the quantity of soil around the sampling positions as determined by the *InterArChive* project protocol was somewhat less abundant in the mass grave context, as a result of the co-mingling of bones and proximity of the bodies. Burial samples were predominantly collected from around the skull and pelvic regions at the Ridgeway site. In fact, sampling from such regions was deemed extremely important because of the disarticulation of the skulls that had been placed in two discrete piles in the southern end of the pit whilst torsos were discarded randomly. A limitation of the Ridgeway excavation was the lack of undisturbed control samples because of the presence of excavation spoil and construction activity. Thus, undisturbed control samples were not available. It has been well documented that the recovery of controls is an important part of any soil or archaeological sampling strategy, allowing comparisons to be drawn between soil adjacent to the burial and soil unaffected by the inhumations (Berg 2002; Pye 2007 186; Davidson *et al.* 2002). The C2 and C3 controls, whilst not providing complete pedogenic contrast (as ped development and spatial relationship between soil components had been disturbed), did provide elemental comparisons and information on textural pedofeature including dusty coatings and as such can be called disturbed control samples.

The sampling of the Fromelles graves was affected not only by the location of the individual bodies in the pits, but also by the ethical requirements of the archaeology team. The sensitive nature of the burials, being in living memory of family members, required the swift removal and identification of remains. The Fromelles excavation, in contrast to Ridgeway, was undertaken with little disturbance to the site and walls of the pits, allowing for the collection of C2 and C3 undisturbed control samples from the pit backfill above the burials. However, no C1 site controls could be obtained at Fromelles because of sampling restrictions due to security measures and the construction of a boundary fence.

Information from this sample would have provided information on bioturbation and background elemental distribution in the soil unaffected by burial disturbance.

Similarities in micromorphological observations across the Fromelles and Ridgeway sites were identified in the formation of dusty coatings in channel voids and on peds. A single deposition events may have been the causal factor in their development, as lamination within the clay fraction of the dusty coatings was absent at both sites. The evidence suggested that the dusty coatings at Ridgeway have occurred after pedogenic development within the burial samples as they lined channel voids and coated peds. Dusty coatings were also observed in the soil-grab samples controls. The morphology was similar, showing no lamination; however there was fragmentation probably as a result of the sieving and homogenisation of the samples (as described in Section 4.2.5.3). A hypothesis that the coatings had developed as a result of internal collapse and disturbance was disregarded, as the control soil-grab samples collected from the side of the pit were unaffected by movement in the burial. The evidence from the controls samples confirmed that the origin of the coatings around the burial was not from within the pit, but from the surface. This, however, was dissimilar to Fromelles, where the C3 control samples provided no evidence of dusty coatings. This suggested that two phases of development had occurred from surface disturbance affecting only the upper C2 control layer, with the burial samples affected by a different disturbance event, as there was no indication of dusty coating in the middle C3 control sample. Disturbance from the excavation process may have provided the mechanisms required to translocate the clay/silt particles within the burial, whilst the removal of grass at the beginning of the excavation may have allowed silt and clay particles to percolate into the top C2 control layer.

The burial samples from Fromelles contained a high level of organic matter in the form of amorphous black and brown fine material, but with no trace of bioturbation from soil flora or fauna. Similarly, the C2 and C3 control samples displayed little evidence of bioturbation, suggesting that the conditions within the soil, with pH fluctuations and anoxic conditions caused by water logging both in the burial and control samples, may not have been optimal for soil macro- and meso-fauna, with constant changes in microbial communities occurring (Haynes and Naidu 1998). In contrast, the Ridgeway samples exhibited evidence of high levels of bioturbation and aggregation. Excremental pedofeatures were identified with particular frequency in the skull and pelvis regions, where evidence of worm trails could be distinguished within the fine matrix. Evidence of bioturbation was not identified in the control samples, but this was probably the result of sieving and homogenisation, which had occurred before impregnation. The formation of granular peds in the skull samples suggested increased levels of organic matter in these sample regions, with bioturbation creating greater distribution of roots and soil fauna creating greater void space (Oades 1993). The development of redoximorphic nodules were identified with higher intensity in the pelvis region and again in the skull region of the Ridgeway site compared to the heel region and control sample, and could also have suggested higher levels of organic matter had been retained by the fine material (Lindbo *et al.* 2010 395). However, the increased development of redoximorphic nodules within such regions not only required increased organic matter but also reduction and oxidation conditions, which may have occurred as a result of soil water through localised waterlogging or through the high levels of biological activity during the decomposition of organic matter. The latter explanation is not conclusive as the soil within the Ridgeway site was free-draining (Boyle 2009).

Further investigation of the coatings and redoximorphic nodules was undertaken and they were compared to the fine material in order to establish the presence of organic matter from the deposition of degradation products across the sampling regions. Particular emphasis was given to phosphorus: one of the most abundant elements in the human body, due the composition of nucleotides found in all human cells in the form of DNA (Tortora and Grabowski 2000b 1005). Phosphorus to iron (P:Fe) ratios were analysed as dihydrogen phosphate ($H_2PO_4^-$) is attracted to dissolved Fe^{3+} thus inducing precipitation of insoluble iron hydroxyl phosphate ($Fe(OH)_2H_2PO_4$) (Brady and Weil 2008 463). In the Fromelles site there was a correlation between the frequency of voids and the levels of P, with the highest concentrations of P being in the skull (A) region (SK1527) sample, which also contained the highest percentage of void space. At both sites it was apparent that P levels were higher in the fine material than the depositional features (coating and nodules). Only the skull sample of SK1525 among all the sampling regions at Fromelles displayed relatively low levels of P in the fine material. This is in agreement with the results from the image analysis showing the lowest level of void space across the Fromelles site. A hypothesise can be proposed that P from the degradation products has been transported away from the body, through the available void space, the anions of the P being attracted to the +ve cations of the molecules within the clay particles and Fe/Al oxides and adsorbed to their surface. The areas with low void space did not always retain the rich degradation fluids close to the body, as previously stated the skull region at Fromelles exhibiting high porosity and high P concentrations. This may also indicate that there has been an abundance of P in the region of the skull and the levels of Fe were not available to allow co-precipitation, thus the excess P has been removed from through the movement of soil water away from the burials. Soil pH can be a contributory factor in the fixation of P, and the high levels of gypsum crystals in the Fromelles samples regions suggested that a neutral to alkaline pH conditions may have been present for optimal fixation (Brady and Weil 2008 470). However, when soil pH decreases (<pH 7.0), gypsum precipitates out and goes into dissolution. The presence of gypsum, throughout the soil matrix and channels voids of the burial samples suggested movement. This may point to pH fluctuations in the soil, providing the mechanism for gypsum to go into dissolution. Evidence of such fluctuations in soil pH could have been identifiable in the foot region, where concentrations of P was lowest in the fine material, however there was a high frequency of gypsum crystals. This suggested differences in pH with the dissolution and crystallisation of gypsum, while less retention of P in the low pH conditions had occurred. The mobility of P increases as the pH decreases with mobility of P occurring from around pH 5.0 (Sollins *et al.* 1988). The foot region displayed high levels of void space (channel voids) compared to other regions (Figure 65), allowing the translocation of gypsum in dissolution; degradation from the burials may not have provided the most favourable conditions for fixation. Rather it was transported in soil water away from the sample region of the foot. At Fromelles, the level of P in the control samples was lower when compared to that of the burials samples. This comparative evidence alone could suggest that the presence of inhumations was a significant factor in the levels of P discovered around the burial samples. Increases in P across the burial samples compared to the controls, however, were reflected to a greater extent in the fine material and retention of P by the clay minerals and Fe/Al oxides, with little being precipitated out into the nodules or coatings.

Statistical analysis of the redoximorphic nodules, dusty coatings and fine material in the Ridgeway and Fromelles sites determined the concentrations of P, S and Fe had a significant interaction to the 'site', 'position' and 'site*position' of the burial. In contrast, 'site' had no interaction to the concentration of S and Fe in the nodules although there was with 'position'. The statistical analysis suggested the S and Fe in redoximorphic nodules did not come from the fine material surrounding the sampling position, with only the level of P being affected by the 'position'. Thus P in the nodules could have derived from the burial.

The presence of tabular-shaped crystals was observed throughout all investigated samples from Fromelles, but particularly the foot regions were particularly noteworthy. In fact, micromorphological analysis identified the mineral as gypsum (Figure 63a) comparable to the reference material of Stoops (2003b 116), and SEM-EDS analysis of the mineral provided confirmation of the elemental composition through the ratio of Ca to S, in the areas scanned. This could imply that a liming disinfectant had been laid over the bodies once they had been placed in the pit, possibly, to help remove the odour of decay and increase the rate of decomposition. Reports from the excavation team noted that many remains were covered by a hard white material that when dry formed a white powdery substance (Pollard *et al.* 2008a). The excavator's initial interpretation of the white powdery substance, scraped away from the remains during post excavation, was that the powder was quicklime. Quicklime (CaO) or hydrated lime ($Ca(OH)_2$) would have hastened the degradation, especially the wool textiles in the burials by raising the pH and temperature during its exothermic reaction with water (Janaway 2002 394). In both quicklime and hydrated lime compounds no sulphur is present. However, the presence of sulphur in the woollen textiles, and identified in the grave, could provide the source of S, which when reduced produces weak sulphuric acid. The development of anaerobic conditions could have been enhanced by waterlogging and the high clay content in the burial pit, together with the presence of the bodies and the decomposition of the organic remains themselves, with Ca and S reacting to form gypsum. Increased levels of gypsum were observed in the foot region (SK1527) suggested a neutral to alkali pH. This may have provided greater degradation conditions for the wool socks, as identified and analysed from SK1750 thus, the preservation of woollen fibres in this sample was lower than that of the skull region (SK1525).

4.9 Summary and conclusion

4.9.1 Sampling

Testing of the InterArChive sampling protocol, micromorphological observations and SEM-EDS investigation on the burials was particularly important to establish differences resulting from mass burial practice in comparison to single inhumations. The work evaluated selected aspects of degradation and attempted to determine the sampling areas that could provide comprehensive information of the interaction between soil and human degradation products. The samples were collected from a 10th century mass grave of Ridgeway, Dorset, and a 20th century mass war grave at Fromelles, France. The pedogenic development of the sites, date of inhumation and articulation of the skeletal remains constituted the main differences between the sites.

Sampling of both sites confirmed the necessity for undisturbed control samples to be collected when possible. However, it was established that disturbed soil-grab samples may provide some background information. The soil-grab samples collected as grave fill controls at Ridgeway not only provided information regarding soil morphology but also gave indicators of background elemental concentrations. However, it must be noted that there were not undisturbed samples collected from areas unaffected by the burial to validate the information obtained. The sampling of the burials was affected by the amount of soil surrounding them, as the nature of the mass grave entailed the co-mingling of body parts separated by low quantities of soil from which to sample. Thus, it was necessary to utilise the *InterArChive* sampling as only a guide, with the sampling of regions around the body mainly determined by soil availability.

4.9.2 Soil development at Ridgeway and Fromelles

The development of the soils across both sites could be attributed to several different pedogenic factors, with the formation of peds and inter-pedal channels at Ridgeway being determined by bioturbation, as shown by the evidence of both root and faunal activity. The concentration of clay and organic matter within the soil at Fromelles seemed to be the key factor in pedogenesis.

4.9.3 Disturbance events

Micromorphological analyses indicated the occurrence of typic dusty coatings at both excavations, suggesting that both sites had encountered disturbance. Though it is likely that the removal of the surface covering at Ridgeway was instrumental in their development, the Fromelles dusty coatings may have occurred through two events, as a result of surface and excavation disturbance. The morphology and location of the coatings at the Ridgeway site indicated that the disturbance occurred after the formation of peds and voids, with no laminations visible. It is likely, therefore, the development of dusty coatings had taken place from a singular phase of fine material translocation. In contrast, the typic coatings at Fromelles were observed in the burial samples, and the C2 control suggesting that the movement of the fine materials initially occurred in the upper part of the grave, in the grave fill. The coatings in the burial developed during the excavation stages, with no coatings in the C3 control. SEM analysis suggested that the degradation products from the burials, notably P, had not translocated with the coatings, the material in the burial coming from the upper layers. Similarly, the levels of P in the redoximorphic nodules did not correlate with the dissolution and precipitation of P with Fe and the movement away from the burials. The elemental analysis of fine material in the burial did, however, indicate elevated ratios of P to Fe, which is indicative of retention of degradation products emanating from the burials. Image analysis of the void spaces suggested the movement of P and gypsum in dissolution was correlated to increased void space, with P being retained in fine material in areas displaying higher porosity.

4.9.4 Textiles

The presence of preserved wool-like textiles observed during sampling and through the micromorphology investigation in the skull region (SK1525), suggested that low degradation rates were occurring. This may have been the result of incorporated white powdery material that had precipitated out into gypsum crystals. The incorporation of white powdery material was visible to the excavation team who believed it to be quicklime. Micromorphological investigation and the SEM-EDS analysis have provided information that could not be established during routine archaeological investigation, but which was important in understanding both the burial practice and the decomposition of the corpses. Most importantly this included the discovery of gypsum crystals, and so the possibility that the white material added to the grave was gypsum or that gypsum was a secondary product that had occurred through the incorporation of quicklime.

4.9.5 Conclusions

The evidence showed that the systematic and comprehensive sampling undertaken by the *InterArChive* project can provide a basis for the sampling of mass graves. However, sampling of mass graves was determined by the presence of soil around the burial, therefore the sampling protocol must be flexible and adaptable in its approach to mass graves with co-mingled remains. The research on the soils in the two mass graves has provided an insight into pedogenesis within these burial contexts, providing indications of artefacts and determined the movement through the soil of decay products emanating from the mass human inhumations.

5 Spatial variations in micromorphological inorganic elemental analysis of fine material and depositional pedofeatures

The aim of this chapter is to define and describe patterns of burial degradation and human internment in archaeological inhumations when there is no physical evidence remaining. This was undertaken through the examination of decay product distribution in the burial and control samples in both single inhumations and mass graves. The investigation was achieved on the basis of analytical results obtained from micromorphological and inorganic chemical analysis of the fine material and depositional features (redoximorphic nodules and dusty coating), based on the methods discussed in Chapter 2, Section 2.6 for the five sites described in Chapters 3 and 4 (South Leith, Mechelen, Syningthwaite, Ridgeway and Fromelles).

The main objectives are:

1. To identify pedogenic and elemental patterns that can indicate there was deposition of a corpse within the grave and that the chemical signatures have been retained in the fine material surrounding the burials. To recognise pedogenic features pertaining only to the burial, through comparison of burial and control samples, and determine whether the features that had developed were caused by the interment.
2. To recognise differences in the frequency of dusty coating and redoximorphic nodule development across grave fill controls and burial samples collected in single inhumations and mass graves. Observe the distribution and frequency of redoximorphic nodules to establish the areas within the burial where reduction, oxidation and increased organic matter conditions have occurred. This could therefore provide evidence of putrification fluids derived from the burial creating these conditions. The development of dusty coatings may provide evidence of particles suspended within soil water through either surface or internal disturbance events or the deposition of soil particles and could indicate movement of decay products within the soil surrounding the burial.
3. To determine the spatial variations of P:Fe in depositional features and in the fine material between sample positions, graves and sites. This could verify whether the age of the grave, location or soil type had affected the retention and movement of decompositional products from the burial.

4. Understand the role burial ritual had on the translocation of degradation products and their incorporation into the depositional features.

5.1 Decay products produced from human inhumation

From initial interment, the different decomposition stages a human burial goes through to reach skeletal form can take on average around 25 years (Fiedler and Graw 2003 291). Surrounding environmental factors such as temperature, moisture and the presence of oxygen may determine the degradation rates. Consequently, differences in interment practice and burial environment may cause changes in the rates of decay. For instance, the increase in decay in a coffined burial in comparison to a shrouded burial, in part because of the aerobic conditions and air spaces that coffined burials may provide (Mant 1987).

5.1.1 Translocation and precipitation of decay-derived phosphorous

During putrification P is released by cells and then, in turn, is released by the body into the surrounding environment. In historical burials of the last 1000 years, it has been normal practice to place a corpse into a coffin, before interment into the soil was undertaken (Williams 2011), therefore the P released during decomposition could initially puddle in the coffin. The weight of soil placed on the coffin through grave backfilling may cause the collapse of the lid, allowing some soil to enter the immediate burial environment. The decay fluids in the coffin may mingle with the ingress soil from the collapse of the lid, before the lower coffin integrity has been compromised (Janaway 2002 395). However, the fluids within the coffin may be retained for an extensive period of time before the integrity of the coffin fails. The process of putrification liquids being retained in a complete coffin was noted at the site of Spitalfields where many of the 17th and 18th century AD coffins still had liquids from decomposition present (Reeves and Adams 1993) Phosphates released from the body into the soil are mobile; however decreased pH of the soil from the release of degradation derived products, can provide conditions favourable for adsorption of P to compounds such as Al_2O_3 and Fe_2O_3 , thus rendering it unavailable (Schlesinger 1997 99).

Dissolved Fe^{2+}, and P ($H_2PO_4^-$) are electrochemically attracted, producing insoluble iron hydroxyl phosphate precipitates ($Fe(OH)_2H_2PO_4$) (Dent *et al.* 2004; Brady and Weil 2008 463). The precipitation of P with Fe into redoximorphic nodules in the burial environment may have been encouraged by the alternating reduction and oxidation environments that prevail within the coffin as degradation fluids are released and possibly pool around the body (Janaway 2002 395). Anoxic conditions may attract the growth of anaerobic microbial communities providing conditions favourable for the development of redoximorphic nodules (Lindbo *et al.* 2010 130).

P, however, may also undergo anion exchange reactions that result in it being adsorbed onto and into clay particles (Brady and Weil 2008 464), rather than precipitating into redoximorphic nodules. Clay particles have the capacity to strongly adsorb P, which after emanating from the burial, can typically become immobilised in the fine material of the soil (Adderley *et al.* 2000).

5.1.2 The development of depositional features

The subsequent section discusses the development of two depositional features identified in the controls and burial samples across all sites: redoximorphic nodules and dusty coatings.

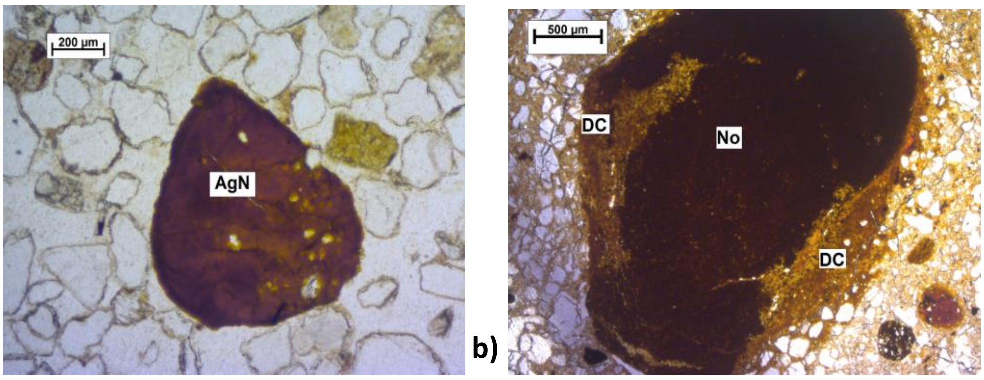
a) 

Figure 72: Redoximorphic nodules: a) An aggregate (AgN) nodule from the left knee region of Grave 6B, South Leith, (PPL); b) A typic nodule (No) surrounded by dusty coatings (DC) suggesting that the nodule has ceased to develop, observed in the hand region of Grave G2, Syningthwaite, (PPL)

5.1.2.1 *Redoximorphic nodules*

The presence and properties of redoximorphic nodules within soil has been used as a hydrological indicator to determine varying levels of soil waterlogging at both macro- and micro-scales (Lindbo *et al.* 2010 129). At the macro- scale, mottling, the name in some instance given to redoximorphic nodules, is associated with the movement of the water table and cycles of wetting and drying linked to seasonality (USDA-NRCS 2010), and has been used in the field to identify Fe reduction, translocation and oxidation processes. However, redoximorphic nodules may also be indicative of increased levels in microbial activity within certain areas of the soil, one reason being an increased level of organic matter (Haglund *et al.* 2001 164). Hence, in a burial context where there is evidence of Cadaver-Decompose-Islands (CDI: an area of high nutrient composition from inhumation decay) (Carter and Tibbett 2008 33), the formation and concentration of nodules around the burial may be attributed to the increased levels of organic matter, waterlogging or both factors (Lindbo *et al.* 2010 130). It is also possible that these factors exist in the confines of a coffin due to pooling of putrification products in the lowest part of the coffin, under and around the body (Janaway 2002 395).

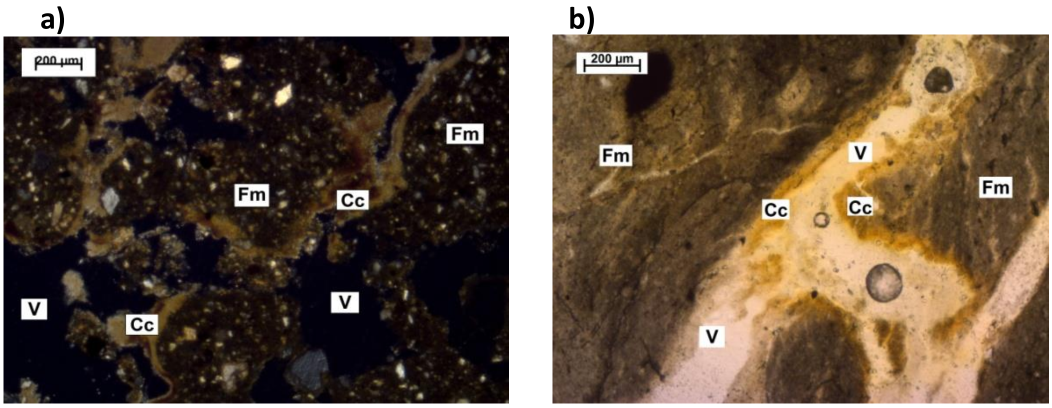


Figure 73: Dusty coatings a) Light brown coloured dusty coatings (Cc) developed within inter-pedal channel voids (V) with dark internal fine material (Fm) within sub-angular blocky ped from the pelvis (B) region, Ridgeway (XPL); b) Dusty coatings (DC) on the inter-pedal channel void walls (V), with dark fine material (FM) from the skull (B) region, Fromelles (PPL)

5.1.2.2 *Dusty coatings, Fe and water regimes*

Several formation processes can occur in the development of dusty coatings in soil profiles, including the removal of surface vegetation exposing the soil to the disturbance of soil particles and disruption from rain splash (Usai 2001b). As rainwater seeps through the soil profile, clay platelets from the exposed soil surface are suspended in the water, with deposition of the suspended solids (depending on the percolation rate, the soil water and other factors) can give rise to the formation of depositional coatings (Kuhn *et al.* 2010 221). The morphological and textural differences in coatings can be observed under XPL and PPL, and differences in boundaries between the fine material and the dusty coating may be identified. The silt and sand-rich coatings may often contain clay-rich layers. The formation of layers within a coating can, in some instances, be an indicator of different water regimes that have deposited material forming the coating (Kuhn *et al.* 2010 229). The percolation of water through the soil profiles may also promote the movement of anthropogenically generated micro-charcoal, forming a dotted appearance within the coatings. The colour of the dusty coating can indicate the presence of stable bonds formed between Fe and clay particles in the upper horizons, yellow/red colouration may indicate different concentrations of Fe (Fiedler *et al.* 2012). The movement of soil particles and the subsequent development of dusty coatings may provide a mechanism for movement and deposition of degradation products.

5.1.3 Identification of features and the processes of analysis

The methodology employed in the collation of micromorphological observations and SEM-EDS inorganic elemental analysis of the fine material and depositional features are described in Chapter 2, and data and their interpretations for the single and mass grave inhumations (From the Mechelen, Syningthwaite, South Leith, Ridgeway and Fromelles) are illustrated in Chapter 3 and 4.

5.2 Spatial patterns of burial decay products in the fine material

This section looks at spatial variation in pedogenesis and elemental levels of P in the fine material through micromorphological observations and SEM-EDS analysis in order to provide information on the fate of degradation products in the burial samples.

5.2.1 Soil composition and spatial variations in the pedogenic characteristics of the fine material

The composition of soils across the different sites varied greatly as described in Table 27. The micromorphological analysis of the fine material indicated significant differences in the degree of pedogenic development within and also between sites. The following section identifies and discusses the differences observed as summarised in Table 27 and Appendix 3.

5.2.1.1 *Fine material characteristics in plain polarized light (PPL)*

The fine material across the sites displayed different characteristics under PPL, with Fromelles exhibiting dark brown/black colouration and a cloudy limpidity in all the burial and control samples. In contrast, the burial samples from the Ridgeway grave were observed to have an orange/ brown colour and dotted limpidity. This was also identified in the Ridgeway grab-soil samples from the grave fill controls.

There were no distinct differences in the appearance of the control and most burial samples from the Syningthwaite site, with burial samples and grave fill controls displaying a similar orange/brown colour and dotted limpidity. The inside the skull region from Grave G1, however, presented a cloudy appearance (PPL) in contrast to the other burial samples. Similarly, the predominant characteristics of the fine material in the left elbow, left hand and left foot regions together with the C3 control samples from Grave 6B of the South Leith site, also exhibited a cloudy limpidity and orange/brown colour. The hand region in Grave G1 and G2 both displayed low isotropic properties with high levels or dark brown humified organic matter possibly masking the presence of clay domains.

The fine material of the lower graves (Graves 384, 414, 415, 422 and 423) at the Mechelen site presented a predominantly dotted limpidity, with the upper layer Graves G26, G27 and

2037 all exhibiting speckled appearance. Similarly, the colour (yellow/orange/brown) of the fine material in the upper layer graves was distinctly different from that of the lower graves where it was darker (orange/brown/black). This could have suggested that, with the exception of the hand regions in Grave G1 and G2 of the Syningthwaite site, only the Mechelen site displayed difference in the appearance of the fine material under PPL. The differences were identified between layers and not between the control and burial samples, where the controls and corresponding burial samples showed similar characteristics.

5.2.1.2 *Distinctions in the b-fabric*

Objective one of this chapter was to identify patterns within the fine material that may determine the deposition of burial degradation products. There are two explanations derived from the micromorphological observations of the *b*-fabric that may elucidate the difference in spatial patterns and *b*-fabric: 1) the differences in the development of *b*-fabrics was derived from the inclusion of burial degradation products; or 2) the levels of clay in the soils surrounding the burials varies as a result of a site, thus affecting the development of the *b*-fabric.

The Fromelles site displayed the highest levels of clay and also 'microshearing'[2] (Kovala and Mermut 2010 114), with no microshearing identified in the South Leith samples where there was a low level of fine material and clay in the soil identified by micromorphological analysis , as indicated in Table 27. The presence of the fine material and clay particles were not limited to the burial samples at the South Leith site but were also observed in the control samples. There was a high density of poro- and linear striations in the Fromelles samples, this indicating there had been shrinking/swelling activity and alignment of clay domains within the predominantly clay matrix. This activity suggests the factors (high levels of clay) required for the development of microshearing features observed throughout the Fromelles burial samples were at a high level. However, the shrinking/swelling activity requires the processes of wetting and drying, which could have derived from the production of putrification fluids, with striations being predominantly positioned in the burial samples. This latter explanation, however, seems unlikely with the most likely explanation being the development of striation in the burial samples through waterlogging, as described by Pollard *et a* (2008a) during the initial exploratory excavations.

[2] Microshearing occurs as a result of shrinking/swelling of the soil through alternating wetting and drying leading to the reorientations of clay domains in a face to face alignment that can be identified as striation in the *b*-fabric.

The Mechelen site showed uniformity in the speckled *b*-fabric of the control and burial samples across most of the site, similar to the arrangement of the clay colloids at Ridgeway, suggesting clay particles were even distributed throughout the fine material. Only Graves 2037 and G26, in the upper layers at Mechelen, displayed an undifferentiated *b*-fabric. The most convincing explanation for the differentiation between Grave 2037 and G26, when compared to the other six graves, is the result of increased levels of humus masking the interference colours in the fine material, which contain increased levels of identifiable ferruginised root and decomposed organic matter (Milnes and Farmer 1987). In contrast, the lower layer graves contained different levels of *b*-fabric development with graves adjacent to each other (Grave 422 and 423, Grave 414 and 415) displaying speckled and striated *b*-fabric characteristics. It is most likely these characteristics developed as a result of different pressures exerted on the grave material during the shrinking/swelling processes inducing the clay domain orientation and alignment. The differentiation in *b*-fabric characteristic may, therefore, point not to degradation processes but to different water regimes being preset in the graves and a possible fluctuation of ground-water levels in adjoining graves. The variation in *b*-fabric across the lower layer graves further suggests differential water table movement across the site.

In contrast to the other sites, the appearance of linear striated *b*-fabric throughout the fine material in the Syningthwaite graves suggests that there could have been similar stresses on the clay domains throughout the control and burial samples. The most suitable explanation for this is that the clay content throughout the control and burial samples was similar and level of wetting and drying across the samples were also similar. The evidence at Syningthwaite would substantiate the finding at Fromelles and Mechelen that suggests the differences in b-fabric are not related to the degradation processes but to soil water movement. The striations observed in the inside skull region, indicating that shrinking/swelling processes had also occurred would, therefore, point to ingress of initially soil and then soil water into the skull region. Thus, the initial hypothesis that suggested the degradation products were key to the development of the *b*-fabric is not validated. Rather, it is the presence of soil water and water fluctuations that has been the main factor in its development.

Table 27: Soil characterisation, c/f distribution and ped development in the burials from Mechelen, Syningthwaite, South Leith, Ridgeway and Fromelles

Site	*Grave*	*Soil characterisation*	*c/f relative distribution*	*Ped development*	*Amendments*
Mechelen	*G26* *G27* *2037* *384* *414* *415* *422* *423*	A high content of sand particularly in Grave G26 and G27. Overall, producing a loam soil that was affected by seasonal water table fluctuations in the lower layer graves	~c/f distribution of 1:2	Strongly developed platy peds in the upper and mid layer C2 and C3 controls and Graves G26, G27 and 2037 Apedality in burial samples of Grave 422 Moderately developed sub-angular block in all other graves	Sealed by urban activity: car park
Syningthwaite	*G1* *G2* *G3*	Clay-rich fine material that may have allowed localised areas of water logging throughout the soil	~*c/f* relative distribution of 1:2	Weak ped development. C2 and C3 controls: Sub-angular blocky peds. Weak to medium ped development in the burial samples	Located adjacent to farm buildings and may have had soil improvement applied, documentary evidence of land management for this site was unavailable
South Leith	*6B*	Free draining calcareous dune sand	~*c/f* relative distribution of 4:1 in all samples except the C3 control elbow and foot region:~*c/f* distribution 1:2	Low levels of ped development, moderately developed sub-angular blocky ped in the C3 control and elbow region	Sealed by urban activity: Road surface
Ridgeway		Free draining chalky soil	~c/f distribution of 1:2	Moderate to strong development of sub-angular blocky peds in controls and burial samples. Strongly developed granular peds in the skull regions	Permanent rough pasture
Fromelles		Clay rich and poorly drained soil	Controls: *c/f* relative distribution 2:3 Burial samples: *c/f* distribution of 1:4	C2 control: Moderately developed sub-angular blocky C3 control: Strongly developed platy Burial region: Strongly developed angular blocky	May have been affected by compaction from grass cutting for animal fodder

5.2.2 Initial mean P:Fe ratio in the fine material

Although pedogenic differences in fine material were observed between and within sites (as discussed in Chapters 3 and 4 and again in Table 27) it was necessary to identify correlations between the concentration of P to Fe in the fine material across the control and burial samples from the single inhumations and mass graves.

5.2.2.1 *A summary P:Fe levels in the fine material by sampling position, grave and site*

The data in Table 28 displays the patterns of P:Fe ratios surrounding the single and mass burials, with increased levels of P identified particularly in the skull and pelvic regions of most graves. It was clear, nevertheless, that several graves did not display this pattern, with Grave 2037 from Mechelen being identified as having the highest ratio of P:Fe in the C2 and C3 controls, whilst significant increases in the foot region were recorded in the Fromelles mass grave and Grave G26 from Mechelen.

Table 28: Summary of the mean ratios of P:Fe in the fine material from the single inhumation and mass graves as examined in Chapters 3 and 4. Areas with P or Fe below instrumental detection levels are shaded out

Type of Grave	Site	Grave	C1	C2	C3	B. Skull	Skull	Inside skull	Left Elbow	Hand	Pelvis	Sacrum	Left Knee	Foot
Single Inhumations	Mechelen	***G26***					0.35				0.09			2.37
		G27					0.20				0.22			0.20
		384			0.20	0.02	0.31							
		2037		0.31	0.24		0.21							0.21
		414					0.24				0.79			
		415					0.35			0.36				0.17
		422		0.14		0.10	0.89			0.28		0.06		
		423			0.44		0.49				0.78			0.41
	Syningthwaite	***G1***		0.02			0.04	0.08		0.03				0.02
		G2	0.07				0.02	0.76		0.03				0.01
		G3		0.02	0.01		0.04					0.09		0.03
	South Leith	***6B***		0.03	0.02		0.01		0.52				0.14	0.10
Mass Graves	Ridgeway	***Site***		0.11	0.01		0.07				0.08			0.08
	Fromelles	***Site***			0.02		0.26							
		Max		0.31	0.44	0.10	0.89		0.52	0.36	0.79	0.06	0.14	2.37
		Min		0.11	0.01	0.02	0.01		0.52	0.03	0.03	0.06	0.14	0.01

5.2.2.2 *Statistical analysis of the P and Fe elemental data*

Statistical analysis was carried out on the SEM-EDS data to test the hypothesis that: there is a relationship between the sampling position in the grave, the grave itself and the interaction between the sampling position and the grave to the levels of P and Fe detected in the fine material and depositional features (previously identified in Chapters 3 and 4). Methods of statistical data analysis were applied as discussed in Chapter 2, Section 2.7.2),.

All data was initially tested for normality using the Anderson-Darling normality test and all data was found to be normally distributed. Two-way analysis of variance (Two Way ANOVA) with Tukey-Kramer (95% confidence) multiple comparisons were used to test the data.

Table 29: 2 way ANOVA results (p-values) of grave, sample position and interaction effects on the P and Fe concentrations in redoximorphic nodules, dusty coatings and fine material of the grave fill controls and burial samples (significant p-values (<0.05) have been highlighted)

	p-value					
	Redoximorphic nodules		*Dusty clay coatings*		*Fine material*	
	P	Fe	P	Fe	P	Fe
Grave	0.000	0.000	0.002	0.000	0.000	0.000
Sample Position	0.000	0.011	0.566	0.253	0.000	0.288
Grave Sample Position*	0.000	0.000	0.000	0.455	0.000	0.000

The results of the statistical analysis (Table 29) showed the '*Grave'* factor to be statistically significant, with a p-value of <0.05 (95%) for both P and Fe in the redoximorphic nodules, coatings and fine material. Similarly, the interaction of '*Grave*Sample Position'* was statistically significant (p-value <0.05) in all elemental concentrations across all features, except the Fe concentrations in the dusty coatings. The '*Sample Position'* factor indicated there was only a significant correlation between the levels of P in the redoximorphic nodules and fine material.

The evidence from statistical analysis implied there was a relationship between elemental concentrations of P in the fine material and '*Grave'* and '*Grave*Sample Position'* factors. The 2 way ANOVA also indicated that the level of Fe in the grave and the interaction between '*Grave* Sample Position*' was statistically significant. The analysis of variance, therefore, further confirmed that except for the '*Sample Position'* factor and the concentration of Fe, there was a relationship between levels of P and Fe in the fine material of both the single inhumation and mass grave burials.

The statistically analysis supports the SEM-EDS results that were discussed in Chapters 3 and 4 and confirms the initial statistical analysis that was undertaken on the mass graves of Ridgeway and Fromelles (Sections 3.6 and 4.7). The increased levels of co-precipitated P:Fe found the fine material around the burials, particularly in the skull, pelvis and foot regions of the burial when compared to the control samples can be part of a diagnostic tool, thus providing answers to the initial objective (Section 1.9.1.1).

5.2.3 P levels in the fine material as determined by mean P to Silica (Si) ratio

To further confirm the spatial variation of P in the fine material of the burial and control samples, analysis of the mean P:Si ratios were analysed to corroborate the statistical relationships identify between P and Fe concentrations. Si was used to determine the levels of P as it is the most ubiquitous element found in the analysed soils, and could therefore, be found in soils when other minerals had been removed (Schlesinger 1997 92). P:Si ratio was employed to further ascertain there had been changes in the concentration of P when there was little Fe/Al oxides present in the fine material.

5.2.3.1 *Spatial distribution of P to Si in the single inhumations*

The mean ratio of P:Si are shown in Figure 74 for the samples from Mechelen, South Leith and Syningthwaite, and for Ridgeway and Fromelles.

The highest P:Si ratio was observed in the skull, pelvis and foot regions of Grave G26 from the Mechelen site, the skull and foot regions both displayed similar levels (3.1). Grave 384 presented a high ratio of P:Si in the hand region. The C2 and C3 controls from Graves 2037 and 422 indicated that the P:Si ratios were greater than in the sacrum and skull respectively.

Similarly, the skull and inside skull regions of the Syningthwaite graves displayed increases in P:Si, with a higher ratio than the grave fill control samples. The sacrum (Grave G3) and pelvic (Grave G1) regions exhibited higher ratios of P:Si when compared to the C1 site control and grave fill controls (C2 and C3), the latter controls being below detectable levels. The ratio of P:Si in the skull region of Grave 6B from the South Leith site, and the left elbow sample, were also too low to detect. High ratios of P:Si were, nevertheless, exhibited around the left elbow, left knee and foot regions when compared to the C2 and C3 grave fill controls from South Leith.

It is evident that spatial patterns in the of P:Si in the fine material were identified both in site specific graves and between sites. The mean level of P:Si was significantly higher in most burial samples than in the corresponding C2 and C3 grave fill controls, this implies that there are factors occurring in the burial samples and not in the controls that are affecting the levels of P. Increased mean ratios of P:Si were identified in the skull and pelvic regions of most graves in the three single inhumation sites. Grave 6B from South Leith and Grave G26 and 422 from the Mechelen site also displayed elevated P:Si ratios in the foot region of the burials, compared to the corresponding grave fill controls (Table 28 and Figure 74). The foot region samples from Mechelen (Grave G26 and 422) also showed a significant increase in the ratio of P:Fe (Table 28) when compared to the other samples across the site. The most likely justification for the increased P:Si identified in the burial samples, but not in the control samples, is that it was derived from the interred body. The main difference that was determined between the grave fill controls and the burial soils is the deposition of human remains. The increased ratio of P:Fe further suggested that degradation products, emanating from the burial during decomposition, had been retained to varying degrees within the fine material surrounding the burial. The higher ratios P:Si in the skull and pelvic regions suggested there had been increased intensity of degradation products retained in the fine material in these particular regions. The most reasonable explanation for the high levels in these areas is that these parts of the body would contain a higher percentage of P, being the fleshier parts of the body, thus containing more P. The results, however, further suggest that there had been increased concentrations of decay product in the foot region of several graves (Mitchell *et al.* 1945). The most rational reason for this is either through addition of pre-burial organic matter such as absorbent materials to the coffin through burial ritual (Hadley 2010 297) or through post-burial pooling of the degradation products at the feet region.

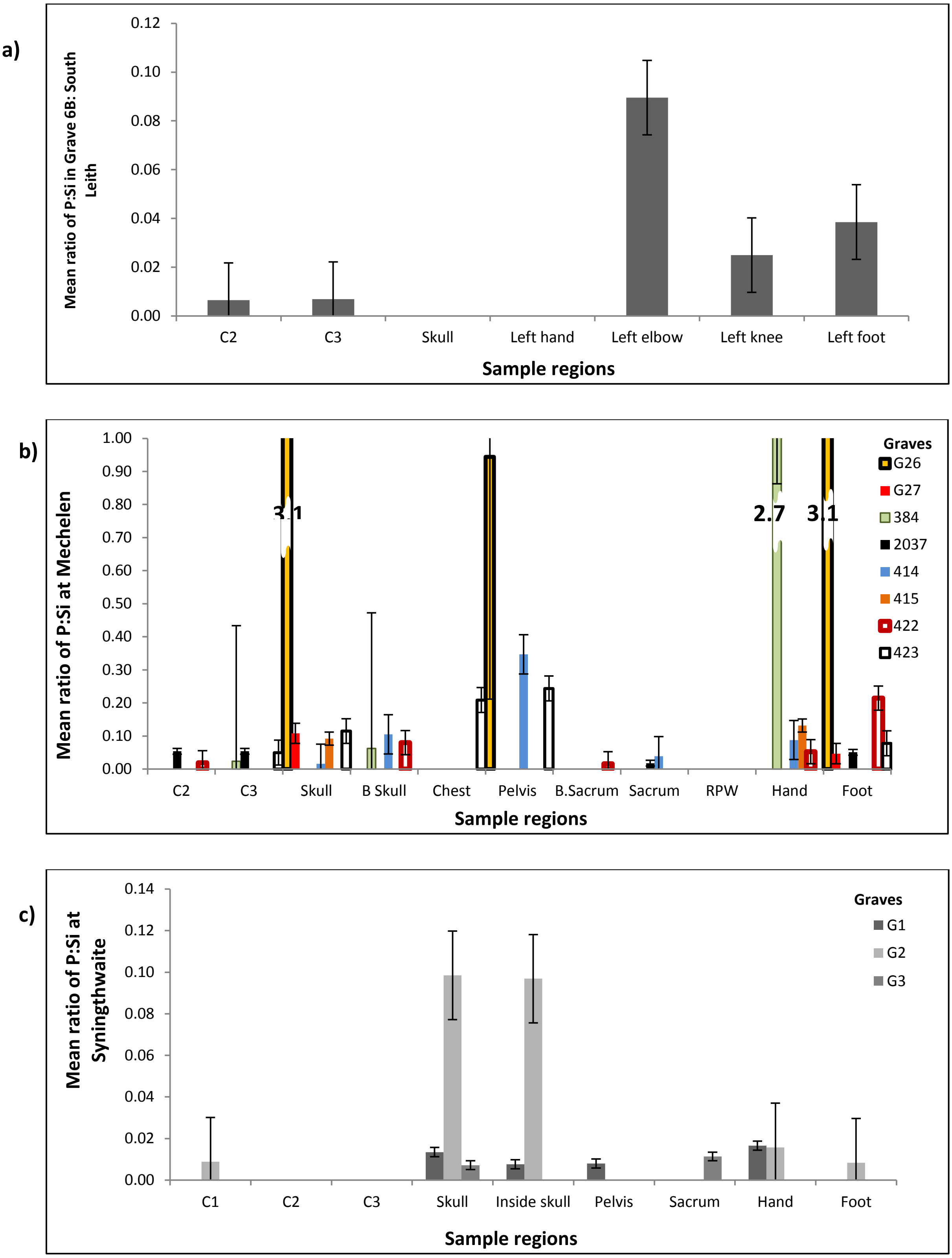


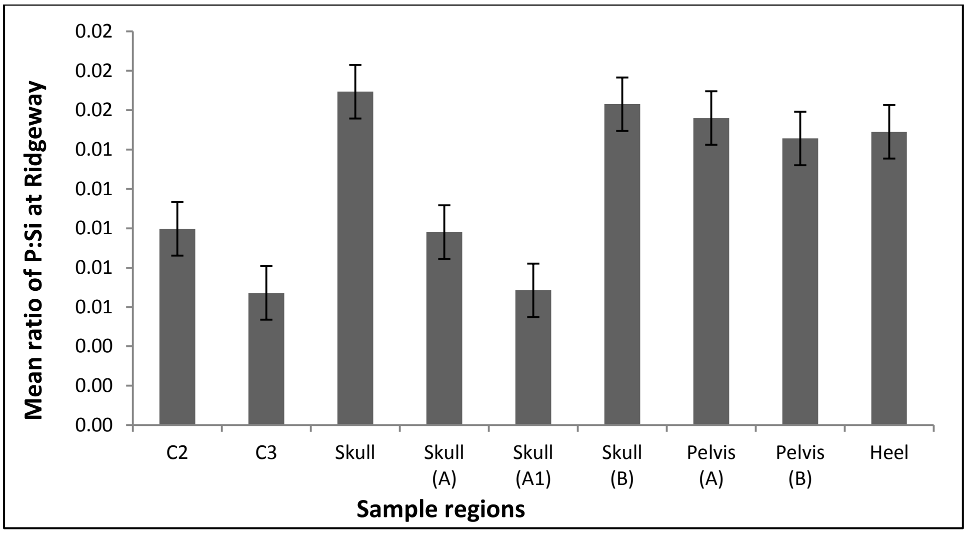
Figure 74: Mean ratio of P:Si in the fine material of the control and burial samples from the single inhumations of: a) Mechelen graves (Grave G26, G27, 384, 2037, 414, 415, 422 and 423); b) Syningthwaite graves (Grave G1, G2 and G3); c) South Leith grave (Grave 6B). The error bars display 1 standard error of the data mean

5.2.3.2 *Spatial distribution of P to Si in the mass graves*

The P:Si ratios across the sample regions of the Ridgeway site (Figure 75a) indicated that there were higher ratios of P:Si in all burial samples, except skull (A) and (A1) regions when compared to levels in the C2 and C3 controls. The C2 control displayed higher ratios of P:Si than that of the C3 control but the controls were comparable with the skull (A) and skull (A1) region samples, the latter skull samples being collected from the same skull region.

The P:Si ratios in the burial samples from the Fromelles site (Figure 75b) are only displayed in the skull and skull (B) region samples, with the control, skull (A) and foot region samples exhibiting a P:Si ratio of zero.

a)



b)

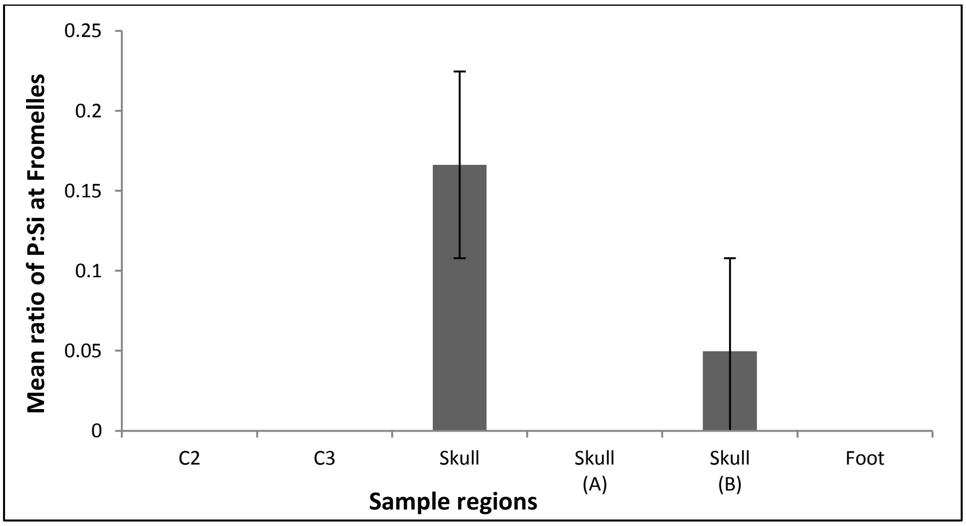


Figure 75: Mean concentration of P:Si in the fine material of the control and burial samples from the mass graves of: a) Ridgeway; b) Fromelles. The error bars display one standard error of the data mean

The spatial patterns within the mass graves of the Fromelles and Ridgeway sites are comparable with the patterns of P:Si found in the single inhumations. This is clearly shown in Figure 75a and b, with P:Si ratios in the control samples lower than in the burial samples. The highest ratios of P:Si were identified in the skull and pelvic regions, this being especially notable in the Ridgeway grave. The elemental signatures identified in the mass graves seem to have been consistent with decomposition products emanating from areas of the bodies richest in flesh; such as the skull and pelvis regions.

5.2.4 Discussion on the elemental and micromorphological patterns in the fine material

A major property observed in the individual burials was the correlations between sample positions and the ratio of P:Si, identified in most graves and most clearly in Grave G26 and Grave 384 of the Mechelen site. Across all graves, ratios of P:Si within the sampling regions of the skull and pelvis appeared higher when compared to that in most other burial and control samples. Exceptions to this were only the foot regions of Grave G26, and the hand region of Grave 384 at Mechelen both with higher ratios of P:Si, and the skull region sample from South Leith where the mean P:Si and P:Fe were zero.

The abundance of fine material in South Leith, Grave 6B, was low, with an average *c/f* distribution of 4:1 and the skull region displaying the lowest level of fine material (*c/f* 14:1). The difference in the *c/f* distribution suggested that there may had been changes in soil stability across the grave (Six *et al.* 2000). Higher levels of fine material were observed around the foot, knee and elbow region samples and C2 control, consistent with high levels of organic matter from the wood-like material identified during micromorphological investigation around the left foot, left elbow and left knee regions, but not found in the C2 control, where similarly increased levels of P:Si were detected. The initial assessment could point to burial practice providing the stabilisation agents to the fine material in the burial, with wood-like material thought to be derived from the coffin, stabilising the fine material in the left foot, left knee and left elbow regions. Similarly, the C2 control, collected above the burial in the grave fill, displayed high levels of fine material compared to the skull and hand regions. The low level of fine material in the left hand and skull regions of the burial could also be linked to the position of these sample regions not adjacent to the side of the coffin, so that the fine material was free to be washed immediately through the profile, differently from the other burial samples, these all being in contact with the coffin. The retention of fine material in the C2 control could also have been attributed to position, in contact with other coffined burials adjacent to the sample position (Chapter 3, Figure 22), hence possibly slowing the percolation of soil water. Thus, the initial theory (Chapter 3, Section 3.3.6): the burial of a coffin may provide the necessary conditions for the stabilisation of fine material and its retention in sandy soils can be posed. It was not higher organic matter from the degradation of the burial that helped to retain the fine material through stabilisation (Six *et al.* 2000), but the coffin and wood fragments from the coffin preventing soil water wash-through, therefore increased fine material becoming evident in the regions of the burial that were immediately adjacent to the structure.

Higher ratios of P:Si were identified in the sampling areas that also contained an increased frequency of fine material (left elbow, left knee and left foot); in contrast the skull and left hand regions showed little fine material and low P:Si levels. The results suggested a relationship between burial practices and the retention of degradation products. This implied that the reserved fine material around the burial had retained degradation products, however, only where there was increased fine material. Overall, it is apparent that the higher levels of P:Fe identified in the fine material at South Leith site were further confirmed by the higher P:Si ratios.

Similar patterns of elemental deposition could be identified at the other sites. Table 28 and Table 30 illustrate the increased ratios of P:Fe and P:Si in the skull and pelvis regions, across most single inhumations and , subordinately, in the foot regions of some graves. The highest values were identified in the skull, pelvis, hand and foot regions of the upper layer Graves G26 and lower layer Grave 384 at the Mechelen site but the same trend was also observed in the other graves across the site, but with less pronounced increase of the P:Si ratios. Only occasionally (Grave 422), increased levels of P:Si were also observed in the foot regions. It seems that there may have been similar levels of degradation products entering the soil in the skull, pelvis and foot regions and human anatomical form suggests that the skull and pelvic regions could have contained a greater level of flesh and thus a possibly higher level of decomposition products.

The upper and lower layer graves at the Mechelen site displayed different fine material characteristics (with a dotted limpidity, dark colouration (PPL) and striations), especially within the foot region, in comparison with the lower layer 12-13th century graves (Graves 384 and 422). It was believed that these had been affected by the fluctuation of the local water table. Conversely, the upper 17-18th century Grave G26 was characterised by a lighter fine material and a speckle limpidity (PPL) and *b*-fabric (XPL). The difference in the elemental and micromorphological characteristics of the fine material, the age of the individual graves and the contrasting environmental conditions, although from the same site, implied that the fine material surrounding the burials at Mechelen have retained P derived from degradation processes, regardless of physical properties and external pedogenic pressures.

Similar P deposition patterns to Mechelen were identified in the Syningthwaite graves where the burial samples from the three graves demonstrated an increased ratio of P:Si in the skull, pelvis and hand regions, particularly in Grave G2. However, increases in the of P:Si ratio were also observed in the hand region of Graves G1 and G2. The preferential distribution of P suggests that there could have been increased levels of degradation products in these sample regions. Micromorphological observation confirmed the presence of dark brown humified material in the same areas of high P:Si ratios in the hand region of Grave G1 and G2, whilst fungal schlerotia were identified in the right hand region of Grave 2 (Chapter 3, Figure 40). The other sample regions of the Syningthwaite graves, however, did not display humified organic matter, in areas with an increased ratio of P:Si. The Syningthwaite site not only provides C2 and C3 grave fill controls but also a C1 site control. In both such controls and burial samples, ped development and the alignment of clay domains occurred uniformly across the site. Differences in aggregation and ped development in the fine material were only observed in the samples from the inside skull region of Grave G2, where granular peds had occurred as a result of bioturbation, as indicated by the high frequency of coalesced excremental pedofeatures (Chapter 3, Figure 40). This skull region also displayed an increase in the P:Si ratio suggesting that there higher levels of degradation products, which may have attracted soil organisms that had been retained in the skull cavity.

A spatial variation of the P:Si patterns similar to that observed in single inhumations, could also be identified in the mass graves of Fromelles and Ridgeway. In fact the 10th century Ridgeway site also displayed increases in P:Si in the skull, pelvis and foot samples. Here, however, the bodies had been decapitated before burial, and the severed heads were buried in a separate part of the burial pit way from the torsos. Hence, the increase in P:Si in the skull region occurred separately from, and was not affected by decomposition of the other body parts. The level of P:Si, in the 20th century Fromelles site, the high ratios of P:Si was only observed around the skull region samples as no pelvis region sample had been collected. In both mass graves, however, it was evident that P:Si ratios were greater in the burial samples than in the grave fill controls (Figure 74).The most significant difference in the fine material of the mass graves was the development of the predominantly clay soils of the Fromelles graves and controls that displayed a high frequency of striated *b*-fabric (XPL), a cloudy limpidity and dark/black coloration (PPL). In contrast, the samples from Ridgeway exhibited a dotted limpidity, and orange/brown colour (PPL) and speckled *b*-fabric (XPL).

Such difference in the fine material indicated there have been different isotropic stresses where variation in pedogenic development had occurred.

5.2.4.1 *Variability in the fine material between sites*

A clear difference between the sites investigated is their age and the length of time the burials have been interred. The oldest of the burial sites was the 10th century mass grave of Ridgeway, and the youngest the other mass grave at Fromelles; the interment of the bodies approximately 92 years before excavation.

Differences could be identified between the macro-analysis of the fine material of the free draining calcareous soils of the Ridgeway site and that of the waterlogged Flanders clay of the control and burial samples from Fromelles. The contrasting site conditions did not affect the patterns of higher P:Si ratios in the burial samples when compared to ratios in the controls. Evidence from Ridgeway clearly illustrated the spatial relationship between increased levels of P:Si in the skull, pelvis and, unexpectedly, the heel region of the burial, when compared to the levels in the grave fill controls. It is evident that the actual ratios of P:Si in the Ridgeway site were lower than Fromelles. Although this may have been the result of lower levels of P at Ridgeway, it could also point to a higher retention of P in the soil, or to its adsorption over time by the predominantly clay-rich fine material; there was a considerable time difference between the initial interment and the collection of samples.

The variability in texture between sites was also identified in the single inhumations, with the *c/f* distribution significantly greater in the South Leith site than in Mechelen, Syningthwaite and the two mass grave locations. Areas where the highest ratios of P:Si were recognised, also displayed increased levels of fine material. The site at Mechelen exhibited a sandy matrix with an increased abundance of humic material, but the ratios of P:Si still showed a spatial pattern with increased deposition in the fine material surrounding the skull, pelvis and, in some graves, foot regions. The Syningthwaite site displayed the most significant difference in P:Si between burials, with Grave G2 exhibiting a considerable P:Si ratios in the skull region and inside skull region samples when compared to other regions. When Syningthwaite P:Si was compared with those of the other single inhumations sites, similarities emerge with those of similar interment age, both at South Leith and Mechelen , the exception being the 12-13th century Grave 384 at Mechelen. Such an anomaly could have resulted from the truncation of the grave by later interments, as described in Chapter 3, Section 3.4.2.

5.3 Spatial patterns in the Micromorphology and elemental analysis of depositional pedofeatures

This section focuses on the spatial variability, frequency and P:Fe ratios in the redoximorphic nodules and dusty coatings. The initial question posed was: did the redoximorphic nodules and dusty coatings in the grave fill control and burial samples post-date the burials? Further to this, can the pedogenesis of the depositional features help identify microscopic burial remains in the grave soils?

5.3.1 Forms of redoximorphic nodules

There were two distinctive types of redoximorphic nodules within the burials and across the sites: typic and aggregate. The typic nodules displayed no internal coarse material, whilst the aggregate nodules contained coarse material from the surrounding sample region (Figure 72). The aggregate nodules in the matrix displayed orthic[3] characteristics suggesting that they had formed *in situ* and had not been displaced or moved as a result burial activity, but instead had formed in the grave fill control and burial samples post-burial. Typic nodules were also discovered within the matrix of the burial and control samples. The typic nodules displayed either gradual or sharp boundaries, with the fine material. Typic nodules with gradual boundaries were thought to be orthic and developed post-burial. The sharpened boundaries of the typic nodules are believed to indicate that they were disorthic[4], as they were typical of the surrounding matrix and displayed no truncation. However as result of wetting and drying and soil leaching this cannot be confirmed (Stoops 2003b 118).

5.3.2 Micromorphological observations of redoximorphic nodule frequency

Table 30 displays the frequency of redoximorphic nodules identified during micromorphological observation of the single inhumation and mass grave sites. The Syningthwaite site exhibited a greater frequency of the nodules across Graves G1, G2 and G3 when compared to the other sites, with particularly high frequencies found in the skull region of Grave G1. Similarly, the Ridgeway and Fromelles sites also displayed a high frequency of redoximorphic nodules; however, these were identified in the pelvis regions and C3 control samples respectively.

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[3] Orthic when referring to a redoximorphic nodules indicated that it had formed *in situ* and had not translocated to another part of the area/stratigraphic layer

[4] Disorthic is the formation and subsequent displacement of redoximorphic nodules so they are longer have a similar parent material to their location.

Table 30: Summary of the location and frequency of redoximorphic nodules across the single inhumations and mass graves investigated in Chapters 3 and 4

Type of Grave	Site	Layer	Grave	C2	C3	B. Skull	Skull	Inside Skull	B. Chest	Hand	Elbow	Pelvis	B. Sacrum	Sacrum	Knee	Foot
Single	Mechelen	*L1*	*G26*													*
		L2	*G27*									**				**
		L3	*2037*	*	*									**		**
		L4	*384*			**			*	*			**			
		L4	*414*	*			**			*		*				
		L4	*415*		*		*			*						
		L4	*422*			**										
		L4	*423*				*									
	Syningthwaite		*G1*	**	**		***	**		**		**				
			G2	**	**		**	**		**		**				**
			G3	**			**							**		*
	South Leith		*6B*	**	**		**			**	**				**	**
Mass	Ridgeway		*Site*	*								***				
	Fromelles		*Site*	**	***		**									**

*B= sample collected below the sample region; Frequency levels: *= low; **= moderate; ***= high*

Grave 6B from South Leith displayed a similar frequency of nodules across all sample regions. Moderate frequencies were typical of the skull and pelvic regions of the Mechelen site, with higher frequencies commonly observed in the burial samples when compared to the controls

5.3.2.1 *Differences between graves from the same site*

The increased frequency of the redoximorphic nodules in the burial samples in comparison with the controls across the Mechelen site suggested that redox conditions had occurred to a greater degree in the burials. The occurrence of the nodules in the lower layer Graves 414 and 422 was moderate in the skull and below skull regions. In contrast, the upper layer Graves G26, G27 and 2037 had a greater frequency of the nodules in the pelvis and foot region of the burial samples. This does not confirm the conclusions drawn from the development of the *b*-fabric in these graves, as the development of redoximorphic nodules can be used as a diagnostic tool for periodic waterlogging (USDA-NRCS). The increase in the number identified implies that there is a greater increase in water fluctuation in the upper graves. The most likely explanation is the redoximorphic conditions have occurred either through increased water fluctuation or as a result of increased fluid fluctuation from the burials. The site at Mechelen, located near the River Dijle, although free-draining, it may have been affected by localised seasonal flooding and waterlogging. The development of nodules within the lower layer graves could point to localised waterlogging. However, if fluctuation in the groundwater was to have occurred, it would be expected that the nodule frequency would be consistent across all graves in the lower layers of the site, and not only within localised areas of the individual graves. Redoximorphic nodule development in the upper graves indicated that there had been a greater level of reduction and oxidation in the lower limb regions of the burials. These graves, however, were buried within free-draining sand ~5m above the lower layer graves (Chapter 3,Figure 18) and were unlikely to have been affected by seasonal waterlogging. The patterns that have emerged from the burials (as described in Section 5.3.2 and Table 30) do not point to the effects of waterlogging from the water table, but to localised retention of soil water or the retention of burial-derived fluids within certain areas of the grave such as the skull, pelvis and foot regions. The latter explanation is the most probable, with the soils in the upper grave being free draining. The frequency of nodules within the grave fill controls were low, this could point to low levels of waterlogging within the soil backfill areas. Increased nodule frequency in the graves suggested that the burials may have prevented water and degradation products from draining away from the body providing localised areas where reduction and oxidation conditions could occur. Furthermore, the lower frequency of nodules in the grave fill controls suggests there was less fluctuation in reduction and oxidation conditions, but also lower development of redoximorphic nodules, whilst also being little derived burial organic matter to encourage redox conditions catalysed by soil micro-fauna.

The development of redoximorphic nodules in the burial and control samples from the Syningthwaite site suggested conditions had been similar, with moderate frequencies exhibited in all control and burial samples. The only sample to have displayed a high frequency of nodule development was the skull region of Grave G1. This would suggest the factors that determine the development of nodules were increased in this region, through factors such as the higher waterlogging potential derived from higher levels of clay within the fine material around the skull.

The development of nodules at the Ridgeway site also suggests that, similar to South Leith and Mechelen, waterlogging was not the key factor in the high frequency of nodules identified in the pelvis region. The site was free-draining calcareous limestone (as described in Chapter 4, Section 4.2.2), hence it was expected that the occurrence of waterlogged conditions and the incidence of reduction and oxidation conditions would be minimal. The increased level of organic matter derived from the pelvis region may have been one of the factors, together with increased degradation fluids that could have caused a high frequency of nodule development within the pelvis region compared to the low frequency in the C2 grave fill control. In contrast, the mass grave at the Fromelles, which was predominantly composed of clay, and thus poorly drained, had displayed a high frequency of nodules in the C3 control, when compared to the moderate levels exhibited in the C2 control, skull and foot region samples.

5.3.2.2 *Identification of redoximorphic site conditions*

As already indicated, the Fromelles site percolation of soil water could have been impeded, as a result of the high level of clay, providing localised and seasonal waterlogging, especially in the C3 control (Turner and Wiltshire 1999). The presence of redoximorphic nodules in the burials, and to a greater degree in the C3 grave fill control, suggested fluctuating reduction and oxidation conditions had occurred more frequently above the grave. The implication of this suggests seasonal wetting and drying occurring to a greater degree in the C3 control, which has a higher *c/f* distribution, whilst the burial samples below, which contained a lower c/f distribution, experienced little seasonal drying as indicated by the low levels of striations observed in the fine material, staying waterlogged for prolonged periods of time. Furthermore, the conditions at Fromelles could point to the development of redoximorphic nodules being diagnostic of water movement, especially in the C3 control.

Syningthwaite, in contrast to Fromelles, displayed a c*/f* distribution of 1:2 although the fine material was typically clay-dominated, so alternating reduction and oxidisation conditions through the prolonged retention of soil water could have occurred (Turner and Wiltshire 1999). Thus, there was a high potential for the frequency of redoximorphic nodules to develop equally across the control and burial samples. The only samples to show dissimilar decreased trends were the foot region of Grave G2 and the skull region of Grave G1. There were no visible signs during the excavation of foot bones in Grave G2 foot. The low level of redoximorphic nodule development in this region could, therefore, be the result of not only low waterlogging but also low organic matter levels and subsequently low soil micro-fauna presence, thus providing decreased redox conditions. Conversely, a high frequency of redoximorphic nodules identified in the skull region of Grave G1 may be the result of higher levels of organic matter emanating from the skull region. Thus, a hypothesis for the different levels of nodule development at Syningthwaite is that the development of redoximorphic nodules was the result of both increased organic matter in the sample regions along with slow localised soil-water drainage as a result of the high clay content in the fine material.

In contrast, the lower level graves at Mechelen, although initially thought to be affected by water table fluctuation, did not contain nodules across all of the C2 and C3 controls or burial samples, but rather across the different burial layers of the site regardless of their age or stratigraphic position and potential for waterlogging. Comparable development of redoximorphic nodules could be seen at Ridgeway where the burial samples displayed a greater frequency of nodules. At both Mechelen and Ridgeway the conditions in the areas were believed to be calcareous. In both sites there was a greater development of nodules in the burial than the controls. This was not observed in the calcareous sands of the South Leith site, where the frequency of redoximorphic nodule development was similar in both the control and the burial samples. The most striking difference compared to the other free-draining site was the low level of fine material and proximity of the other graves (South Leith), with one truncating the right side of the burial (Chapter 3, Section 3.3.2). The moderate development of nodules at this site could, therefore, be the result of localised retention of degradation products, which would contain high levels of organic matter both from the studied grave (Grave 6B) and also from the close proximity of the surrounding graves.

5.3.3 Elemental composition of the redoximorphic nodules

The data from the analysis of the redoximorphic nodules in Grave 6B from South Leith (

a) indicated increased ratios of P:Fe in the burial samples when compared to the grave fill controls. The data from the left knee region displayed the highest ratio of co-precipitation, with the skull and left foot region samples both displaying a lower ratio of P:Fe than the C2 grave fill control.

c indicated the ratio of P:Fe in the redoximorphic nodules from the inside skull sample region of Grave G2 was significantly greater than the other burial samples. Similarly, the skull sample from Grave G2 also displayed a greater ratio of P:Fe than the other graves and grave fill controls. The location of the nodules across the grave samples would indicate there was a greater frequency of P:Fe in the skull and foot regions. However, the C1 site control from Syningthwaite displayed higher ratios of P:Fe in the nodules than all control and burial samples except Grave G2: skull and inside skull regions.

The Mechelen site demonstrated an increase in the frequency of redoximorphic nodules in the skull regions of the eight graves. A higher ratio of P:Fe was identified in the sacrum and C2 control from Grave 2037. The nodules in the hand region of Grave 415 have the highest levels of P:Fe across the site and within the grave. The lowest ratio of P:Fe were identified in the foot region of the same grave (Grave 415).

Syningthwaite and Mechelen sites provided clear evidence there were higher mean ratios of P:Fe within the nodules from the skull regions of the single inhumations when compared to that of the C3 control. The pattern of P:Fe across the Mechelen site suggests there had been little co-precipitation in the foot region of the graves where evidence of redoximorphic nodules was observed. This therefore suggests the P has remained within the fine material. It is evident from Appendix 4 that in the foot region of Grave 415 the concentration of P may be the limiting factor in co-precipitation as higher levels of Fe were available. Conversely, the level of Fe in the pelvis may have been the limiting factor in the level of P able to co-precipitate into the nodules of this sample region.

The Syningthwaite site displayed elevated P:Fe ratios in the skull region and inside skull region of Grave G2, while the pelvis sample from Grave G1 is the only other area in the three graves to demonstrate co-precipitation levels greater than the grave fill control samples. The levels of Fe (Appendix 4) in the nodules in the inside skull region of Grave G1 were significantly greater than those of Grave G2, however, the levels of P within both inside skull samples from each grave were high, thus providing an increased P:Fe ratio in the Grave G2 sample. The low level of P in the skull and C3 control of the South Leith site also indicated limited levels of co-precipitation into the nodules.

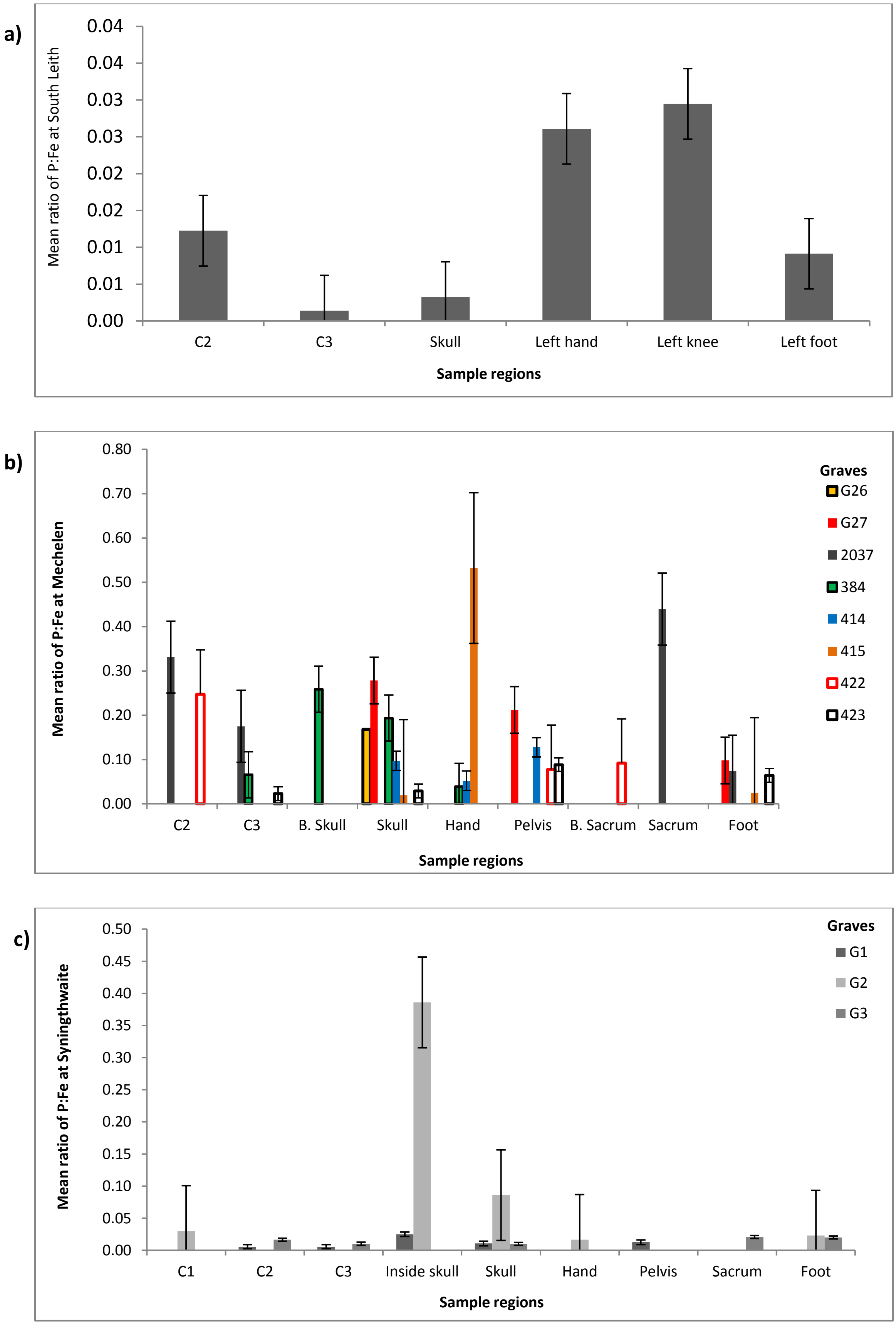


Figure 76: Mean ratio of P:Fe in the redoximorphic nodules of the control and burial samples from the single inhumations of: a) South Leith; b) Mechelen and c) Syningthwaite. The error bars display 1 standard error of the data mean

The evidence in the three sites would point to the level of P across the samples regions as the predominantly limiting factor in the ratio of P:Fe contained in the nodules, with only Fe levels in the foot (Grave 423) and the pelvis (Grave 422 and 423) regions of the Mechelen site determining the level of P in the redoximorphic nodules.

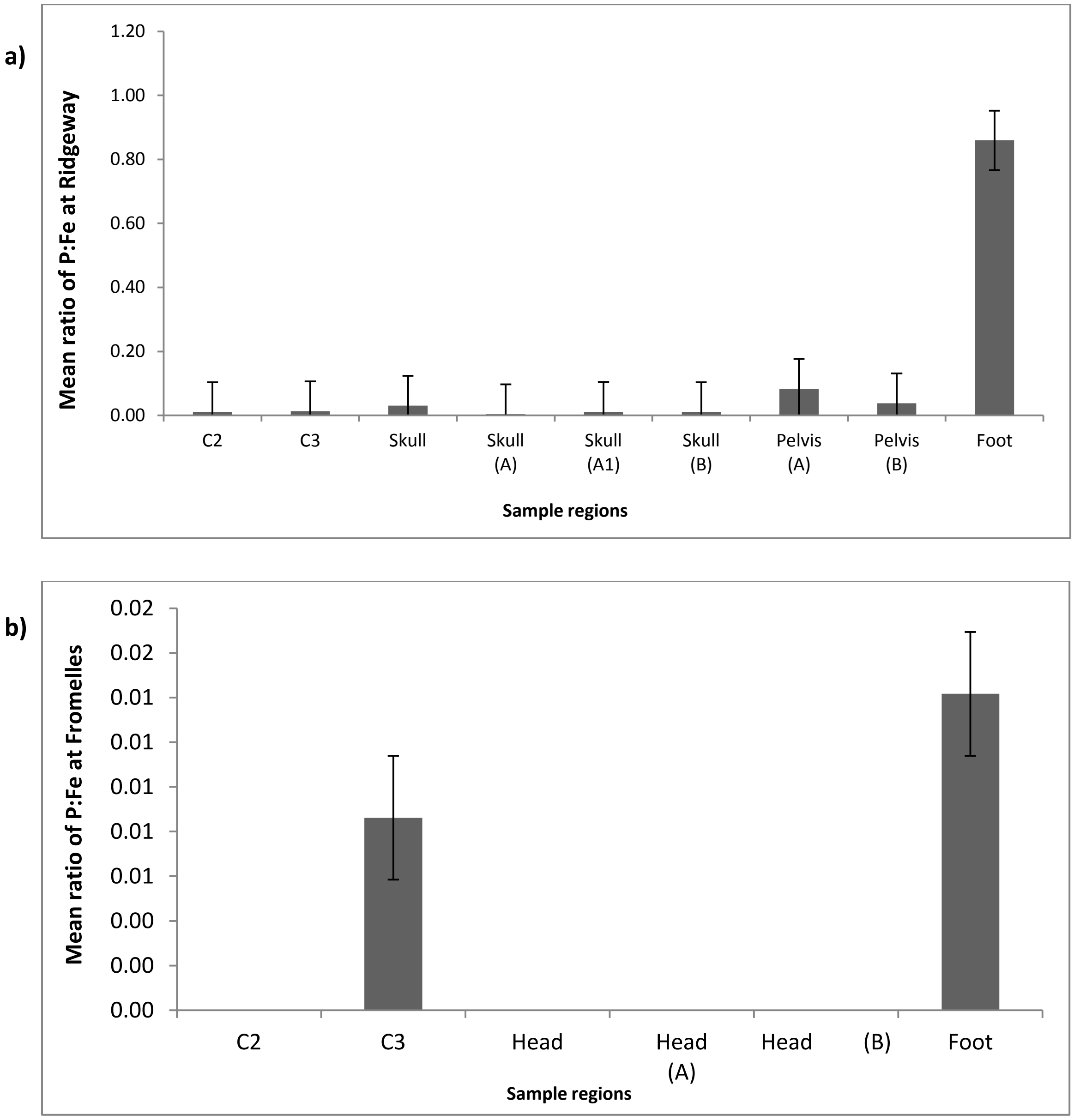


Figure 77: Mean ratio of P :Fe in the redoximorphic nodules of the control and burial samples from the mass graves of: a) Ridgeway and b) Fromelles. The error bars display one standard error of the data mean

The ratios of P:Fe in the Ridgeway site was evidently higher in the pelvis and foot regions; with the C2 and C3 controls displaying lower P:Fe than in all the burial samples.

In the Fromelles site only in the redoximorphic nodules in the C3 grave fill control and the foot sample contained detectable concentrations of P, with the control exhibiting lower P:Fe than the foot.

At Ridgeway there was a significantly lower ratio of P:Fe in the nodules in the skull region when compared to the pelvis and foot region samples. The ratio of P:Fe in the skull region was comparable with the nodules in the grave fill control. The initial explanation for this difference in P:Fe ratios could be the method of burial, the skulls were placed in a different area of the grave from the torsos. The lower ratio of P:Fe in the control samples could be the result of them being above the burial, with no significant upward migration of the degradation products through the soil. The higher ratios of P:Fe in the foot and pelvis region samples seem to have been affected by the degradation products from the burial and the mass co-mingled torsos buried together. In contrast, the nodules in the C2 and skull region samples at the Fromelles site exhibit a P:Fe ratio of zero, with only the redoximorphic nodules in the foot region displaying co-precipitation of P with Fe into the nodules. The ratio in the C3 control, although lower is only fractionally lower (0.02). The results indicated that there was little movement of P with Fe into the nodules across the Ridgeway burial and controls.

5.3.4 Comparison of micromorphological and elemental data: redoximorphic nodule

The frequency of nodules at the Mechelen site and the P:Fe ratios in these nodules did not seem to correlate. Moderate frequency (~5%) of both typic and aggregate redoximorphic nodules in the foot region of Grave G27 and 2037, and similar observations in the pelvis region of Grave 2037 corresponded to a high P:Fe ratios. Conversely, the high levels of P:Fe in the foot region of G26 and the hand region of Grave 415 did not correlate with the low frequency (2%) of nodules in these burial samples. The sample from the below skull region of Grave 422 contained redoximorphic nodules, however the elemental analysis suggested there had been little identifiable co-precipitation of P with Fe (Figure 76). The evidence from the Mechelen site, therefore, suggested these were inconsistent. It did, however, support the statistical analysis (Section 5.2.2.2). One hypothesis to explain these results is that the soil water movement was impeded by the burial, and so increased the fluctuation of reduction and oxidation conditions and the development of redoximorphic nodules. It could, therefore, be that the increased frequency of nodules within the controls and burial samples was the result of the internment preventing the percolation of soil water, thus providing the conditions for nodule development. Only P derived from the degradation products that had pooled around the body, and that was not absorbed by the minerals within the fine material, would have been available to co-precipitate into the redoximorphic nodules. This suggests the elemental concentration of P within the nodules was determined by the quantity of P pooled in the soil from the body and the adsorption potential of the fine material.

The pattern of nodule frequency and low P:Fe ratios were identified across the Ridgeway and Syningthwaite site. The skull region of Grave G1 from Syningthwaite exhibited an increased frequency of redoximorphic nodules (6-10%) (Table 18) containing low P:Fe (Table 28). The skull region samples from Ridgeway displayed detectable P:Fe but exhibited no nodules, this suggested that fluctuating reduction and oxidation conditions hadn't developed and the soil water and degradation fluids drained away freely. It was the pelvis region of the Ridgeway samples that showed an increased frequency of nodules, and correspondingly an increased in P:Fe, this suggested P was available for co-precipitate with Fe and reduction and oxidation conditions had occurred. This correlation between P:Fe and the frequency of redoximorphic nodules at Ridgeway may further indicate that the increased level of degradation products within this region of the burial had prevented the movement of soil water and putrification fluids away from the burial.

The Fromelles site contained high levels of clay in the fine material, whilst P:Fe in the redoximorphic nodules of the burial and the controls was also low. This could have indicated that there had been adsorption of P by the clay minerals in the burial sample, this was confirmed by the high P:Si ratio in the fine material (Figure 74). With only low levels of P:Fe detected, the frequency of nodules within the burial samples was low possibly as a result of persistent waterlogging, thus alternating conditions of oxidation and reduction conditions could have been rare. Conversely, the C3 control displayed a high frequency of nodules, but there was no P in this control sample to co-precipitate with the Fe.

5.3.5 Elemental composition of the dusty coatings

The following section discusses the spatial variation in the development of dusty coatings and their elemental composition. Although observed during micromorphological investigation, coatings were only analysed by SEM-EDS where they could be identified by backscatter electron imaging.

5.3.6 Micromorphological observations of dusty coatings

Table 31 displays the frequency of dusty coatings identified through micromorphological observations of the single inhumation and mass graves.

Table 31: Dusty coatings identified through micromorphological observation across the single inhumations and mass graves investigated in Chapter 3 and 4

Grave Type	Site	Layer	Grave	C2	C3	B. Skull	Skull	Inside Skull	Hand	Elbow	Pelvis	B. Sacrum	Sacrum	Knee	Foot
Single inhumations	Mechelen	*L1*	*G26*				*								
		L2	*G27*				***								
		L3	*2037*												
		L4	*384*		**	*			*						
		L4	*414*				***		***		****				
		L4	*415*		**				**						**
		L4	*422*	*		*	**		*		*		**		**
		L4	*423*				**								**
	Syningthwaite *(Layered)*		*G1*	***	***		**		***		*				
			G2	**	*		****	***	**		**				**
			G3	**	***		****						*		
	South Leith		*6B*		*					*					
Mass Graves	Ridgeway		*Site*	**	**		**				***				****
	Fromelles		*Site*	***			**								**

*B= sample collected below the sample region. Frequency levels: *= low; **= moderate; ***= high; ****=very high.*

5.3.6.1 *Differences in the location and frequency of dusty coatings*

In the Mechelen site there was a higher frequency of dusty coatings in the skull, hand and pelvis regions of the graves. The high frequency of coatings was particularly evident in

Grave 414, where the pelvis region displayed the highest frequency. The below skull region from Grave 422 and 384 both display similar low frequencies, whilst the foot region of Graves 415, 422 and 423 all exhibited moderate development (3-6%). There was an increase in the frequency of dusty coatings in the C3 control, compared to the C2. However, there was limited evidence to determine deposition patterns in the grave fill controls at the Mechelen site.

Dusty coatings were in low frequencies at the South Leith site, with only the C3 control and left elbow samples exhibiting any. This correlates with the low levels of fine material observed across the site, the left elbow sample region displaying the highest levels of fine material, whilst the C2 control directly above the C3 control also having a high level of fine material. The low level of dusty coatings identified at South Leith can, therefore, be justified by the low levels of fine material, with little material being available for their development.

The highest dusty coating frequency at the Syningthwaite site was observed in the skull region of Graves G2 and G3. The C2 and C3 grave fill controls from Grave G1, and the C3 control from Grave G3 also contained a high frequency of coatings. The lowest frequency of coatings was observed in the pelvis and foot regions of Graves G1 and G3.

The development of dusty coatings across the Syningthwaite site pointed to increased disturbance in the controls and upper limb and skulls regions of the graves. The lower leg regions and foot regions of Graves G1 and G2, respectively, however, had been disturbed by prior excavations, and the low frequency of coatings in these areas could indicate that their development had not occurred as a result of former excavation disturbance, but had occurred after the excavation activity. The similar frequency of coatings in the controls and grave samples around the skull region suggested that their development may have occurred at the same time; however, frequency is not a diagnostic tool for coatings development. Rather their morphology is a more accurate diagnostic tool, with all dusty coatings having a similar composition. The coatings of inside skull region samples, which were protected by the skull, intimates there development had occurred through internal disturbance. As such, these coatings may have been derived from localised disturbance inside the skull caused through bioturbation activity or movement through disarticulation of the skull, as disturbance through the fluctuation of water could have created laminations (Kuhn *et al.* 2010 221). This was further confirmed by the presence of a high level of excremental pedofeatures, therefore, confirming the formation factors relating to these particular coatings.

The burial samples from the Ridgeway site displayed a greater frequency of dusty coatings in comparison with the grave fill controls. The collection method of the control samples at the Ridgeway site may, however, have skewed the results of the micromorphological observations. Although fragmented the dusty coatings were observed in the grave fill controls (C2 and C3 controls) the samples, collected by the grab-soil sample method as described in Chapter 2, Section 2.3. There were, however, no non-archaeological disturbed controls collected to provide comparison samples to the 'disturbed control' samples, this may have invalidated these samples. Yet, taking these samples into account, fragmentation of the coatings could have increased the frequency of observations in the C2 and C3 control samples. The frequency is, nevertheless, related to the percentage of coatings observed within the whole thin section, so similarity to the undisturbed samples should give an accurate representation of their frequency. Observations across the burials indicated the highest frequency of dusty coatings was exhibited in the pelvis and foot regions, and pointed to a possible increase in the level of disturbance of the fine soil material in these sample regions. However, the development of morphologically similar coatings in the control samples and the burial samples suggested that they may have been deposited during the same precipitation event; nevertheless it could be argued the dusty coatings originated from the same parent material but from different events, however, the change in soil water percolation would have been recorded through lamination in the coatings. The higher frequency of coatings in the pelvis region points to a greater level of fine material being deposited in this region by the soil water. The development of dusty coatings in the upper grave fill, similar to those in the burial indicated, therefore, disturbance above the grave, and not through settling within it. Thus the coatings in the Ridgeway site could not have occurred simultaneously with the degradation of the burials and so could not be diagnostic of degradation processes and products.

In contrast, the Fromelles site displayed a moderate frequency of dusty coatings in the burial samples compared to the lower frequency exhibited in the C2 control. This indicated different levels of disturbance in the control and burial samples, unlike Ridgeway. The subsequent movement of fine material by soil water that provided the material for the development of dusty coatings in the C2 control, can be explained either by the movement of heavy machinery across the site bi-annually, , or through initial excavation activity and the deployment of mechanised digging equipment (Pollard *et al.* 2008a). In the case of the coatings in the C2 control, the most valid explanation would be the latter; with a laminated dusty coating being formed if the causal factor had been bi-annual movement of equipment across the site. The absence of dusty coatings in the C3 control could point to the development of coatings in the C2 control and burial sample being unrelated, although there is no lamination in the coatings from the C2 or burial. The coatings identified in inter-pedal channels of the burial samples were truncated by planar voids, and so indicated that they had been deposited prior to the planar void development. Two different hypotheses for the development of dusty coatings could be posed: 1) Coatings had developed during the initial settling of the grave back fill, post burial; 2) Excavation activity exposed the burial layers and then rain events had occurred allowing fine soil/sediment particles to percolate in the soil water through the burial; the planar voids occurring after sampling due to the clay soil drying out. In both hypotheses the planar voids would have occurred after the coatings were deposited, however the exact cause of the depositional event cannot be confirmed.

5.3.6.2 *Differences in dusty coatings between sites*

The Syningthwaite site exhibited laminated dusty coatings, whilst the morphology of the dusty coatings at the other sites suggested the development of these coatings had, as they occurred through singular soil water deposition events. The layering in the dusty coatings at Syningthwaite indicated their development had occurred as a result of changes in the velocity of soil water and suspended fine material through the profile (Kuhn *et al.* 2010 229). There are two reasons for this type of development of the dusty coatings: 1) deposition had taken place either during several deposition events or; 2) there was one singular action with the intensity of soil water movement through the soil profile varying. The morphology of the laminations did not vary but the colour, normally affected by the level of Fe in the fine material did (as discussed in Section 1.3.1.2), therefore, the most likely explanation being that the coatings were formed over successive deposition events as there was different level of Fe present. The frequency of coatings within sample regions was also notably greater at the Syningthwaite site, suggesting there were fewer pathways for the dispersal of soil water, when compared to sites such as the free draining South Leith and Ridgeway. The high level of clay at the Syningthwaite site being the main reason for the low porosity of the soil and the slow movement of the soil water (Dudoignon *et al.* 2007).

The frequency of dusty coatings at the Mechelen site was lower than at Syningthwaite, Ridgeway and Fromelles. The free-draining, sandy/humic soil at Mechelen did provide areas of low porosity where soil water percolation was impeded, allowing clay/silt suspended within the soil water to be deposited as slow dispersal of the soil water occurred (Kuhn *et al.* 2010 229). However, the lower layer graves at Mechelen showed an increased frequency of coatings, particularly in the skull region, similar to the distribution pattern observed at Syningthwaite and the mass graves of Fromelles and Ridgeway. However, sampling in the skull region of all the analysed graves was undertaken to a higher frequency; hence, the development of depositional patterns could be compared to a greater degree. The increase in coatings in the lower layer graves at Mechelen could be related to the increased level of organic matter within the soil, thus a lowering of the porosity or the development of the coatings could relate to the fluctuation of the localised water table and the movement and deposition of fine material. In this case, however, the lack of laminations would suggest there has only been one phase of deposition, thus ruling out the water table as a source, the most likely explanation for the development of the coatings in the lower graves, therefore being, disturbance from the upper layer excavations activity.

5.3.6.3 *Elemental analysis of the dusty coatings identified in the single inhumations*

P to Fe levels in the dusty coatings were only identified in the left elbow sample of Grave 6B at the South Leith site (

a). In contrast, there were higher levels of coatings observed at Mechelen, with the chest sample from Grave 423 having the highest P:Fe ratio whilst the skull and foot region samples of this grave also exhibiting higher levels of P:Fe. Grave 422 did display the higher levels of coating development and P:Fe but the P:Fe ratio within was highest in Grave 423..

The Syningthwaite site displays dusty coating in all graves, with the inside skull sample from Grave G2 exhibiting the highest ratio of P:Fe. It is evident Grave G3 displayed the highest ratio of P:Fe in the foot region, with all samples, except the hand region of Grave G2 and the pelvis region of Grave G1, displaying higher P:Fe in the dusty coatings than in those of the C1 site control and the C2 and C3 grave fill controls.

The development of dusty coatings at the South Leith site were localised to the left elbow region, where it has been shown that there were increased levels of fine material with a high ratio of P:Si. This suggests the development of the dusty coatings was determined by the amount of fine material in the burial sample, whilst also forming a barrier, thus causing reduced percolation allowing the deposition of dusty coatings. High levels of fine material were identified in the C2 control and several of the burial samples, with the C3 control exhibiting coatings, this could further suggest the a slowing of soil water percolation in this region, as a result of the barrier of fine material in the C2 directly above the C3, thus an accumulation and formation of dusty coatings. The lack of dusty clay coatings across the other sample regions, however, does not provide adequate evidence to conclude that there is a clear correlation between their development and the presence of increased fine material in this burial.

The ratio of P:Fe in the dusty coatings of the Mechelen site was higher in Grave 422 and 423 from the lower layers than any other graves at the site. This suggested a greater ratio of P:Fe in the fine material percolating through the soil profile from graves in the upper layers. The coatings in the chest region of Grave 423 displayed the highest ratio of P:Fe at Mechelen. However, when the levels of P:Si and P:Fe were examined in the fine material from the same sample (Figure 74) it was evident that the levels in the coatings exceeded those of the fine material. The ratio of P:Si within the coatings of the chest region from Grave 423 indicated elevated levels of P (P:Si = 0.19) compared to the fine material from the same sample region. The elemental levels within the dusty coatings of the chest region (Grave 423) implied that the fine material within the coatings had not originated from the localised area. However, it could suggest that there is preferential adsorption of P as a result of the increased level of translocated clay. The ratio of P:Fe in the foot and skull region of Grave 423 and the levels in the dusty coatings examined in Grave 422, however, suggested this material could be derived from the localised sample region.

The highest ratio of P:Fe in the dusty coatings at the Syningthwaite site occurred in the inside skull region of Grave G2. The high ratio of P:Fe corresponds to high ratio of P:Fe identified in the fine material and the redoximorphic nodules. The development of coatings inside the skull suggested that there had been internal disturbance, and this may have derived from a high level of bioturbation activity, identified through the presence of coalesced excremental pedofeatures (Chapter 3,Figure 33). Alternatively, the deposition of fine material inside the skull could have occurred as a result of the movement of the water table and localised waterlogging of the sample region, resulting in the movement of fine material in soil water. This may also apply to the inside skull region sample from Graves G1 and G2, where increased levels of P were detected in the fine material and the redoximorphic nodules and ; it is possible the material in the coatings inside the skull from Graves G1 and G2 are from the localised area. Similarly, the foot region of Grave G3 indicates a corresponding relationship between the elemental levels in the surrounding fine material and dusty coatings. It is also evident the P:Fe levels in the dusty clay coatings analysed in the burial samples were greater than in the C1 site control and C2 and C3 grave fill controls. This suggested the coatings at the Syningthwaite site may have derived from localised fine material and was, therefore, post burial developments affected by decompositional material emanating from the burial. Statistical analysis of the relationship between P and Fe in the dusty coatings further confirms that there is a relationship between elemental concentration and the 'Grave factor', whilst P concentrations are also have a significant relationship to the interaction between '*Grave*Sample Position',* with a p-value of < 0.

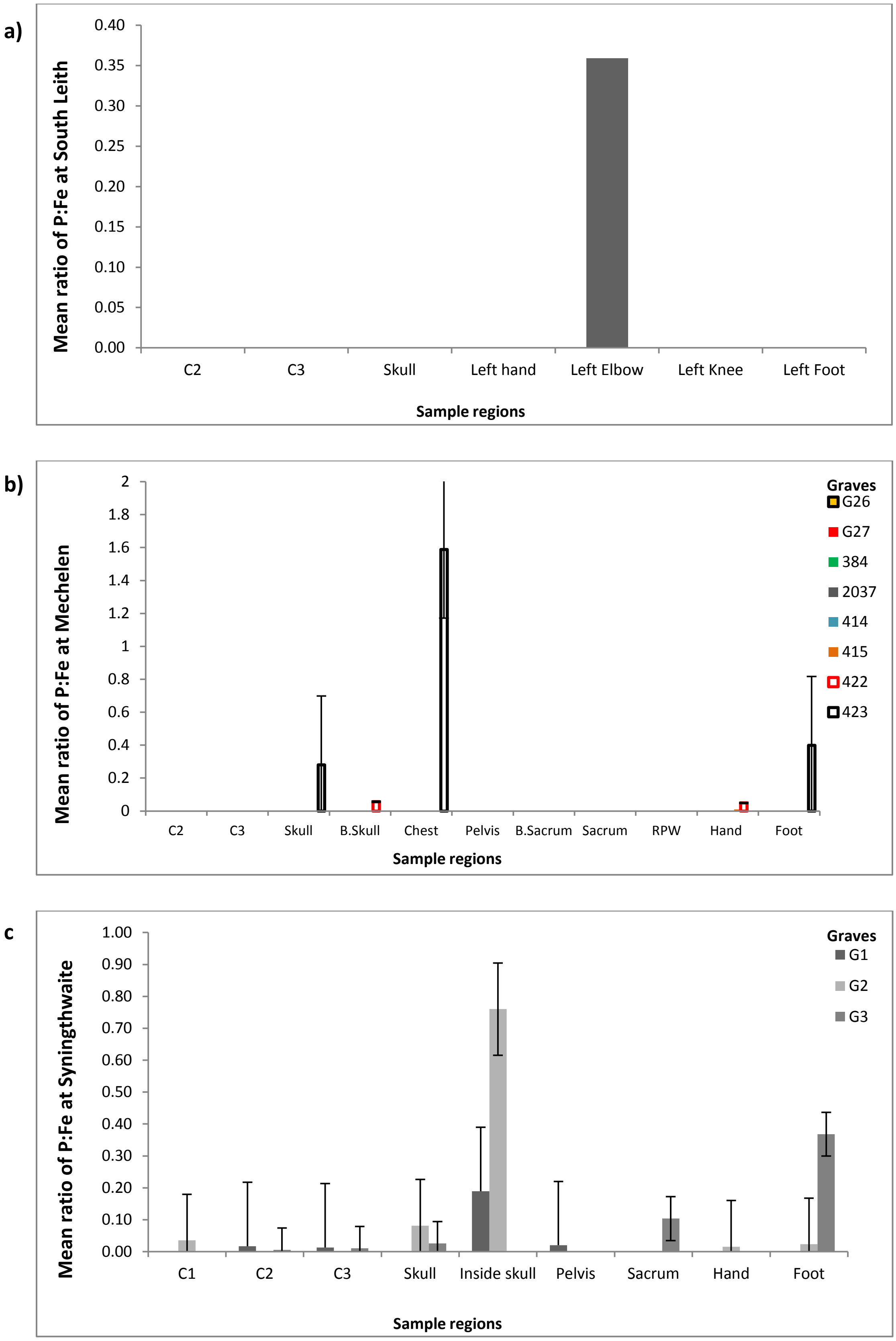
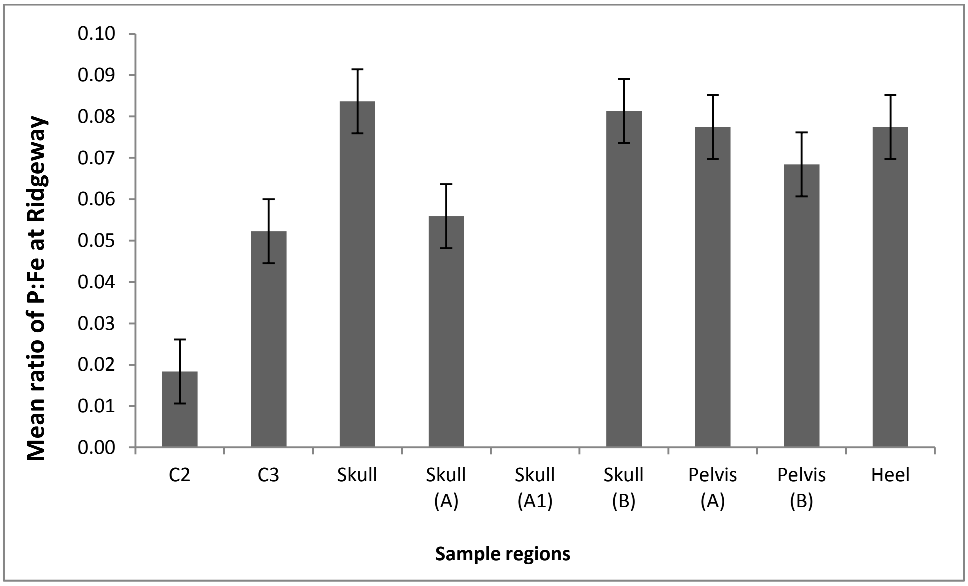


Figure 78: Mean ratio of P:Fe in the dusty coatings of the control and burial samples from the single inhumations at: a) South Leith; b) Mechelen and; c) Syningthwaite. The error bars display 1 standard error of the mean

5.3.6.4 *Elemental analysis of the dusty coatings identified in the mass graves*

Figure 79a displayed the ratios of P:Fe in the dusty coatings from the Ridgeway site, with all areas of the burial samples showing higher levels than the coatings in the C2 and C3 grave fill controls. The highest ratio of P:Fe within the burial was exhibited in the skull and skull (B) region samples, with the pelvis (A) and heel regions displaying slightly lower ratios.

a)



b)

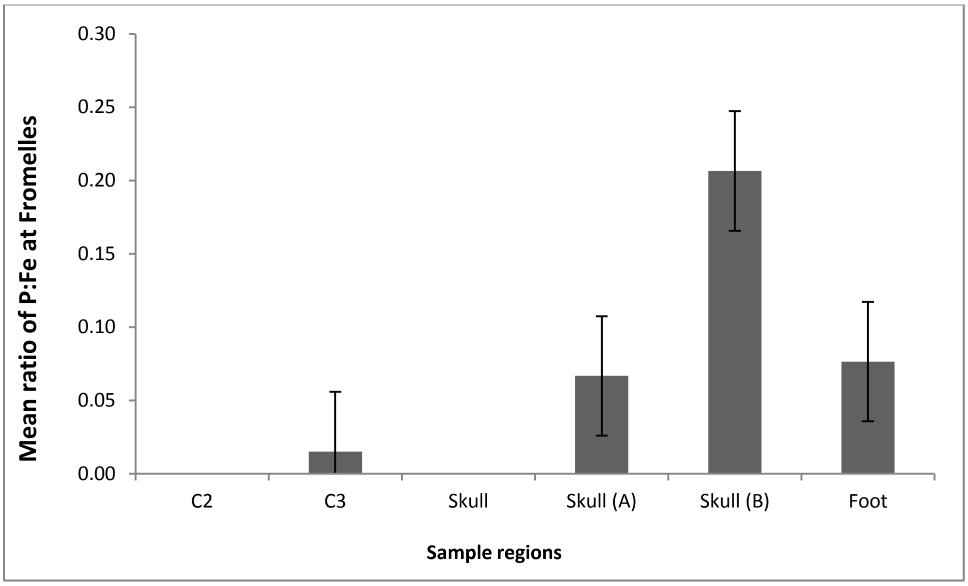


Figure 79: Mean ratio of P:Fe in the dusty coatings of the control and burial samples from the mass graves of: a) Ridgeway and b) Fromelles. The error bars display 1 standard error of the mean

The ratios of P:Fe in the dusty coatings at the Fromelles site (Figure 79b) exhibited a higher ratio in the burial samples when compared to the C3 grave fill control. The foot and skull (A) regions had similar levels to those in the skull (B) region, showing the greatest ratio of P:Fe overall.

Ratios of P:Fe in the dusty coatings in the control samples from both the Fromelles and Ridgeway mass graves are lower than the burials, this indicated that the material from the composition of the dusty coatings in the control could not have been affected by degradation products from the burial below. The fine material deposited as dusty coatings in the burial had, however, derived from the burial as exhibited in the higher levels of P:Fe, and as such the fine material composing the dusty coatings may have been affected to a greater degree by the degradation products within the grave. The ratios P:Fe in the coatings of the burial from the Ridgeway site pointed to disturbance of the fine material and the movement of soil water within the burial, whilst the lower ratios in the controls suggested their development was a result of surface disturbance and fine material percolating in soil water from within the grave fill.

5.3.6.5 *Variability of elemental ratios in the dusty coatings between sites*

Across the single inhumation and mass grave burials it is evident there is a greater level of P:Fe in the dusty coatings within the burial samples compared to that of the grave fill controls. This is particularly evident in Fromelles, Ridgeway and Syningthwaite sites, where, in the skull region, there was a higher ratio of P:Fe within the dusty coatings compared to the fine material. In comparison, the inside skull region samples from Graves G1 and G2 at Syningthwaite were anomalous to the other sample region results as there was a closed system within the skull, with little input of fine material from the surrounding environment. Thus, the dusty coatings that had developed within the inside skull region had occurred through movement of localised fine material, therefore, the P :Fe ratio in the fine material and coatings were similar. These results further indicate retention of degradation products in this sample region.

5.3.7 Comparison of micromorphological and elemental data: dusty clay coatings

The clearest pattern across all sites was exhibited by the frequency of dusty coatings in the skull regions. The Mechelen and Syningthwaite sites displayed moderate to high ratios of P:Fe in the skull thin sections. It was evident P:Fe in the dusty coatings analysed at Mechelen did not compare to the ratio of P:Fe in the localised fine material. Graves 423 and 422 from the lower layer at Mechelen were the only burials to display a higher ratio of P:Fe in the dusty coatings than in the fine material, with Grave 422 this was identified in the below skull region. This could imply that higher ratio of P:Fe in the dusty coatings from the lower layer graves (Graves 422 and 423)were from burial degradation products. The degradation fluid emanating from the burials was being translocated in soil water from the upper levels of the burials and not from the adjacent samples. The other burial samples from Syningthwaite, Fromelles, Ridgeway and South Leith were distinctly different to the upper layer Mechelen graves, with increased levels of P:Fe in the coatings, when compared to the localised fine material and control samples. The frequency of dusty coatings in the burials samples compared to the controls was greater at most sites with only Fromelle and Syningthwaite displaying an increased frequency in the burials. The development of dusty coatings, therefore, pointed to their formation being dependant on the levels of available clay and fine material in the burial. The materials from Syningthwaite and Fromelles had a high clay content and coatings contained increased ratios of P:Fe when compared to the sites with higher sand content (South Leith and Mechelen) which were characterised by low P:Fe ratios. The development of coatings in the burial and control samples from the Ridgeway site suggested that they had been formed during similar deposition events, however, the levels of P:Fe in the burial coatings suggesting that they were derived from the fine material around the burials, as they displayed higher levels of P:Fe when compared to the controls. The coatings at Ridgeway could therefore have occurred during a culmination of disturbance events, affecting both the surface control layers and burial samples, possibly through internal collapse of the burial.

5.4 Summary

The examination of the fine material within the single inhumations and mass burials across five sites (Mechelen, South Leith, Syningthwaite, Ridgeway and Fromelles) has established, through micromorphological observation and inorganic elemental analysis, that degradation products from burials were detected within the soil surrounding the internment. The soils sampled from the burials, when compared to the grave fill controls (C2 and C3), are characterised by pedogenesis and elemental composition differences which can be attributed to the deposition and retention of decomposition products derived from human burials.

Elemental patterns were identified in the fine material within and between the burials across the different sites and soil types. There were distinct patterns of increased P:Si and P:Fe ratios within the fine material of the skull and pelvis region samples from most single inhumation and mass graves. Additionally, the foot region within several graves displayed a high ratio of P:Fe; thought to have derived from burial decomposition. The elemental levels in the control and burial samples varied with consistent patterns, with the P:Si and P:Fe ratios in all control samples throughout the sites. The spatial arrangement of the fine material observed through micromorphology, however, did not provide conclusive evidence of burial decomposition as it was characterised by inconsistent patterns and variability in *b*-fabric, limpidity and *c/f* distribution throughout the site.

Micromorphological observation of redoximorphic nodules within the burials indicated greater frequencies within the skull, pelvis and foot regions of the burials. The elemental analysis confirmed that the redoximorphic nodules in several of the graves had an increased ratio of P:Fe in the skull, pelvis and foot regions. This, however, was not identified in all graves, with some burial samples exhibiting lower levels of P:Fe in the nodules when compared to the fine material, pointing to P retention to a greater degree in the fine material. There was a low frequency of redoximorphic nodule in the grave fill controls, with increased nodule development in the burial samples. This indicated that although some of the redoximorphic nodules in the burial were inherited, the increased nodule development was due to the presence of the burial. The increased development of redoximorphic nodules within the burial, furthermore, pointed to both burial ritual and decomposition products, which had provided the fluctuations in reduction and oxidation conditions.

The frequency of dusty coatings was greatly variable, with development in both the control and burial samples. Elemental analysis of the coatings confirmed that they had, in some graves, derived from material other than that immediately surrounding the burial, with P:Fe ratios higher in the coatings than the fine material local to the sample region. The morphology of the coatings in the control and burial samples exhibited the same characteristics, which indicated they had developed at similar times. The development of dusty coatings was, therefore believed to have occurred post-burial but could not be conclusively attributed to burial-derived decomposition products.

Micromorphological observation and inorganic elemental analysis provided a broad analytical tool in the collection and examination of soils from both single and mass human inhumations. The evidence presented, clearly indicated that the presence and spatial variability of pedogenic and elemental patterns from burial degradation were contained within the soil surrounding archaeological human burials and were identified visually and chemically in the fine material and through the visual and chemical development of redoximorphic nodules.

6 Findings, conclusions and recommendations

The research presented in this thesis was undertaken to investigate the effects that archaeological, specifically historical, human inhumation had on the surrounding soil. The overall aim of the thesis was aligned with the aims of the *InterArChive* project which were: to assess the nature of both archaeological and historical burial records preserved at the micro-scale within grave soils, particularly where physical organic and inorganic remains are no longer visible. This chapter will present and discuss the key research findings and recommendations for future micromorphological and inorganic element work on soils from archaeological human inhumations, the results are summarised in Table 32.

6.1 The findings of the study

The key findings of the research are presented and discussed below in relation to the objectives initially proposed in Chapter 1.

6.1.1 Identification of diagnostic features for the dispersal of degradation products

The first objective was to establish the micromorphological features that were most diagnostic for the dispersal, transportation and distribution of degradation products. It was believed that the type, location and frequency of voids were the best characteristic in the determining the disposal of decomposition products in the grave.

The most frequently observed void shapes were inter-pedal channels, identified across both the control and burial samples from the single and mass inhumations. Undifferentiated, perpendicular and parallel orientation of the voids to the ground surface, above the grave and the body, were identified in most samples. Exceptions to this were observed in the control and burial samples from Mechelen and the C3 control sample from Fromelles, where void orientation parallel to the body/ground surface suggested that compaction had occurred to the peds thus aligning the channel voids. The parallel orientation of the voids in the upper layer Mechelen graves can be explained by the presence of a car park located over the grave, therefore the foundation for compaction and the subsequent formation of parallel void orientation. Similarly, the presence of parallel void at Fromelles was the result of activity on the exposed soil surface, where the C3 control was collected, because of archaeological excavation.

Granular peds were observed in high frequencies in the skull region of several Ridgeway burials and in the inside skull regions from Syningthwaite. Granular ped development was confined to the skull samples, with no evidence of them in the controls. This suggested that increased organic matter from the burial located in the skull regions, could provide the conditions for increased bioturbation, giving rise to mechanisms supporting the formation of granular peds and complex packing voids through the separation of soil aggregates. Granular peds were predominant at the South Leith site with low levels of fine material identified in several burial samples, and the highest levels in the controls. Here, there was a distinct difference in void development between the controls and the burial samples and between the C2 and C3 controls, the former displaying infrequent inter-pedal channel voids. The sandy matrix and granular peds at the South Leith site were thought to be causal not only in the dispersal of the degradation products from the burial, but in that of the fine material, as most notably observed in the skull region.

The identification of the dispersal of degradation products was recognised in the fine material surrounding the channel voids within the burial samples, from both the Syningthwaite and Mechelen sites. Here, the SEM-EDS analysis of the fine material, adjacent to the voids and in the peds, identified increased carbon levels, deposited in the burial samples from the parallel voids of Mechelen and the randomly orientated perpendicular/parallel voids from Syningthwaite. It was evident that there were higher levels of C at Mechelen than at Syningthwaite. Increased carbon depositions in the fine material within the peds were predominantly higher than in the fine material surrounding the voids at both Syningthwaite and Mechelen. Grave G26 in the upper layer and Grave 422 in the lower layer at Mechelen displayed increased C levels in the fine material from the centre of the peds, with Grave 423 adjacent to Grave 422 displaying increased levels in the voids. The increase in carbon levels was particularly prominent in the fleshier parts of the burial, particularly in samples from around the skull and pelvis regions. Grave G26 was particularly interesting, with C levels lower in the skull region than in the foot region. The increased C in the foot region of this grave correlated with a higher observed frequency of redoximorphic nodules and an increased concentration of P in the foot region, all indicators pointing to increased organic matter from burial decay products. There was, however, no evidence to suggest that the burial was on a slope or that the grave-cut had been excavated unevenly prior to the interment. Due to the results arising from these grave, a slope towards the foot region of the burial is the most likely explanation to the increased in C and redoximorphic nodules.

The development of planar voids was particularly evident in the sites that displayed higher levels of clay content in their fine material (Syningthwaite and Fromelles). The voids were located throughout the control and burial samples from these sites, and cut through many of the inter-pedal channels and dusty coatings that had formed within the voids. This indicated that the planar voids had occurred at a later stage of pedogenesis, after the other void types and the coatings had developed. This implied that they were not part of the dispersal network, but had secondary formations within the soil. Secondary planar voids were particularly notable in the Fromelles burial samples, where only channel voids and fine material contained gypsum crystals that were thought to have developed as a secondary mineral or to have been deposited by soil water post-burial. The burial samples at Fromelles varied in the frequency of gypsum. The skull sample with lowest void space displayed no gypsum, whilst the foot region exhibited the highest levels of gypsum corresponding to the highest level of channels voids. This provided further evidence for the transportation and deposition of burial ritual products through the channel voids.

To summarise the granular ped distribution pointed to increased levels of bioturbation from the incorporation of higher organic matter concentrations, particularly in the skull regions, with the inorganic elemental analysis of the channel voids confirming an utilisation of the void structures in dispersal of burial ritual and decay products away from the burial notably, in the pelvis and foot regions. It was confirmed, however, that increased organic matter in the form of higher carbon levels could not be established to a greater degree in the burial voids of the skull region. Hence, the development of different voids types as identified through micromorphological observations can be instrumental and diagnostic of the dispersal of decomposition products within the burials, through the identification of pedogenic features, such as complex packing voids that separate granular peds, which may relate to increased organic matter.

6.1.2 Identification of pedogenic features related to increased organic matter

The second objective was to ascertain the type of pedogenic features that could be related to the pooling of organic matter derived from the burial.

Pedofeatures identified across the burial samples and specifically associated with increased levels of organic matter, were related to soil faunal activity. The initial micromorphological observations identified high frequencies of bioturbation evidence in the skull and pelvic regions of the burial samples, were excremental pedofeatures were present. This was particularly apparent in samples from the inside skull region in the Syningthwaite graves (Graves G1 and G2), where most of the fine material in the region was typically derived from coalesced and partially degraded excremental pedofeatures. There was little evidence of macro- and meso-faunal activity in the form of excremental pedofeatures in the grave fill controls or the C1 site controls collected. The only burial samples that exhibited a low frequency of excremental pedofeatures were from Fromelles where continuous waterlogging and anoxic conditions within the burial samples were not conducive to soil faunal activity, although organic matter could have been present.

Root penetration was also observed in most graves with the only exception at the Fromelles site where, as previously stated, the high level of waterlogging could have prevented bioturbation. The identification of root penetration in the samples was particularly notable in the skull and pelvis regions. It was, therefore, evident that bioturbation through root penetration and soil fauna was particularly frequent in regions of the burial corresponding to body parts with higher relative amounts of flesh such as the skull and pelvis regions, with a higher frequency in several foot regions where increased nodules were present.

6.1.3 Spatial and causal relationship of depositional features

The third objective was to establish the presence of features related to increased organic matter from the pooling of burial decay material.

Depositional features such as redoximorphic nodules and dusty coatings were observed and their frequency and spatial distribution identified.

The redoximorphic nodules exhibited similar distribution patterns to the excremental pedofeatures, with a higher frequency of in the skull and pelvis regions, with several graves having an increase in the foot region, when compared to the control samples. The nodules were identified in areas were the deposition of decomposition products was expected to increase as a result of human physiological structure. Thus, it was supposed that the nodules were related to the pooling of putrification fluids, providing reduction and oxidation conditions together with increased levels of organic matter. The pooling of decomposition liquids between the body and the soil, within the fine material, could have caused periods of waterlogging, during fluxes of decay, providing the optimum environment for nodule development and deposition of minerals from decay products, through co-precipitation of P. The frequency of nodules in the control samples was lower than the burial samples, with only the C3 control from Fromelles having comparable levels to the burials. Although, not as a consequence of decay fluids but as a result of reduction and oxidation conditions derived from fluctuation in water levels, between the C3 and burial layers, in the highly clay soil from the site.

In contrast, no specific difference was observed in the spatial distribution of the dusty coatings between the burial and control samples, specifically in the Mechelen graves. The age of the graves, location within the site and, position in the stratigraphic layers did not correlate with differences in the spatial development of the coatings between or within graves. The frequency of dusty coatings exhibited a correlation to the levels of clay within the fine material. The Syningthwaite and Fromelles sites both had a high level of clay within the fine material and displayed a higher frequency of coatings in both the control and the burial samples, indicating a greater movement down the stratigraphy within soil water.

Control samples collected by the soil-grab method from the Ridgeway site did provide evidence to indicate that the coatings across the grave had similar morphology. Although the control samples had been processed and homogenised, the morphology of the coatings in the grave fill controls (C2 and C3) were similar to that of the burials. This suggested that the coatings may have developed at the same time and during similar soil water percolation events, whilst the visual composition of the material deposited in the coatings was also comparable.

6.1.4 Inorganic elemental analysis of the depositional features and fine material

The fourth objective was to identify spatial patterns and trends in the inorganic elemental concentrations of the fine material and depositional features to identify areas were burial decay could still be detected in the surrounding soil. SEM-EDS analysis of the depositional features and fine material in the control and burial sample specifically focused on phosphorus derived from human decomposing products.

Analysis of the fine material of the burial, when compared to the control samples, confirmed the initial hypotheses that soil surrounding the burial would contain increased levels of burial decay products. Increased concentrations of P were identified predominantly in skull and pelvis regions of the burial, with several graves also displaying increased concentrations of P in the foot region. The increased frequency in the pattern of redoximorphic nodules development in the samples regions of the skull and pelvis is supported by the increased elemental concentrations in the fine material within the skull and pelvis regions. Similarly, the patterns identified in the single inhumations were also exhibited in the fine material of the skull and pelvis regions in the mass graves. Lower P concentrations were identified in most grave fill controls; the exception was Syningthwaite, where the application of agricultural amendments to the soil may have occurred as a result of the site location adjacent to the priory buildings. The most discernible difference at the sites, between the fine material in the grave and that in the grave fill controls, was the incorporation of human remains, thus pointing to this being the causal factor in the increases in P concentration.

It was expected that the increased elemental levels identified in the fine material would also be detected in the dusty coatings. This formed the hypothesis that there would have been an association between the elemental composition of the dusty coatings and the fine material local to the sample region within the grave. However, based on the results of the SEM-EDS analysis it was evident that there was no similarity between the ratio of P:Fe in the fine material and the dusty coatings within the same burial sample. This was not the case for all graves, as the lower level graves at the Mechelen site displayed increased ratios of P:Fe in the dusty coatings. The increase of P:Fe in the dusty coatings could have occurred through the accumulation of fine material deposited from the graves in the mid and upper layers. The ratio of P:Fe in the coatings from the burial samples were, in many of the graves, lower than in the controls. Thus, analysis of the dusty coatings suggested their formation may have occurred through the deposition of fine material derived from different areas, not affected by the decomposition of human burial. The difference in the P:Fe ratio between the fine material and the coatings, in the lower layer graves at Mechelen could be related to adsorption of P after deposition, affecting the elemental composition, and not through decompositional products from burials.

Increased frequencies, observed in the burial samples, suggested the development of redoximorphic nodules was correlated to the presence of material derived from burial decomposition. This was not entirely supported by the results of the inorganic elemental analysis. Although increased P:Fe could be identified in the nodules of the skull, pelvis and foot regions of the burials, that corresponded to the increased frequency, several burial samples from the Mechelen and Syningthwaite sites displayed little difference in elemental composition between the burial and control samples.

The increased frequency of nodules within the burials samples indicated there had been fluctuating reduction and oxidation conditions, whilst P was not present. P was, however, identified in the fine material within the same samples, indicating only limited P was available for co-precipitation into the nodules as the majority had been retained in the fine material possibly through adsorption by clay minerals and Fe/Al oxides. Furthermore, this implies the frequency and spatial distribution of the redoximorphic nodules were diagnostic of burial remains, and point to the fluctuation in redox conditions present in the burial samples. These conditions were attributed to the pooling of decay products that were prevented from draining away from the body because of the barrier created by the coffin and body in the grave.

6.1.5 Hypothesis testing using statistical analysis

The fifth objective was to test the hypothesis that the levels of P and Fe in the fine material, redoximorphic nodules and dusty coatings exhibited a relationship to the grave and the position of the sample collected. Two-way ANOVA was used to test relationships between the different sampling positions and graves and the concentration of elements associated with the decomposition of a human burial. The skull sample had been collected at most sites, but the collection of pelvis, hand, foot and control samples varied according to the burial position and availability of soil surrounding the burial. Therefore the data were assigned to four sample regions (Chapter 2,Figure 9) to allow statistical analysis.

Statistical analysis demonstrated there was a relationship between sampling position and the concentration of P and Fe in the fine material. This reaffirmed the depositional trends in P:Fe and P:Si ratios, recognised in the skull and pelvis and to a certain extent the foot region within the graves. There was no significant relationship between Fe concentrations in the fine material and sampling position. This further supported that the levels of P in the fine materials were not determined by the position of the burial sample, but rather by the levels of Fe. Similarly, there was a significant relationship between the levels of P and Fe in redoximorphic nodules, and the grave, sampling position and interaction between the two factors. In contrast, there was no significant relationship between the levels of P and Fe in the coatings and sample position. The statistics did confirm there was a relationship between the grave and levels of P and Fe in the dusty coatings as identified in the results obtained from the Mechelen graves.

6.1.6 Identification of archaeological artefacts using micromorphology

The final objective was to show how artefacts within the burials that could no longer be identified by the naked eye or standard archaeological techniques could be identified with micromorphology.

The discovery of burial artefacts was possible for the Mechelen and Fromelles sites, where the application of micromorphological observation and elemental analysis provided evidence of funerary processes.

The discovery of pseudomorphic textile fragments in the undisturbed samples collected below the skull in Grave 414 at Mechelen indicated that a fabric had been placed under the skull. Hence, either the body had not been laid in an empty coffin (but one with textiles) or it could have been shrouded.

Textile fragments were also identified in the foot region from the Fromelles site, were elemental analysis and micromorphological observation suggested the textile to be wool.

The identification of a white substance surrounding and interspersed with the burials at the Fromelles site was carried out by the combination of micromorphology and SEM-EDS analysis. Initial inspection by the naked eye had suggested to the archaeological excavation team that the substance was quicklime. They team had no documentary evidence that suggested quick lime had been added to the graves. Micromorphological identification of gypsum crystals within the soil matrix, however, provided evidence that much of the powdery substance was actually gypsum. Whilst recognising that pedogenic processes affecting the quicklime within the soil may have produced secondary minerals in the form of gypsum. It is also possible that gypsum itself was actually incorporated into the soil.

Evidence from the single inhumation and mass burial sites provided a wide-ranging set of data through micromorphological observation and inorganic elemental analysis. The information indicated that there was spatial variability and recurring elemental patterns identified in the graves. The evidence also indicated the spatial patterns related to the interaction between inhumation-derived decompositional material and pedogenic processes (Table 32).

Table 32: Summary table of the inferences from the micromorphological and elemental research of burial decay products

	Redoximorphic nodules	Dusty coating	Fine material
Location in the burial	Controls and the burial samples (orthic: formed *in situ,* not translocated from another soil fabric type*).*	C2 and C3 grave fill controls and the burial samples collected adjacent to and below the remains. Deposited in voids and coarse material.	Throughout the control and burial samples, locate between the coarse material fractions.
Highest concentration of features	Skull, pelvis and foot region of the burial.	Identified in disturbed/undisturbed control and undisturbed burial samples.	Concentration of fine material is dependent on the soil type; sandy soils display lower levels that a clay or loam soil.
Observed Micromorph characteristic	Typic: generally rounded in shape and red/purple/black in PPL and black/red in XPL Aggregate concretions that have developed around and contain in situ coarse material, they display similar colours to typic in PPL/XPL.	Typic: visually similar composition throughout the coatings made of clays and silts Laminated: differences in composition and/or colour and deposited in layers.	**Limpidity (PPL)** Cloudy: opaque appearance. Dotted: contains dark dots >50µm. Limpid: transparent. ***b*-fabric (XPL)** Speckled *b*-fabric: randomly arranged clay domains. Poro- and grano-striations: clay domains aligned around voids (poro-) and coarse material (grano-) through shrinking and swelling activity.
Typical elemental properties detected	P:Fe ratios where elevated in some of the nodules analysed but this was not observed in all regions of increased frequency.	The elemental properties were variable with many control samples exhibiting higher levels of P than the coatings.	Increased levels of phosphorus in the fine material when compared to the control samples. Increased P:Fe and P:Si ratios were also detectable in the burials when compared to the controls.
Source of development	Redoximorphic nodules are concretions of translocated Fe and/or Mn that are associated with reduction and oxidation processes through wetting and subsequent drying of the soil (Lindbo *et al.* 2010 129). Increased levels of redoximorphic nodules in the areas of the skull, pelvis and feet suggest putrification fluids derived from decomposition of the burial had provided redox conditions for their development and so an increase in the levels of *diagnostic* nodules.	Development of dusty coatings is through the deposition of silts/ clays through the percolation of soil water through the soil profile. The silts/clays having provenance from disturbance or rain splash occurring on the surface of the soil. Lamination may occur during either a series of percolations events or through varying flows of soil water through the soil profile (Kuhn *et al.* 2010 220).	The fine material is ultimately the component that most reflects pedogenic processes occurring within the soil (Bullock *et al.* 1985 50) and is derived through the chemical and physical weathering of parent material and inputs from the surrounding environment.
Implication of the results	The level of redoximorphic nodules observed, when compared to the controls through micromorphological analysis, can be an initial indicator for determining the presence of burial remains in a grave cut. This provided provisional data that can be substantiated by elemental analysis of the fine material	Dusty coatings although present in many of the burial and controls samples could not be linked to decay products through micromorphological observation of element analysis. They could be indicators of disturbance but could only be timed to some point after burial	The fine material can retain decay products in the form of inorganic phosphorus. The highest levels being retained in the skull, pelvis regions, thus determining the utilisation of a grave cut for a body indicating and further to this the possible orientation of the body.
Are the features diagnostic of burial decay?	✓	X	✓

6.2 Evaluation of the investigation and future recommendations

It is believed that the *InterArChive* protocol in its present form has provided a systematic and comprehensive set of data from single and mass inhumations at South Leith, Mechelen, Syningthwaite, Ridgeway and Fromelles and has enabled pedogenic patterns related to human burial decomposition to be identified.

6.2.1 Evaluation of the sampling strategy and future recommendations

The results obtained indicated the need for amendments to the sampling protocol. It is suggested that a reasonable approach could be to attain greater differentiation between burial and control samples through the identification of pedogenic processes continuing in the surrounding undisturbed soil and, where possible, investigating in greater detail the faces/slide of grave cuts. This could be achieved in the field by increasing the number of control samples, and would allow a more secure identification, interpretation and comparisons to be drawn between the grave fill and soil adjacent to the body, minimising problems of anomalous results. Furthermore, the advised protocol for the sampling of burials must be flexible, as the position of the burial within the grave often determines the location and number of samples collected. This is particularly relevant to the collection of samples at mass grave sites. It is necessary, if a sampling location cannot be obtained, to sample as closed to the body part as possible, thus providing a greater complement of samples. Similarly, if undisturbed control samples cannot be collected, then soil-grab samples can be obtained in order to provide a greater level of verification to soil development.

The most significant results were achieved in the areas of the skull, pelvis and foot where considerable levels of bioturbation had been identified, with excremental pedofeatures and root penetration concentrated in these regions. This can furthermore be highlighted by the analysis of inorganic elements within the fine material and redoximorphic nodules from these regions, providing information regarding degradation fluids and the method of release into the burial soil. Further benefit may be obtained from additional systematic sampling of all the soil below the burial plane. However, it is important to be aware that the relevance of the observations in the pelvis, skull and foot areas has been brought to light particularly through comparison with other grave samples collected near the other body parts.

6.2.2 Evaluation of the analysis and recommendations

The application of both micromorphological observation and inorganic elemental analysis has provided a comprehensive data set. Micromorphological investigation of the undisturbed soil thin section presented a broad record of pedogenic features that proved to be diagnostic of the soil type and interaction between the degradation products from the burial and soil development. The development of peds within the graves confirmed the different environmental stresses that were occurring in the soil, whilst the location and type of depositional features also pointed to interactions between the soil, burial decay products and internal/external disturbance activity.

Complimentary inorganic elemental analysis was undertaken based on the information gained by micromorphological analysis and the initial identification of pedogenic features. The analysis provided further verification to the micromorphology, confirming differences in mineral composition and providing clear evidence of spatial variability within the graves, whilst confirming the retention of burial degradation products. It is recommended that further analysis of spatial variability is undertaken in order to identify the patterns of carbon (organic matter) retention within the fine material. This information has already produced information regarding the difference in carbon levels surrounding the voids and in the peds; additional information, however, regarding variations in levels across the different void types and fine material composition may help to give a clearer indication of organic matter movement.

6.2.3 Future application of the techniques

To further develop the techniques employed in the research it would first be necessary to refer back to the sampling. Systematic sampling below the plane of the body, once this has been removed, would provide evidence that the micromorphological and inorganic elemental analysis techniques can identify with certainty, the results determining whether a burial had been present within a grave cut. This would validate that the techniques and could provide substantive evidence to archaeological investigation when no visible artefacts can be seen by the naked eye.

The most significant applications of the sampling and analytical techniques undertaken in this research would be to utilise them in all archaeological and forensic burial excavations. Not only would the methods provide further evidence of a burial, within a forensic inquiries, decomposing in situ, the analysis may provide micro-artefacts that could be used to substantiate investigative evidence. Further to this, the application of the methods within an archaeological context could provide an indication of burial practice that may not have been identified through conventional excavation methods.

Ultimately this research has looked to past analytical developments and has been able to apply them to contemporary objectives in order to unlock the microscopic information that has survived in historical grave soils.

7 Appendices

Appendix 1: Micromorphological sampling protocols
This is the basic protocol developed and adopted by the InterArChive project in the observation of soils from human inhumations.

Slide Number: this is the unique number given to each thin section

Position: The region of the body, grave fill or excavation site that the sample has been taken from.

Coarse and fine material

Slide Area: Different areas within the slide that have different coarse/fine distribution patterns, numbered so that differences can be seen within and between slides.

Limpidity: This refers to the fine material under PPL and the transparency of the material, the properties correspond to that of Stoops(2003b) 2003 with 2 extra categories added from Usai (1996) recording protocols. This can also be a good indicator of fine material development.

- Limpid
- Speckled
- Dotted
- Cloudy
- Opaque
- Masked

% Fine Material: The percentage of the fine material seen within the whole slide.

Colour @30µm (PPL): The colour of the fine material in plain transmitted light as the average thickness of the thin section is 30µm.

Colour @30µm (XPL): The colour of the thin section as a whole in XPL

b-Fabric: The birefringence of the fine material can also be an indicator of the fine material development and describes the patterns and orientations of the fine material as seen through interferences colours in XPL. The descriptions come from Stoops (2003b):

- Speckled
- Striated
- Strial
- Crystallitic
- Undifferentiated

% Coarse Material: The percentage of coarse material throughout the whole thin section.

Coarse material: Minerals, Coarse Organic Matter and Rocks have the same criteria of observation and recording as suggested by both Bullock *et al* (1985) and Stoops (2003b).

- Colour in PPL
- Colour in XPL
- Weathering
- Shape
- Frequency (of the whole slide (Bullock *et al.* 1985 24/25; Stoops 2003b 48)).
- Size Range (*all measurements undertaken were in µm*):
    - <50
    - 50-100
    - 100-200
    - 200-500
    - 500-1000
    - 1000-2000
    - >2000

c/f –Related Distribution Pattern: Individual fabric unit (coarse/fine) arrangement in relation to others as per Stoops (2003b 43):

- Enaulic
- Gefuric
- Porphyric
- Monic
- Chitonic

Elements of Fabric: As per Stoops (2003b 38)with relation to the orientation and distribution patterns of the basic fabric units to coarse material and each other.

% of the Slide: This looks at the percentage area of the thin section and breaks it down into differences.

Peds

Different types:

- Apedal
- Granular
- Crumb
- Angular-Blocky (A-B)
- Sub-Angular Blocky (SA-B)
- Platy
- Lenticular Platy

Ped Size:

Ped size (μm) table as adapted from Bullock et al (Bullock et al. 1985 42).

Size	*Crumb*	*Granular*	*Sub-Angular Blocky*	*Angular Blocky*	*Platy*	*Prismatic*
Ultra Fine	<50	<50	<100	<100	<50	N/A
Very Fine	50-1000	50-1000	1000-50000	1000-50000	50-1000	<10000
Fine	1000-2000	1000-2000	50000-10000	50000-10000	1000-2000	10000-20000
Medium	2000-5000	2000-5000	10000-20000	10000-20000	2000-5000	20000-50000
Coarse	5000-10000	5000-10000	20000-50000	20000-50000	5000-10000	50000-100000
Very Coarse	10000-20000	10000-20000	>50000	>50000	>100000	>100000

Distribution and Orientation: Both referred and basic with regards to the peds in relation to both the ground level (normally know) and the body (sometimes known).

Abundance: Amount seen within the whole thin section.

- 02-2%
- 2-5%
- 5-10%
- 10-20%
- 20-30% ….

Development:

- Weak
- Moderate
- Strong
-

Voids

Accommodation:

- Not
- Partially Accommodated (Pt Accom)
- Accommodated (Accom)

Void Type: (Stoops 2003b 64)

- Packing Voids
- Vesicles
- Channels
- Chambers
- Vughs
- Planes
- Cracks

Abundance: Within the whole thin section

- <2%
- 2-5%
- 5-10%
- 10-20%
- 20-30%
- 30-50%
- >50%

Void Size: (µm)

- <50
- 50-100

Increments of 100 to a maximum of >2000

Distribution and Orientation: Both referred and basic with regards to the peds in relation to both the ground level (normally know) and the body (sometimes known).

Sorting: As per page27 of Bullock *et al* (1985 27) and is an term for the spread of coarse particles in the slide.

- Unsorted
- Poorly
- Moderately
- Well
- Perfectly

Pedofeatures

Type of pedofeature: as per the Stoops descriptions in chapter 8 (Stoops 2003b 101).

Pedofeature Size: this is the actual size of the pedofeature, measure in µm.

Location: This is either in the matrix or the voids and can give an indication of the void formation processes and also the pedofeature formation processes.

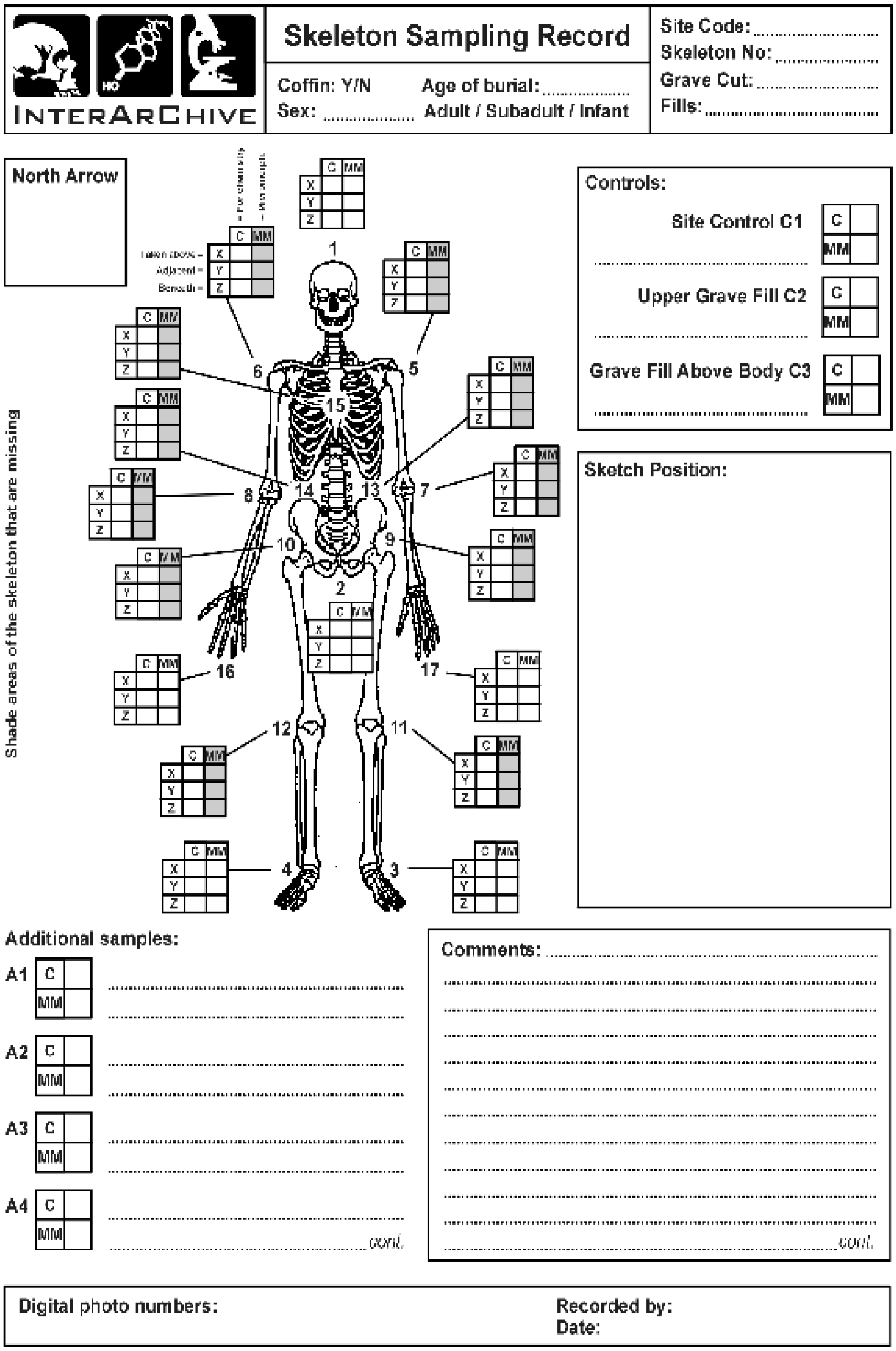
Distribution and Orientation: Both referred and basic with regards to the peds in relation to both the ground level (normally know) and the body (sometimes known).

Abundance: This is within the whole slide

- <2%
- 2-5%
- 5-10%
- 10-20%
- 20-30%
- 30-50%
- >50%

Colour: Under both PPL and XPL light sources.

Appendix 2: A sampling sheet utilised during field recording



InterArChive

Skeleton Sampling Record

Coffin: Y/N Age of burial: ....
Sex: .... Adult / Subadult / Infant

Site Code: ....
Skeleton No: ....
Grave Cut: ....
Fills: ....

North Arrow

= For chemistry
= Microscopic

Taken above =
Adjacent =
Beneath =

	C	MM
X		
Y		
Z		

Controls:

Site Control C1 .... C / MM

Upper Grave Fill C2 .... C / MM

Grave Fill Above Body C3 .... C / MM

Sketch Position:

Additional samples:

A1 C / MM ....
A2 C / MM ....
A3 C / MM ....
A4 C / MM .... cont.

Comments: ....
.... cont.

Digital photo numbers:

Recorded by:
Date:

Appendix 3: Micromorphological summary tables of the single inhumation and mass grave sites (South Leith, Mechelen, Syningthwaite, Ridgeway and Fromelles)

South Leith

Grave Date	*Sampling Region*	*Coarse Fraction*		*Micromorphological Summary*
		Mineral (Mean% frequency)	*Organic (Mean % frequency)*	
6B	C2 C3 Skull Left Elbow Left hand Left Knee Left Foot	Quartz (40%) Basalt (5%)	Wood (2%) Charcoal (20%)	Homogenous sorting within the control and grave samples; monic distribution. Dominant partially weathered quartz (50-500 µm) with subordinate basalt in most samples. Predominantly dotted limpidity, cloudy in the left elbow, left hand d left foot. Skull sample has limpid appearance, and undifferentiated *b*-fabric similar to left hand, left elbow and C3 control. Speckled *b*-fabric in all other samples Micro-charcoal in all regions but with higher frequency in the left hand region. Ferruginised wood-like material identified in left hand and left foot samples. Granular peds separated by packing voids. Intra-pedal vughs only in the left hand and C2 control

Mechelen

Grave Layer(L) Date	*Sampling Region*	*Coarse Fraction*		*Micromorphological Summary*
		Mineral (Mean% frequency)	*Organic (Mean % frequency)*	
G26 c.17-18th C L1(U)	Skull Pelvis Foot C1 Control	Quartz (40%) Glauconite (5%) Calcite (2%)	Root (2%) Bone (5%: foot 20%) Wood (5%) Charcoal (2%)	Enaulic/chitonic related distribution, 30:70 *c/f* the foot region being the exception with 70:20 *c/f* due to high level of bone. Coarse fraction is predominantly sub-angular, weathered quartz (50-500 µm), weathered, and rounded glauconite throughout the grave. Calcite >2000µm observed only in the site control. Speckled limpidity and *b*-fabric with a yellow/orange/brown colour (PPL) High levels of rubified clay throughout the grave. Ferruginised root only in the pelvic region with micro-charcoal and degraded bone throughout, wood-like material also in grave samples. Linear orientated, sub-angular compressed blocky peds (platy) in all regions (c. 20-30%) except in the pelvis and part of the control which were apedal. Inter-pedal partially accommodated parallel orientated channels in most regions.
G27 c.17th C L2 (U)	Skull RPW *(Right Pelvic Wing)* Feet	Quartz (40%) Glauconite (5%) Calcite (5%) Sandstone (5%)	Root (10%) Bone (5%) Charcoal (2%)	Enaulic/chitonic related distribution, with sub-angular weathered quartz in all regions. Sandstone only observed in the foot region (c.1300 µm), with calcite only in the skull (>2000 µm). Speckled limpidity and *b*-fabric with a yellow/orange/brown colour (PPL) Rubified clay and ferruginised roots in all samples, with RPW having ≥20% frequency. Wood-like organic matter in the foot region (>2000 µm). Platy peds in all regions, with inter-pedal channels, displaying parallel alignment to the body/ground level.
2037 c.14-15th C L3 (M)	Skull Sacrum Left Foot Feet	Quartz (50%) Glauconite (10%) Sandstone (2%)	Root (5%) Bone (5%) Wood (2%) Charcoal (2%)	Similar distribution to Graves G26 & G27, with 60:80 *c/f* ratio and a poor to moderate sorting Sub-angular weathered quartz in all regions, with weathered, rounded Fe-stained glauconite Orange/brown/black colour to the fine material with dotted limpidity, cloudy in the left foot. Slightly speckled *b*-fabric. Sub-angular peds throughout the grave with granular peds in the C3 control Inter-pedal channels and intra-pedal vughs throughout the grave, with packing voids only in part of the skull region.
384 c.13-14th C	C3 Skull Below Skull Below	Quartz (40%) Glauconite (10%) Calcite (5%)	Root (5%) Bone (5%) Shell (2%) Wood (10%)	Sub-angular weathered quartz in all regions (50-1000 µm), with weathered, rounded Fe-stained glauconite Calcite in C3 control, below chest and feet region, with rubified clay in all thin sections. Dotted limpidity throughout, with brown/yellow/black

L4 (L)	Chest Right Hand Left Foot		Charcoal (5%)	colour (PPL) and speckled *b*-fabric, striations in right hand and left foot. Roots not observed in C2 control and feet* region. Micro-charcoal and charcoal seen in all slides (50-2000 µm), bone displayed in all but the left foot** region. Planes in C2 control, with intra-pedal vughs and packing voids in the Skull region. The skull also displaying platy peds. Shell and large fractions of charcoal Below Skull, with micro-charcoal in all sample regions, with bone and root also present throughout.
422 c.12th- 14th C L4 (L)	C2 C3 Below Skull Skull Sacrum Left Hand Right hand Below Feet	Quartz (40%) Glauconite (20%) Calcite (5%)	Root (5%) Bone (10%) Shell (2%) Wood (2%) Charcoal (2%)	Gefuric/chitonic related distribution, poorly sorted Sub-angular weathered quartz in all regions, the pelvis region (50-500 µm), with rounded, weathered glauconite in all samples. Sandstone (skull), calcite (feet) and rubified clay also present. C2 control displaying mollusc shell and amorphous organic matter, displaying humic staining, also observed in the left foot, pelvis and skull regions. Dotted limpidity in the fine material and an orange/brown/black colour (PPL) across control and burial samples, with a speckled *b*-fabric Micro-charcoal (≤50-300 µm), and wood (c.700 µm) found in small fractions; High frequency of degraded bone. Apedality observed in the pelvis, C2/C3 controls
414 c.12th- 13th C L4 (L)	C2 Below Skull Skull Pelvis Right Hand	Quartz (40%) Glauconite (10%) Calcite (5%)	Root (5%) Bone (5%) Shell (5%) Charcoal (5%)	Sub-angular blocky peds, with platy peds below the skull separated by inter-pedal channels Enaulic/ Gefuric, poorly sorted *c/f* distribution Sub-angular weathered quartz in all regions, with weathered, rounded Fe-stained glauconite Large singular calcite fraction in the C2 control (>2000 µm). Predominantly brown/black colour and dotted limpidity, right hand cloudy and masqued, with cloudy appearance below the skull and pelvis samples. Speckled *b*-fabric in all samples with striations below skull. Shell fragments only observed in the pelvic region, with fragmented bone throughout the sampling regions. Ferruginised root in the pelvic and right hand regions. Apedality in the C2 and below skull, sub-angular peds in all other samples, pelvic and right hand regions indicating compaction (platy peds)
415	C3 Skull Right Hand Left Foot	Quartz (40%) Glauconite (10%) Calcite (5%) Chert (5%)	Charcoal Bone Wood Shell Root	Chitonic/enaulic related distribution pattern and moderately sorted *c/f* distribution. Sub-angular weathered quartz, calcite and chert identified across most samples. Dotted limpidity in al samples with cloudy appearance in the right hand, brown/yellow/black colour in the right hand speckled *b*-fabric, striations in the right hand.

				Shell in the right hand and left foot samples, with charcoal, wood and rubified clay also identified in the 3 controls and burial. Sub-angular blocky peds (Medium/coarse) separated by inter-pedal channels and packing voids.
423	C3 Skull Below Chest Below Pelvis Feet	Quartz (40%) Glauconite (10%) Calcite (5%) Chert (5%) Microcline (2%) Vivienite (20%)	Charcoal (10%) Bone (10%) Shell (5%) Root (5%)	Enaulic related distribution across the grave with a moderate degree of *c/f* sorting. Weathered sub-angular quartz, calcite and rounded glauconite in all samples with high frequency of vivienite (Below pelvis). Dotted limpidity in all samples with a brown/yellow/black colour and speckled *b*-fabric Below chest had a high frequency of bone, with shell fragments in the feet and C3 control samples. Micro-charcoal throughout the control and burials samples. Sub-angular blocky ped separated by inter-pedal channels in all samples, except below pelvis that displaying only granular peds separated by packing voids.

Syningthwaite

Grave Date	*Sampling Region*	*Coarse Fraction*		*Micromorphological Summary*
		Mineral (Mean % frequency)	*Organic (Mean % frequency)*	
G1	C2 C3 Skull Skull Content Over Pelvis RPW Right Hand Pelvis	Quartz (50%) Calcite (20%) Chert (5%) Sandstone (10%) Cements (5%)	Bone (5%) Shell (2%) Charcoal (5%) Root (2%)	Enaulic related distribution in all regions, with a 3:2 *c/f* distribution Quartz (*c*.40%) with rounded sandstone (>2000 µm), cements and chert (50-400 µm) in all in all burial and control samples. Calcite in the right hand and pelvis region. Orange/brown/yellow fine material with dotted limpidity and speckled *b*-fabric, striations in the C3 control, skull, pelvis and inside skull samples Ferruginised root fragments in right hand, pelvis and C2 control samples, micro-charcoal (<50µm) and charcoal seen throughout. Sub-angular blocky peds in all samples; apedality in the skull region. Inter-pedal channels and intra-pedal vughs, with intersecting planes in both pelvic region samples (2nd generation development)
G2	C2 C3 Skull Skull Content Right Hand Pelvis Heel Feet	Quartz (40%) Vivienite (2%)	Bone (2%) Root (2%) Charcoal (2%)	Poorly sorted *c/f* distribution; right hand and skull region had moderate to well sorted coarse material. Enaulic related distribution with 2:3*c/f* distributions. Sub-angular weathered quartz (50-500 µm); vivienite only in C2 control. Shell in the C3 control; fragmented bone in all samples except the skull and inner skull. Fie material had a dotted limpidity, with cloudy in the inside skull, pelvis and right hand samples, orange/brown colour (PPL) and speckled/striated *b*-fabric. The right hand high frequency of micro-charcoal; larger fragments of charcoal throughout the grave (50->2000 µm). Weakly developed sub-angular peds in all regions; apedality in skull and heel. Inter-pedal voids are none accommodated with intersecting planar voids.
G3	C2 C3 Skull Sacrum Foot	Quartz (50%) Chert (5%) Calcite (5%)	Root (2%) Charcoal (5%) Bone (2%) Shell (5%)	Enaulic related distribution in all regions; 3:2 *c/f* distribution Partially weathered sub-angular quartz and chert in all samples; calcite in C2 control and foot region. Sandstone in all samples except the foot region. Shell in the skull and C2 control; fragmented bone (50-2000 µm) in all regions. Fine material displayed a dotted limpidity in all samples, with speckled/striated *b*-fabric, orange/brown/yellow colour (PPL). Sub-angular blocky peds identified throughout the sample with inter-pedal and intra-pedal channels. 2nd generation planes dissected channel voids in the skull and C3 samples.

Ridgeway

Skeleton No:	*Sampling Region*	*Coarse Fraction*		*Micromorphological Summary*
		Mineral (Mean % frequency)	*Organic (Mean % frequency)*	
	C2 C3	Quartz (20%)	Bone (2%) Shell (5%)	Enaulic related distribution in all regions, with a 2:3 *c/f* distribution with speckled *b*-fabric and dotted limpidity
SK3738	Skull	Calcite (10%)	Charcoal (2%)	Quartz (*c*.20%) partially weathered in control and burial samples
		Flint (5%)	Root (2%)	Calcite and flint in all samples, with poor to moderate sorting of coarse material
SK3751	Skull (A) Skull (A1) Skull (B)			Root fragments in pelvis (B) and skull (A), shell throughout burial and control samples, with charcoal in pelvis (B).
SK3755	Pelvis (A) Pelvis (B) Heel			Sub-angular blocky peds in all samples; granular peds in Skull (A) and (A1). Inter-pedal channels and intra-pedal vughs, planar voids in the Heel and pelvis (A) and (B). Packing voids in the skull (A) and (A1) samples

Fromelles

Skeleton No:	*Sampling Region*	*Coarse Fraction*		*Micromorphological Summary*
		Mineral (Mean % frequency)	*Organic (Mean % frequency)*	
	C2 C3	Quartz (10%)		Porphyric related distribution in the controls (*c/f* 2:3) with monic in the burial samples (*c/f* ~1:19). Cloudy limpidity and striated b-fabric, with speckled in skull (B).
SK1525	Skull			Brown/black colour (PPL) to the fine material
SK1527	Skull (A) Skull (B) Foot	Quartz (5%) Gypsum (20%)	Bone (10%) Textile (5%) Wood (2%)	Quartz (*c*.10%) in the control samples, Quartz (*c*.5 %) in the burial samples, none in skull (A). Gypsum crystals (*c*.20%) in all burial samples Sub-angular blocky peds in the C2 and C3 control Angular blocky peds in all burial samples; 30% sub-angular block peds in skull (B). Inter-pedal channels with intersecting planes in the control and burial samples (2^{nd} generation development)

Appendix 4: A summary table of the mean P and Si concentrations detected in the fine material across the sampling regions of the single inhumation and mass grave sites. C1 site control from Syningthwaite P=0.32, and Si=37.51. (All measurement are in Wt%)

P

Type of Grave	Site	Layer	Grave	C2	C3	B. Skull	Inside skull	Skull	Hand/L.Elbow	Pelvis	B. Sacrum	Sacrum	Knee	Foot
Single Grave	Mechelen	L1	G26											
		L2	G27											
		L3	2037											
		L4	384											
		L4	414											
		L4	415											
		L4	422											
		L4	423											
	Syningthwaite		G1	0.54			0.65	0.76	0.74	0.40				
			G2				0.11	0.10	0.19					0.02
			G3	0.01	0.25			0.14				0.98		0.23
	South Leith		6B	0.11	0.11			0.03	1.68				0.27	0.40
Mass Grave	Ridgeway		Site		0.02	0.04		0.21		0.36				0.35
	Fromelles		Site		0.14			0.48						

Si

Type of Grave	Site	Layer	Grave	C2	C3	B. Skull	Inside skull	Skull	Hand/L.Elbow	Pelvis	B. Sacrum	Sacrum	Knee	Foot
Single Grave	Mechelen	L1	G26											
		L2	G27											
		L3	2037											
		L4	384											
		L4	414											
		L4	415											
		L4	422											
		L4	423											
	Syningthwaite		G1	124.78			93.33	81.08		78.35				
			G2				2.99	6.34	6.56					0.46
			G3	3.42	161.57			41.38				94.98		100.13
	South Leith		6B	23.39	19.00			50.83	18.6				17.81	12.68
Mass Grave	Ridgeway		Site	4.75	5.65			17.21		9.82				24.08
	Fromelles		Site	28.64	28.89			14.70						29.19

Appendix 5: A summary table of the mean P and Fe concentrations detected in the redoximorphic nodules across the sampling regions of the single inhumation and mass grave sites.C1 site control at Syningthwaite: P=2.22 and Fe=64.14. (All measurement are in Wt%)

Type of Grave	Site	Layer	Grave	P											Fe									
				C2	**C3**	**B. Skull**	**Inside skull**	**Skull**	**Hand/ Elbow**	**Pelvis**	B. Sacrum	**Sacrum**	**Knee**	**Foot**	**C2**	**C3**	**B. Skull**	**Inside skull**	**Skull**	**Had/ Elbow**	**Pelvis**	**B. Sacrum**	**Sacrum**	**Knee**
Single Grave	Mechelen	*L1*	*G26*					8.85											52.61					
		L2	*G27*					2.33		3.13				5.20					8.37		14.77			
		L3	*2037*	2.16	2.42							7.98		2.50	6.52	13.84							15.31	
		L4	*384*		2.89	3.45		2.76	3.39							43.97	13.35		14.26	85.98				
		L4	*414*					2.00	3.09	7.55									17.10	66.95	59.17			
		L4	*415*					0.17	7.84					0.60					8.58	14.71				
		L4	*422*	1.05						0.18	0.92				4.25						2.32	10.02		
		L4	*423*		0.08			0.65		0.73				0.14		3.48			22.27		8.26			
	Syningthwaite		*G1*	0.20	0.37		2.55	1.76		1.40					36.34	70.11		101.86	164.62		82.05			
			G2				0.48	0.38	0.86					0.21				17.91	20.21	32.33				
			G3	2.39	1.56			0.28				3.14		2.11	143.60	152.30			28.18				149.76	
	South Leith		*6B*	0.09	0.08			0.18	1.85				1.13	0.29	7.34	49.91			55.40	45.63				38.35
Mass Grave	Ridgeway		*Site*	0.15	0.01			0.31		0.29				0.31	14.86	1.06			29.47		5.24			
	Fromelles		*Site*	0	0.15			0.66						0.34	16.83	33.65			6.78					

Appendix 6: A summary table of the mean P and Fe concentrations detected in the dusty coatings across the sampling regions of the single inhumation and mass grave sites. The C1 site control levels for Syningthwaite P=0.12 and Fe=9.76. (All measurement are in Wt%)

Type of Grave	Site	Layer	Grave	P											Fe										
				C2	C3	B. Skull	Inside skull	Skull	Hand/ Elbow	Pelvis	B. Sacrum	Sacrum	Knee	Foot	C2	C3	B. Skull	Inside skull	Skull	Had/ Elbow	Pelvis	B. Sacrum	Sacrum	Knee	Foot
Single Grave	Mechelen	*L1*	*G26*																						
		L2	*G27*																						
		L3	*2037*																						
		L4	*384*																						
		L4	*414*																						
		L4	*415*						0.11											13.17					
		L4	*422*			0.06			0.33								1.00			27.35					
		L4	*423*					0.32						2.10					1.23						4.74
	Syningthwaite		*G1*	1.87	0.39		5.40			1.37					108.07	31.97		29.02			28.64				
			G2				1.44	1.03	0.36					0.02				3.74	11.98	21.87					4.64
			G3	0.28	0.32			0.60				1.69		1.91	22.32	32.54			14.57				16.16		16.68
	South Leith														12.46					20.42					
			6B		0.06				7.20																
Mass Grave	Ridgeway		*Site*	0.03	0.02			0.13		0.22				0.25	0.26	0.33			1.82		2.87				3.24
	Fromelles		*Site*	0	0.16			0.46						0.29	3.38	3.54			7.60						3.91

Appendix 7: Mosaic Image Capture

This process is undertaken to ensure features can be re-aligned/found once the observations have been undertaken

Place slide in the copper slide holder with the bottom edge of the slide aligned to the edge of the plate, as seen below in Appendix 7, Figure 1.

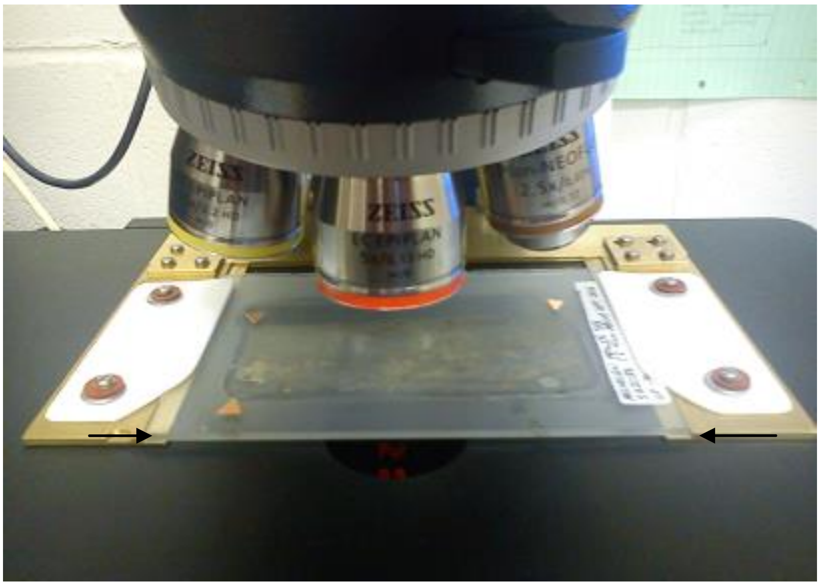


Figure 1: Image of the slide in position in the slide holder (the slide is lined up with the edge of the slide holder).

- Activate AxioVision and open the X/Y coordinate function.
- Press - **AUTO** and then **HOME** (do this twice to ensure the stage returns to the same position each time).
- Open up mosaic and mosaic acquisition
- Move the stage manually, using the adjusting handle, to triangle A (Figure 2) on the slide and note the x/y coordinates (do not move the stage at this point).
- This will also be the first point for the mosaic
- Move the stage, again manually, once the first mosaic point has been captured to triangle B and note the x/y coordinates (this is not a point of capture for the mosaic)
- Move the stage to position C and note the x/y coordinates while also making this the opposite, mosaic coordinate.

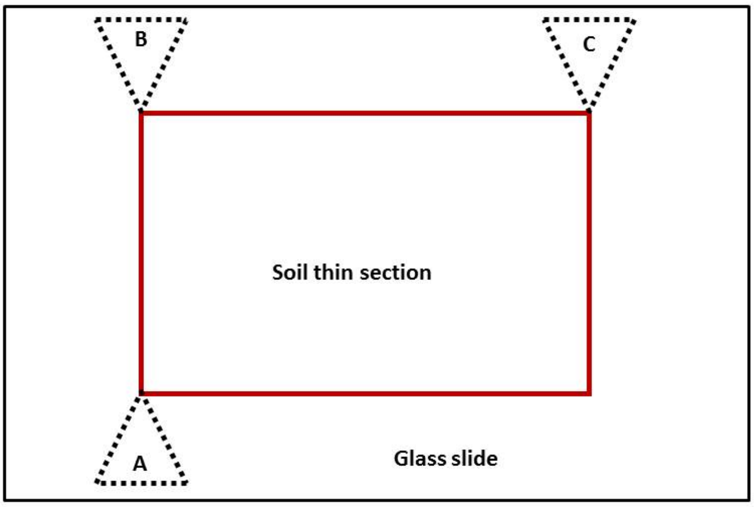


Figure 2: Diagram of the slide with copper triangles attached

Once this has been completed, before capturing the mosaic you must check

- Objective (5X)
- Focus on the computer screen and not the microscope
- Picture Properties (Frame, capture resolution) as the capacity of the computer to store large images can be problematic.

Appendix 8: Image analysis protocols for void analysis

Image analysis using, AxioVision Release 4.8.2 and Imaging Plus, Automatic Measurement Plus and Mosaic Modules, was undertaken to determine the representative percentage of void space within a region of interest (ROI) from each soil thin section analysed.

Image capture for analysis

Capture 3 images of the using the technique discussed in image analysis, however not the whole image will need to be captured, only a RIO, and so the copper triangle will not be points of reference.

Images to capture:

- Cross-polarized (XPL) this is when the polarizer is positioned at 90^0
- XPL with the polarizer at 30^0
- XPL with the polarizer at 60^0

Colour thresholding of individual images

A binary picture (threshold image) must be created for each individual XPL image captured (90^0, 60^0 and 30^0). Colour segmentation must be undertaken to separate the soil fractions from the voids, particularly the quartz fraction that can be mistaken as void features under XPL.

This process is accessed through:

Processing > Segmentation > Threshold Interactive

Here the image is uploaded to this function and the =void areas of the image highlighted with the cursor. The areas highlighted during this process will be the voids that can be seen in the colour image. A binary image is then produced, with white representative of the voids and the black being the coarse/fine material from the soil thin section.

Image layering

The three binary images are then layered over each other with the 90^0 image at the bottom, the 60^0 image placed on top and then finally the 30^0 image, using the steps:

Processing > Arithmetic > Add

This laying of the images will produce a greyscale image.

Binary image

The processes that were applied in step 2 (Thresholding of individual images) are applied to the composite image. This will produce a binary (black [coarse/fine material] and white [voids] image) image of the composite.

Determining measurement area

To measure the white areas [voids] you must first instruct the image analysis of where is black (soil fabric) or white (voids) that have to be measured, this is done by:

Processing > Morphology > Grey

Image processing measurements were applied using the interactive measurement of percentage pixels. It is therefore necessary to set the count for pixels to 4 (this determines the number of pixels measure at the edges if the voids and image) before completing this stage of the processing.

Setting measurement parameters
The measurements can then be set to the parameters required.

Measurement > Auto Measure > Set Measurement Parameters

The factors applied to the measurements were:

- Area % (μm^2) (The percentage of voids in the ROI)
- Area Filled (μm^2) (The whole RIO measured)
- Number of Regions (Total number of voids counted)

These setting were saved within the user settings and applied to all samples.

Applying measurement parameters

Once the measurement parameters had been set this was applied to the sample through the process of:

Measure >Auto Measure > Start Selective Measurement

An Excel spread sheet was then generated with the measurements and the results graphed.

Appendix 9: Point Count Analysis Procedures

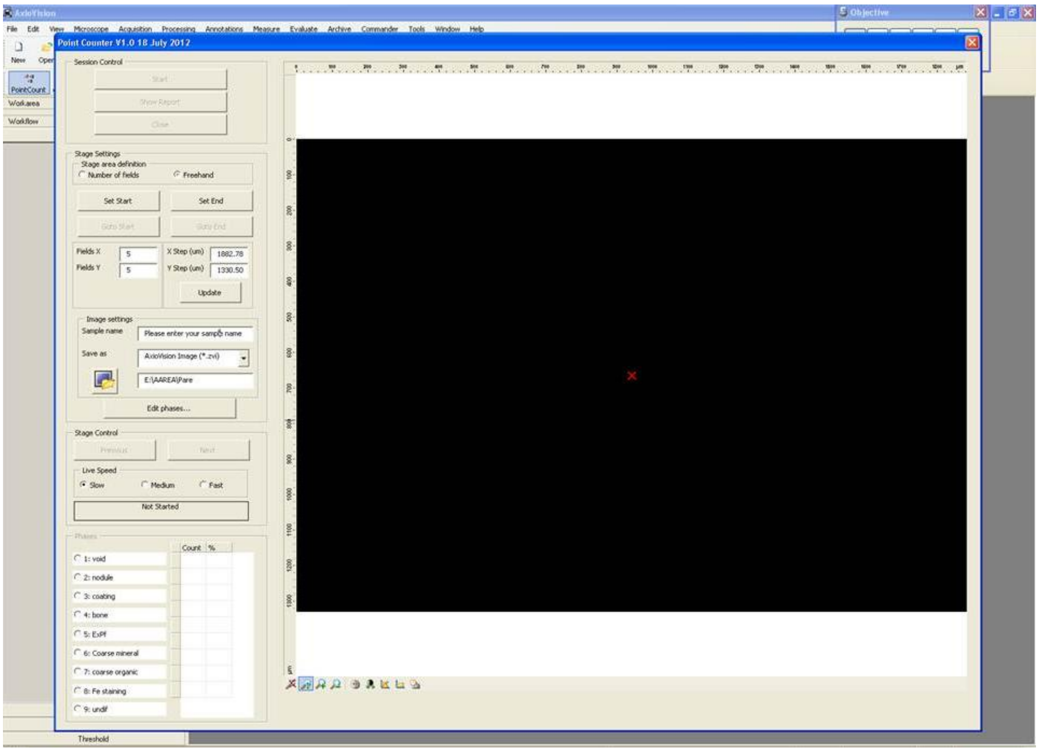


Figure 1: The computer screen observed when the Point Count module has been activated.

Initial set up of the measurement

Place a soil thin section slide in the brass slide holder of the AxioScope.A1 (as shown in Appendix 7, Figure 1) and identify the region of interest (RIO) that requires measuring. This would normally be the RIO that has had Image Analysis applied and that displays a certain fabric type.

Microscope set up

Set the microscope objective (5X's is recommended), start up the Point Count V1.0 18 module within the Axio.A1 software package. Changing the objective once the settings have been logged can cause problems in analysis.

Focus the image from the soil thin section onto the computer screen that can be seen (as above).

Positioning the Start and Stop points

Select a folder for the information to be stored in and name the file.

Position the objective, using the manual adjustment handle, over the lower right corner on the ROI as seen in Figure 2, this is the start point, press select Start. Move the objective to the top left corner of the RIO and select Stop. The position of the start and stop point for the analysis can then be evaluated by clicking on the Set Start and Set Stop options.

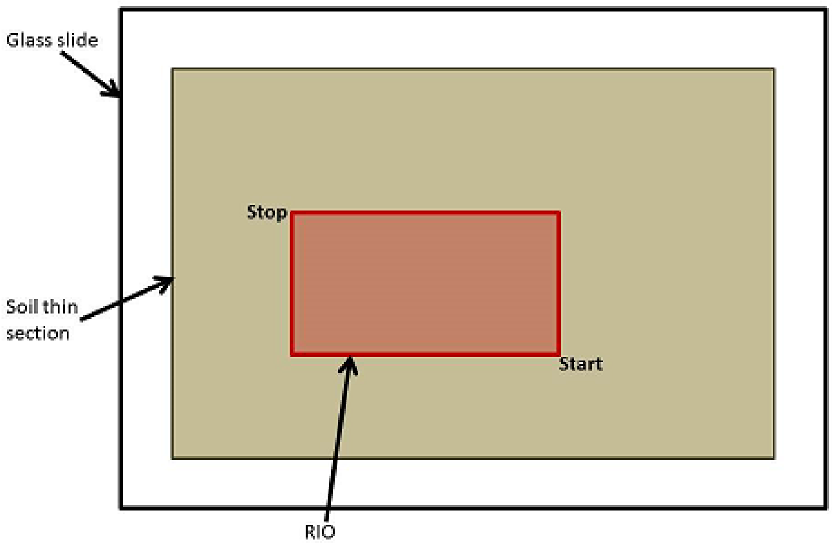


Figure 2: The location of the start and Stop areas of the Stop areas for setting up the Point Count analysis of a specific region of interest in a soil thin section.

Setting the count parameters

To edit the phases you wish to could select the Edit Phases option, you can measure up to nine different elements.

To determine the distance between each count enter the value into the X Step and Y Step fields (the measurements are in µm) and then press update, this will inform you of the number of could being undertaken.

Determine the live speed you require the motorised stage to move at (Fast, Moderate or Slow) and then begin analysis by selecting start at the top of the screen.

Counting

To count use the mouse to choose the Phased identified under the red-cross on the visual image of the computer screen. Once the Phase has been chosen the stage will move the pre-determined measurement to the next position. The stage will move from the Start position to the Stop position, once this has occurred the count will not allow any move Phases to be recorded and the stage ceases to move.

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