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RGPM Waltham Abbey

Palaeoenvironmental Reconstruction

by Dean James

The Royal Gunpowder Mills, Waltham Abbey: A Palaeoenvironmental Reconstruction

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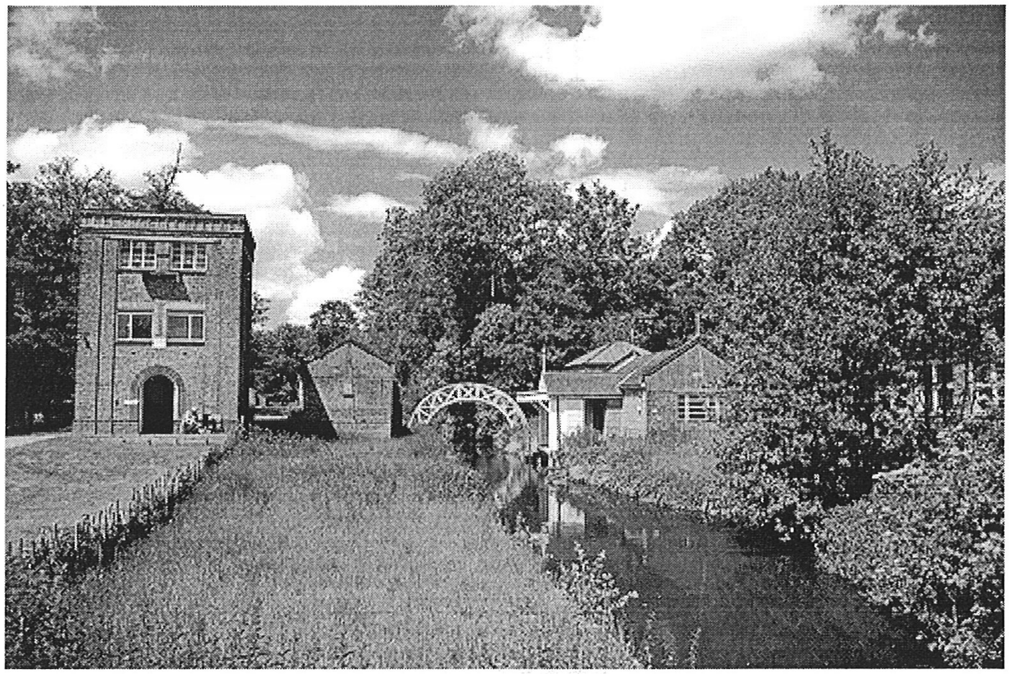

Figure 1: A Wildlife Tower(originally an hydraulic accumulator) overlooking the Millhead Stream of the Royal Gunpowder Mills

Taken from http://www.flickr.com/photos/barryslemmings/155988545/

Acknowledgements

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Abstract

River floodplains can provide a myriad of information that relate to anthropogenic changes that occurred in the past. The Old River Lea, a natural channel of the now recognised River Lea, has undergone extensive changes in relation to the development of the gunpowder industry. Two cores have been collected from local marshlands and an extensive multi-proxy analysis has been carried out to assess the anthropogenic impact on the Old River Lea. Charcoal was of greatest importance as it is a primary constituent in the production of black powder. Results show that charcoal provides a strong correlation that could be related to the gunpowder industry. An analysis of cation exchange of potassium found peaks at similar depths to charcoal that are related to black powder production. Magnetic susceptibility also shows correlations with an increase in charcoal, whereas particle size and Loss on Ignition results provided weaker correlations.

Introduction

River floodplain sediments have been used for a number of palaeoenvironmental studies that have answered important questions in history (Wheeler et al., 2010). The River Lea, an estuary *(a tributary)* of the River Thames, has rarely been studied for its palaeoenvironmental data but, studies have provided fruitful results on its sediment accumulation and preservation ability (Warren, 1912; Chambers et al. 1996, Deephams Sewage Works, 2001). This study seeks to validate whether the River Lea floodplain can be studied extensively for its palaeoenvironmental evidence by providing an historical reconstruction of the Royal Gunpowder Mills. Using a multi-proxy analysis approach, the results should provide answers to previously unanswered questions that surround the history of the Royal Gunpowder Mills through cross correlation with historical and archival data.

Aims and Objectives

Aim:

- To provide a chronology of the history of the Royal Gunpowder Mills, Waltham Abbey through a multi-proxy analysis

Objectives:

- To provide evidence of gunpowder production levels through charcoal analysis and potassium determination
- To use magnetic susceptibility to document land use changes correlating with gunpowder production
- To use Loss on Ignition as a proxy for changes in organic content related to the production of gunpowder
- To use Particle Size analysis to document changes in stratigraphy caused by gunpowder production

A History of the River Lea

The River Lea (or Lee) is the largest of the tributary streams of the River Thames in the Lower Thames area and its modern floodplain is less than 0.8km (Gibbard, 1994). The river, formed just after the last glacial maximum, begins in Leagrave, Luton in the Chiltern Hills and reaches its end joining the River Thames at Bow Creek, east London. Areas of northern *(southern?)* Britain were subjected to mass glaciation, forming a dam that impounded the water flow of the Thames that resulted in the creation of a lake (Catt, 2011). Through climate warming, the mass melting of these glaciers caused the lake to overflow and establish the present day course for the river channels in the Lower Thames Valley, including the River Lea. This has helped to establish its current geological setting.

The underlying geology of the River Lea is quite complex. At its bedrock, the River Lea is underlain by London Clay, a marine geological formation of the Lower Eocene Epoch, between 56-49 Ma (Sumbler, 1996). Above this, London Clay has since been coated by a thin veneer of complex sands, gravels and clays left behind by rivers and glaciers since the last Ice Age formed approximately 25,000 BP (Gibbard, 1994; Lucy, 1999). However, since the River Lea's formation at the start of the current interglacial, the original sands, gravels and clays, have been covered by floodplain alluvium extending to no more than 1km east or west of the river (Gibbard, 1994).

A Brief History of Gunpowder and the Royal Gunpowder Mills

It is generally accepted that gunpowder is one of the four greatest inventions developed from ancient China. First trialled by alchemists as an elixir for immortality in the 9th century AD, its propellant power was eventually discovered and by the end of the 12th century, Chinese developed formulas of gunpowder that were capable of penetrating cast iron metal containers

(Needham, 1986). At a similar time, gunpowder was in its infancy in the Arab world. By the 14th and 15th century AD, civilisations across Asia and Europe had gained intimate knowledge of gunpowder and were seeking to develop it further (Marsh & Mclaren, 1982). Yet, it was not until the early 16th century that gunpowder had finally made its way into Waltham Abbey with little knowledge that it would make the town famous.

The beginning of the gunpowder industry in Waltham Abbey is relatively unknown. The first reference of gunpowder in Waltham Abbey was from a contract in a Calendar of State Papers in 1561 agreed by Marc Antonio Erizzo and John Thamworth for the purchase of saltpetre and sulphur, two of the three ingredients for the production of black powder, though it is unknown whether these were purchased to produce gunpowder (Simmons, 1963). This coincides with a hypothesis developed by W. Winters that suggests that some mills that had been built adjacent to the River Lea, were producing gunpowder by 1560 (Simmons, 1963), though evidence for this is lacking. A map of Waltham Abbey produced in 1590 shows that a Fulling Mill was already in existence in a similar location to the present gunpowder factory, suggesting that the means to produce industrially were available (Royal Gunpowder Mills website, 2009). Though the date of first operation for the Royal *(not 'Royal' until 1789)* Gunpowder Mills *(at Waltham Abbey)* is unknown, by 1662, it had already been in use for some years (Simmons, 1963). Fairclough believes that the industry started a little later in 1665 when the original Oyle mills were converted to powder mills by the Hudson family (Fairclough, 1985). However, it was not until 1789 that the Royal Gunpowder Mills was used to its full potential.

Pre-1789, the Royal *(see above)*Gunpowder Mills was only a small scale industry producing approximately 600 barrels per year, mainly for private buyers (Crocker, 1999). During the1650's and onwards, during the Dutch Wars and War of Spanish Succession, demand for gunpowder greatly increased (Crocker, 1999; Buchanan, 2006). In 1789, the Royal Gunpowder Mills received its present day title due to its acquisition by the government because it could not rely on the private sector for gunpowder used in the military, despite their domination (Crocker, 1999). It was also purchased along with two other mills, for the same reason, that were considered significantly more industrious than any other manufacturer: Faversham (1759) and Ballincolig (1804). After its acquisition, the Waltham Abbey Mills enjoyed its most fruitful production period, coinciding with the Napoleonic wars between 1792 and 1815, producing more than 20,000 barrels of gunpowder per year at its peak (Simmons, 1963; Marsh and Mclaren, 1982; Crocker, 1999; Kelly, 2005; Buchanan, 2006). After this period, however, gunpowder drastically diminished due to an absence of war for more than 50 years. *(The Crimean War started in 1854)* During this period, *(from the 1870's,)*development in propellants and explosives would ultimately cause the demise of the gunpowder industry for Waltham Abbey.

After the conclusion of the Napoleonic Wars in 1815, the production of black powder declined significantly. Production levels fell to one twentieth of the previous years' production to approximately 1,000 barrels each year after the defeat of Napoleon (Simmons, 1963; Crocker, 1999; Royal Gunpowder Mills website, 2009). As gunpowder levels declined, employment levels declined and financial cuts had to be made. This included the on-site production of charcoal from 1831 as transportation costs were too high to maintain (Simmons, 1963; Crocker, 2002). Similarly, an opening was created *(from the 1880's)* for the development of new, efficient *(or - more powerful chemically based)* explosives in the form of guncotton, nitro-glycerine and cordite. Gunpowder production was eventually overtaken by guncotton because of its future development into smokeless powder in 1884, despite guncotton being an inefficient *(or - too powerful to be used as a)* propellant (Davis, 1943; Simmons, 1963; Crocker 2002). Developments in gunpowder, either in its manufacturing process or its efficiency development, could not delay the progress of guncotton and a factory was created in 1872 and production commenced (Simmons, 1963). Gunpowder production continued up until the factory's conversion into a Research and Development institute *(Establishment)* in 1943 (1945), though never on the same scale as the mid-18th century (Royal Gunpowder Mills website, 2009). The gunpowder factory remained closed until 2004 *(2001)* where *(when)* it was re-opened as a museum *(heritage centre)* by the Duke of Edinburgh *(Gloucester)*, after the site was fully de-contaminated of any harmful material.

A Multi-Proxy Analysis of Anthropogenic Change

Human activity in and around the Royal Gunpowder Mills could be reflected in the sedimentary record through the analysis of charcoal. Charcoal is one of the primary constituents in the production of black powder and was produced locally from the mid 19th century (Simmons, 1963; Crocker, 2002; Kelly, 2005; Royal Gunpowder Mills website, 2009). The northern areas of the Royal Gunpowder Mills were densely populated with trees that were known to make high quality charcoal: Alder (*Alnus sp.*), Crack Willow (*Salix fragilis*), and Alder Buckthorn (*Rhamnus frangula*). Once the woodland had become fully developed, trees were regularly coppiced (cut back to just above ground level) every 15 years, over a period of 150 years, to provide the highest quality charcoal possible to increase the efficacy of gunpowder (Royal Gunpowder Mills website, 2009). This should be reflected in the sedimentary record as an increase in charcoal fragments would be indicative of an increase in gunpowder production. Similar palaeoenvironmental studies based on charcoal analysis have provided significant data that have answered previously unanswered questions (Flenley and King, 1984; Willcox, 1999; Willcox, 2000; Mann, 2008; Mieth and Bork, 2010)

A chemical analysis can also provide increasingly useful information on the gunpowder industry. Along with charcoal *(and sulphur)*, saltpetre (potassium nitrate) was used as an ingredient in the production of black powder. This was, essentially, used as the oxidiser in the combustion *(or – the accelerated combustion process of explosion in)*` gunpowder. Although three types of nitrates were used in the evolution of gunpowder, potassium nitrate, sodium nitrate and calcium nitrate, potassium was considered the best because of its activity when combusted, most likely due to its ability to exchange electrons (Buchanan, 2006). An increase in potassium should therefore indicate a correlation with an increase in gunpowder production.

The production of gunpowder can be reflected in the sediment cores by analysing magnetic susceptibility. The clearance of forest within the grounds of the mills would promote the increase in soil erosion. This increase in soil erosion would likely increase the magnetic susceptibility of the in-washed sediments (Dearing, 1983). Thus, an increase in magnetic susceptibility may provide results that correlate with the production of black powder. Also, magnetic susceptibility has been correlated with particle size. Lowe and Walker (1997) suggest that coarser grained particles may show an increase in magnetic susceptibility levels. Larger sediment particles present within the sediment cores may, therefore, be attributed to deforestation for charcoal.

Particle Size would be able to provide information related to the clearance of forest for the production of charcoal. As forest is cleared, soil erosion would wash larger particles into the deposited sediment profile of the floodplain. Increases in particle size could reflect forest clearance events related to black powder production. It could also be presented as stratigraphical markers that may help with the dating of the sediment cores. For example, a study conducted by (insert author here) found that particle size can be related to the dating of the sediment cores. It has also been linked to magnetic susceptibility in which coarser grained sediment particles may present higher magnetic susceptibility levels, providing evidence for forest clearance (Lowe and Walker, 1997).

Loss on Ignition (LOI) is an indicator of organic content and carbonate content. A study of this proxy can provide fruitful information regarding the levels of deforestation. Therefore, levels of organic content could provide results that correspond to the levels of black powder production through the Royal Gunpowder Mills history. Increased levels in deforestation for the production of charcoal may be reflected in the LOI record as periods of low organic and high carbonate content.

Literature Review

Wheeler, J.; Swindles, G. T.; and Gearey, B. R. (2011) 'Finding Bosworth Battlefield: a multiproxy palaeoenvironmental investigation of lowland sediments from Dadlington, Leicestershire, England' in *Journal of Archaeological Science* **37**: 1579-1589

This paper presents a multi-proxy palaeoenvironmental analysis of an area proposed to contain the site of Bosworth Battlefield, near Dadlington, Leicestershire. The battle itself was significant in the history of royal succession, as this battle claimed the life of Richard III, the last of the Plantagenet kings, leading to the coronation of Henry VII – the first Tudor monarch. Wheeler et al. attempt to answer an important question that has stemmed from this battle, and the lack of primary evidence: where did the actual battle take place? Secondary information provided by Polydore Virgil claimed that the battle took place on a 'marsh,' though as this is secondary information, it does not provide direct evidence of the site. By conducting a lithostratigraphic analysis and pollen analysis of cores across a transect, Wheeler et al. were able to conclude that even though direct evidence relating to the battle could not be found, the results provided a wider landscape context, illustrating the presence of local wetlands that existed throughout the Medieval period. Methods used by Wheeler et al. are typically well established methods, such as pollen analysis and a lithostratigraphical analysis. An alternative method that was briefly touched upon was a palaeoecological analysis. Though some testing was conducted, a wider analysis may have provided fruitful information to answer the question, as changes in palaeoecology would indicate a change in landscape, from wetland to farmland, for example (Flower et al., 1992; Cundy et al, 1998). This article follows a similar argument presented in the Chambers et al. (1996) paper on Holocene pollen and molluscan records by providing strong arguments that wetlands contain a wealth of preserved information relating to historical or geological events.

Chambers et al. (1996) 'Early Holocene pollen and molluscan records from Enfield Lock, Middlesex, UK' in *Proceedings of the Geologists Association*, 107, 1-14

This study concentrated on understanding the local environmental changes that occurred during the early Holocene and assessing certain regional trends, as well as studying the impact Mesolithic activity had on the environment in the London Region, as Chambers et al. believed that distribution of data on early Holocene vegetation is skewed to the north and west of the country. The site location of Enfield Lock was suitable as an archaeological excavation was carried out simultaneously to this report and could help in their methods for dating. Using charcoal analysis, pollen analysis, molluscan data, such as identifying molluscs found, and vegetational data, for example, identifying plant species and Loss on Igntion, Chambers et al. found that the marl and clay sediments found were due to a rise in water level and deforestation and erosion, respectively. They had also found from the pollen analysis, that the area was pine and birch dominated, although there was a change to alder due to a change in water levels. Their charcoal analysis, however, could not determine whether or not the charcoal present was due to anthropogenic induced or natural fire. As no artifacts were found during the excavation, but have been found nearby in the town of Broxbourne, it has been suggested that the fires were natural in origin. More sediment samples could have been collected to provide a greater detail of evidence for their argument. Alternatively, other locations along the River Lea could have been taken into consideration, for example the Tottenham Marshes, where there is known evidence of geological history (Warren, 1912).

Methodology

Pilot Study

A pilot study was undertaken at Waltham Abbey to evaluate the potential evidence in achieving the aim of this report. Due to the unknown rates of sedimentation, and the uncertainty for lack of charcoal evidence along the Old River Lea, an initial, prospecting core was taken. The core was sampled at 20cm intervals for charcoal analysis and 5cm intervals for Loss on Ignition testing. The charcoal analysis revealed charcoal fragments were found at all intervals along the length of the core, correlating with a decreasing trend in charcoal towards the base of the core. Loss on Ignition provided valuable insight into the variation of organic content through time. Natural variations had occurred throughout and provided potential evidence that correlates with anthropogenic changes caused by the Royal

Gunpowder Mills. Other proxies were to be conducted when final core samples were collected and transported to the labs.

A second pilot study was conducted at Faversham, Kent as an alternate study site to achieving the aim of this project. The Chart Gunpowder Mills was considered one of the earliest gunpowder mills in the UK and was established c. 1560. It was not until approximately 200 years later that the mills were put to their full use as the government purchased the mills from the Gruber family in 1747 (Percival, 1969). From this point onwards, the mills had been involved in some of Britain's major battles, for example, the battles of Trafalgar and Waterloo, until its closure in 1934, along with two other mills located close by at the Oare Gunpowder Factory, due to its close proximity to Continental Europe, making it vulnerable to attack during periods of war (Percival, 1969). The sample site was conducted at Faversham Creek approximately 1km away from the original Chart Gunpowder Mills site. The tidal creek provided a good location for evidence as sedimentation rates were consistent and constantly monitored. A core collected and subjected to a similar analysis as the first pilot study at Waltham Abbey. Charcoal analysis proved fruitful as charcoal fragments were found along the length of the core at fluctuating levels. The Loss on Ignition testing also showed results of fluctuations in organic matter that could have corresponded with the history of the gunpowder factory. However, this site was eventually discarded due to further research on the tidal creek itself, which resulted in the discovery of a major silt flushing event that occurred at the beginning of the 20th century (Wallingford, 2006) that may have led to the loss of evidence that related to the factory's history. Though charcoal was present along the core at similar intervals to the first pilot study, the provenance of the charcoal may have been different to the evidence being sought.

Study Site: Wake Hide, Lea Valley Park, Waltham Abbey

The sample site was conducted north of Waltham Abbey in an area of floodplain located directly east of the Old River Lea (Fig. 3.4). The locality was previously unused marshland until **(year?)** when the Lea Valley Park introduced grazing to the site, as well as the establishment of a dragonfly sanctuary. This site was chosen based on its previous history of being untouched, as well as the Old River Lea being a natural, unmodified river course providing an area of deposition. The River Lea (Lee)Navigation was subsequently avoided as it was constructed during the 18th century and provides no area for deposition. Furthermore, a government document indicates that the Old River Lea during the 19th century was susceptible to flooding caused by a silting up of the river, providing regular depositions to the locality studied[1]. Core samples were taken directly west of a wake hide that overlooks a flooded area of land (Fig 3.4). Geologically, the locations in which the cores were taken are considered to be in areas of newly deposited floodplain sediment (see GeologyMap). Cored sediments show that sedimentology was consistent with clay material. Moreover, the sample sites were taken in marshlands that were quite saturated. Biologically, long grasses covered the initial sites. These were cleared to gain easier access to taking samples. At core 2, the area was very saturated, making coring easier than core 1.

Cartographic Section

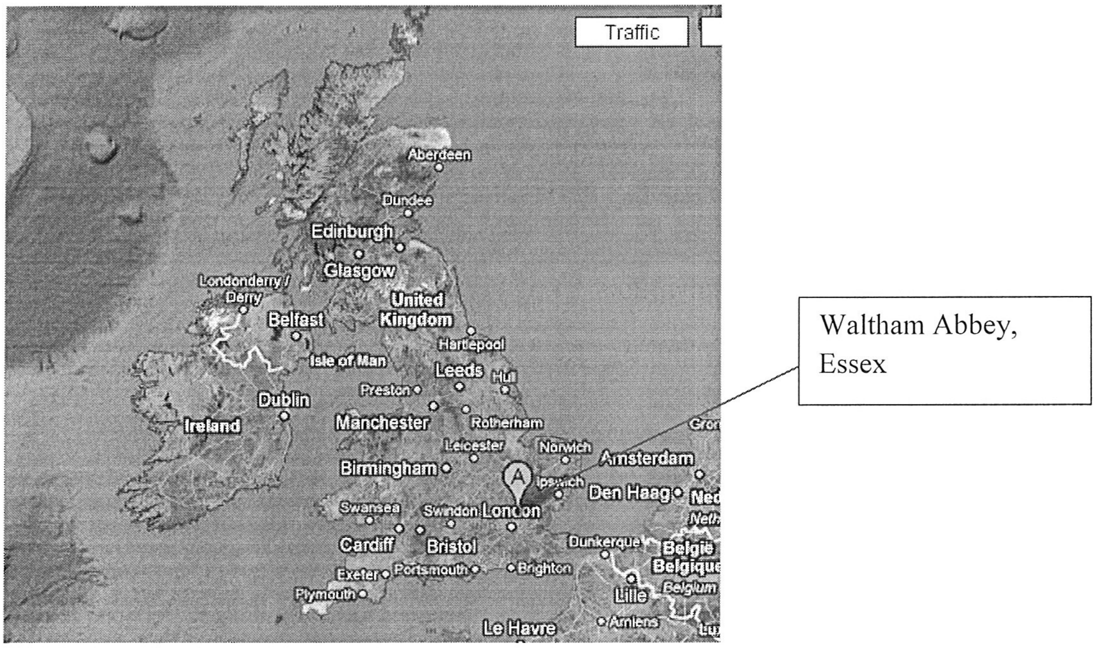


Figure 3.1 – Location of Waltham Abbey within the UK

[1] Spoken by Sir Henry Selwin-Ibbetson during questions to the Secretary of State for War, 18th July 1889. Found at http://hansard.millbanksystems.com/commons/1889/jul/18/the-old-river-lea-the-powder-works-at#S3V0338P0_18890718_HOC_25

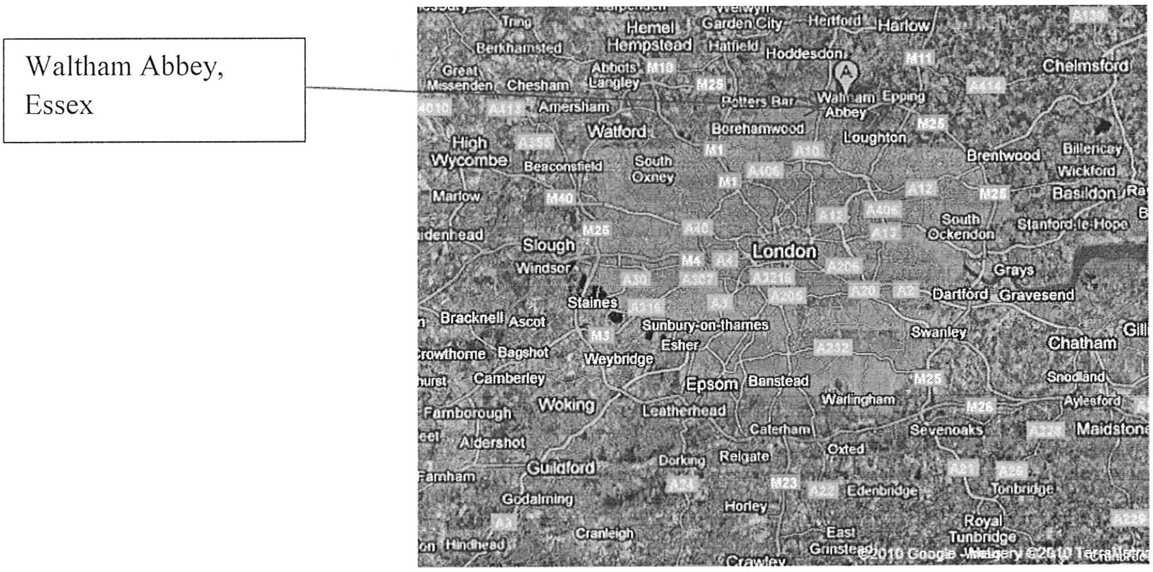


Figure 3.2 – Location of Waltham Abbey in comparison to London

Figure 3.3 – Royal Gunpowder Mills in relation to Waltham Abbey

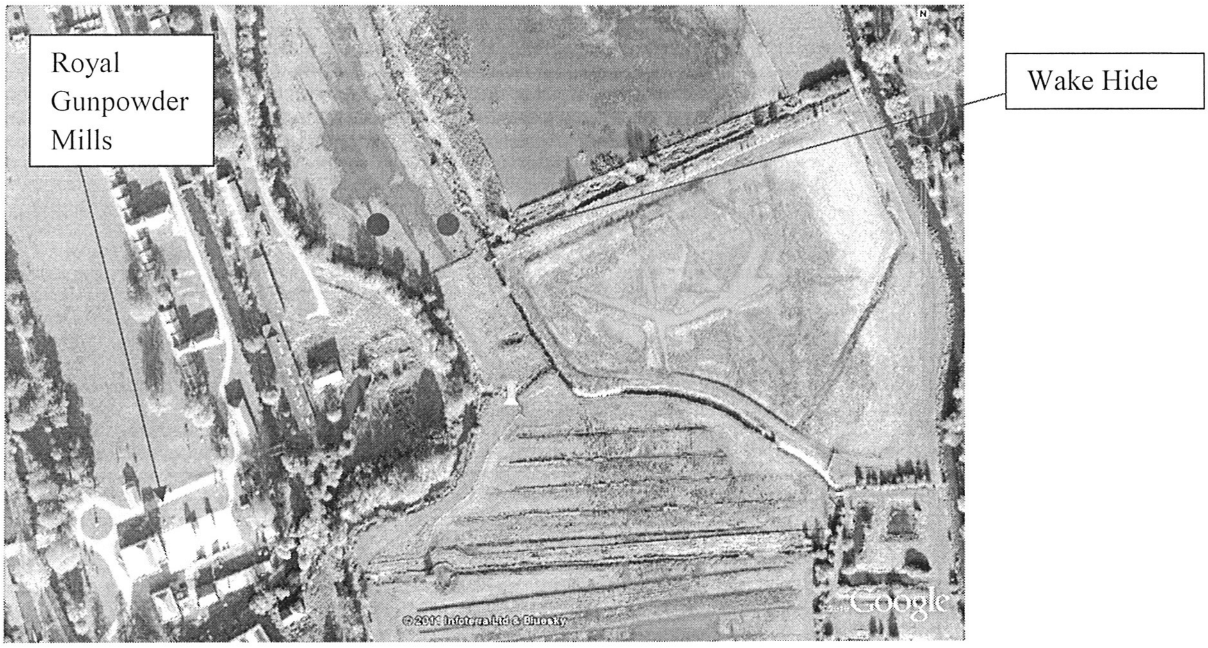


Figure 3.4 – Locations of cores within study site (Blue = Core 1; Red = Core 2)

<u>Core Sample: Method</u>

Coring Apparatus

- 50mm diameter auger corer
- Plastic pipes for cores (60mm diameter x 1000mm length)
- Tape measure
- GPS
- Cling Film
- Pallet Knife

Coring Method

Two cores were collected on the Old River Lea in separate locations on the floodplain directly east of the river. Cores were obtained as follows:

- Assemble coring equipment
- Place coring equipment upright and core downwards keeping the corer as straight as possible to avoid distortion
- Remove core after the corer reaches a maximum depth
- Remove material from corer and place into cling film covered guttering
- Clean corer to avoid cross contamination

- Repeat steps 2-5 until a sufficient amount of core has been gained (add extensions to core with increasing depth)
- Cores were transported and stored in a cool environment and kept wrapped at all times to prevent contamination and drying of the sediment

Care was taken to avoid core distortion so as not to upset the sediment record that may provide inaccurate datasets. The sediment in core 1 was particularly difficult to core through because of clay-like alluvium. Material was collected in ~20 cm increments due to this. Core 2 was easier to core through primarily due to the saturation levels of the site with material being collected at ~40cm increments. Excess saturation may have caused cross contamination of evidence when retrieving the core from the ground. A peat cutter may have been more suitable for the collection of material as this would have aided in penetration of the ground surface.

Charcoal Count

Apparatus

- Binocular microscope
- Small petri dishes
- Large petri dish
- Drying oven
- Clicker

Method

- Samples of 1cc were taken, every 2cm, along the length of the core (except in core 1 where after 60cm, sampling was increased to every 5cm to adhere to initial research deadline)
- Subsamples were soaked in a small amount of Hydrogen Peroxide (30% w/v) and left to dry in the oven at 50°C for 4 hours
- Samples were passed through a 100μm sieve until water ran clear.
- Samples were covered by paper towel (to avoid contamination) and left to dry in the oven overnight at 50°C
- Samples were dry counted, using a binocular microscope, in a large petri dish placed on top of a grid made from graph paper to aid with counting.

It should be noted that when undertaking macro- and microscopic charcoal frequency counts, it is difficult to distinguish between primary and secondary charcoal. Secondary charcoal may become embedded in the sediment record through a variety of mediums. For example, wind action attributes to the accumulation of charcoal form regional (distant) or extralocal (nearby but not within the watershed) fire events; and surface run-off, as well as through flow, may also contribute to the addition of charcoal (Whitlock and Larsen, 2001). Therefore, misinterpretation of data can become a factor when analysing charcoal quantities. Further misinterpretation of data may come from improper methods of counting charcoal (Whitlock and Millspaugh, 1996).

N.B. Method was adapted from Whitlock and Larsens (2001) *Charcoal as a fire proxy*

<u>Magnetic Susceptibility</u>

<u>Apparatus</u>

- Medium sized beakers
- Pestle and mortar
- Bartington MS2 magnetic susceptibility reader
- Bartington 36mm internal diameter dual-frequency Sensor Type MS2B
- Safety goggles
- Mass Balance
- Sample Tray
- Cling film
- Marker pen

Method:

- 1cm width samples were taken every 2cm along the entire length of the core (except in core 1 where after 60cm, sampling was increased to every 5cm to stick to initial research deadline)
- Samples were placed in glass beakers and soaked in de-mineralised water over night
- Samples were dried in the oven, overnight at 50°C
- Sediment was crushed using pestle and mortar and packed into 10cm^3 measuring pot. Those that were not filled all the way were packed with cling film to calculate volume specific magnetic susceptibility

- Weight of sediment was taken to 3 decimal places
- Magnetic Susceptibility was calculated using the Bartington Sensor MS2B
- Volume specific and mass specific susceptibility were then calculated

Potassium Determination

Apparatus:

- Filter Paper
- Extra small funnels
- 5ml pipette
- 1M, neutral, ammonium acetate
- 500ml de-ionised water
- Inductively Couple Plasma Mass Spectrometer

Method:

- Take ~0.25g of soil and mix with 5ml of 1M, neutral, ammonium acetate
- Shake for five minutes
- Filter the extract
- Measure the extract using the Inductively Coupled Plasma Mass Specrometer

The limitation of this method is that a total determination of potassium is not being measured. Due to health and safety reasons, total potassium determination was not advised due to the method containing hydrofluoric acid, which is incredibly volatile. The method chosen to determine potassium is a cation exchange method. As potassium sulphide, a bi-product of the ignition of gunpowder, is soluble in water, potassium becomes easily exchangeable with the soil particles. Therefore, a measure of cation exchange may provide an insight into what potassium levels could be at different periods in the history of the factory.

Particle Size Analysis

Apparatus

- Medium sized beakers
- Syringe
- Horiba LA950 Particle Analyser

- De-mineralised water

Method:

- 1cm width samples were taken every 2cm along the entire length of the core (except in core 1 where after 60cm, sampling was increased to every 5cm to stick to initial research deadline)
- Samples were placed in glass beakers and soaked in de-mineralised water over night
- Hydrogen peroxide (30% w/v) was then added at periodic intervals of 2 hours over two days until all organic matter was dissolved
- Sub-samples were taken via syringe and analysed by Horiba LA950 Particle Analyser
- Sub-samples were used three times to determine the variability of each sample
- The mean of the three results were then calculated and graphically represented.

One of the greatest difficulties with particle size analysis is the preparation for an adequate sample size. Fluvial deposits vary both laterally and vertically as a result of spatial and temporal changes in the local depositional environment and as a consequence of variations in flow conditions over time (Gale and Hoare, 1991). Therefore, it may be apparent that results may include other information that was laid down under different conditions than those during the timescale being studied.

Loss on Ignition

Apparatus

- Porcelain crucibles
- Muffle furnace at 550°C and 950°C
- Mass Balance

Method:

- Samples of approximately 1g were taken at 2cm intervals along the entire length of the core
- The mass of the crucible was then weighed to three decimal places
- 'Wet' sediments were then placed in crucibles and weighed
- Samples were placed in the oven overnight at 100°C

- 'Dry' sediment sample weight was taken
- Samples were placed in a muffle furnace at 550°C for 4 hours. Weight was taken after cooling
- Samples were placed back in the furnace at 950° for 4 hours. Weight was taken after cooling
- Percentages for moisture content, organic content and carbonate content were calculated

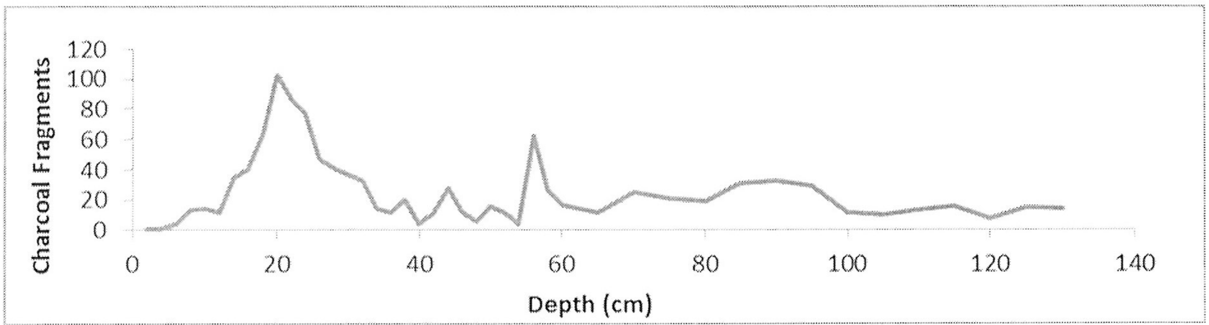
The Loss on Ignition method provides a quick, inexpensive estimation to the percentage of organic content within a soil sample (Dean, 1974). Gale and Hoare (1991) evaluate that the conventional high temperature ignition method is "...widely regarded as flawed," as the method itself may only destroy the readily oxidised components of the material. It may also result in the loss of carbon dioxide from components within the material, and may also cause a partial dehydration of minerals containing H_2O or OH^-, leading to actual losses of mass upon ignition, differing significantly from the theoretical loss in mass assuming total ignition of only plant organic material.

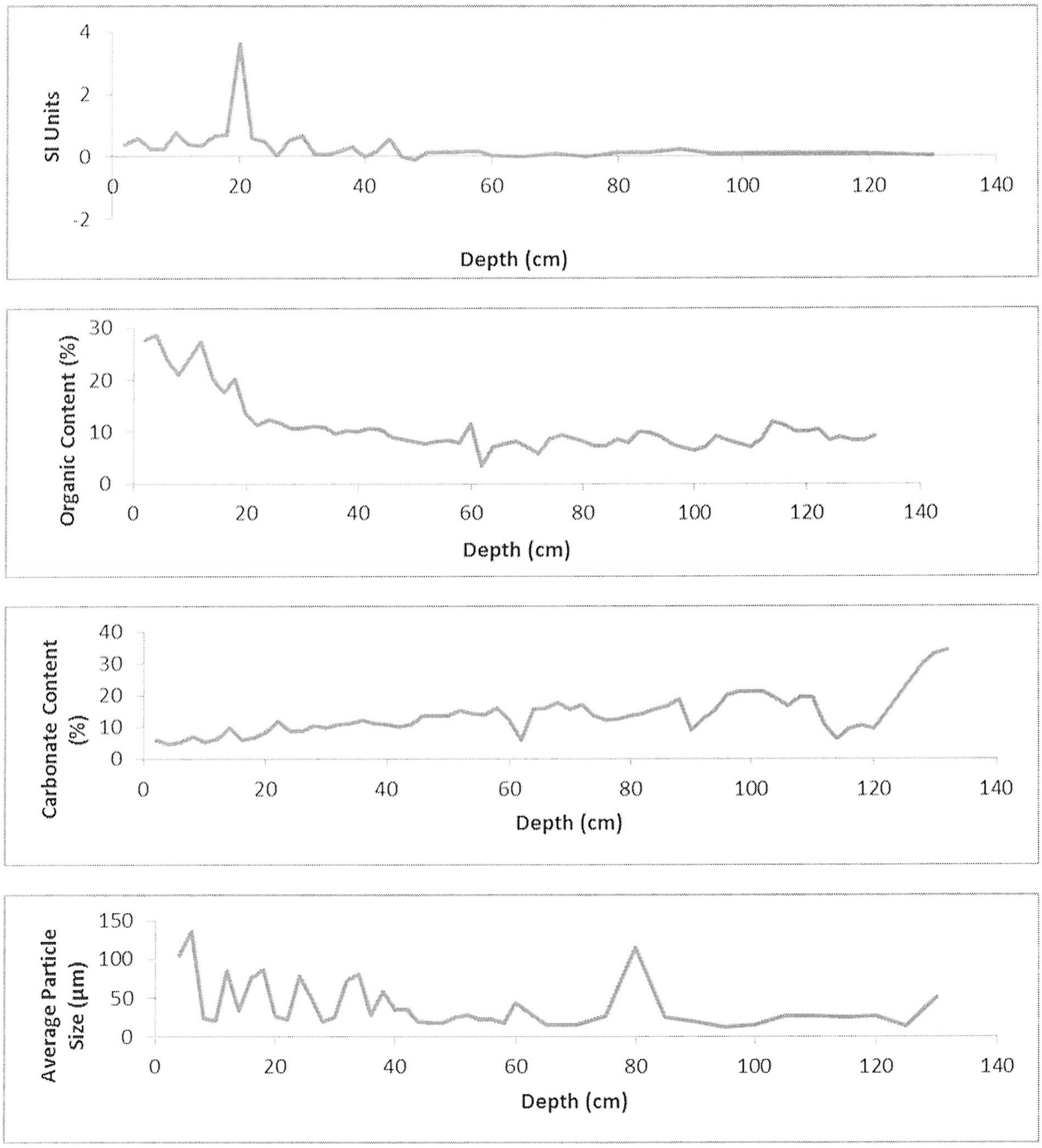
Dating of Core Samples

Without the use of ^{14}C dating available during the construction of this report, the correlation of levels of proxy data sets to exact dates on a historical time scale may be inaccurate. The use of sedimentation rates of a river may be used to define the base date of the core. However, sedimentation rates vary annually and deposits are not laid uniformly. This means that dates may be inaccurate if changes in sedimentation rates are not accounted for. As no sedimentation rates have been recorded for the River Lea at Waltham Abbey, only significant anomalies in the data sets will be given estimated dates based on archival data of gunpowder production records.

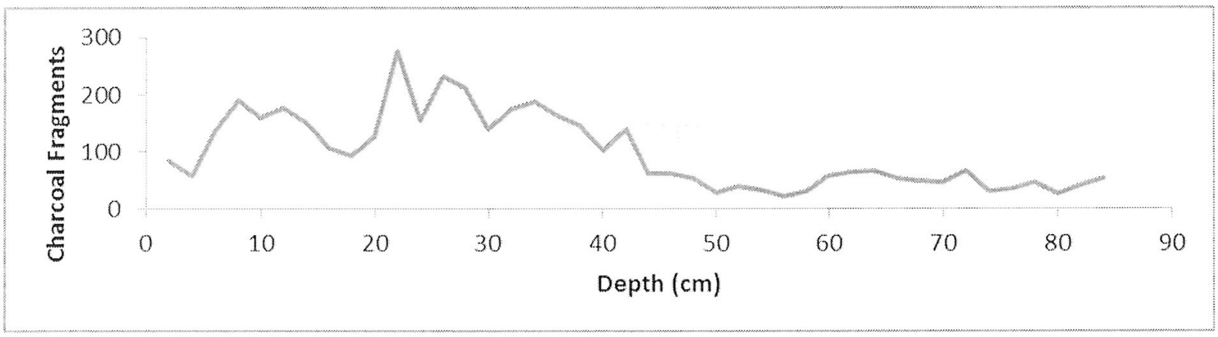
Results

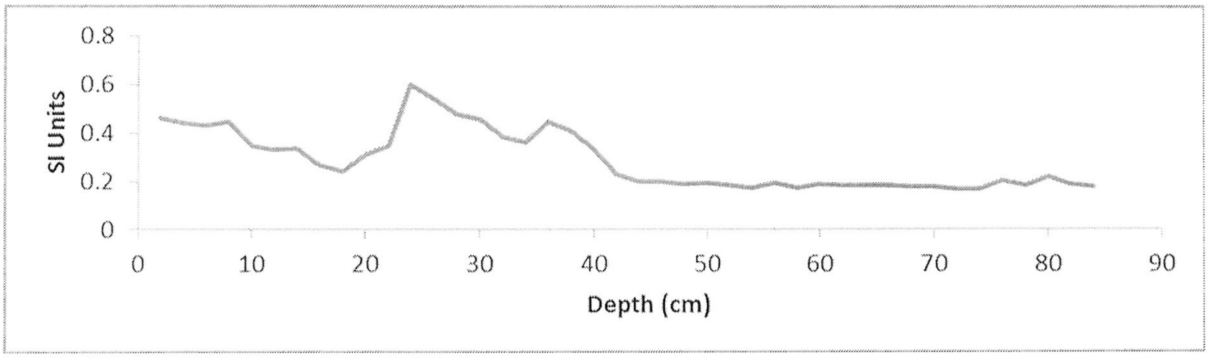
Fig 4.1 – Core 1 Results

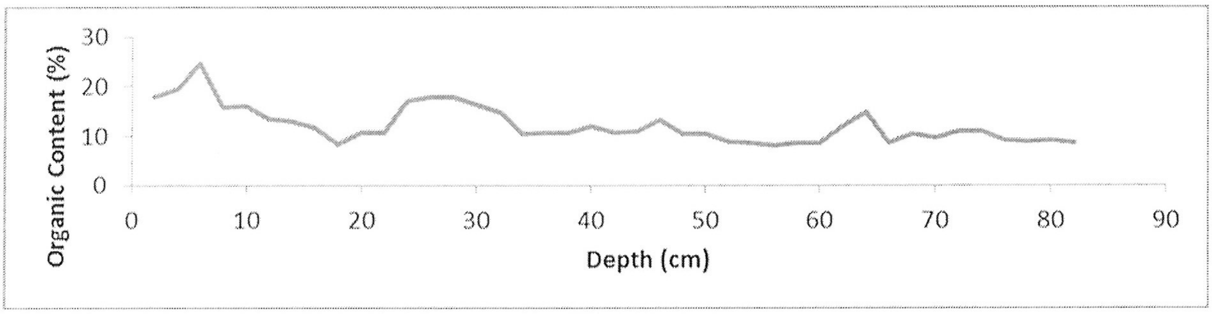


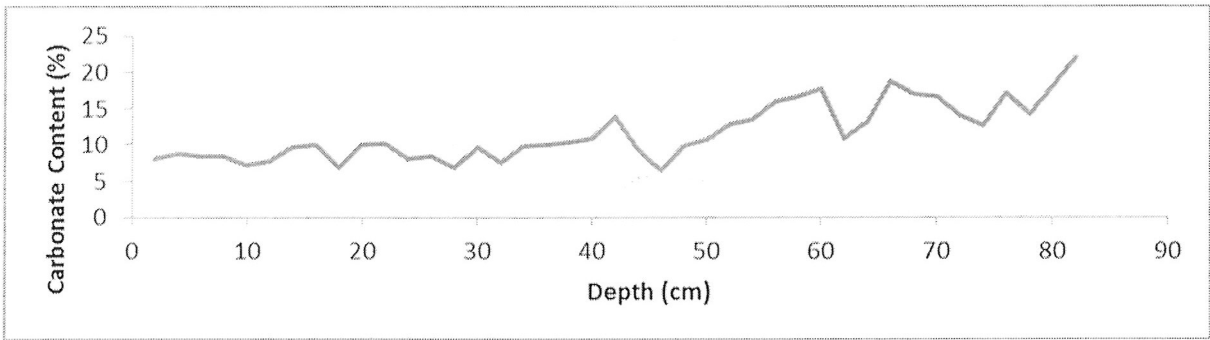


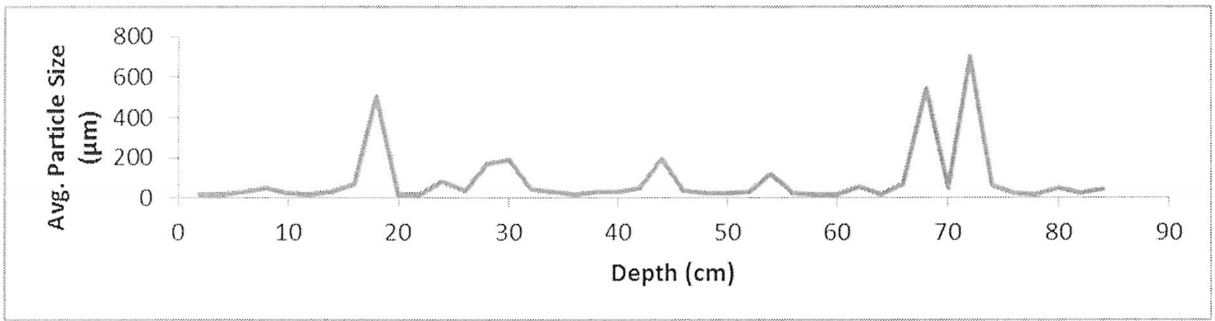
<u>Fig 4.2 – Core 2 Results</u>

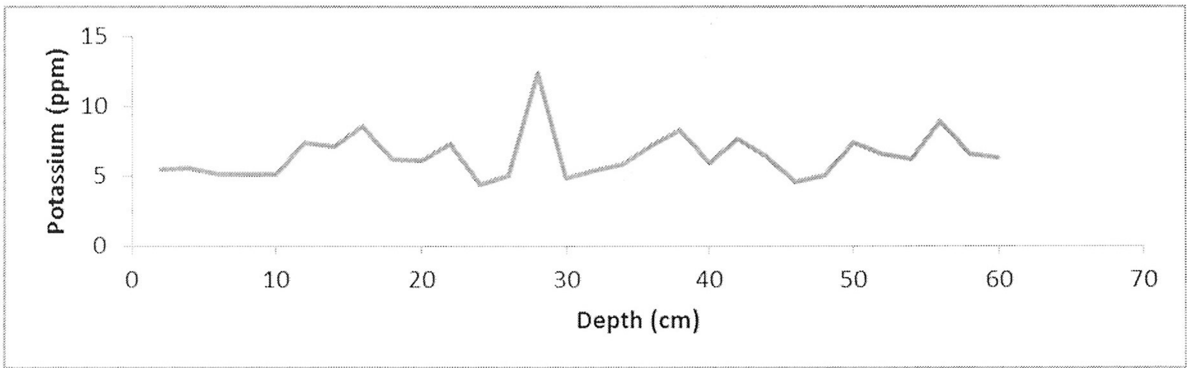



SI Units
Depth (cm)


Organic Content (%)
Depth (cm)


Carbonate Content (%)
Depth (cm)


Avg. Particle Size (µm)
Depth (cm)


Potassium (ppm)
Depth (cm)

Charcoal Count

Core 1

From the bottom of the core (134cm) up to approximately 100cm, the number of charcoal fragments is low (below 20 fragments per sample). Between 100cm and 90cm there is a sharp increase in charcoal fragments (up to 36 fragments) before a gradual decline begins between 90cm and 60cm. At approximately 60cm, charcoal fragments spike in the space of a few centimetres, with up to 62 charcoal fragments present at its peak, before rapidly declining to four fragments at 56cm. At depths between 56cm and 38cm, charcoal fragments vary dynamically. Three peaks in charcoal exist at 50cm, 44cm and 38cm respectively. At 38cm, a small drop in charcoal is followed by a rapid increase in charcoal (up to 104 fragments) between 36cm and 22cm. After 22cm depth, charcoal rapidly declines to 16 fragments at 16cm depth. A small incline is found at 16cm, before declining at 10cm to two charcoal fragments found at 2cm depth.

Core 2

Core two follows a similar pattern of results to core 1. From the bottom of the core (84cm) up until 64cm, there is a small increasing trend in the number of charcoal fragments, with two distinct troughs at 80cm and 74cm of around 25 and 30 charcoal fragments, respectively. At 60cm, a similar amount of charcoal fragments as in core 1 are found. However, this is not shown as a peak like in core 1, as it is preceded by a higher charcoal amount at 64cm depth. From 60cm up until 50cm, charcoal fragment count is quite low, hovering around fragments per sample. At 50cm depth, until 22cm depth, charcoal count increases in a gradual fashion compared to core 1. Between these depths, noticeable troughs are present at 40cm, 30cm and 24cm. At 22cm, charcoal count reaches its peak at 277 fragments. Charcoal fragments begin to decline at this point, up until 18cm, where resurgence in charcoal is noticed. Between 18cm and 4cm, charcoal count reaches 190 fragments at its highest point (8cm) before declining to 58 fragments at 4cm. There is another small resurgence in charcoal fragments at 2cm (83 fragments).

Magnetic Susceptibility

Core 1

Magnetic susceptibility between depths of 134cm and 60cm remains relatively stable at low levels. A very small peak is noticeable at approximately 90cm, with a measurement of 0.2 SI. From 60cm depth, magnetic susceptibility becomes more variable. Between 60cm and 50cm, susceptibility is relatively stable. SI drops below zero at 48cm before sharply increasing to 0.57 SI at 44cm. Similarly at 40cm depth, SI drops below zero before sharply increasing again to 0.33 SI at 38cm. At 36cm, SI drops to 0.19 before rapidly increasing to 0.66 at 30cm where it is followed by a trough at 26cm. A spike appears at 20cm of 3.61 SI before declining rapidly to 0.69 SI at 18cm. Two more peaks are noted at 10cm and 4cm, respectively.

Core 2

Results for core 2 show similar trends to core 1 in magnetic susceptibility albeit on a smaller scale. Between 84cm and 46cm, magnetic susceptibility remains stable. Two small peaks are visible at 80cm and 76cm depth. At 46cm, magnetic susceptibility begins to increase rapidly to 0.45 SI at 36cm depth, before declining to 0.36 SI at 36cm. Susceptibility sharply climbs to peak at 24cm before decreasing to 0.24 SI at 18cm, creating a sustained peak between 46cm and 18cm depth. Susceptibility begins to gradually increase between 18cm and 2cm, with peaks noted at 14cm and 8cm, similar to core 1.

<u>Organic Content</u>

Core 1

Organic content within core 1 shows little variation along the core length. From the base of the sediment core, a decreasing trend in organic content is apparent with a gradual decline from 13% organic content at 114cm to 8% at 68cm. There are fluctuations of organic content between these depths with minor peaks noted at 106cm, 90cm, and 74cm. At 62cm, organic content reaches its lowest point at ~4%. A rapid increase begins where a peak is reached at 58cm of ~12%. At 56cm, organic content begins to increase gradually until 22cm. At 20cm, organic content increases sharply until its peak of 28% at 4cm depth. A peak is noticeable between these depths at 14cm where organic content reaches ~27% before sharply decreasing to ~21% at 10cm depth, creating a natural peak.

Core 2

Core 2 follows a similar pattern of organic content in core 1, though anomalies are more apparent in the former. From the base of the core (84cm) to 68cm, there is a small increasing and gave away sniper *(and other firing positions)*locations (Davis, 1943). Other *(chemically based)* explosives, such as nitro-glycerine, guncotton and cordite, were also developed during similar periods of time, along with developments in explosives used in the mining industry, *(see above)* which sent black powder into decline.

In core 2, there is resurgence in charcoal that begins at 18cm depth. This could be related to the initiation of World War One. Black powder production at this time may have been limited due to the upgrade in propellants technology during the last century primarily the introduction of smokeless powder would have overtaken from black powder. Yet, gunpowder production has increased during times of conflict, most notably the Napoleonic Wars, though this could be missing from the palaeoenvironmental data. However, this resurgence is only prominent in core 2 (Fig 5.1) and adds doubt as to whether this small peak is related to gunpowder production, though magnetic susceptibility in core 2 increases at a similar point in core 2, supporting the notion that gunpowder production increased in the 20^{th} century.

Though one peak of charcoal is shown, a wholly accurate record that encompasses the majority of the history of the gunpowder mills would include another peak prior to the one shown in the charcoal graphs. Before the on-site production of charcoal commenced in 1831, the production of black powder experienced its first success during the time of the Napoleonic Wars. This war increased the demand five-fold up from ~1,000 barrels pre-1809 to 22,000 barrels at its peak in 1815 (Simmons, 1963; Crocker, 2002, Royal Gunpowder Mills website, 2009). After this period, it then experienced a slump in production to just ~2,000 barrels just a few years after the defeat of Napoleon Bonaparte (Simmons, 1963; Crocker, 2002). As on-site charcoal production did not being until 1831, this event has only provided half of the gunpowder mills history as palaeoenvironmental evidence.

(The internal canal system developed gradually over a long period. The Lee Navigation gradually replaced the Old River Lea from the late 1760's. (see my website http://www.leeandstort.co.uk/)) Production of charcoal eventually moved to Waltham Abbey in 1831 as William Congreve, *(the first)* director of the gunpowder mills between 1789 *(1787)* and 1828 *(1814),* noted that a change in how charcoal was produced (switching from pit production to cylindrical *(cylinder)* production) increased the efficiency of gunpowder (Winters, 1887). *(Congreve did more than note, he oversaw an extensive programme of experiment and development of the cylinder method)*Thus, due to the movement of charcoal production to an on-site status, it is more likely that the charcoal increase correlates with this movement, dating this particular point to 1831 (Fig 5.1).

The increase in charcoal between ~40cm and ~20cm is quite sharp and could therefore be related to an increase in gunpowder production in response to the mining boom (Fig 5.1). *(All production at the Mills since 1789 was for military use – not commercial)*After 1831, gunpowder production was still relatively low due to no conflict. During this period, the likes of guncotton and nitro-glycerine were first being discovered, paving the way for a development in explosives and their efficacy. However, by 1870 it had been reported that ~27,000 barrels *(of what?)* had been produced by 150 employees operating 32 mills (Royal Gunpowder Mills website, 2009). The most likely reason that accounts for this dramatic increase in charcoal abundance is that production was stepped up to help sustain an increasing demand for coal during the industrial revolution, as it was a cheaper, more efficient fuel to power steam engines than wood fuel (Beck, 1999). Waltham Abbey had established itself as a leader throughout the military and civil sectors in Britain by becoming a leader in manufacturing propellants and explosives, and its technological developments and innovations had become widely distributed through these sectors (Tucker, 2001).

The decline in charcoal from ~20cm in both graphs can be attributed to the change in explosive technology from the mid-19th century. Following the boom of the demand needed of gunpowder for the mining, quarrying, tunnelling and railway construction, *(see above)* production fell into decline due to the development in propellant and explosives technology. In 1875, Alfred Nobel gelatinised collodion cotton *(with nitroglycerine)* as blasting gelatine which is 25% more powerful than Dynamite (Royal Gunpowder Mills website, 2009) a perfect substitute for gunpowder. In 1884, Paul Vielle produced the first smokeless powder after military commanders, since the Napoleonic Wars, had been complaining that the smoke produced after the combustion of gunpowder inhibited the use of signals on the battlefield, Charcoal

Without the aid of ^{14}C dating, placing dates on the charcoal record were increasingly difficult. The first significant peak in charcoal is prevalent in core 1 at ~56cm depth (Fig 4.1). Compared to charcoal levels before and after this peak, this level of charcoal has exceeded background concentrations. With little information on dating the base of the core, it is difficult to predict an age of this peak and with it, a suitable explanation. One possibility comes from the production of Iron in the 14th century. An iron smelting house was discovered and excavated in 1972 on the outskirts of Waltham Abbey but within the boundaries of the Waltham Abbey church, suggesting that an old iron industry or forge once existed (Huggins, 1973). For the iron industry to exist, fuel was needed in the form of trees, subsequently producing charcoal. However, this peak does not occur at a similar depth in core 2 thus, the peak of charcoal leaves two other possible explanations. Either core distortion was at fault for the creation of this unknown peak, or an unaccounted, natural fire may have provided the charcoal that has resulted in this anomaly.

A second, more significant begins in both cores at ~40cm depth and continues until ~20cm. This peak in charcoal is represented in both cores, though in core 1, the number of charcoal fragments is significantly less than core 2 and could be due to the increased distance from the river (Gale and Hoare, 1991). The incline in charcoal fragments is significantly higher when compared to the rest of the chart suggesting that a major event has occurred during this time period. As no major fires, natural or human induced, were recorded, it can be assumed that the charcoal present has resulted from gunpowder production. As with other studies that are based around charcoal used as a proxy for human induced events (Mann, 2008; Mieth and Bork, 2010) an increase in charcoal that is above background levels is considered to be the start of an anthropogenic incident. It can be assumed that the first major increase in charcoal can be closely associated with the beginning of the gunpowder industry in the 16th century.

However, this assumption can be proved incorrect as charcoal was not produced on-site or in the surrounding area of the gunpowder mills since its inception. All gunpowder ingredients were originally imported along the Old River Lea into the Millhead Stream and into the canal system of the Royal Gunpowder Mills *(or locally sourced charcoal and saltpetre could have been delivered by wagon)*, though sulphur was imported via the East India Company, *(the Mills sulphur came from Sicily,)* whilst charcoal and saltpetre (*All saltpetre ultimately came from Bengal via the East India Company)*were imported from local areas (Fairclough, 1985).

24μm at 120cm. This remains stable until 105cm where particle size decreases slightly to 18μm at 100cm. Between 100cm and 90cm, particle size increases slightly, where at 85cm, particle six increases rapidly and peaks at 115μm at 80cm depth. After a rapid decrease in particle size at 75cm, particle size peaks again at 58cm before stabilising between 56cm and 42cm. Particle size becomes increasingly variable between 42cm and 2cm, with numerous peaks present in small intervals. Peaks occur at 38cm, 34cm, 24cm, 18cm, 12cm, and 6cm, with all peaks, except the peak at 6cm, having a particle size of approximately 80μm.

Core 2

Core 2, in comparison to core 1, is not as variable in particle size, though numerous peaks are apparent in the data set. From the bottom of the core at 84cm depth, to 74cm depth, particle size is relatively stable and low at approximately 20μm. At 74cm, the first peak of a double peak begins and peaks at 702μm at 72cm. Particle size diminishes quickly at 70cm before creating the second peak at 542μm at 68cm. Particle size rapidly decreases to approximately 20μm at 64cm depth, before stabilising up until 56cm depth. At this point, particle size creates another, smaller peak, increasing to just over 100μm average size. At 52cm, particle size normalises until 46cm where it peaks at approximately 200μm. Particle size diminishes and stabilises once again between 42cm and 32cm, before peaking at 32cm at approximately 190μm. Average particle size gradually decreases until 20cm, where it increases sharply to peak at approximately 500μm at 18cm depth. Particle size then decreases and stabilises at approximately 20μm between 16cm and 2cm, save for a minor peak at 6cm.

Potassium Determination

Core 2

Due to time constraints, a cation exchange analysis was conducted on samples collected between 0 and 60cm from core 2 to determine potassium levels at varying depths. From 56cm depth to 30cm depth, potassium level fluctuate between ~9ppm and ~4.5ppm, with peaks occurring at depths of 56cm, 50cm, 42,cm and 38cm. At 28cm depth, potassium levels sharply increase to the highest level within the dataset at 12.34ppm. Potassium decreases to ~4ppm at 24cm, before fluctuating between ~4ppm and ~8.5ppm between 24cm and 2cm, with peaks occurring at 22cm, 16cm and 12cm, respectively.

Analysis

trend in organic content. At 66cm depth, a small sustained peak occurs, rising to 15% organic content at 64cm, before decreasing to ~9% at 60cm. This peak occurs at a similar depth to a peak occurring in core 1. Organic content shows a slight increasing trend from 60cm until 34cm. There are two minor peaks that may be noted at 46cm and 40cm depths, respectively. At 34cm, a large sustained peak begins, with organic content reaching its peak of ~18% at 26cm. Organic content sharply declines to its lowest of ~8% at 18cm depth, which is not apparent in core 1. An increase in organic content begins at 18cm, peaking at ~25% at 6cm depth. This sharply declines to ~18% at 2cm depth.

Carbonate Content

Core 1

Core 1 shows a decreasing trend in carbonate content across the entire length of the core. Carbonate content rapidly decreases between 134cm and 116cm. At 116cm to 94cm, carbonate content increases to ~20%. Another sharp decrease is noted at this point, dropping to below 10%. The next notable decrease in carbonate content is at 62cm depth where, after gradually decreasing between 92cm and 66cm, carbonate content rapidly declines to ~6%. From 58cm to 2cm depth, there are few noticeable peaks or troughs within the sediment core. A small, sustained trough is visible between 48cm and 36cm, and two peaks at 24cm and 16cm, respectively, are also noticeable.

Core 2

Core 2 follows a similar, negative trend across the core length when compared to core 1. The first trough occurs between 84cm and 76cm where carbonate content reaches its lowest at ~13%. At 64cm, similar to core 1, carbonate content decreases rapidly to ~11%. From 60cm to 46cm, carbonate content declines at a significant rate, to ~6% at its lowest, before increasing to ~14% at 44cm depth. Between 38cm and 2cm, carbonate content stabilises at ~8%. The final noticeable trough occurs at 20cm, decreasing to ~7%. It is most noticeable because before and after this depth, carbonate content is stable at ~10%.

Particle Size

Core 1

Core 1 shows that particle size appears to be quite varied along the entire length of the core sample. From 130cm to 125cm there is a sharp decrease in particle size before increasing to

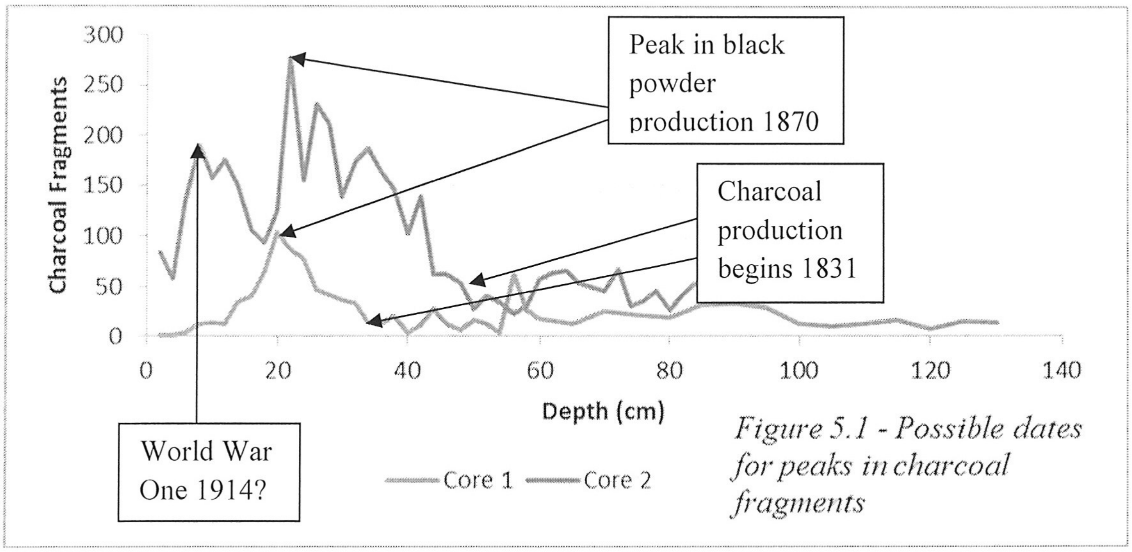


Figure 5.1 - Possible dates for peaks in charcoal fragments

<u>Potassium Determination</u>

Results in potassium determination have provided interesting information. The major peak of the data set occurs at ~28cm depth at 12.34 ppm. This roughly coincides with the increased peaks in charcoal, occurring at ~28cm depth, which can be related to the increase in demand for gunpowder during the latter half of the 19th century (Fig 5.2). However, it is difficult to analyse whether the major peak at this point is anthropic or a natural variation in potassium within the soil. Fluctuations before and after this peak suggest that the potassium available for cation exchange at 28cm is above normal as potassium varies between 4ppm and 8ppm. According to Barrett et al. (1973) potassium within clay samples may become "fixed" to clay minerals becoming unavailable for plant growth. As the underlying geology of the study site is London Clay, the floodplain alluvium is similar in substance. Thus, it is possible that the data set may be inaccurate as potassium at varying depths may be fixed to clay particles and are not readily available for measurement.

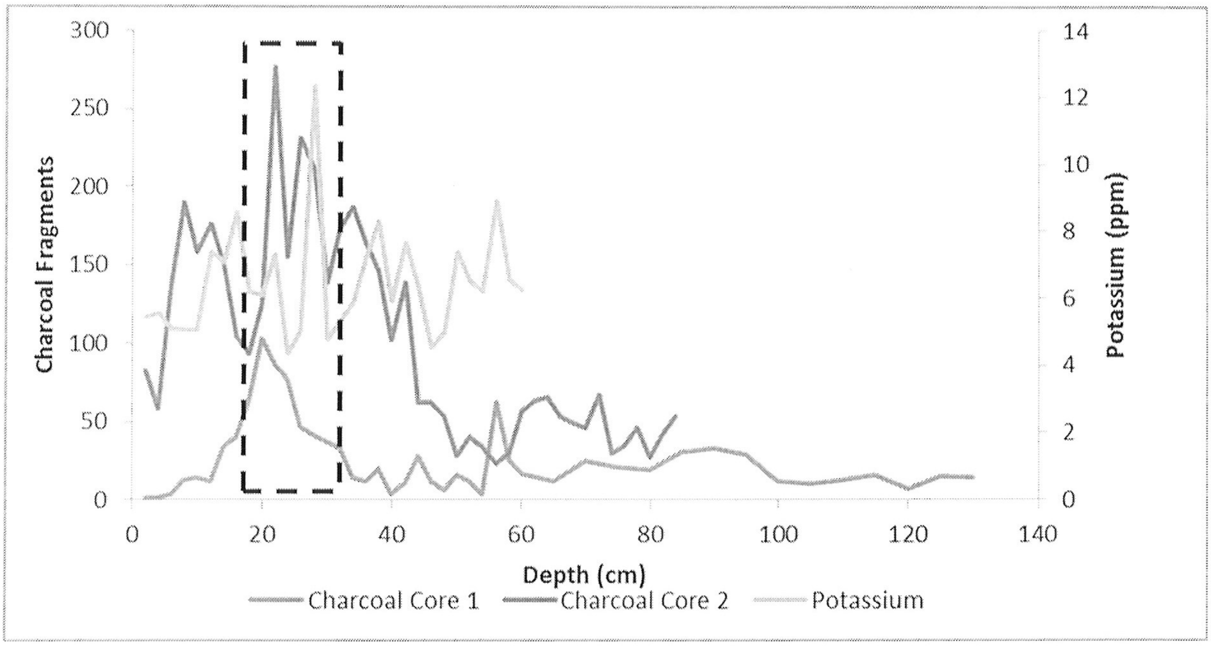


Figure 5.2 – Correlation between Potassium and Charcoal peaks

Magnetic Susceptibility

Mass specific magnetic susceptibility of the core sediment samples is expected to be a probable indicator for deforestation due to the consequent erosion of sedimentary material. The precipitated material can be used as an indicator for how extensive deforestation was at the time of erosion. Both cores show little change in magnetic susceptibility from the base of their cores up until ~40-50cm (Fig 5.3). After this point, both cores experience major changes in magnetic susceptibility, albeit on different scales. Core 1 shows one sharp increase at ~20cm depth, whereas core 2 experiences a sustained peak between ~40cm and ~20cm. These increases in magnetic susceptibility are likely to correspond with the coppicing of woodland on site post-1831, when charcoal production was moved on site. With demand ever increasing for gunpowder for the mining industry during the industrial revolution (Tucker, 2001), it is probable to assume that the peaks in magnetic susceptibility are correlated to the intensive coppicing of trees for charcoal.

Magnetic susceptibility can also be used in conjunction with charcoal analysis. This is apparent in both cores as both sets of graphs corroborate. Haematite in the soil can be converted to magnetite when heated in the initial phases of combustion (Gale and Haore, 1991). Magnetite can also be the end product of burning (Longworth et al. 1979), suggesting that the intensive coppicing produced a large amount of charcoal as a consequence for the increased demand in the mining and railway industry during the Industrial Revolution.

Charcoal increases at similar depths in both cores, arguing in favour for the theory that magnetic susceptibility and charcoal production are intimately linked.

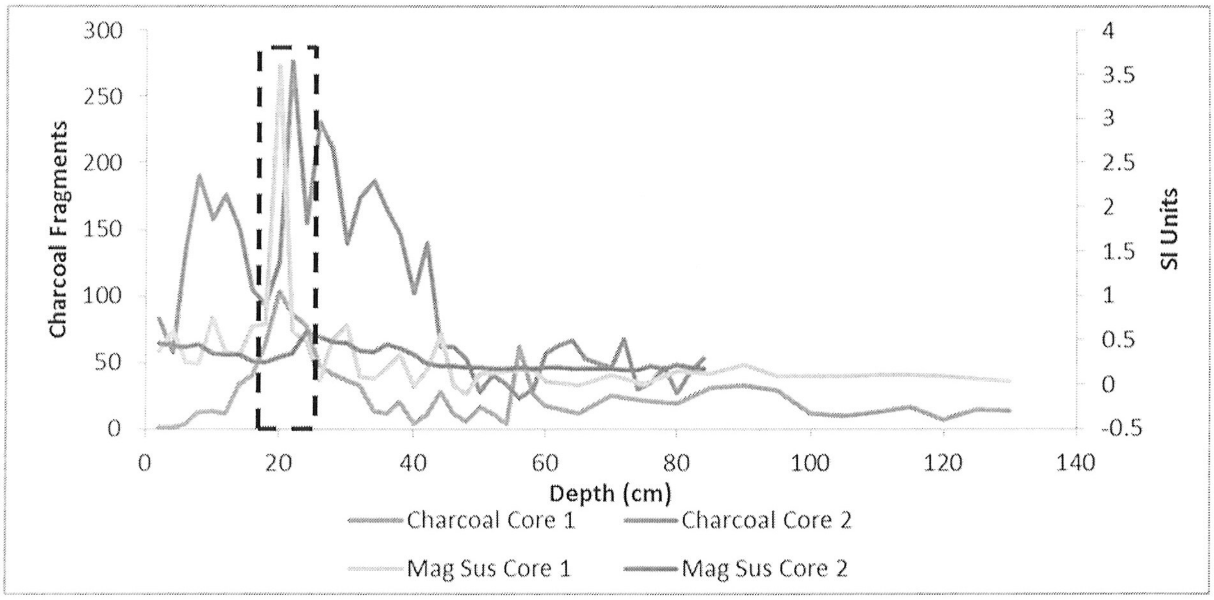


Fig 5.3 – Correlation between Magnetic Susceptibility and Charcoal peaks

<u>Loss on Ignition</u>

Using the loss on ignition method to measure the organic content percentage within soils should show an increase in gunpowder production related to the coppicing of trees for charcoal (Fig. 5.4). At ~30cm depth, a rounded, sustained peak is prevalent up until ~20cm depth. This peak could be correlated with the increased demand for gunpowder production. A similar peak is less noticeable in core 1. A sharper increase is noted at ~20cm depth. However, though it declines marginally afterwards, it sharply increases again. This may be due to the depth of the present organic layer. Organic layers can vary with depth depending on different factors, such as, the amount of decomposing material available (Klass and Verstraten, 2003).

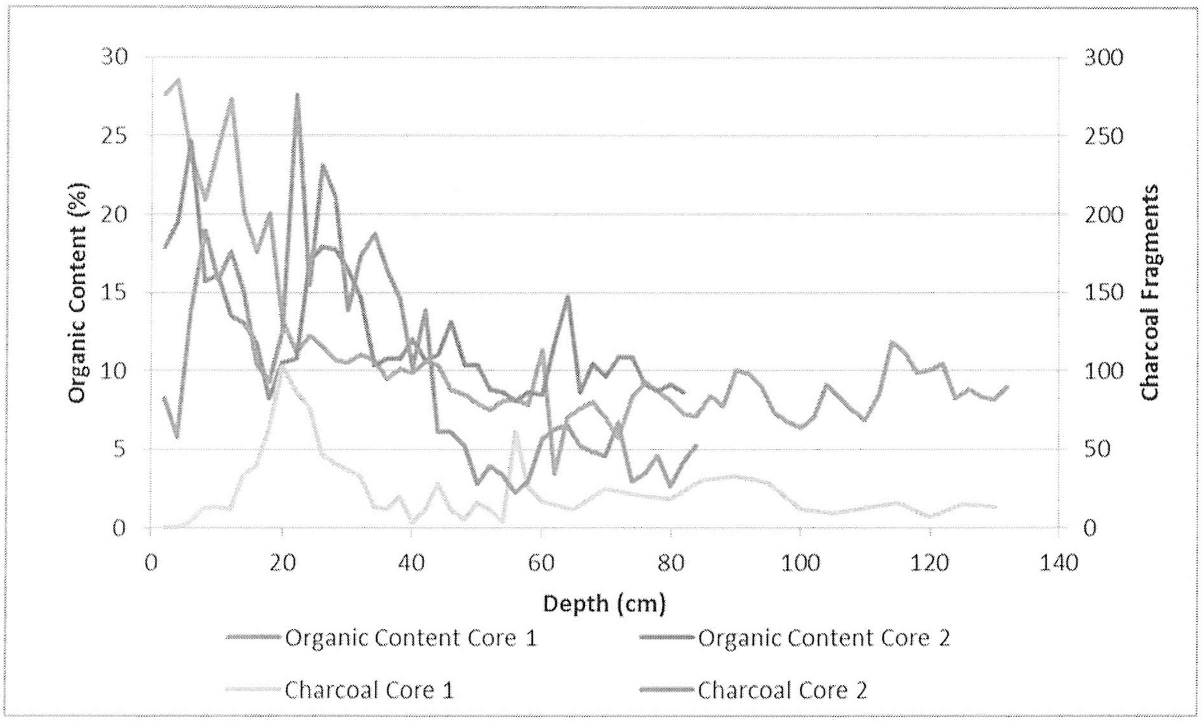


Figure 5.4 – Little correlation between Organic Content and the number of Charcoal Fragments

A second peak is noticeable in both cores at ~60cm depth, where sharp increases are recorded (Fig. 5.5). Increases in organic content at this depth suggest that the surrounding landscape experienced an increase in organic matter. The increase, however, appears before the main charcoal increase and suggests two possibilities. Firstly, that the increase in organic matter may have been attributed to the pre-empting of moving charcoal production on site, which provides a potential date of post-1800 but pre-1831. Yet, it cannot be ruled out that this has no relation to gunpowder production and could be corroborated with other external factors, for example, a change in climate would increase or decrease organic matter (Nesje and Dahl, 2001; Arsenault et al., 2007).

Carbonate content in both cores follow a similar decreasing trend towards the surface of the core. Peaks and troughs occur at similar depths throughout the length of each core. At 60cm depth, carbonate content decreases with organic content. This suggests either i) this is a short period of deforestation that may encompass the beginning of the gunpowder industry in the 17th century or ii) it suggests a short cold snap in climate. No other evidence found in the results correlate to the gunpowder industry.

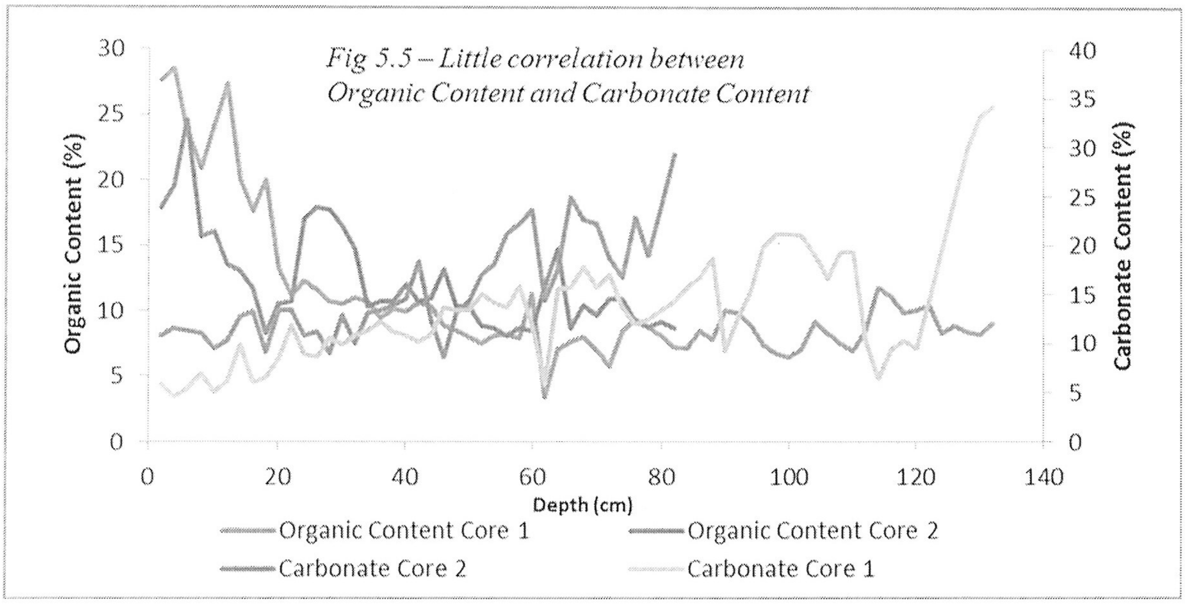


Fig 5.5 – Little correlation between Organic Content and Carbonate Content

Particle Size

Particle size can be important to a palaeoenvironmental study as it provides important stratigraphical markers that can help with the dating of core samples. Both core samples have provided various peaks that can aid with dating, as well as offering further evidence that supports the notion that gunpowder production can be reconstructed using palaeoenvironmental proxies. However, it is apparent in both cores that results do not match with each other fully. Only three peaks from both cores correlate at ~80cm, ~24cm and ~18cm, though each core provides different results of average particle size (for example, core 1 was taken further from the river than core 2 which accounts for the difference in average particle size results). The most relevant peaks, ~24cm and ~18cm depth, can be related to the coppicing of trees for charcoal production, as this would result in an increase in particle size (Gale and Hoare, 1991). Similarly, these peaks loosely correspond to results found in the magnetic susceptibility analysis (Fig. 5.6). It has been documented that an increase in particle size would provide an increase in magnetic susceptibility (Lowe and Walker, 1994). Both cores correlate similarly between magnetic susceptibility and particle size, suggesting the increase in particle size was due to the coppicing for charcoal.

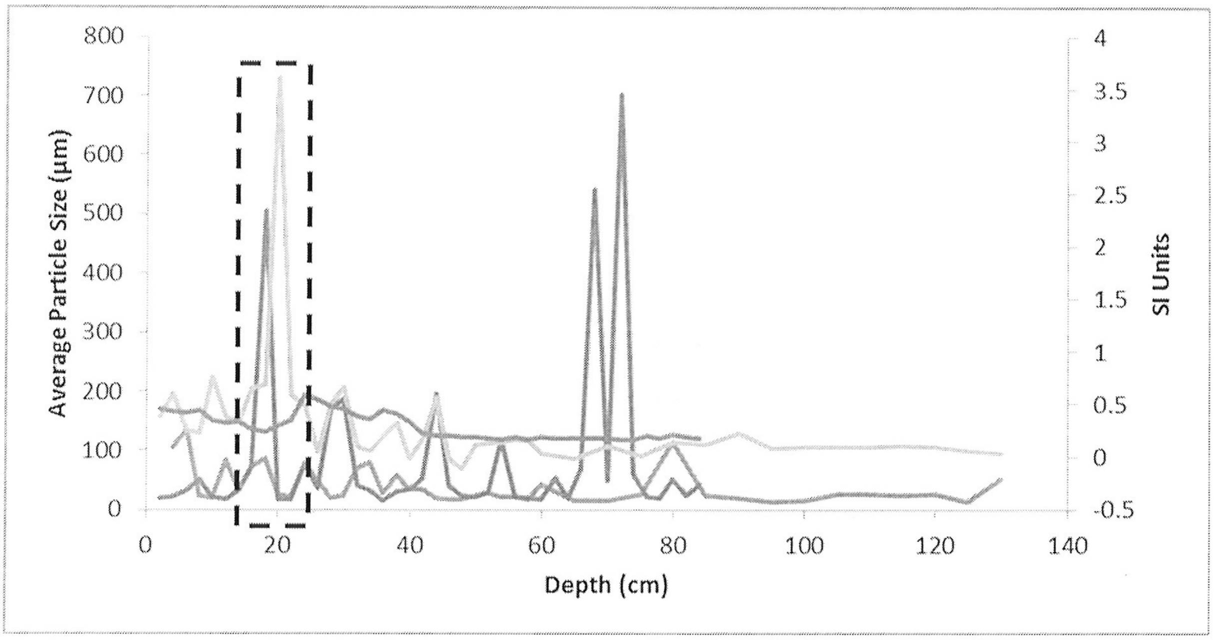


Figure 5.6 – Correlations between Magnetic Susceptibility and Particle Size

The random increases in particle size have provided a question of uncertainty around this debate: has consistent flooding altered the evidence available for gunpowder production? It is possible for constant flushing of material to alter the evidence that has been found. However, other proxy results object to this hypothesis. Evidence relating to any type of palaeoenvironmental study that may be conducted in the future would not be subjected to alteration through flooding, and that it would have the opposite effect by continually depositing material for analysis.

<u>Further Study</u>

Logistical constraints inhibited the measurement of total determination of potassium and such, an alternative method had to be prepared. An experiment on total potassium determination would have accounted for all potassium within the soil and most certainly would have provided greater, more accurate results relating to the Royal Gunpowder Mills and its production than the method used in this study.

Due to the unavailability of facilities that can provide accurate dating for ^{14}C, dating both core sequences have been difficult as stratigraphical data has also been lacking due to the composition of the sediment cores being very similar along the entire length of each core. I feel that if ^{14}C dating was available, questions could have been answered more thoroughly and precisely than the study has provided.

Future studies that build upon information provided in this report could look into a palaeoecological analysis that could help with further dating of core samples. Palaeoecological studies can look for changes in landscape that can provide essential dating when cross referenced with other works. For example, palaeoecological studies can be used in conjunction with Loss on Ignition testing as a change in palaeoecology that are more suited to wetlands would correspond with changes in organic and carbonate content of an area.

Conclusion

This study has sought to provide a foundation for further palaeoenvironmental studies in the Lea Valley area by reconstructing the history of the Royal Gunpowder Mills. Two cores have been carefully reconstructed with results being analysed with caution. Thorough assessments of both cores have provided a part reconstruction of the history of the mills. Charcoal analysis and magnetic susceptibility provide assumptions that suggest the whole history can be reconstructed. However, archival evidence contradicts this as charcoal should only increase post-1831, due to the commencing of on-site charcoal production. Core 1 concurs with this hypothesis, suggesting a twin peak reconstruction in these proxies. Core 2 contradicts this by providing twin peaks across a similar time frame. However, the twin peak in core 2 has most likely been caused by either distortion of the core, non deposition or erosion, or redistribution by bioturbation or microbial activity (Farmer, 1991).

Organic and carbonate content, potassium determination and particle size have provided challenging evidence. A decrease in organic content is not apparent during periods of intense production, whilst potassium determination, though it shows an increase at a similar depth concurring with intense production, it is incorrect to propose if the two correlate, due to logistical constraints with sample preparation. Particle size is difficult to interpret in fluvial systems. However, particle size does increase during the factory's most intensive period. In conclusion, core reconstructions have provided a useful insight into the anthropogenic effect the Royal Gunpowder Mills has incurred on the surrounding landscape, as well as providing a stepping stone for future palaeoenvironmental studies around the River Lea.

Appendix

Bibliography

Alloway, B. J. and Ayres, D. C. (1997) *Chemical Principles of Environmental Pollution.* Chapman and Hall, Suffolk.

and W.M. Last, eds., *Tracking Environmental Change Using Lake Sediments. Volume 3:*

Arsenault, T. A.; Clague, J. J. & Mathewes, R. W. (2007) 'Late Holocene vegetation and climate change at Moraine Bog, Tiedemann Glacier, southern Coast Mountains, British Columbia' in *Candian Journal of Earth Sciences* **44**: 707-719.

Barrett, W. B.; Engle, C. F. & Smith, R. M. (1973) 'Factors Influencing the Levels of Exchangeable Potassium in Gilpin and Cookport Soils' accessed via http://www.archive.org/stream/factorsinfluenci622barr/factorsinfluenci622barr_djvu.txt on 12/1/2011

Beck, R. B. (1999) *World History: Patterns of Interaction.* Evanston, Illinois.

Berglund, B. E. (1986) *Handbook of Holocene Palaeoecology and Palaeohydrology.* John Wiley and Sons, London.

Buchanan, B. J. (2006) *Gunpowder, explosives, and the state: a technological history.* Ashgate Publishing Limited, Aldershot.

Candidate No. 90967 (Year Unknown) *Geography Undergraduate Thesis - A Palaeoenvironmental Reconstruction of the Hamble Estuary: A Record of the Anthropogenic Impact.* University of Sussex.

Catt, J. (2011) *Introduction to the Geology of Hertfordshire: Geology on your Doorstep* accessed at http://www.hertsgeolsoc.ology.org.uk/IntroToHertsGeology.htm on the (11/1/2011).

Chambers et al. (1996) 'Early Holocene pollen and molluscan records from Enfield Lock, Middlesex, UK' in *Proceedings of the Geologists Association*, 107, 1-14.

Crocker, G. (2002) *The History of Gunpowder*. Shire Publications, Buckinghamshire.

Cundy, A. B.; Collins, P. E. F.; Turner, S. D.; Croudace, I. W. & Horne, D. (1998) '100 years of environmental change in a coastal wetland, Augusta Bay, southeast Sicily: evidence from geochemical and palaeoecological studies' in *Geological Society, London, Special Publications* **139**: 243-254.

Davis, T. L. (1943) *The Chemistry of Powder and Explosives*. Angriff PR. California.

Dean, W. E. Jr. (1974) 'Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods' in *Journal of Sedimentary Petrology* **44**: 242-248.

Dean, J. R. (1998) *Extraction Methods for Environmental Analysis*. John Wiley and Sons, Chichester.

Dearing, , J. A. (1983) 'Changing patterns of sediment accumulation in a small lake in Scandia, southern Sweden' in *Hydrobologia* **103**: 59-64.

Fairclough, K. (1985) 'Early gunpowder production at Waltham' in *Essex Journal* **20** (1).

Farmer, J. G. (1991) 'The perturbation of historical records in aquatic sediments' in *Environmental Geochemistry and Health* **13**: 76-83.

Flenley, J.R. & King, S.M. (1984) 'Late Quaternary Pollen Records from Easter Island' in *Letters to Nature* 307: 47-50.

Flower, R. J.; Dearing, J.D.; Rose, N. L.; Patrick, S. T. (1992) 'A palaeoecological assessment of recent environment change in Moroccan wetlands' in *Wurzburg Geogr Arb*, **84**: 17 – 44.

Gale, S.J. and Hoare, P.G. (1991) *Quaternary Sediments.* Belhaven Press, London.

Gibbard, P. L. (1994) *Pleistocene History of the Lower Thames Valley.* Cambridge University Press, Cambridge.

Huggins, P. J. & Huggins, R. M. (1972) *Waltham Abbey: Excavation of Monastic Forge and Saxo Norman Enclosure 1972-73*. Essex Archaeology and History, Essex.

Hull, G. (2001) *Deephams Sewage Treatment Works, Ardra Road, Edmonton, London Borough of Enfield: An Archaeological Evaluation for Kennet Properties Ltd.* Accessed at www.tvas.co.uk/reports/pdf/00-43summary.pdf

Jarvis, K. E. et al. (2003) *Handbook of Inductively Coupled Plasma Mass Spectrometry.* Viridian Publishing, Surrey.

Kelly, J. (2005) *Gunpowder: The History of the Explosive that Changed the World.* Atlantic Books, London.

Longworth, G. et al. (1979) 'Mossbaur effect and magnetic studies of secondary iron oxides in soils' in *The Journal of Soil Science* **30**: 93-110.

Lowe, J. J. and Walker, M. J. C. (1997) *Reconstructing Quaternary Environments*. Longman Group Ltd., Harlow.

Lucy, G. (1999) *Essex Rock: A Look Beneath the Essex Landscape*. Published by Essex Rock and Mineral Society, Essex.

Mann, D., et al (2008) 'Drought, vegetation change, and human history on Rapa Nui' in *Quaternary Research*, 69: 16-28.

Marsh, E. G. & Mclaren, M. (1982) 'A short history of gunpowder and the role of charcoal in its manufacture' in *The Journal of Materials Science* **17**: 3385-3400.

Mieth, A. & Bork, H.R., (2010). 'Humans, climate or introduced rats – which is to blame for the woodland destruction on prehistoric Rapa Nui' in *Journal of Archaeological Science*, 37: 417-426.

Needham, J. (1986) *Science & Civilisation in China: The Gunpowder Epic.* Cambridge University Press, Cambridge.

Nesje, A & Dahl, S. O. (2001) 'The Greenland 8200 cal. yr. BP event detected in loss on ignition profiles in Norwegian lacustrine sediment sequences' in *Journal of Quaternary Science* **16** (2): 155-166.

Nierop, Klaas G. J.; Verstraten Jacobus M. (2003), 'Organic matter formation in sandy subsurface horizons of Dutch coastal dunes in relation to soil acidification' in *Organic Geochemistry* **34** (4): 499–513.

Percival, A. (1969) 'The Faversham gunpowder industry (part 1)' in *Industrial Archaeology* **5**: 1-42.

Reeve, R. (2002) *Introduction to Environmental Analysis*. John Wiley and Sons, Chichester.

Sumbler, M. G. (1996) *London and the Thames Valley*. British Regional Geology series (4th ed.).

Tucker, L. (2001) 'The Royal Gunpowder Mills – Waltham Abbey: Notes and News April 2001' accessed at http://www.glias.org.uk/news/193news.html on [4/2/2011].

Wallingford, H. R. (2006) Faversham Creek Navigation Study commissioned by Swale Borough Council.

Warren, S. H. (1912) 'On the Late Glacial Stage in the Valley of the River Lea, subsequent to the Epoch of River-drift man' in *Quarterly Journal of the Geological Society* **68**: 213-228.

Wheeler, J.; Swindles, G. T.; and Gearey, B. R. (2011) 'Finding Bosworth Battlefield: a multiproxy palaeoenvironmental investigation of lowland sediments from Dadlington, Leicestershire, England' in *Journal of Archaeological Science* **37**: 1579-1589.

Whitlock, C. and C. Larsen (2001) 'Charcoal as a fire proxy' in J.P. Smol , H.J.B. Birks and Last, W. M. *Tracking Environmental Change Using Lake Sediments: Terrestrial, Algal and Siliceous Indicators (Volume 3)* Kluwer Academic Publishers, Netherlands.

Whitlock, C. and Millspaugh, S. H. (1996) 'Testing assumptions of fire history studies: an examination of modern charcoal accumulation in Yellowstone National Park' in *The Holocene* 6: 7-15.

Willcox, G. (1999) 'Charcoal analysis and Holocene vegetation history in Southern Syria' in *Quaternary Science Reviews*, Special issue INQA symposium Ankara, the late Quaternary in the Eastern Mediterranean, 711-716.

Willcox, G. (2000) 'Evidence for ancient forest cover and deforestation from charcoal analysis of ten archaeological sites on the Euphrates' in Thiebault, S. *Charcoal Analysis: Methodological Approaches, Palaeoecological Results and Wood Uses,* 141-145.

Williams, M. et al. (1998) *Quaternary Environments*. Arnold Publishers, London

Winters, W. (1887) *Centenary Memorial of the Royal Gunpowder Factory, Waltham Abbey* (No publisher found).