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Mark Anthony Trickett

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DIET, HEALTH AND MIGRATION IN POST-MEDIEVAL COVENTRY AND CHELSEA THROUGH BIOGRAPHICAL RECONSTRUCTION, OSTEOARCHAEOLOGY AND ISOTOPE BIOGEOCHEMISTRY

by

Mark Anthony Trickett

Ustinov College

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Volume 1 of 1

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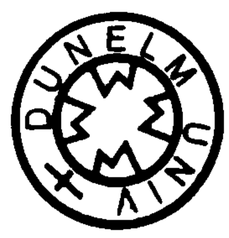
Department of Archaeology

University of Durham



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Abstract

Biogeochemical research has over the past four-and-a-half decades improved our understanding of human interaction with past environments. The application of different isotope systems has allowed archaeologists to interpret ancient diet, migration and pollution. Although well established in archaeology, biogeochemical interpretations are burdened with questions not only as to the methodology employed but also whether the data presents a consistent picture of past human activity. The use of biographically identifiable individuals offers a means by which the isotope systems may be tested against extent documentary evidence.

A sample of forty-five individuals, almost half of which were named individuals, were obtained from the sites of Holy Trinity (Coventry) and St. Luke's (Old Street, Chelsea) and the stable isotopes of carbon, nitrogen, oxygen, strontium and lead analysed. The biographies of the named individuals were reconstructed through analysis of extant historical documentation and used to provide a framework of interpretation for the biogeochemical techniques applied. Comparisons are made between the two sites in relation to the biogeochemical techniques employed, biographical reconstruction and osteoarchaeological evidence for disease, migration and diet to address methodological issues and broader questions on 'industrialisation' during the eighteenth and nineteenth centuries.

The osteoarchaeological evidence suggests separation of the two groups into discrete populations, one that is characterised by occupationally-derived osteoarthropathies (Coventry), and the second, Chelsea, which has an absence of these pathologies. This supports the historical character of the two cities: Coventry as an industrial city in contrast to Chelsea, a "village of palaces" or pleasure resort. Biogeochemically, carbon and nitrogen isotopes revealed a picture of status-based access to protein resources in a diet that is particularly dominated by freshwater fish, terrestrial omnivores such as pig, or a combination of the two. There is, however, little evidence for a difference in access to such resources between the sexes. Likewise, strontium and oxygen isotopes are capable of differentiating between the two populations and therefore in identifying local and migrant individuals, though limitations in the sample prevent the full utilisation of this data. In one case (Milborough Maxwell) the isotopic techniques were able to reveal trans-Atlantic migration between England and the Caribbean. Analysis of lead isotopes of the two populations indicates that while there is little to differentiate the two sites, heavy metal exposure is greater for the eighteenth and nineteenth centuries than for previous periods.

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Also, to all those unsung heroes whose fingers I most likely trod on in this journey. Grandmothers and friends alike. Finally, to K… *cariad*, and wife.

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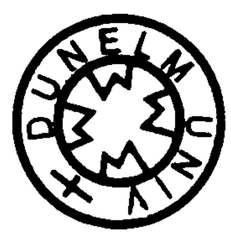

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Equation 2: Calibration of human biophosphate to surface/ground water. 273

1. Introduction

At its heart, archaeology revolves around the answering of five basic questions: 'who', 'what', 'where', 'when' and 'how'. Ultimately these questions address the provenance and cultural affiliation of a given artefact, and remain pertinent for most, if not all, material recovered from the archaeological record. Archaeometric studies of human remains are similarly constrained by these fundamental questions, even as they refine our understanding of the past. Yet previous studies have been inherently limited by the nature of the archaeological sample, primarily concentrating on prehistoric human remains that by their nature lack one fundamental piece of information: who. Without an awareness of the life history of a studied individual, inferences drawn from the archaeometric data are limited by an understanding of the observed patterns within previous studies. Thus, the use of an archaeological population of biographically identifiable individuals allows not only an original study of the populations themselves, but also a means by which the archaeometric theories may be tested against the historical record.

This project aims to address the variable of 'who', as well as the broader archaeological and methodological issues, through a number of original avenues of study. Firstly, the project utilises two populations of biographically identified individuals, in parallel with individuals for whom no biographical details have been determined, from two excavated post-medieval sites in the United Kingdom: eleven named and three un-named individuals from Holy Trinity, Coventry (mid-eighteenth to late-nineteenth century); and ten-named and twenty-one un-named individuals from St. Luke's, Chelsea (late seventeenth century to mid nineteenth century). Secondly, previous biogeochemical studies have either concentrated upon large populations, with a concomitant small number of isotopic systems utilised, or a small population with a larger number of isotopic systems (Katzenberg *et al.* 1995; Grupe *et*

al. 1997; Müller *et al.* 2003; Budd *et al.* 2004*a, b, c*). This study utilises five elements and their respective isotopic systems – carbon, nitrogen, oxygen, strontium and lead – in an attempt to provide a broader picture of the lives of the study population in terms of diet, migration and health. Finally, the project compares three separate, but inter-related, bodies of evidence: the historical record in the form of the biographies of the named sample; the archaeological record through the osteoarchaeological study of the human remains themselves; and, finally, the biogeochemical record in the isotopic analysis of bone and teeth.

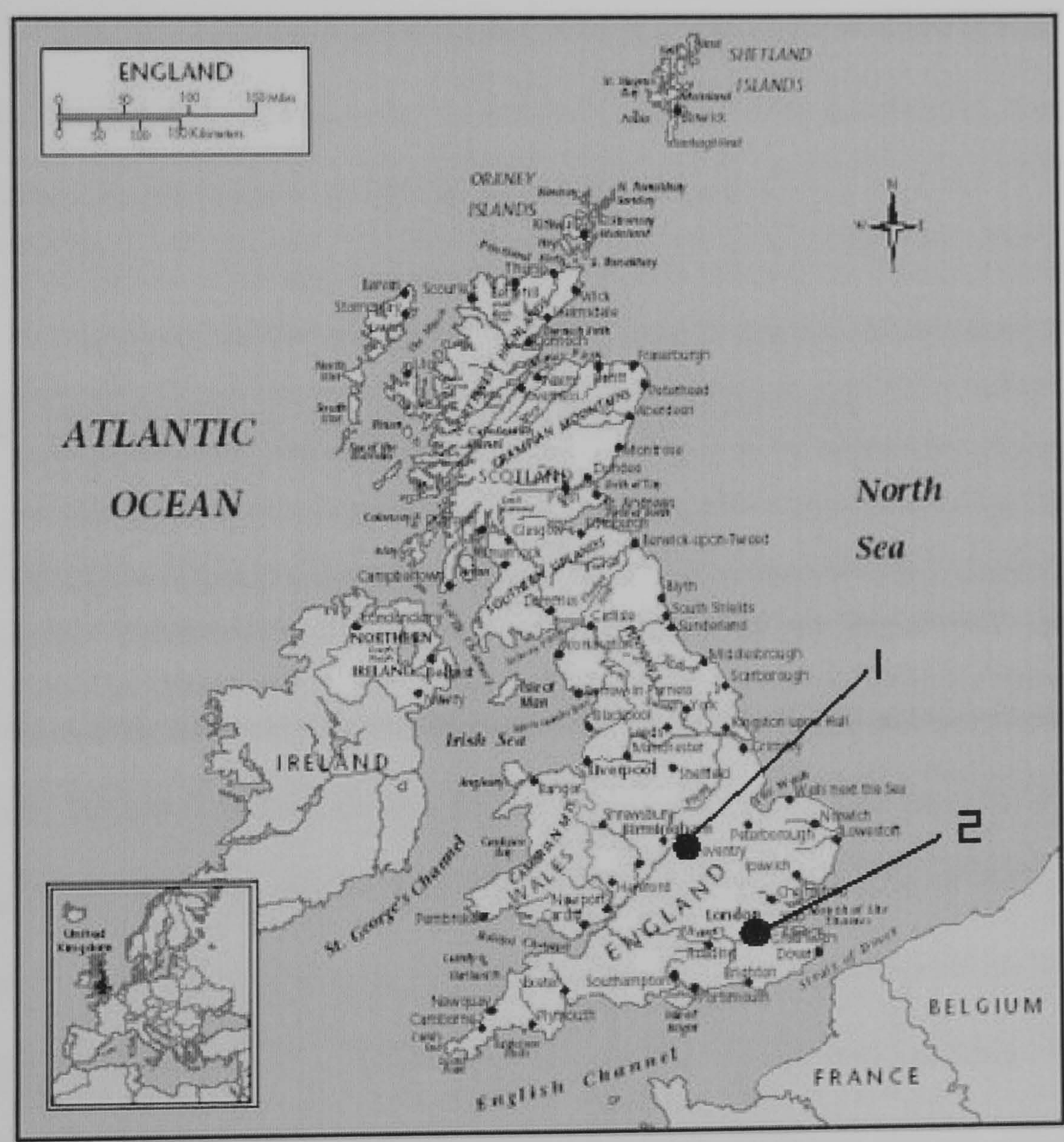


Figure 1: Map of the United Kingdom indicating the position of Coventry (1) and Chelsea (2).

The comparative approach with the various disciplines allows a previously unavailable insight into not only diet, health and migration in seventeenth to nineteenth centuries of Coventry and Chelsea, but also a retrospective look at the robustness of the archaeometric techniques themselves. For example, does the analysis of strontium and oxygen isotopes provide a picture of migration which is consistent with that provided in the historical record, and are they capable of determining childhood residence as is suggested in the biogeochemical literature? If not, what are the implications for previous biogeochemical studies? Similarly, carbon and nitrogen isotopes have been used to indicate variation in social status, acquisition to different resources, etc. Is this borne out in the biogeochemical record? Does the biogeochemical record reveal a decrease in generalised indicators of health as one moves from the early seventeenth century to the nineteenth century, a century that is all but synonymous with the 'Industrial Revolution'?

1.1. Biogeochemical Analysis of Past Populations

Biogeochemical analyses have a long history within the discipline of archaeology and anthropology, extending back three to four decades to the mid-1970s with the initial utilisation of trace element analysis (Brown 1973; Gilbert 1975; Lambert *et al.* 1979). Such techniques are based upon the concept that specific elements that have little physiological use (e.g. strontium) are present in the body at a rate proportionate to their dietary intake (Sandford 1993). The enthusiasm for these techniques continued into the early-to-mid 1980s when there was a dawning realisation that the process was far more complex than originally envisaged. Integration of trace elements into the body varied by species, sex and the tissue analysed and was not necessarily linear in respect to diet (Burton and Wright 1995). Furthermore, taphonomic processes allowed for the exchange of biogenic material within the depositional environmental in a process referred to as diagenesis (Pate and Brown 1985;

Klepinger *et al.* 1986; Pate and Hutton 1988; Sillen *et al.* 1989; Pate 1994). Various techniques have been developed to ameliorate the questions introduced by the concept of diagenesis, for example solubility profiling (Sillen 1986, 1992), though more recent use of isotope analysis have been used to question the effectiveness of such techniques (Trickett 1999, Budd *et al.* 2000; Trickett *et al.* 2003). Parallel to the development of single trace element studies, multi-element studies employed a suite of measurements of various elements to determine the relative contribution of protein-vegetable sources to human diet (Gilbert 1975; Lambert *et al.* 1979; Geidel 1981; Sillen 1981; Geidel 1982, Sillen and Kavannagh 1982; Sillen and Smith 1984, Sillen 1986; Sealy and Sillen 1988; Francalacci 1989; Sillen and LeGeros 1991; Sillen 1992, 1996). Despite the variations, diagenesis of skeletal material continually brought the results into doubt. This was further compounded by the aforementioned lack of 'who' and 'where': just how variable are the trace element results if one cannot say, even within boundaries, what these people ate nor where they were resident.

1.1.1. Carbon and Nitrogen Isotopes

Developing from early articles on the variation in carbon isotopes used for radiocarbon dating, the use of carbon and nitrogen isotopes were later substantiated in the ground-breaking work of van der Merwe and subsequent studies in North America (Hall 1967; Bender 1968; van der Merwe and Vogel 1978; van der Merwe 1982; Ambrose 1993). Such studies are ultimately predicated around the variation in the $\delta^{13}C$ (see Chapter 4) between plants with different photosynthetical pathways and, in environments where both plants are consumed as part of the diet, indicate the relative quantities consumed of each (Sealy 2001). Such studies have been used to indicate not only the relative contribution of C_3 *vs.* C_4 plants, but also the adoption of specific plants into the diet of specific populations (Keegan 1987;

Buikstra and Milner 1991). Similarly, both carbon and nitrogen isotopes can be used to differentiate between terrestrial and marines resources, either through C_3-C_4 differentiation, or variation of $\delta^{13}C$ or $\delta^{15}N$ (Schoeninger and DeNiro 1984; Schoeninger 1985; Ambrose and DeNiro 1986*a*, *b*; Keegan and DeNiro 1988; Ambrose 1993; Iacumin *et al.* 1996; Ambrose and Katzenberg 2000; Sealy 2001).

In relation to Chelsea and Coventry, carbon and nitrogen isotopes potentially offer insight into a number of features of the diet during this period: (1) the relative contribution of aquatic (marine [sea] and terrestrial [lake and river]) and non-aquatic resources, as well as the potential contribution of C_4 plants (i.e. maize and millet); and (2) variation in diet by socio-economic status and therefore, inferences with regard to food resource procurement and locality.

1.1.2. Oxygen Isotope Ratios

Oxygen is a primary component of water and, therefore, the ground waters that are utilised by human populations for drinking. The isotopic composition of this drinking water varies over geological time, i.e., between ice ages or interglacial periods, and their variation is tied in with global weather patterns (*cf.* Fricke *et al.* 1995; Clark and Fritz 1997). This creates a phenomenon by which distance from the ocean, and the temperatures of that ocean, reflect upon the oxygen isotope composition of precipitation (Clark and Fritz 1997; Alley and Cuffrey 2001). As the water that humans drink ultimately derives from precipitation, and as this water is incorporated into the skeletal tissues, this forms the basis of archaeological provenance studies using this element (Dangela and Longinelli 1993; Fricke and O'Neil 1996; Longinelli 1996; Reinhard *et al.* 1996; Sealy 1998; Widemann *et al.* 1999; Schoeninger *et al.* 2000; Thackery 2000; Sealy 2001). Although dependent on the accurate

reconstruction of contemporary climate and therefore groundwater, the analysis of oxygen isotopes has the potential of recording lifetime movement through the analysis of biophosphates from varying skeletal tissues (Stuart-Williams *et al.* 1996; Stuart-Williams and Schwarcz 1997; White *et al.* 2000; Budd *et al.* 2004*a, b*).

Provenance determination through the interpretation of oxygen isotope ratios of skeletal tissues has been attempted in Mesoamerica, though with mixed results, as well as identifying place of residence for early 19th century soldiers (Schwarcz *et al.* 1991; Stuart-Williams *et al.* 1996; White *et al.* 1998, 2000). More recent work integrating numerous sites in the United Kingdom indicate that while oxygen isotopes ratios are useful in identifying populations and, more specifically, population outliers (Budd *et al.* 2004*a, b*; Millard 2004). Furthermore, the specific means by which measured oxygen isotopes in biophosphates are translated into climate and precipitation models are increasingly being regarded with some scepticism (Millard 2004).

As the locality of the individuals in Coventry and Chelsea are known within reasonable boundaries, e.g. from the historical record, their use allows an indication of the precision with which the oxygen isotope ratios and their calibrations can be used to determine provenance. Further, given that the population of the post-medieval period is shown historically to be fairly local, a feature further attested in the reconstruction of individual biographies, questions of the variability of biochemical incorporation of oxygen into skeletal tissues can also be addressed.

1.1.3. Strontium Isotope Ratios

Strontium has been used in the reconstruction of palaeoenvironment and, indirectly, palaeodiet through an understanding of the geological contribution of strontium to flora and

fauna. Using such techniques, the physical and biological sciences have been able to analyse food webs, such as the use of marine *versus* terrestrial food resources, etc.

Provenance studies are predicated on the variability of strontium composition of geologies as well as the varying ages of production, with radiogenic strontium increasing as a function of time and the decay of rubidium. As the rate of radioactive decay is significant only on the geological scale, this can therefore be utilised to indicate the lithology upon which an individual was either raised or upon which they derived their dominant food resources (dependent on the skeletal tissue analysed). Complexities arise in geological diverse areas where varying factors – differential physical *vs.* chemical weathering, pediogenesis and the contribution of rock strontium to soil and labile ('mobile') strontium – all contribute to present a situation where the underlying rock strata do not equate to bioavailable strontium. In northern Europe, and elsewhere, there is also a 'blurring' phenomenon resulting from glacial activity in the Pleistocene (Faure 1986; Duff 1993).

Strontium becomes increasingly more useful when one moves away from the paradigm whereby the isotopic signature encoded in human – and more broadly mammalian – tissues defines the *place* of childhood residence. Indeed, given the variation in local strontium isotope ratios, it would be difficult to define a given residence even if, for example, an individual never migrated more than one or two kilometres in their life (Budd pers.comm.) Instead, if used to exclude areas that are increasingly unlikely to have served as the source of labile strontium, then strontium can help to determine childhood residence with increasing probability (cf. Müller *et al.* 2003).

As with oxygen isotope analysis, strontium isotopes can be used to define variation of isotopic ratios within a given population and, from there, define the population. Similarly, using oxygen isotopes in parallel to strontium aids in the exclusion of locales with similar

strontium isotope signatures and thereby increases the accuracy to which childhood migratory point of origin might be suggested (*cf.* examples in chapter 4, section 2.3).

1.1.4. Lead Isotope Ratios

Lead isotope analysis has been utilised in geology and a variety of fields of scientific study, many of which ultimately aim to trace the source of both 'natural' and 'artificial' lead exposure both through history and within specific periods (Kersten *et al.* 1994; Erel *et al.* 1997; Budd *et al.* 1998; Dunlap *et al.* 1999; Chiaradia and Cupelin 2000; Aberg *et al.* 2001; Alfonso *et al.* 2001; Brännvall *et al.* 2001; Budd *et al.* 2004*b*). In prehistoric populations exposure to lead has been shown to be representative of geographically diffuse sources with increasing homogenisation of lead isotope values with increased exposure to lead from ore sources (Budd *et al.* 2004*c*), while modern teeth show isotopic values to be consistent with lead from modern pollution, e.g. tetra-ethyl lead from pre-1970s anti-knock agents, paint, local pollution, etc. (Aberg *et al.* 1998).

Although in a post-metallurgical society where there is increasing tendency to homogenisation of recorded lead isotope values, what does this tell us about the experience of the individual in terms of *quantity* of pollution to which they are exposed? While modern First World nations might enjoy a pollution level similar to that in prehistory (i.e. 0.5-1 ppm), those during the intermediate periods of prehistory experienced increasing levels of lead pollution (Richards 1999; Budd *et al.* 2004*c*). Yet how did the post-medieval period reflect compare with that of the medieval period? Or the Romano-British?

While prehistoric individuals can be traced to specific sources or at least non-local sources thereby indicating provenance, the homogenisation of post-metallurgical specimens makes this impossible. Within the Coventry and Chelsea samples, childhood lead exposure can be

determined through the measurement of tooth enamel lead isotope values and concentrations. With sufficient biographical details on any given individual it should also be possible to determine whether there is a quantifiable difference between lead exposures by socio-economic status or, simply put, are low- or high-status individuals being exposed to pollution and, if so, what is the source?

1.2. Coventry and Chelsea: Contrast and Continuity?

Coventry and Chelsea represent two fundamentally different experiences of the post-medieval period. While Coventry was a town with a long-standing industrial history, Chelsea was a 'village' founded upon an aristocratic past and acknowledgement as a 'riverside pleasure resort', a beautiful and readily accessible alternative to the grime of the metropolis. The following sections address specific historical issues relevant to this project.

Coventry's history extends back to the early medieval period where, despite being located at some distance from major trade routes, it began to rapidly flourish partially as a result from proximity to Birmingham and London (Bailey 1783, 1784; Universal 1873; VCH 1969). By the fourteenth century it was the fourth largest city in the United Kingdom and firmly established in the woollen trade – such was its prominence that the city was made into a county in and of itself. In the fifteenth and sixteenth centuries, Coventry went into decline as a result of enclosure and other agricultural changes, as well as broad-ranging changes in the economy. With the introduction of the silk industry, however, Coventry's fortunes changed and economic revival followed.

During post-medieval period, however, the important point to stress is that Coventry was always closely associated with industry, whether this was domestic industry or the later

factory-based industries (Press 1990; Demedowicz 2000). Whether ribbon-weaving or watch-making, the majority of the population seemed to have been involved with some form of industrial activity.

Chelsea, on the other hand, is a village and later part of a city dominated by the service industry. Called the "Village of Palaces" by L'Estrange (1800*a,b*), the history of Chelsea more than reasonably earns this title, (i.e., Originally being the site of the 'rural' retreats of such personages as Henry VIII, Catherine of Aragon, Thomas More, and other notables of London). Indeed, its history is documented as stretching back to the Mercian kings of the eighth and ninth centuries AD. From 1682, with the construction of the Royal Hospital, the population began to increase, the result of an aristocratic influx in and around the hospital and leading into Chelsea village itself. By the eighteenth century Chelsea had gained repute as a 'pleasure resort', acting as a convenient and pleasurable escape from London. The main street was lined with inns and even more isolated taverns within the fields. It became a haven for the 'artists' (Blunt 1918, 1921; Bryan 1869; VCH In Press).

During the late eighteenth and early nineteenth century Chelsea expanded from a 'village' to a suburb of the metropolis itself (VCH In Press). Expanding from the Royal Hospital both east and west, rows of houses and 'villas' began to fill in land leased from the old manorial estates. Between 1831 and 1842 a yearly average of 91 houses were constructed as the suburb expanded (LMA MR/B/SR/18). Yet despite a burgeoning industry in the mid-nineteenth century and beyond, Chelsea in the time of the individuals studied here would have been a healthy village that just before the closure of the famous Chelsea Bun House was rapidly moving away from its manorial and aristocratic origins. Reminders of those origins were everywhere, from the names of streets derived form the original estate grounds upon which they were built, (i.e.. Beaufort Street/Row and the Beaufort Estate, Lawrence

Street and the Lawrence estate, and most famously Cheyne Walk, Cheyne House and the Cheyne estate (James 1950; VCH In Press)).

Historically, therefore, Coventry and Chelsea were socio-economically different, offering a contrasting picture of the eighteenth and nineteenth centuries of England. At the same time, this offers up a conundrum with regards to the documentary evidence: can it be viewed as entirely accurate? While a period division of spatiotemporal experience can be useful in delineating the broader experiences of a culture, further research often reveals that the *specific* experience brings the division into question. Not only can processes experienced over a region vary dramatically from what might otherwise be considered the "average experience;" but also individual regional experience merges across the boundaries of any defined age. Thus the general experiences recorded in the wider body of historical literature can potentially be as misleading as any document, such as a will, probate record or diary that records the specific interpretations of an individual (*cf.* diary excerpts in Pooley and Turnbull 1998).

1.3. Research Questions

The combination of biogeochemical, osteological and historical evidence presented in this thesis allows for a unique look at the eighteenth and nineteenth century of Chelsea and Coventry, and more generally up to the period of industrialisation.

1.3.1. Carbon and Nitrogen: A Question of Diet

The analysis of carbon and nitrogen of the Chelsea and Coventry samples present a number of potential questions:

1. Is there a difference between the diet of Coventry and Chelsea, two locations that historically have a different socio-economic experience of the post-medieval period?
2. If diet does vary between the sites is it purely a function of socio-economic status or may other variables be responsible?
3. Does diet vary significantly between males and females at the two sites?

1.3.2. Strontium and Oxygen: Migration and Locality

Locality and migration are issues of great importance in not only archaeology but also for the wider applications to other disciplines, including forensic science.

1. Are the populations of Coventry and Chelsea isotopically discrete?
2. Can migrants or locals be securely identified in the isotopic record?
3. Do the calibration formulae utilised in oxygen isotope analysis return a value consistent with the known local groundwaters at these sites?

1.3.3. Lead: Pollution and Continuity of Experience

In an increasingly industrial population where mineral fuel resources were being exploited in volumes unparalleled elsewhere in the world until the twentieth century, definition of everyday exposure to pollution is of significant interest to archaeologists and historians alike. Questions that will be addressed by this integrated study include:

1. Are there significant differences in the 'pollution' exposure between Coventry and Chelsea, nominally low- and high-status respectively?
2. Can the lead levels measured in human dental enamel be specifically associated with clinical effects of lead 'poisoning'?
3. What is the dominant source of lead in the post-medieval period and how does this vary from the later-medieval and earlier periods?
4. How does lead exposure vary through time? Is the post-medieval period different from others in terms of lead exposure? How is it similar?

1.3.4. Osteological Interpretation

Osteology has been used in this project to produce information to parallel biographical reconstruction, offering a wider interpretative framework for discussion of the life experience of a given individual.

1. Is the osteological record of the two sites consistent with the historical record?
2. How does the osteology vary between the sites and, indeed, how are they similar?
3. How is the osteological record similar or dissimilar to that established through the analysis of other post-medieval skeletal collections?

A summary is presented at the end of each chapter to facilitate integration of the disparate evidence types.

1.4. Thesis Structure

Chapter 2 introduces the major forces behind industrialisation, providing a framework of interpretation for the themes of industrialisation that the biogeochemical evidence touchs upon: agricultural enclosure and the subsequent regionalism of food supply; the nature of diet in the eighteenth and nineteenth centuries; standards of living experienced by the 'average' Briton, etc. It further introduces the histories of the city of Coventry and the village, and later suburb, of Chelsea to provide a context for the study sample analysed herein.

The third chapter focuses upon the archaeology of the Chelsea and Coventry. It provides a brief summary of the archaeological excavations that were responsible for the recovery of the human remains used in this project as well as the causes, effects and prevalence of pathologies revealed through palaeopathological analysis of the sample.

Chapter 4 provides an introduction to the general theories behind the utilisation of biogeochemical isotope studies in archaeology, including brief explanations of the processes that lead to their variable interpretation. Each of the elements investigated as a part of the project – strontium (Sr), lead (Pb), carbon (C), nitrogen (N) and oxygen (O) – are covered in a consistent structure, discussing the geology, geochemistry and biochemistry of the elements. The archaeological interpretations of these studies are also included to provide a framework of interpretation for subsequent discussion, but also by means of briefly reviewing the significant articles within the discipline. The methods utilised in analysing the disparate types of data – historical, genealogical, osteological and biogeochemical – are discussed in Chapter 5, while the results of these analyses are presented in the Chapter 6.

2. Industrialisation in the Eighteenth and Nineteenth Centuries and the Experience of Chelsea and Coventry

The eighteenth and nineteenth centuries are a complex period in European and British history. Their study and interpretation is the subject of contentious debate in the historical and archaeological literature. This chapter concentrates on those aspects of this period of 'industrialisation' most directly linked to the study at hand. That is, the nature of diet, migration and health as it pertains to the eighteenth and nineteenth centuries and the osteoarchaeological sample used in the study.

2.1. Industrialisation: A Socio-Economic Context

The process of industrialisation in Britain can be seen as the interplay of a large number of factors including, but not limited to: the formation of the 'Great Estates' and the process of land enclosure (e.g. Daunton 1995; King and Timmins 2001); resultant specialisation away from subsistence activities; the development of the domestic industry infrastructure and regional urban centres (Bairoch and Goertz 1986; McCloskey 1994; Clarke 2000; Daunton 2001; Evans 2001; Kings and Timmins 2001); improvements in communications, and a resultant ability to facilitate regional goods speciality (Turnbull 1987; Barker and Gerhold 1995); and a burgeoning population with improving standards of living (Wrigley and Schofield 1981; Goldstone 1986; Wrigley 1988; Lindert 1994; Woods 1995).

While the above inter-related features all told into the process of industrialisation in general, only those that have a specific impact upon the subject of the thesis – diet, migration and more broadly health – are discussed in detail below.

2.1.1. Agricultural Reform and Enclosure The processes of agricultural improvements, the consolidation of land into an increasingly small land-holding group, the process of enclosure, and the improvements in the communications infrastructure created distinct areas of agricultural production. In essence, this created an expanded agricultural hinterland, allowing procurement of food resources from an increasingly larger and specialised area. For the purposes of archaeometric studies of birth and early childhood through strontium isotope analysis, or in determining likely food types for carbon/nitrogen studies based upon local procurement networks, the implications become increasingly obvious. How can one determine localised isotopic patterns when contributing factors such as food resources extend this network (cf. Aberg *et al.* 1998)?

The mechanism of improvement of agricultural yield has multiple aetiologies. While contemporary writers make mention of the importance of the great agricultural publicists who advocated alterations in husbandry and crop rotation practices, such as the alleged introduction of the turnip in 1726 to improve the turnover of fallow fields, there is strong evidence to suggest that these techniques were already in place by the yeomanry of the period (Usher 1921; Moffit 1963; Daunton 1995; King and Timmins 2001). A substantial surplus profit could rapidly be generated with the increased productivity resulting from the alteration from four-course tillage to a three field system (Moffit 1963). Similarly, improvements in drainage systems and the utilisation of manures (either organic fertilisers or, for example, 'marle and lime') would also increase agricultural productivity (Moffit 1963; King and Timmins 2001). Furthermore, the increased utilisation of animals, particularly horses, as a means of increasing productivity was also seen in England at a level far above that in Europe (Langdon 1986; Daunton 1995). This, when coupled with the utilisation of practical technologies, allowed marked improvements in agricultural yield.

In parallel to the agricultural changes, the formation of the so-called 'Great Estates' – the establishment and formalisation of territory into the control of an increasingly smaller group of landholders – preceded the process of "enclosure" (Usher 1921; Daunton 1995; King and Timmins 1921). This gradual consolidation took a number of routes, from the withdrawal of tenants from the common open field system, through to private agreement to formalise piecemeal consolidations over an extended period of time, and finally to Parliamentary Acts of Enclosure (Allen 1982; McCloskey 1994; Daunton 1995). Indeed, while concern has been raised for the particular importance of land enclosure (McCloskey 1994) with the suggestion of more equitable land transfer than the Marxist view that it was simply usurpation of land and land rights, the consolidation of agrarian land under the management of landed gentry who had the ability to move away from more feudal practices of tenant farmers did much to increase economic potential of land (Moffit 1963; North 1981; Kussmaul 1990; Mokry 1993; Newman 2005).

The ultimate effect of these 'improvements', was to formalise an integrated agricultural economy moderated by other features of industrialisation, such as continued improvements in the communications infrastructure of the period (Moffit 1963; Daunton 1995; King and Timmins 2001). Indeed, regionalisation of the economy could almost be considered a *sine qua non* feature of the period of industrialisation – the seemingly synergy of regional specialisation with a diversification of such specialities within a given region. Yet, despite this, areas traditionally associated with only small-scale agrarian activity, i.e. Lancashire, are shown to have knowledge to rival the traditional 'bread baskets', while those that were traditionally agrarian, such as Co. Durham and other areas within the north-east, are associated with significant industrial production (King and Timmins 2001).

Agricultural reform and change during the seventeenth through nineteenth centuries developed through a number of inter-related processes, all of which had wide-ranging

implications for the socio-economic fabric of industrialising Britain. While the specific impact of these processes – improvements in agricultural efficiency, consolidation of land within the 'Great Estates' or large landholdings, and enclosure, etc. – remain a topic of debate in the historical literature, together they served two major functions:

- **Freeing up labour**: Increasing yields allowed a smaller proportion of the population to provide food resources for an increasing population (Toynbee 1921; Wrigley and Schofield 1981; Schofield 1994; Evans 2001).

- **Regional agricultural specialisation**: Most important for the purview of the thesis, efficiency improvements freed the farmer from the production of cereal crops and allowed increasing specialisation, thereby providing an integrated agrarian economy. Thus cereal crops, a major part of the diet in the eighteenth and nineteenth centuries, increasingly came from areas of light, chalk soils that could be supported by the utilisation of animals and horse-drawn ploughs, such as Hampshire, East Anglia and Norfolk (Kings and Timmins 1991; Daunton 1995). For the purposes of biogeochemical study of birth or childhood residence, this serves to increase the range of food resource procurement and inherently blur the concept of 'residence'.

In relation to the specific experience of Coventry and Chelsea, the important, general point to make is that the regionalisation of agrarian and pastoral economies would have acted to expand the area that resources could be procured from beyond the primary "agricultural hinterland" of any prehistoric and earlier medieval model. If food was commonly obtained from areas beyond this immediate hinterland, can one define an agricultural hinterland and, therefore, a defined biogeochemical region?

2.1.2. National and International Migration

Migration during the period of industrialisation was a continuing phenomenon, taking place over variable distance and across socio-economic class, and is summarised by Pooley and Turnbull (1998: 46):

> "The features that emerge most clearly are the relative paucity of long distance moves in the eighteenth century, the increasing development of large urban areas as the foci for migration activity, the dominant role of London in the British migration system in all periods, the declining importance of movement from rural areas as rural depopulation began to take effect, the increasing significance of long distance interchange of population between large urban centres, and the particular importance of local circulation at all time periods and in all regions."

In terms of broad values for the frequency and distance of migration, simple values can be produced from family history studies (Polley and Turnbull 1998: 50, 56): the average individual in period 1750-1839 made 4.8 'migratory moves,' with a mean residency in a single place of 10.9 years, over a median distance of 37.7 miles (Pooley and White 1991; Engerman 1994; Pooley and Turnbull 1998; King and Timmins 2001; Long 2005). These values remained remarkably consistent in subsequent periods (*cf.* Pooley and Turnbull 1998: 56).

Migration occurred – and occurs – for a wide variety of reasons, including change in personal economic status (changing socio-economic class, marriage, etc.), a desire to exploit different work environments, different social environments, and the travel distances between these. Simply, people tended to move to locales that held for them an economic advantage, whether through improved employment, living conditions, or the exploitation of some other phenomenon, such as kin-networks (Baines 1998: 1; Pooley and Turnbull 1998: 120). While the majority of these moves were short distance, personal experience could vary tremendously, such as with the longer distance migration of skilled workers, or even that experienced in long-distance migrations to the 'colonies,' such as the Americas and the

Caribbean, for reasons of exploration, settlement or exploitation of local resources (Baines 1998; Pooley and Turnbull 1998: 276-279).

As inferred above, short-distance migration was by far the most common form of migration experienced by individuals and family groups in the eighteenth and nineteenth centuries (Baines 1998; Pooley and Turnbull 1998; Long 2005). Indeed, almost 50 per cent of all moves occurred over distances of less than ten kilometres, and, of those migratory moves, the most common was over distances of less than one kilometre. Of these migrations, approximately 45-50 per cent occurred as a result of work, once again usually to a place that was of economic or social gain (increased wages or employment opportunity, moving to aid sick family members, retirement, etc.) The most frequent migrants were domestic servants, members of the armed service and skilled non-manual workers, while the unskilled agricultural worker, as with the farmer, enjoyed in the eighteenth century the greatest stability (Pooley and Turnbull 1998: 53).

Movement between counties did occur, but short-distance movement that originated and ended within a given region was by far the most common experience for individuals in the eighteenth and nineteenth centuries. Further, movement into a region was often reciprocated with an equal volume of movement out of a region (Pooley and Turnbull 1998: 75). The exceptions to this pattern were the counties situated near to rapidly expanding urban areas, such as London, and the West Midlands. In the latter case of the West Midlands, which includes the city of Coventry, it is regarded as reflective of the relatively early experience of industrialisation.

While regional movement was relatively balanced, movement to London, and in later periods, the south-east of England was dominant throughout the eighteenth and nineteenth centuries (Pooley and Turnbull 1998: 77). Indeed, London was the focus of the largest

proportion of migrants that migrated from greater than 100 kilometres and, further, was a similar focus for migration from the larger provincial towns (Pooley and Turnbull 1998). Thus, London, along with the North West of England and South Wales, the latter of which were strong industrial areas, experienced increased populations during this period through migration and local population increases. Counties that experienced a population *decline* did so to these industrial areas during the late eighteenth and early nineteenth centuries, with all but the West Midlands experiencing a reversal of this situation in the later nineteenth century (Pooley and Turnbull 1998: 76).

Urban migration is commonly thought of as the trend for individuals to in-migrate to a city from either a rural situation, or from a town or smaller city in terms of the urban hierarchal (Pooley and Turnbull 1998; Long 2005). The experience of the eighteenth and nineteenth centuries, however, shares many of the same trends as with the twentieth and twenty-first centuries. As much as in-migration might occur, out-migration through the process of suburbanisation, movement to smaller towns or the countryside, as well as pseudo-regional migrations with urban expansion, all figured into the migratory experience of the individual.

Contemporary writers of the nineteenth century presented a view of London through the lens of the continual in-migration of workers, feeding the beating heart of England. Dickens in *Dombey and Son* comments through one of his characters:

> "She often looked with compassion... upon the stragglers who came wandering into London, by the great highway hard by, and who, footsore and weary, and gazing fearfully at the huge town before them, as if foreboding that their misery there would be but as a drop of water in the sea, or as a grain of sea-sand on the shore, went shrinking on, cowering before the angry weather, and looking as if the very elements rejected them. Day after day, such travellers crept past, but always, as she thought, in one direction—always towards the town." (Dickens 1982, Chapter 33, paragraph 76)

Dickens was himself to immigrate into London in 1822 with his family, moving from Kent to Camden Town (Sheppard 1971: 2-3).

Family history studies, however, reveal a pattern that differs from the common perception — rather than continual in-migration, both in- and out-migration were broadly balanced (Pooley and Turnbull 1998: 103). Thus, while popular representation of the stripping of the countryside of its workers to populate the burgeoning urban conurbations did occur, the total migratory experience was once again defined by short, relatively frequent migrations either within a settlement, to a settlement of similar size, or to a smaller settlement (Pooley and Turnbull 1998: 103). Indeed, in-migration could not have been solely responsible for the substantial population increases seen in the towns of the late eighteenth and early nineteenth centuries. Rather, while in-migration was present, local increases of population – birth and fertility rates, as well as changes to nuptiality, *versus* mortality rates – was the greater contributor.

Thus, the migratory experience for the urban environment broadly consisted of a number of types:

- In-migration, balanced by out-migration, with movement from the rural to the urban environment; from smaller towns and provincial cities to large cities, including London; and the opposites of these.
- Internal short-distance migration.

As with other migratory experiences, in-migration and short-distance, internal migration was commonly the result of employment change, either voluntary or that mandated by an employer (Pooley and Turnbull 1998: 119). Such short-distance moves were commonly into adjacent streets, either in reaction to changing requirements in housing or to reduce the

commute distance, but could also involve moves into suburban areas (Pooley and Turnbull 1998: 125). In contrast to inter-urban migrations, these short-distance migrations were more common in older individuals and family groups, such as to more appropriate housing or to reduce the time of the work commute (Pooley and Turnbull 1998: 135). Indeed, the length of the commute was fundamental to the movements of urban dwellers as it was to the agricultural labouring population, with a change in employment locale initiating a change in residence, e.g. 92 per cent of journeys to work in the period 1750-1879 were less than 5 kilometres (Pooley and Turnbull 1998: 172).

The relatively higher wages of the urban environment created an additional rural-urban migratory pattern to the circular pattern witnessed in both rural and urban environments (i.e. residential mobility). This could either be life-time migration or a temporary addition to the life cycle, with the former becoming more common as cities continued to develop towards the middle and end of the nineteenth centuries (King and Timmins 2001). Migration during the period was predominantly performed by males, domestic servants and skilled labourers tending to migrate longer distances than agricultural labourers (Pooley and Turnbull 1998). On the other hand, female migration was generally predicated around marriage bonds (Pooley and Turnbull 1998). The remaining quarter of migration would most likely have been composed of apprenticeship relocations, migration to distant kin, or through involuntary movement brought about as a result of the application of settlement laws that disallowed residence if the individual was a burden on society (Wohl 1983; Daunton 1995; Pooley and Turnbull 1998; Sweet 1999; King and Timmins 2001).

While not the most common experience of migration, movement between the outlying colonies of what would ultimately become the British Empire also offered another avenue for people during the period of industrialisation.

The British Caribbean during the seventeenth through nineteenth centuries was a burgeoning territory concentrating upon the production and export of sugar and rum, and by far the wealthiest of these colonies were Jamaica, Antigua, Barbados, Dominica, Grenada, Monsterrat, Nevis, St. Kitts, St. Vincent, Tortole and Tobago (Rose *et al.* 1940; O'Shaugnessy 2000). Both the wealthy and the poor would migrate to the Caribbean and the American colonies from the sixteenth century onwards, some one million people all told (Horn 1989; Gragg 2003). These primarily English migrants turned to the Caribbean as a means of 'seeking their fortune' and, while almost one-third of them would die within three years of arriving, the idea that "their fathers went out poor and the children come home rich" was a powerful attraction (O'Shaugnessy 2000: 4). Indeed, the British Caribbean and the American colonies in general, were viewed merely as a stepping stone to allow a change of fortune and, ultimately, a return to the mother country (Burnard 1996; O'Shaugnessy 2000). By the end of the eighteenth century approximately three hundred West Indians annually returned to Britain (O'Shaugnessy 2000).

Although the British Caribbean attracted a wide socio-economic spectrum, from the elite plantation owners to the tradesman, the latter partially a result of the proportionately large mortality rate experienced by immigrants, it was the elite that would most likely enjoy a return to Britain, such as with the example of Lady Nugent, wife of the Governor of Jamaica, and resident of Jamaica between 1801-1805 (Wright 2002). Indeed, many of the powerful landholders were absentees and controlled their property from England (O'Shaugnessy 2000), as seen with the example of Sir Rose Price, absentee landholder for all of thirty-seven years of property ownership in Jamaica (Craton 1978: 264; Reeves 1997). For those born in the British Caribbean, it was not uncommon for the children of the elite to return to England for their education, and of those approximately one-third would remain in England (O'Shaugnessy 2000:19). Such an example is provided by John Price Nash, who trained as a mechanic – likely in the Midlands – and who returned after a decade

2.1.3. Diet in the Later Medieval and Post Medieval Period

For the greater majority of individuals in the eighteenth and nineteenth centuries, diet remained largely unchanged from that of the early and late medieval periods (Hammond 1993; Pearson 1997; Roberts and Cox 2003). In the early medieval, this diet consisted primarily of the consumption of locally produced cereals – wheat, rye, barley and oats – in the form of staples such as bread, porridge and ale (Reed 1990; Hagen 1992; Cameron 1993; Cantrell II 2000; Kaplan 2000; Küster 2000*a*). This grain-based diet would have been supplemented by legumes such as peas and beans, limited fruit, vegetables and herbs (Hagen 1992; Cameron 1993; Fowler 2002). Commonly consumed vegetables during the period included garden or wild produce such as cabbage, lettuce, onions, leeks, garlic, turnip, carrots, parsnip, beet and cucumbers as well as various herbs (Hagen 1992; Cameron 1993; Fowler 2002). Fruits included apples, plums, damsons, cherries, quince, nuts and various berries that, along with honey, were the primary source of sugar in the diet (Hagen 1992; Cameron 1993; Fowler 2002). Meat would also have been consumed sparingly, at least for those of the lower socio-economic classes, and be comprised primarily of cattle, pigs and sheep, but also supplemented with wild game such as small birds, conies (juvenile rabbits), etc. (Hammond 1993; Fowler 2002). Similarly, fish and other aquatic resources, including both marine and 'terrestrial' (i.e. freshwater) examples, were also variably exploited dependent on socio-economic class, locale and period (Spencer 2000; Privat *et al.* 2002). Indeed, a Parliamentary Act of 1548 dedicated Saturday to the consumption of fish (Spencer 2000), with fish being imported into the cities, as well as the ever popular shellfish such as oysters, lobsters, crabs, shrimps and prawns (Spencer 2000).

Figure 2: The most common and popular fish sold by eighteenth century hawkers was mackerel, which was rivalled, surprisingly enough, not by the herring so common in modern England, but by the smell. The cry includes the words "four for a shilling" but this was the cheapest price. At the start of the season, mackerel were often sold for as much as one-and-sixpence each (source: 18th century ballad, "The Merry Christ-Church bells" cited in Sheasgreen and Bywaters 1998; Sheasgreen 2002; artwork: Francis Wheatley, modern).

The diet of the elites of the period would have been remarkably similar to that experienced by the average individual with the exception that the quality of the material consumed would have been higher, and the variability of products greater (Cameron 1993; Spencer 2000). Fish could be kept in ponds and gardens used to supplement other produce, etc., which freed the elites from the poorer diet of the lower classes (Dyer 1988; Spencer 2000).

By the late medieval period, the diet had remained largely unchanged, though the development of regionalisation (see above) and the integrated market economy allowed the introduction of a greener range of food products into the average diet (Drummond and Wilbraham 1957). Cereals remained a staple, though regional specialisation resulted in the preferential use of some cereals over others, i.e. wheat-bread in Essex and Surrey, barley- or rye-bread in Norfolk and Worcestershire, wheat and rye in the northeast and oats in the upland northwest (Dyer 1989). Vegetable and fruit products would also have been similar,

though with the introduction of leeks, radishes and spinach (Drummond and Wilbraham 1957; Dyer 1989). Meat consumption remained similar to that of the early medieval period, though with a significant expansion in the utilisation of fish-based products (Bond 1988; Dyer 1988; Steane and Foreman 1988; Dyer 1989).

Following Enclosure, however, the diet of the lower classes was significantly diminished, as illustrated by Spencer (2000: 1222), where an average farm labourer, his wife and four children would consume in a week "eight loaves of bread, two pounds of cheese, two pounds of butter, two ounces of tea, a half-pound of boiled bacon and two points of milk". Indeed, Hanway, a reformer in the eighteenth century, commented:

> "The food of the poor is good bread, cheese, pease and turnips in winter with a little pork or other meat, when they can afford it; but from the high price of meat, it has not lately been within their reach. As to milk, they have hardly sufficient for their use." (cited in Drummond and Wilbraham 1957: 208)

Once again, upper-class diet in the later medieval period had greater variability than that of the lower socio-economic classes, most particularly in the consumption of meat-products, particularly fish (Dyer 1989; Nash 2000; Labarge 2003). Imported items were also a component of the elite diet, from spices to fruits from Portugal or the Levant (Dyer 1989; Küster 2000*b*; Labarge 2003). Likewise, sugar was also imported, though probably not until the fourteenth century, and was used by the elites for both dietary consumption and the preparation of medicines (McKendry 1973; Black 1992; Hobhouse 1999; Labarge 2003). Only by the nineteenth century did sugar become less expensive and, therefore, available to a wider range of socio-economic classes (Raffald 1970; Spaulding and Spaulding 1999; Galloway 2000; Partridge 2001).

The integrated market economy of the eighteenth and nineteenth centuries offered a wider variety of foods to the urban inhabitant than previously experienced by the rural inhabitant,

or individuals from earlier periods. With the improvement of communications networks, such as the expanding turnpike system and the expansion of the canal network, the speed of inland communications dramatically improved, thereby allowing diversification of goods at the market place of the town and city (Daunton 1995; Sweet 1999; King and Timmins 2001; Roberts and Cox 2003). This was further driven by the transition from the "organic" economic model of the eighteenth century and earlier to that of the "mineral" economy, (i.e. an increased reliance upon coal in the development of domestic technologies and as a drive for the development of the previously mentioned communications system (Stead 1985; Wrigley 1988; Roberts and Cox 2003)).

In the common perception of the period, the relative abundance of food for the English person was often remarked upon (Macfarlane 1997). For example, the traveller, De Saussure, commented upon the abundance and diversity of food produce in the market place during his visits to London in the eighteenth century:

> "In these markets an abundance of every kind of salt and fresh water fish is to be found; also vegetables and poultry of every description." (De Saussure 1902: 171; De Saussure 1995)

Perhaps surprisingly, the fish that were favoured by those of lower socio-economic class were commonly available in markets throughout Britain (Privat *et al.* 1992; White 2000; Müldner and Richards 2005). The Coventry market, for example, first sold fish in the thirteenth century outside Priory Gate (VCH 1904, 1908, 1969), and London's fish market is most evocatively illustrated by the illustration, above.

This variability and abundance of foods was not seen as unique to London but, rather, one that was experienced by Britain as a whole (Macfarlane 1997). Chadwick commented upon the supply of meat produce to the city of Manchester during the nineteenth century meant

that each individual would annually be consuming 105 lbs of beef (Chadwick, cited in Macfarlane 1992). Similarly, in the late eighteenth century Leadenhall market, was said to sell more meat in a month than was eaten annually in Spain (Macfarlane 1992). The increasing demand during the eighteenth and nineteenth centuries is marked by the expansion of the market places that served the demand of their urban fabric and hinterland (O'Meara 1889; Shaw 1985; Bairoch and Goertz 1986). Market gardens were another source of food, most famously in and around Chelsea, Lewisham, Blackheath, Wanstead and Ilford, before substantial suburbanisation in the later half of the nineteenth century closed many of these facilities (Hammond 1993; Spencer 2000; VCH In Press). For those with greater access to liquid capital, taverns and inns could also offer a source of food, a particular source of income to some of the individuals from the Coventry sample analysed here, e.g. John Ballard (Roberts and Cox 2003).

Development of the commercial infrastructure in the nineteenth century allowed for greater distribution of food resources around the city, rather than requiring individuals to attend the markets (Adburgham 1979; Weatherill 1996; Spencer 2000). By the mid-nineteenth century, the middle-classes would not even need to leave their homes, with butchers, grocers, etc., coming to their doorstep (Spencer 2000).

While urban diet might have steadily improved, in terms of availability of food products if not the specific experience of the individual, rural diet actually worsened as enclosure, as described above, took away the common rights of the peasants (Gaskell 1836; Rowntree 1902; Roger 1908; Drummond and Wilbraham 1957; Pike 1966; Hammond 1993; Daunton 1995; Porter 1998; Roberts and Cox 2003). For example, the loss of the right of common pasture removed the ability for many families to maintain livestock and, therefore, an important source of protein and secondary resources. Spencer (2000: 1222) also notes that

enclosure impacted upon the culinary arts, when an "entire generation [lost] cooking skills and traditional recipes forever".

2.1.3.1. Maize, Millet and Sugar Cane

While the predominant crops of the England focussed around wheat grains, ryes, etc., of C3 plants, a small number of species extant in Europe and Britain during the medieval period utilised the C4 photosynthesis pathway. The most notable of these were maize, millet and sugar cane, and because of their particular relevance to this project, they merit a separate mention.

Maize, a native species to Mesoamerica, was introduced to Europe following the return of Christopher Columbus in 1492-3, where it was subsequently introduced into Britain. While Europe seemed to accept the crop with little resistance, maize agriculture never took a significant hold in Britain (Messer 2000). Gerard (1597: Chapter 14) described the 'Turkie corne' as, "a more convenient food for swine than for man", and as such it was utilised only in times of stress or famine (Woodham-Smith 1962; Messer 2000). It was, and remains, a common fodder for animals and, as these animals remain a food resource for humans, this route may offer a possible introduction of a C4 biogeochemical signal into the post-medieval British diet. Similarly, the utilisation of millets in Europe during the medieval period is limited, and it is unlikely to have provided a significant contribution to diet (De Wet 2000).

The utilisation of sugar cane in the medieval diet has been previously mentioned, and while there are accounts of its use as a condiment in the eighth century (Galloway 2000), it was not until the twelfth century that it becomes more commonly reference (Hammond 1993; Hagen 1995). It was in this period almost certainly a dietary component of the wealthy, with household accounts indicating that it was utilised by at least the thirteenth century as a

commodity, and also likely in medicines of the period (Brothwell, and Brothwell 1998; Labarge 2003). By the sixteenth century, the price of sugar had significantly dropped, thereby making it not only more affordable to a wider socio-economic range, but also to be consumed in greater quantities by the wealthy (Hobhouse 1999). Indeed, the increasing presence of sugar in the diet is attested by extant recipe books of the period (McKendry 1973; Black 1992; Spaulding and Spaulding 1999). Despite its popularity in the records, it is unlikely that it would significantly affect the biogeochemical signal recovered from human remains.

2.1.4. Standards of Living and Health during 'Industrialisation'

In reconstructing as far as possible the lives of the individuals from Coventry and Chelsea we must ask the question "What was life like?" The opening text of Wohl (1983) was, to a non-historian, particularly poignant in the reconstruction of the experience of past life ways. The quote describes a family of "wealth and social prominence" that, despite their socio-economic status, were unable to escape the "stinks, pollution and health hazards of the day" (Wohl 1983: 1). Their residence was adjacent to the Thames, much like Chelsea itself, and the rising of the Thames following heavy rains would saturate their grounds with the detritus that so commonly flowed down rivers of all manner, let alone the Thames. We also find out that the mother had contracted typhoid as a teenager and that her husband was later to contract the same disease, and her son ten years to the day after that; her husband was to die shortly afterwards but her son would survive against all odds. Indeed:

> "She no doubt consoled herself with the thought that compared to many mothers she had been fortunate, for of her nine children not one had died in childbirth, but then she had had the best and most experienced doctors and midwives." (Wohl 1983: 1-2)

The family was also to experience the vagaries of industrial pollution when visiting other houses, whether that was the "stench from the river" Thames, or the dust and pollution causes by the "local cement factory" (Wohl 1983). The family in question? The royal family

> "This family, with its troubles, tragedies and near-tragedies from bad sewers and filfth diseases, forced to live amidst stink, and water and air pollution, was the Royal Family. However remote it might appear to be, entrenched in its great residences in London, Windsor, and Osborne, it could not remain untouched by the forces which played so large and debilitating, and often so deadly a role in the lives of ordinary Victorians." (Wohl 1983: 1-2)

While the goal of this section is to reconstruct the 'average life' of an individual within the post-medieval period, more specifically the eighteenth and nineteenth centuries, this quote is particularly striking. In a society where socio-economic or class distinction was considered extreme – the difference between the 'haves' and the 'have nots' - the reach of pollution and disease extended even to the rarefied social stratum of royalty, whose 'standard of living' is all but questionable, and becoming in a sense the 'great leveller'. If the above is the experience of the royal family, the Queen of which would give her name to an era, how might it affect the lives of the 'normal' people?

Before one can discuss the concepts of 'standards of living' during the eighteenth and nineteenth century's one must first consider what we actually mean by the term. It is common to associate 'standard of living' as a material consideration, based upon the quantity and quality of goods owned combined with the purchasing power of the individual; the individual is represented, in essence, as a component of the gross domestic product of the village, city or country within which they reside. Standards of living in human experience must also bring into consideration the subject concept of 'happiness' or, put another way, *quality* of life as measured distinctly from *quantity* (materiality) of life. Given the subjectivity of the term 'quality of life' mirrored in contemporary discussion on euthanasia,

and beyond contemporary literature of the period which was as much a political as well as social statement, we are left with but a few indicators of the 'standards of living' during the period. These are (Lindert 1994):

1. **Health**, as measured in terms of mortality and life expectancy, disease/sickness, height and the ability to enjoy ones time outside of the work environment.
2. **Material inputs**, in the form of wages and other contributions (e.g. poor rate, charity, exchange entitlements) to the financial or material well-being of the individual (Daunton 1995).
3. **Material outputs**, in the form of price fluctuations of food resources, house prices (including rentals), with concomitant effects upon population density *per capita* income, etc.
4. **Environmental quality**, which as seen from the quote, above, affects people of all socio-economic class if not necessarily equally.

2.1.4.1. Health and Mortality

While the pathologies that impact upon the human skeleton are discussed in the Chapter 3, these represent only a fraction of those diseases prevalent during the period (Wohl 1983; Roberts and Manchester 1995; Aufderheide and Rodriguez-Martin 1998; Roberts and Cox 2003). As such one must turn to changes in mortality as indicative of the 'quality of life' in terms of health and its interaction with the environment.

Wrigley and Schofield (1981) have shown that life expectancy rises from the beginning of the nineteenth century from 35.9 years to 39.5 years, while fluctuating significantly during the eighteenth century (Wrigley and Schofield 1981; Schofield 1994; Daunton 1995). This experience was non-standard throughout England, with both regional variation and

complexity introduced by migration into the cities (Daunton 1995; King and Timmins 2001). Childhood mortality also dropped during the period creating an increasingly 'younger' population in the nineteenth century than that of the eighteenth century (Wrigley and Schofield 1981; Schofield 1994). The peerage and, therefore, individuals of increased socio-economic class above the 'working class' had a similar increase in life expectancy, though their average was more marked than that of the national average increase in life expectancy (Daunton 1995).

Stature, as well as maturation (i.e. the 'complete' growth of a skeleton seen through epiphyseal fusion), is commonly used as an indicator of health (Roberts and Manchester 1995; Buckler 1997; Larsen 1997, 2000; Roberts and Cox 2003). Reduced stature is ultimately caused by the lack of nutrients in the diet, or some other environmental factor, stunting growth since they are otherwise directed towards the survival of the child. Similarly, poor living conditions or other environmental factors can lead to susceptibility pathogens in the environment, or other environmentally based pathologies. The implications of stature and health pathologies are discussed in greater detail in chapter 3.3.

2.1.4.2. Material Inputs and Outputs – Employment, Wages, Cost of Goods and Spending

One measure of the 'quality' of life in contemporary society is the amount of time that one can spend away from the work environment, both in terms of immediate time away and an extended period pre-retirement, e.g. sacrificing current free-time with that to be gained in the future. There is, however, little evidence for an increase in the average time spent away from the work environment in the eighteenth and nineteenth centuries: people worked, and played, for pretty much the same amount of time that they had always done, with industrialisation creating less 'play-time' until the mid-nineteenth century (Lindert 1994; Daunton 1995). Longer working hours experienced in the factory and textile environment

were balanced against a small proportion of the population engaged in this activity, while the population at large experienced a shift from a twelve to ten-hour working day (Lindert 1994; Daunton 1995). Similarly, increased time at a shift might likewise have reduced the amount of time required by other members of the family to engage in work-based activities. Childhood labour, a feature condemned once more in the contemporary and somewhat moralising literature of the mid-nineteenth century, was a fact that had been established from before initiation of industrialisation, extending back to the later medieval period and beyond.

Variation in real wages and their relation to other aspects of life during the eighteenth and nineteenth centuries has been extensively analysed and commented on by various authors (Wrigley and Schofield 1981; Lindert 1994; Schofield 1994; Daunton 1995; King and Timmins 2001). A consideration of this literature reveals several broad trends. Firstly, that in the mid-to-late eighteenth century that there were very little changes in real wages and that, increasingly regional variation began to reveal discrepancies within the 'national average' (Lindert 1994). This regionalism would continue until the early twentieth century, only then reversing to a southern-dominant wage structure. By the early nineteenth century the real wages of at least men began to steadily increase, with a rate variable depending on the skill base of the individual. Agricultural labourers showed the smallest increase in real wages (£17.2 around 1750 to £23.8 by 1820 and £29.0 by 1850), while skill labourers saw a significant alteration (£40.5, £47.2 and £75.2, respectively), with a national average that lay between these two extremes (£28.7, £34.2 and £52.2, respectively). The average wage values, above, are listed per annum (Lindert 1994).

2.1.5. Sources of Lead Pollution in the Eighteenth and Nineteenth Centuries

Wrigley and Daunton detail the transition from an 'organic' to 'mineral' economy and the subsequent increase in coal production and utilisation, but how prevalent was pollution

within the eighteenth and nineteenth century (Wrigley 1988; Floud and McCloskey 1994; Daunton 1995; Evans 2001; King and Timmins 2001)? In London, atmospheric pollution of fogs and smoke became an increasing problem even in the parks of the mid-eighteenth century (Ackroyd 2000; Picard 2000). Domestic use of coal by the eighteenth century was blackening the facades of buildings even in non-industrial towns (Brimblecombe 1977, 1978; Brimblecombe and Bowler 1992; Richardson 2003; Roberts and Cox 2003). Fogs increased significantly in London from the 1800s such that they became specifically associated with the capital - "London's ivy" as Dickens refers to it (Ackroyd 2000).

Exposure to pollution resulting from domestic life, domestic industry and, later, the full sway of industrialisation would, on the face of things have a dramatic effect upon the population of eighteenth and nineteenth century Coventry and Chelsea. Indeed, while Chelsea, for the majority of the period covered by the project was more a village or town than a suburb, the exposure to pollutants would not have been necessarily lessened because of this.

While atmospheric pollution most commonly provides a dominating image thanks to popular imagery and the descriptions of contemporary authors such as Dickens, biologically the greatest contributor to lead toxicity was dietary uptake (*cf.* Chapter 4). The utilisation of lead can be traced back to the Roman period, where it was used in the production of utensils, ornament and for the storage of wine, where it was found to both sweeten and preserve the wine (Agricola 1556; Eisinger 1982; Nraigu 1983; Weeden 1984). Indeed, the utilisation of lead salts to sweeten both food and drink was common during the period, despite an awareness of the deleterious effects of water carried through lead pipes (Nraigu 1983).

It is perhaps unsurprising that plumbism was, and continues to be, mistaken for alcoholism given its particular association with the production and storage of alcohol. The utilisation of

lead to sweeten wine continued into the nineteenth century and, perhaps might have had a significant impact upon CHE654, Thomas Long, a keeper of wines and liquors (Eisinger 1982):

> "...And I bequeath all my household goods and furniture, books, wines and other liquors, plate, linen and china which may be in and about my dwellinghouse..." (TNA Prob 11/1733 (PCC))

Lead in alcohol would not have been exclusive to the wealthy and their wines, but also to the common person. Cider and beer either used lead vessels or in the case of cider, the addition of litharge (PbO) to the beverage itself at a surprising "one ounce of lead-ore to every quart in measure" (Weeden 1984: 24, 40; Handler *et al.* 1986; Richards 1999). Ceramics, an everyday item of storage, also contributed to the dietary lead burden. Acidic materials stored in lead containers would rapidly leach lead into the food or beverage (Richards 1999). While there was an understanding of the dangers associated with acidic materials in lead-glazed or bearing vessels, Raffald's "The Experienced English Housekeeper", for example, shows little concern with this (Lind 1754; Hardy 1778; Raffald 1782: 342; Fothergill cited in Richards 1999: 165).

Occupational lead exposure was also acknowledged for deleterious health effects, if not specifically plumbism, from the seventeenth century onwards (Weeden 1984). By the nineteenth century those professions that were most susceptible to lead poisoning were listed by Thackrah (1831), including miners, ironworkers, founders, potters and, perhaps most interestingly, brass workers and solderers.

2.2. A History of the City of Coventry

The previous sections have concentrated upon general concepts around the forces of industrialisation and broad-reaching concerns about the nature of standards of living and the quality of life in that same period. Indeed, as an archaeologist first being introduced to the complex forces involved in the eighteenth and nineteenth centuries, and the centuries that preceded them, the grand sweep is as important as the specific context of the study locations themselves. Thus, while one cannot ignore the grand and long-term forces of industrialisation in a socio-economic consideration of the study locations, a separate and individual discussion of Chelsea and Coventry must now be given to provide greater context to a discussion of 'life' during the study period. Specific attention will also be drawn to the hamlet of Radford, originally in the county of the city of Coventry and then within the parish of Holy Trinity, given its identification late, in this thesis in the biographies of one of the sampled individuals from Coventry (see Chapter 6).

2.2.1. The Historic Population of Coventry

From its origins, the population of Coventry was subject to great variation, tied to the vagaries of the rise and fall of its dominant industries. From the twelfth century with a population of 4,187 as revealed through the poll tax, to *ca.* 6,700 by the early 16th century, a period of economic decline that was to reversed by the mid-to-late 16th century (VCH 1969).

In the 18th century, however, the population seems to significantly expand with claims of inhabitants in the range of 12-14,000 (VCH 1969), a number which seems to support the economic expansion experienced in the period, as well as that seen in general in English cities experiencing industrialisation. By 1801 the census determines that Coventry has 16,034 inhabitants and the 'county of the city of Coventry' approximately one-third of that

at 5,547, especially intriguing given the nature of outworking and the 'proto-industrialisation' experienced by Coventry (VCH 1969; Daunton 1995; King and Timmins 2001).

At this point it is argued that immigration into the city outpaces the natural expansion from the local population (Williamson 1994 *contra* Pooley and Turnbull 1998). From 1801 to 1851, the end of the study period, the population expands dramatically. With reference to the period of economic expansions for both the ribbon-weaving and watch-making trades it is intriguing to note the decennial population figures for Coventry:

Parish	**1801**	**1811**	**1821**	**1831**	**1841**	**1851**
Holy Trinity	5,232	5,737	6,745	9,601	11,658	14,586
St. Michael's	10,817	12,186	14,497	17,469	19,123	21,622
HT+SM Total	16,049	17,923	21,242	27,070	30,781	36,208
% Change	-	+11.7	+18.5	+27.4	+13.7	+17.6

Table 1: Estimated Population of Coventry between 1801-1851, with percentage change indicating the relative increase from the previous period (VCH 1908: 101).

The greatest expansion of the population is during both the 'great purl period' – a period of economic prosperity following the Napoleonic War – of the height of ribbon-weaving (see below) and during the transition from apprenticeships in ribbon-weaving to watch-making in the later- to mid-nineteenth century (VCH 1969).

Historically the population of Coventry and Warwickshire has had a diverse ethnic base, being composed of a wide variety of individuals immigrating into the city (VCH 1904, 1908). It is interesting to note that while the population expanded greatly, the actual area covered by the city varied little during the later medieval and post-medieval periods and, not until 1743 did the city begin to exhibit significant changes to its size.

With the burgeoning population of the 19th century, the reaction within Coventry was the construction of significant quantities of 'workers' houses'. The medieval character of the city was already firmly established, evoking an image out of a Dickens' novel, with narrow and winding streets choked with smoke and the bustling activity of city life. With the increasing population and the difficulties in expansion outside of the city, all available land within the city was used, including the various courts and garden strips: "...the erection of small houses in every yard and garden where they can possibly be built, not regarding the fatal effects that may possibly arise from infections, fevers, etc., in crowded habitations" (VCH 1969: 10). By the first and second quarters of the 19th century new land outside of the city was being built upon, including the Hillfields areas (division of the Spon End/Street area) and the development of the Spon End area for watchmakers' houses.

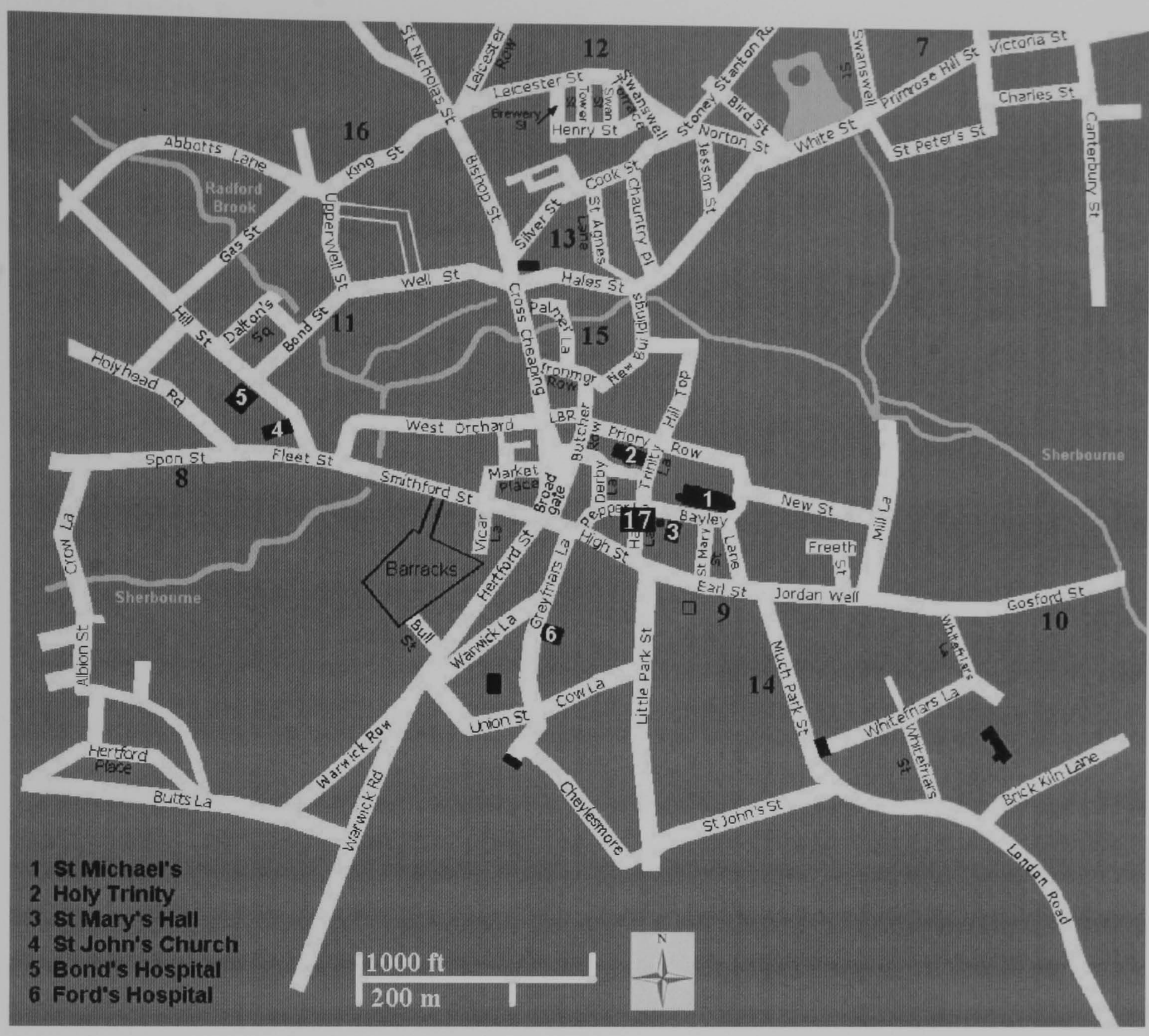


Figure 3: Schematic of Coventry in the mid-nineteenth century showing positions of prominent locations and streets etc. mentioned in the text (schematic from "OS Old Series" [scale 1":1 mile], source: Rob Orland, "Historic Coventry" URL). Locations mentioned in thesis include: (7) Harnall Lane, just north of Primrose Hill St.; (8) Spon St. (including Spon End, Hillfields, and Chapel Fields area); (9) Earl Street; (10) (Far) Gosford St.; (11) St. John's Bridge; (12) Tower St.; (13) St. Agnes Lane; (14) Much Park St.; (15) Palmers Lane; (16) King Street; and (17) The Golden Cross Tavern.

2.2.2. Changing Industries of Coventry and Area Specialisation

While Coventry has primarily been associated with specific industries, especially in the period covered by the Coventry sample in the thesis (see below), other trades have had an impact upon the life of the city, not least the changeable agricultural economy. There are some early indications of the beginnings of such specialisation and aggregation within the town itself. Cloth-making was a dominant force by the fourteenth and fifteenth centuries

(VCH 1969), for example, while metal industry tended to be focussed in the north of the town, while the leather/fur industries, primarily espoused by the tanners, were located in the Spon suburb (VCH 1969). The merchants, who were the heart of the development of Coventry as much as the local tradesman, resided in the wealthier parts of Coventry. particularly Much Park Street, Earl Street, Gosford Street and Chelesmore Lane (VCH 1969).

The early 17th century saw a downturn in the cloth-trade partially due to imports into the city, primarily Gloucester cloth and, later, Spanish cloth which had become popular in London (VCH 1908). While there were partial upturns due to the introduction of new types of cloth, by the end of the 18th century there were only forty individuals directly involved in the cloth-trade. Despite intervention and regulation, the rising problems of unemployment and poverty had, according to the 1662 hearth-tax returns, forced Coventry down from fourth to the nineteenth most prominent city (VCH 1969). At this point the silk-ribbon trade had been introduced for approximately a century and was to become the new economic force in Coventry, revitalising her flagging industries (VCH 1908).

One local industry that deserves a special mention is the development of coal mining in Warwickshire, an industry that would change the scope and pace of industrialisation in England (VCH 1908; Wrigley 1988; Daunton 1995). While coal mining did not take place directly in Coventry until much later, there were significant open seams along the western border of the Warwickshire Coalfield in some fifty collieries (VCH 1908; Bridge *et al.* 1998). By the middle of the 19th century the production and depth at which coal was extracted from increased such that by the end of the 19th century the output from the Warwickshire Coalfield had increased from the low tonnages common in pre-19th century English coal fields to just fewer than 3.1 million tonnes (VCH 1908).

2.2.3 Important Industries of Coventry in the 18th/19th centuries

Two industries deserve further mention for their importance in this thesis the ribbon-weaving trade and the watch-making trade which, in the 18th and 19th centuries all but came synonymous with Coventry. Unfortunately, the nature of the project necessitates only a brief if separate look at these fascinating industries, more so with the ribbon-weaving industry (Press 1960).

2.2.3.1. The Ribbon-weaving Trade in Coventry

The ribbon-weaving trade was first introduced to Coventry at the very end of the 17th century or the beginning of the 18th century and was rapidly to become synonymous with silk production despite manufacture in other locations. It was also a mercurial mistress to the city, with the fortunes of the industry and therefore the lives of the people involved in it.

From its first introduction the ribbon-trade was in competition with continental, particularly French, products which were imported into England. It is at this point that contemporaries considered the height of silk-ribbon production in Coventry, with both the competition and the introduction of invigorating ideas and new styles (VCH 1908). Following the prohibition of silk-ribbon imports in 1765, however, the quality was thought to drop while the quantity of material produced increased with the rapidly inflating ribbon-weaving population.

At the height of the 'big purl (pearl)' period in the first quarter of the 19th century the silk ribbon industry engaged 9,941 with an 11:20 ratio between men and women, engaged 3,008 engine looms and 5,483 single hand-looms (VCH 1908). A significant outworking district around Coventry and town/villages that were almost exclusively populated by ribbon

weavers: Foleshill, Bedworth, Nuneaton, Coton, Atherstone, Bulkington, Rytok, Stoke, Stockingford, Ansty, Exhall, Barnacle, Shilton and Keresley (VCH 1908).

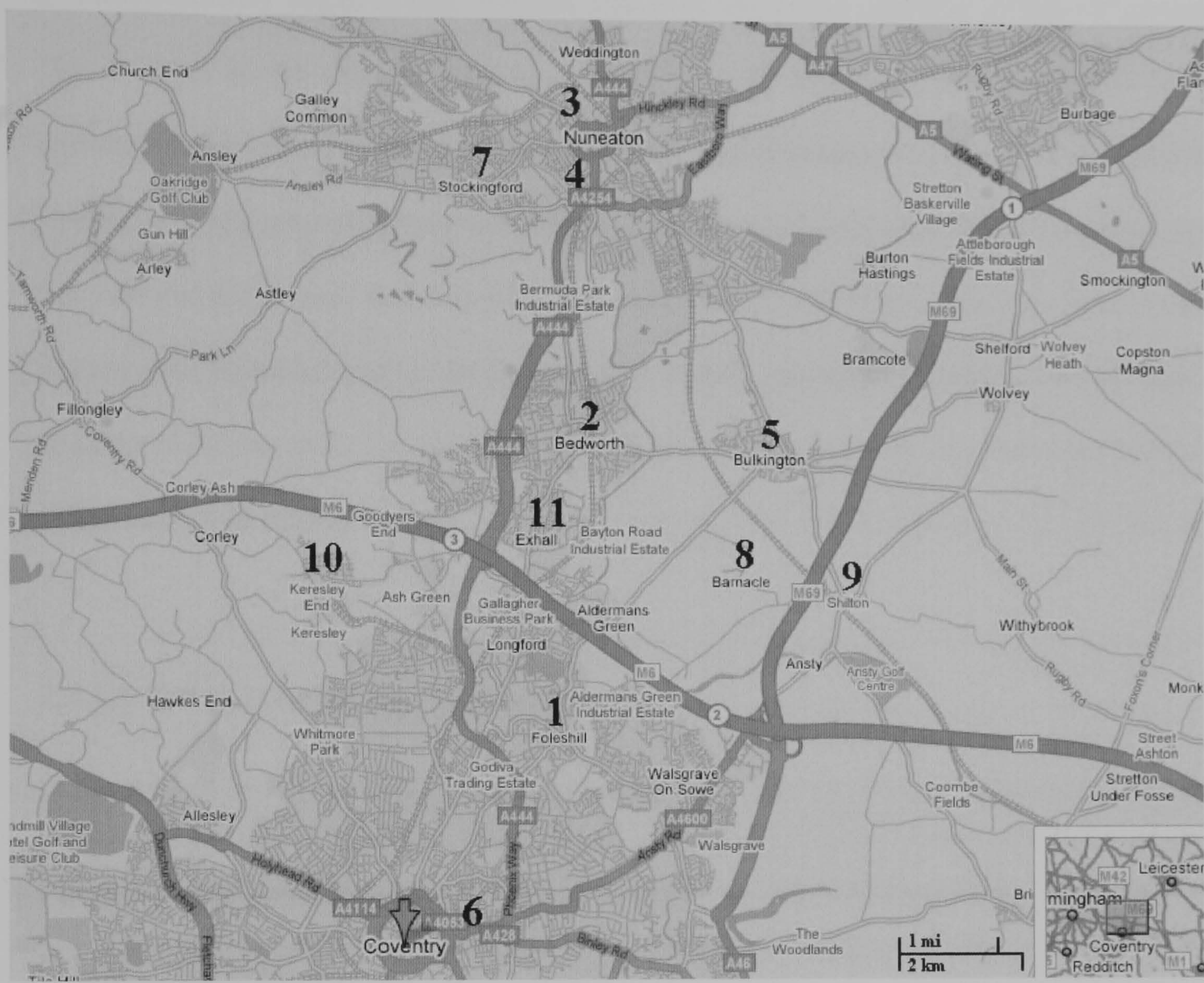


Figure 4: Modern map of Coventry and locale showing the position of ribbon weaving outworking towns mentioned in text: (1) Folehill; (2) Bedworth; (3) Nuneaton; (4) Coton; (5) Bulkington; (6) Stoke; (7) Stockinford; (8) Barnacle; (9) Shilton; (10) Keresley; and (11) Exhall. (Source: GMaps.)

Yet the 'big purl' period was also to see increasing competition from other areas of England, significantly Derby, were power looms had successfully been introduced (VCH 1969). It is perhaps Coventry's unique experience with the cloth-industry, but also more specifically the protection enjoyed from foreign imports between 1765 and 1826, the ribbon weavers of Coventry were highly resistant to the forces and processes of modernisation. With the introduction of the power loom in 1838 there was a slight resurgence in the silk ribbon industry which also brought the manufacturers and the 'undertakers' into conflict with the single-hand loomers both within Coventry and in the outworking districts (VCH 1969).

Despite the introduction of the 'power loom' to the top-room shops that were the stock and trade of the single-hand loom workers as well as the formation of cottage factories. the Coventry industry began to flag with the refusal to accept the 'realities' of the 19th century. The workers in the cottage factories, as well as top-shop weavers, demanded the re-introduction of price lists as controls against the higher productivity rates of the factories, striking until the majority of the factory owners had capitulated (VCH 1969). In many ways this saw the death-knell to Coventry's importance in the silk-ribbon industry as the factory system was replaced with a cottage industry which, ultimately, would never be able to compete with the other developing silk manufacturing areas and, by 1860, had virtually collapsed (VCH 1969).

2.2.3.2. The Watch-making Trade in Coventry

At the period when the ribbon-weaving industry was beginning to fail the watch-making industry was at its height and of national importance behind only London and Liverpool. An industry that relied on too much hand craftsmanship for the powered systems of the time, despite the adoption of the watch-making trade by Birmingham in 1808, it was to go from strength to strength until the adoption of the manufacture of sewing machines, cycles and then, in the late 19th century, automobiles (VCH 1969).

Although sustained development of the watch-making industry did not peak until the second quarter of the 19th century, it first made its appearance in the late 17th century. Trade directories from London reveal that a Coventry watch-maker was working in London in 1695, while earlier in 1686 one was elected sheriff in Coventry and the council authorities were paying two other watch-makers for the maintenance and production of equipment for several clocks (VCH 1969). With the concerns revolving around finances in Coventry during the early 18th century, however, the financing of such works were amongst the first to

be cut and, from that point on, there is little information about the Coventry watch-making trade until the middle of the 18th century when it once again began to get a significant foothold. Watch-makers like their cloth- and silk-weaving forebears were being introduced to the echelons of local government as constables, wardens and bailiffs (VCH 1969).

The high period of the 1830s to 1850s saw a rapid growth of the industry from 52 listed watch-makers in 1830 to 142 by 1850, a period which also saw some 2,000 individuals employed in the trade along with 776 heads of household (VCH 1969). The number of apprentice watch-makers increased dramatically between these two dates, shifting the balance with the weaver's trade in part, perhaps, due to the difference in their standard of living. While the trade had been concentrated in Spon End and Chapel Fields, specific watch-makers housing for both masters and journeyman was constructed in 1846 in the Chapel Fields area (VCH 1969). Indeed, while the houses were not significantly different in size to those of the weavers, the discrepancy in incomes was sufficient to free the married journeyman's wife of the need to work and, in that way alone, could improve the standard of the household in a time of severe bias in sex-related duties. In 1851 the watch-trade had, as with the ribbon-trade before it, created its own districts as well as a scatter of watch-makers across the city and, while it would decline in the second half of the 19th century due to cheaper Swiss and American watches, it has remained a part of the city's industry to this day.

2.2.4. The Hamlet of Radford

While Coventry as the 'city and council' with leet status over 15,000 acres self-evidently had a significant influence over a large number of hamlets, Radford deserves special, if brief, mention as the birthplace or at least early living place of one of the individuals covered by this study. Located approximately one mile north-west of the centre of Coventry,

Radford was primarily one of the weaving districts of suburban Coventry, the population was comprised primarily of weavers with the remainder composed of agricultural labourers (VCH 1969). At one point, intriguingly, it was to become the focus of a local politics in the early 19th century when a fictitious character purportedly based in a 'castle' in Radford makes strong comment about the state of the weaving trade, boisterously calling for the 'drowning of every half-pay apprentice at present employed' (VCH 1969).

No records exist for the population of Radford before 1821, though for the next 30 years the population remains stable in the low 200s until, in 1851 it nearly triples as a result of the introduction of new weaving techniques into the area (VCH 1908, 1969).

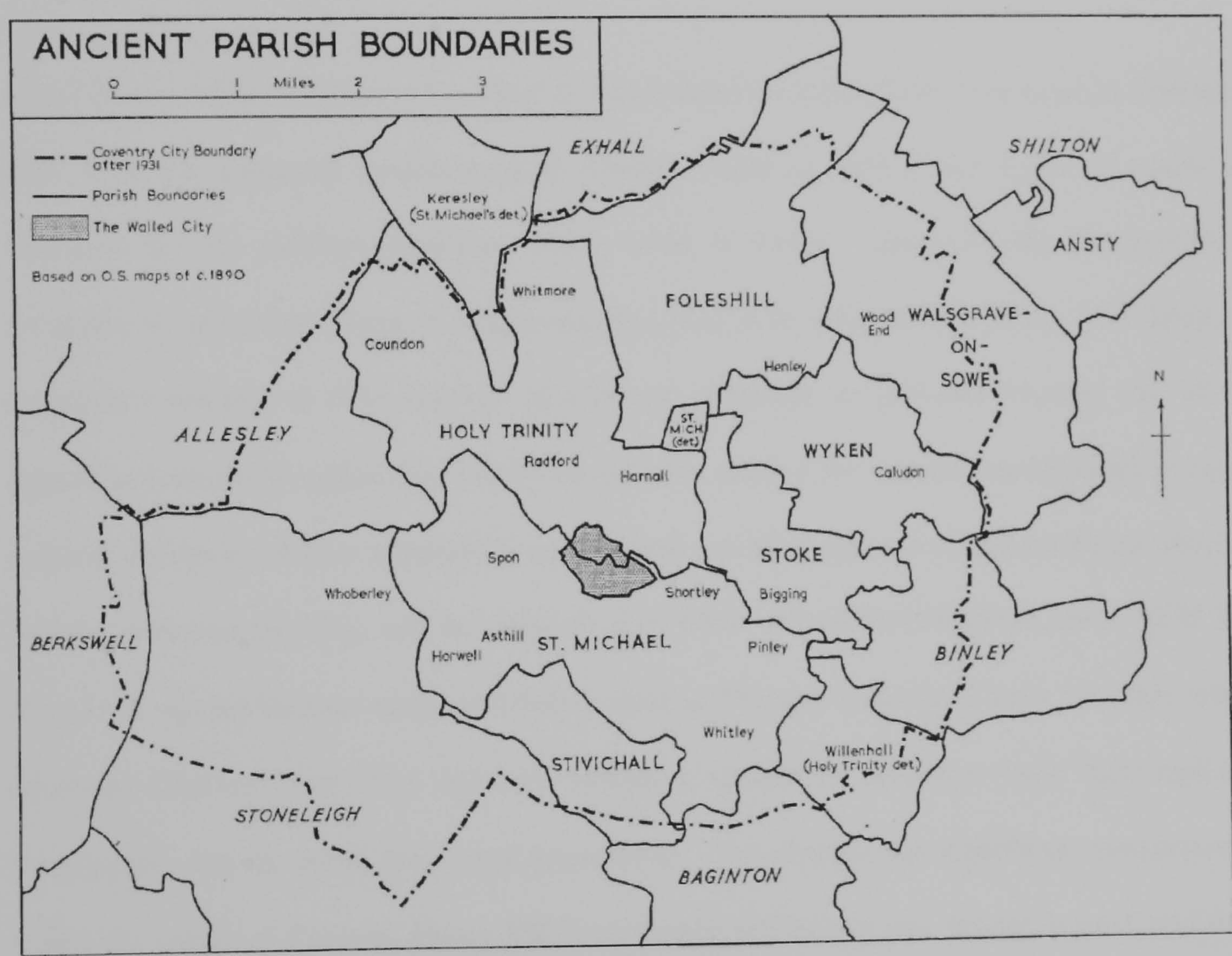


Figure 5: Schematic of Coventry parish boundaries showing the position of the city of Coventry (shaded area) and the hamlet of Radford to the NNW of the city. (Source: British History Online)

2.3. A History of Chelsea

While Chelsea was subject to many of the same considerations as Coventry and other urban areas, it was not until the late 19th century that many changes came to bear. A pleasant locale enjoying good natural communications, Chelsea was favoured between the 15th to 17th centuries by the upper echelons of society and then, both in terms of natural population increase but also as a service industry, and then in through the 19th and 20th centuries from a socially mixed to, once again, a more 'elite' residence.

2.3.1. A General History of Chelsea

Local historians and commentators tend to concentrate on Henry VIII's presence in Chelsea, both with the supposed construction of Chelsea Place as well as his desire to create a 'nursery' for his children (Faulkner 1829; VCH In Press). However, the documentary evidence is somewhat scarce in supporting this, and it is unlikely that Henry VIII spent a significant amount of time resident in Chelsea, although its pleasant location has been argued as potentially indicating that he would have used it for summer entertaining or rest. Further, the manor that he supposedly constructed was likely part of a land exchange, one of several, between the king and his subjects (*c.f.* PRO, SC 6/HENVIII/2101, m.4; VCH In Press). A second famous estate in Chelsea, that of Thomas More the king's secretary who inhabited Chelsea from 1524 and who bought a number of properties both there and in Kensington, was to come into royal possession. Yet despite the significant possessions within the parish of Chelsea, Henry VIII's residence in Chelsea was limited at best, and the records indicate that the various properties were more often used as a summer or residence and retreat by those having the favour of the king, e.g. to escape the depredations of the plague (i.e. L&P Hen. VIII, XIII(1), pp. 332, 343 in VCH In Press).

The importance of Chelsea most likely arose out of the good communications with London, partially a result of the river and proximity to old Roman Roads. It did not, however, contain any more or less upper class settlement than other locations in London, though the density was often remarked on. By the sixteenth and seventeenth centuries it was expanding to include farmers and craftsman and, unsurprisingly, individuals engaged in the food and service industries (Denny 2001). While the majority of the expansion and construction in the period revolved around the construction of new and the renovation of old manors, the construction of lower class residences can also be seen both in the Riverside and Church Lane areas, as well as to both the west and east of the village, more particularly in Eastfield in the latter case. By 1631, 'New', or 'Little' Chelsea had formed along the Fulham Road though the reasons for its growth are unclear.

It is to the construction of the Royal Hospital in Chelsea that dates the period of greatest speculative building, both of middling- and upper-class buildings. Expansion was also evident in the old village, although somewhat cynically thought to be a means of increasing churchgoers and therefore church rents (VCH In Press). The scale of expansion is impressive, the number of houses increasing from 172 in 1674 to 1,350 houses in 1795, the majority of which remained concentrated along the riverside (Wrigley 1967; Rudé 1971; VCH In Press).

By the 18th century, though, Chelsea was becoming associated less with the upper-class residents – Defoe describing it as a "Town of Palaces" – and more with the service and pleasure industry that grew up around both the upper-class residents and Chelsea's favourable location. Taverns which had existed from the 15th century, such as The Rose on Church Road, and the later Ranelagh Gardens coupled to provide a pleasant escape from the pressures and odours of a London undergoing the problems of industrialisation (Bryan 1869; Cathcart-Borer 1973; Ackroyd 2000; VCH In Press). This development was perhaps aided

by the earlier development of a King's Road which would later, with the eventual conversion to public property and the reluctance of the parish officers to take responsibility for the avenues and paths, do much to further integrate Chelsea into the wider suburban and urban landscape. Chelsea's new status was ratified by the London Building Act of 1774 (Clark and Gillespie 2001).

With the continued building taking place in Chelsea in the second quarter of the 19th century the 'elite fabric' of Chelsea, in part related to the quality of the highways the improvement of which was stimulated by the Chelsea Improvement Act of 1845, but also the poor quality of sewage. Particularly concern was raised over Sloane Square with regards to the problems of pestilence and cholera (*The Times*, 12 November 1845; VCH In Press)

At this point the continued development of Chelsea extends beyond the period of the study, further integrating Chelsea into the metropolis and, after the social decline in the mid-19th century, the return of Chelsea as a focus of the artistic 'elite' and, then, fashionable elite residence.

2.3.2. Population History

The historical documents that attest to the population of Chelsea before the nineteenth century are scarce, i.e. the Domesday Book and extant manorial record from the fourteenth century onwards (Lysons 1811: 116; Martin and Williams 2004). In the sixteenth century the population of Chelsea can be seen to be expanding by the number of baptisms in the parish, from approximately five per year in the 1560s, to eight in the first decade of the seventeenth century, through 43 in the 1680s. By the fourth quarter of the 18th century the number of baptisms recorded was at 158 per year and steadily increased (VCH In Press).

In the 19th century, census returns allow for a more accurate determination of the population and its growth, as indicated in the table, below:

Population	**1801**	**1811**	**1821**	**1831**	**1841**	**1851**
Total	11,604	18,262	26,860	32,371	39,796	53,725
Difference	-	6,658	8,598	5,511	7,425	13,929
Increase	-	+36.6%	+32.0%	+17.0%	+18.7%	+25.8%

Table 2: Population of the Parish of Chelsea 1801-1851 with percentage change indicating the relative increase from the previous period (Census 1801-1840; LCC 1901; VCH In Press).

While in 1801 the population of Coventry and Chelsea are remarkably similar, as the nineteenth century progressed Chelsea began to experience a population growth that outstripped the industrial town of Coventry, perhaps not surprising given its proximity to London and the process of suburbanisation (*cf.* Pooley and Turnbull 1998; Clarke 2000).

2.3.3. Economy and Industries in Chelsea

In its early history, Chelsea was a village much like any other, engaged in feudal agricultural activities. With the 15th century this had not changed dramatically, and continued until the 17th century and the adoption of farm, market and, later, nursery gardening to provide London and the 'elite' with produce that was formerly shipped in from the surrounding county. From this period the entertainment and service industries, present from the 15th century in some form or other, e.g. taverns with or without associated bowling greens, begins to become significant with the changing interest in Chelsea from elite London retreat to a distinct socio-cultural district. The specific economies present in Chelsea during the post-medieval period are detailed below, though they broadly remained unchanged until the end of the nineteenth century and outside of the primary focus of the sample in this thesis.

2.3.3.1. Agricultural History and Market Farming

Enclosure was, as with the rest of Britain, to have an impact upon Chelsea. The seventeenth century saw the agriculture of the parish of Chelsea, and that of neighbouring Kensington, transformed both as a result of the enclosure of land for the creation of 'pleasurable gardens' but also as a result of increased demand for the population of London. Despite this, however, common grazing rights were maintained by the commoners throughout the sixteenth and seventeenth centuries and farming continued either on the estates or through sub-leasing of lands within estates.

Horticulture had become popular with the upper classes in this period, tying into the growth of such places as Ranalegh, and the middle classes were soon to follow through social emulation (Picard 2000). Spade agriculture was practised with the rotation of root crops with those of traditional crops allowing the maintenance of the open field system. The heavy use of manure in the form of night soil from London allowed a continuous growth period and for Chelsea to benefit from two to three crops per year (King and Timmins 2001; VCH In Press). Areas particularly associated with market gardening with the areas between Little Chelsea and Stanley Houses, though contemporary visitors were to remark upon the preponderance of the activity (Bryan 1869; VCH In Press). In the nineteenth century, market gardeners were producing 140 acres of crops including potatoes, turnips, rape, peas and beans.

The development of nursery gardens was also noteworthy in Chelsea, an industry involved in the catering to the tastes of the day, though this time concentrated on more exotic flora. While these would survive the expanding urban environment for longer than the market gardens, eventually they too would succumb.

2.3.3.2. Entertainment and Service Industry

The entertainment and service industry provided employment for a significant proportion of the population. By 1831 some 26,213 individuals (~81% of the total adult population) found employment in the retail trade, professional positions, the communications industry and, most significantly, the domestic services (VCH In Press).

Retail Industry: While distributed throughout the built-up areas of Chelsea, a number of distinct locales became associated with the retail trade, namely Church Road and the riverside, King's Road, Marlborough Road and, later, Sloane Street. The majority of these retail outlets were entirely locally driven until the introduction of larger stores in the early 20th century (Aldburgham 1979; VCH In Press).

Service Industry: Once again, the Riverside was most well known for the greatest concentration of inns and coffee houses. Most famous amongst these were The Rose, probably present from the third quarter of the sixteenth century, the Pye or Magpie in which court leets were held, etc. Documentary references to such locations increases into the seventeenth century with the better known inns and coffee houses including the Cricketers, the King's Head, the Magpie, Saltero's Coffee House, the Thames Coffee House, the Yorkshire Gret, the Feathers and the Cross Keys. The area around the Royal Hospital also attracted significant attention, partially due to the upper-class interest in the location. Locales of interest here include Stromboli House and Gardens, Star and Garter Tavern in the Five Fields and, most famously, the Chelsea Bun House in Grosvenor Road (see section 2.4.4).

2.3.3.3. Significant Industries

Chelsea became known for a number of industries throughout its history, more particular for the provision of ancillary goods for the construction industry in the mid-to-later 19th century (e.g. Bryan 1869; VCH In Press, etc.):

Gravel Extraction: The presence of the free-draining gravels was partially responsible for the upsurge of the market-farming phenomenon, but also providing a likely industrial activity from the 12th century with 'digging' taking place both from the riverside gravels of the Thames, the Common and other locations by the 17th century.

Brewing: Given the significant contribution of barley to the agricultural economy of the early manorial system and which was subsequently perpetuated by subsequent tenant farmers, it is perhaps not surprising that brewing would have a significant history in Chelsea. Further, the presence of early taverns, the entertainments industry and, by the mid-19th century, the import of brewers and malters suitable for juror service all go to attest to its importance. As with gravel extraction, brewing had a history in Chelsea from the 12th century and remained a constant feature throughout the period that this project covers. Premises owned by Francis and Samuel Smith known as 'The Swan' in 1664, which were located near the riverside wharfs would also suggest export as well as local consumption.

Chelsea Porcelain: As with 'buns' (below), porcelain has all but become synonymous with Chelsea in the common useage despite the fact that they have not been produced in the area for two centuries. In the 1750s the factory of Nicholas Sprimont, formerly of Soho, was at its height using styles inspired by the nearby Physic Garden. With Sprimont's declining health, however, came a decline of production until, in 1768 the factory closed and its remaining stock passed to James Cox and, from there onto William Duesbury and John Heath. It is from 1770 onwards that Derby ceramics become popular in London, working

from the exclusive clientele developed by Sprimont (Blunt 1925; Hume 1969; Adams 1987; VCH In Press). The Sprimont and the Duesbury and Heath workshop was not the only one present in Chelsea, however, and Thomas Bentley, a partner of the famous Wedgewood, maintained a workshop there until 1774 (VCH In Press).

Metalworking: Other than an established weapon-making industry in Chelsea, a number of foundries were set up in the late 18th and early 19th centuries. The first was owned by Thomas Janaway who produced bells for a wide area in Chelsea from 1759 until his death in 1788, after which it may have continued until 1825 and the sale of the building. Intriguingly there is also mention to the 'queens engines' being produced in the 17th century, possibly a reference to siege engines (VCH In Press).

Floorcloth and Paper-stainers: Both industries benefited from the expansion of housing in Chelsea and in London in general seen in the eighteenth and nineteenth centuries. The former industry had several manufactories in Chelsea from the mid-to-late 18th centuries, involving the painting of canvas with thick layers of paint and then the use of summer blocks in summer to create patterns. Associated first with the Morley family and then the Downings, the trade continued until the third quarter of the 19th century. Similarly paper-staining was situated in a number of factories throughout Chelsea and the trade continued throughout the 19th century.

2.3.4. The Royal Chelsea Bun House

As one of the identifiable points in Chelsea associated with the project, the Chelsea Bun House associated with the Hand family deserves a separate mention. Located opposite the Five Fields at 10 Grosvenor Row and near the end of the expansion in lower-class buildings from the Royal Hospital, the Chelsea Bun House was famous throughout London and

frequented by George II and III (Blunt 1921; James 1950; Cathcart-Borer 1973; Wienreb and Hibbert 1983; Marsh 1984; Miles 2001; Richardson 2003; Miles 2001). Opened by Richard Hand, notorious for wearing a Turkish fez and long dressing gown and acquiring the name "Captain Bun", both he had his wife Margaret ran the Bun House jointly until his death in 1767 (Blunt 1918; Blunt 1921, 1928; Miles 2001). The legacy of the Bun House was to continue and, indeed, grow under the guidance of Margaret Hand – subsequently described as a 'pastry cook' (Sun Fire Office Policy no. 439073, LMA mf 11936/289) – even to become immortalised in several folk songs of the period.

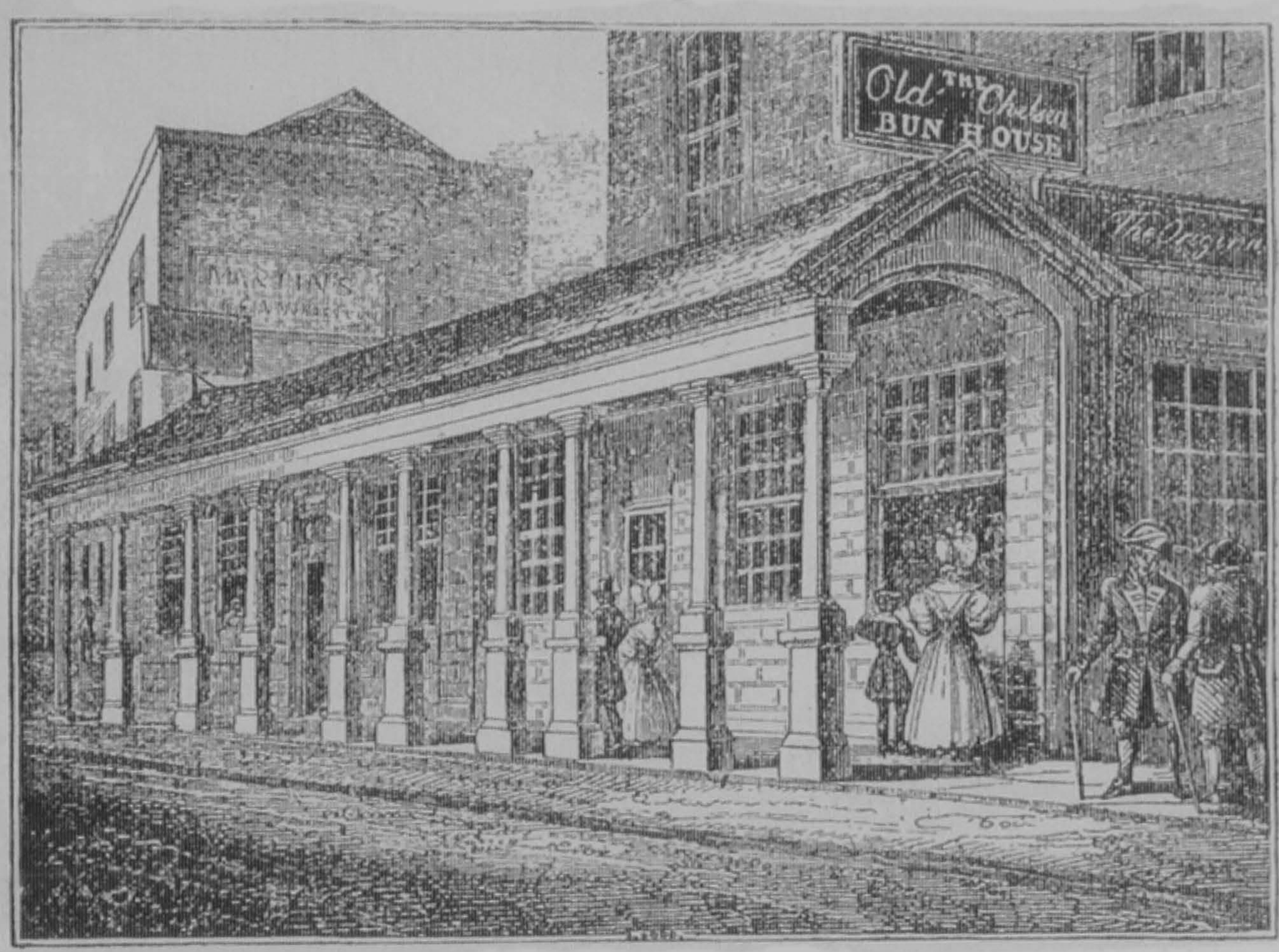


Figure 6: The exterior of the Chelsea Bun House (Anonymous 1899).

The Bun House was said to have a museum that rivalled the famous Don Saltero's, and include artefacts such as: a silver half-gallon mug that, along with five guineas, was the gift of Queen Charlotte – "Old Snuffy", as she was called – and George III, who would often visit and "[munch] buns, much stared at by the curious crowd" (Bryan 1869; Martin 1889); and a couple of 4'-tall lead figurines of Grenadiers 'presenting arms', as well as casts,

portraits and a garden with 'one of the inevitable Grottoes of the day' (Blunt 1921; Richardson 2003; VCH In Press).

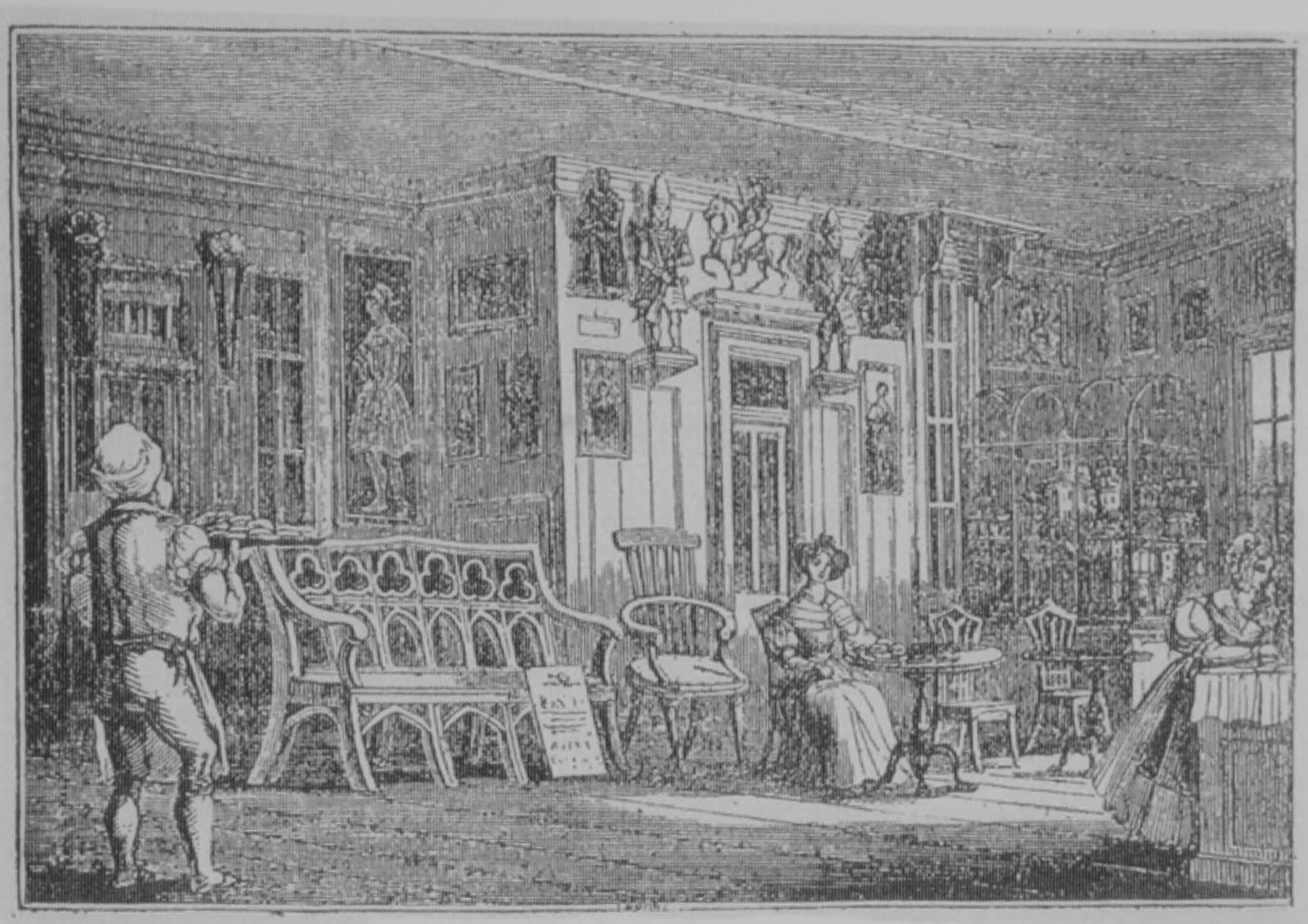


Figure 7: The interior of the Chelsea Bun House (Anonymous 1899).

While the popularity of the Chelsea Bun House seems to have increased with time, it was famous even early in its history when on 2nd May 1712, Swift mentions a visit to the shop and, perhaps, even Mozart who was resident in an adjacent street in the fifteen months he lived in England visited this famous locale (Bryan 1869; Blutn 1921; Holme 1972). By 1793 the demand had become popular with 'certain classes' of people – servants of the nobility, gentry, shopmen mechanics and apprentices (Bryan 1869) – for the produce of the Bun House that Mrs Hand posted notification in a newspaper (Blunt 1921):

> "…in consequence of the great concourse of people which assembled before her house at a very early hour, on the morning of Good Friday last, but which her neighbours (with who she had always lived in friendship and repute) have been much alarmed and annoyed; it having been also intimated, that to encourage or countenance a tumultous assembly at this particular period might be attended with consequences more serious than have hitherto been apprehended; desirous,

> therefore, of testifying her regard and obedience to those laws by which she is happily protected, she is determined, though much to her loss, not to sell CROSS BUNS on that day to any person whatever, but Chelsea buns as usual." (Cathcart-Borer 1973)

Such was the popularity of the shop and its buns that regularly crowds of 50,000 were reported as waiting outside on Good Fridays and, despite the closure of Ranelagh Gardens in 1804 resulting in a tail off in trade, it was still reported as selling just one quarter of a million buns (~£250 of income) on Good Friday, 1839 (Byers 1943; Wieinreb and Hibbert 1983; Miles 2001). With the death without issue of Gideon Richard Hand in 1836, the Chelsea Bun House was transferred to the state and, from there, eventually into the hands of David Loudon (James 1950). In 1839 the Bun House was demolished to allow for the expansion of the adjacent road and its unique collectables sold off (James 1950).

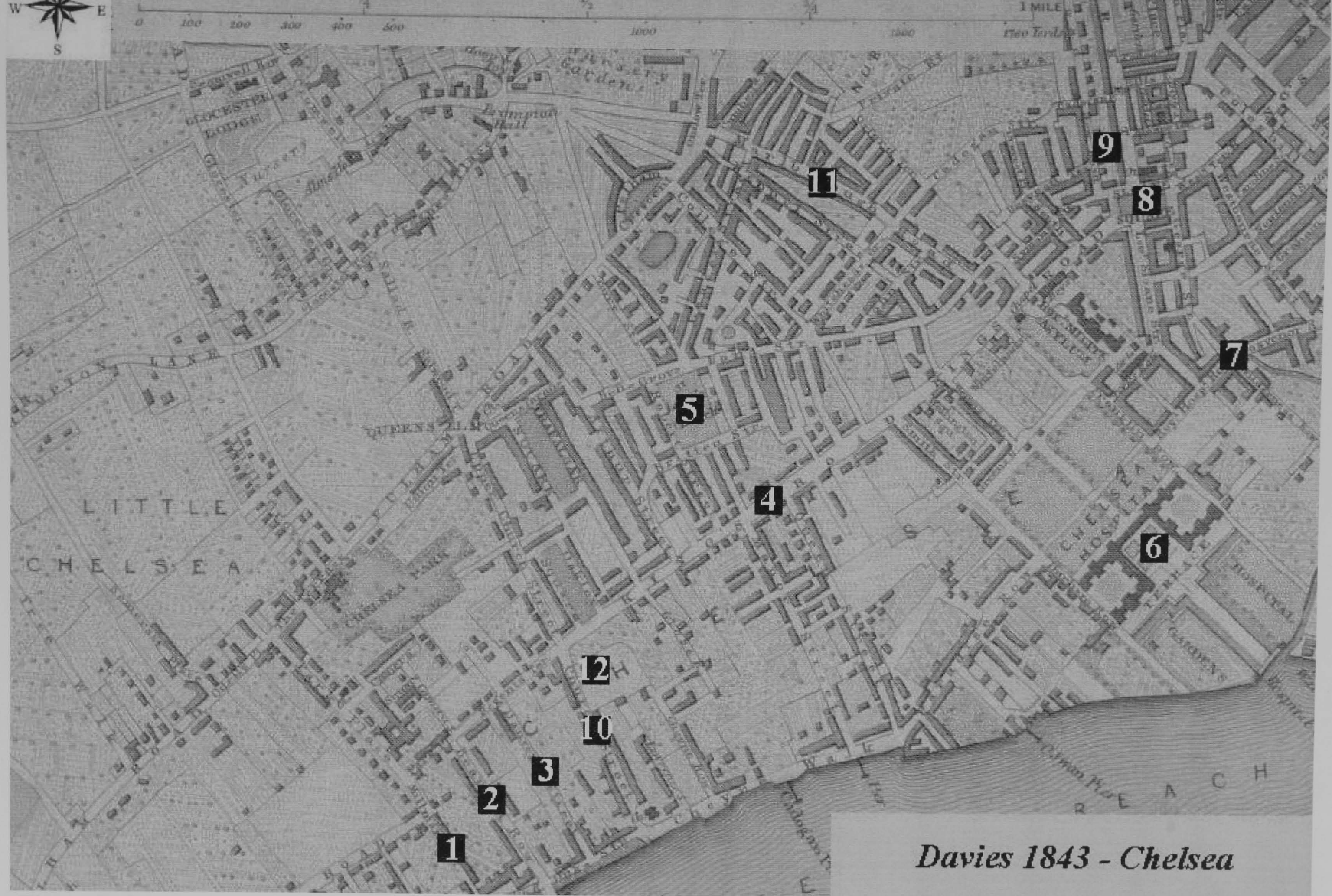


Figure 8: Chelsea and environs (Davies 1843) showing the locations of streets and places mentioned in this thesis: (1) Millman's Row; (2) Beaufort Row; (3) Danvers Lane; (4) King's Road; (5) St. Luke's Church; (6) Chelsea Hospital; (7) Grosvenor Road, approximate location of the 'Chelsea Bun House'; (8) Sloane Square; (9) Upper Sloane Street, backing onto New Road (west); (10) Church Street; (11) Marlborough Road; and (12) Old Church (St. Luke's). Scale from full-size map included.

3. The Osteoarchaeology and Archaeology of Chelsea and Coventry

While the previous chapter focussed on providing a historical context for the two sites, this chapter concerns itself with the material manifestation: the excavation and material culture produced during the 1999 and 2000 excavations of St. Mary's and St. Luke's, respectively, and a focussed discussion of the osteoarchaeological conditions represented within the two cemeteries. Comprehensive discussions of both the distribution of pathological conditions and those conditions themselves can be found in numerous texts (Ortner and Putcashar 1985; Roberts and Manchester 1995; Larsen 1997; Aufderheide and Rodriguez-Martin 1998; Mays 1998; Cox and Mays 2000; Roberts and Cox 2003).

3.1 The Archaeology of St. Mary and Holy Trinity, Coventry

While the human remains were interred within the Parish of Holy Trinity, they were recovered with the excavations surrounding the excavations of St. Mary's cathedral. As such, a discussion of the archaeology of St. Mary's is pertinent. Unfortunately, the primary publication for this site, i.e. Rylatt and Mason (2003), does not cover the site in the same level of detail as the Museum of London report for the St. Luke's excavation. Similarly, the Wakely (2001) report focuses purely upon the human remains and not the site as a whole.

3.1.1 Pre-Eighteenth and Nineteenth Century Archaeology

The archaeological record for the St. Mary's site extends from the Saxon/Medieval period to the late twentieth century and the construction projects undertaken as part of the Phoenix Initiative.

While the evidence for some periods is scarce, the archaeological evidence for the cathedral offers a chronology of almost nine hundred years (Rylatt and Mason 2003). Likely constructed over three to four generations and ending sometime in the second quarter the thirteenth century, the cathedral presents a gestalt of different architectural forms reflective of the period (Tilley 1994; Rylatt and Mason 2003). The cathedral was closed by Cromwell and, following its sale in 1545 to John Hales, was disassembled by the population of Coventry after 1572 as a source of building material (Scarisbrick 1994; Demedowicz 2000; Rylatt and Mason 2003). This period of disassembly is attested to by the recovery of a feral dog pack under the collapse of the vault, as well as the presence of significant quantities of butchered animal remains in the western nave, all dated to the sixteenth century (Rylatt and Mason 2003).

By the seventeenth century the cathedral had been reduced to several courses of stonework, though several towers remained standing and, in at least one case, inhabited (Rylatt and Mason 2003).

3.1.2 The Graveyard (c. 1776-1890; Phase 6)

The graveyard of St. Mary's church was extended over the area of the former nave and aisles of St Mary's cathedral in 1776. Burials continued until 1856 with the interment of Frances Drefson, though burials had become increasingly rare in the preceding years, with only 38 since 1849 (Coventry MF1273/19). Despite the 1852 Burial Act (15 & 16 Vict c85), burial within family tombs continued until as late as 1890 (Wohl 1983; Rylatt and Mason 2003). Indeed, one skeleton from the Coventry assemblage ("M.F." according to the recovered coffin plate) was buried following 1852 and no record of the said burial was found in the parish records.

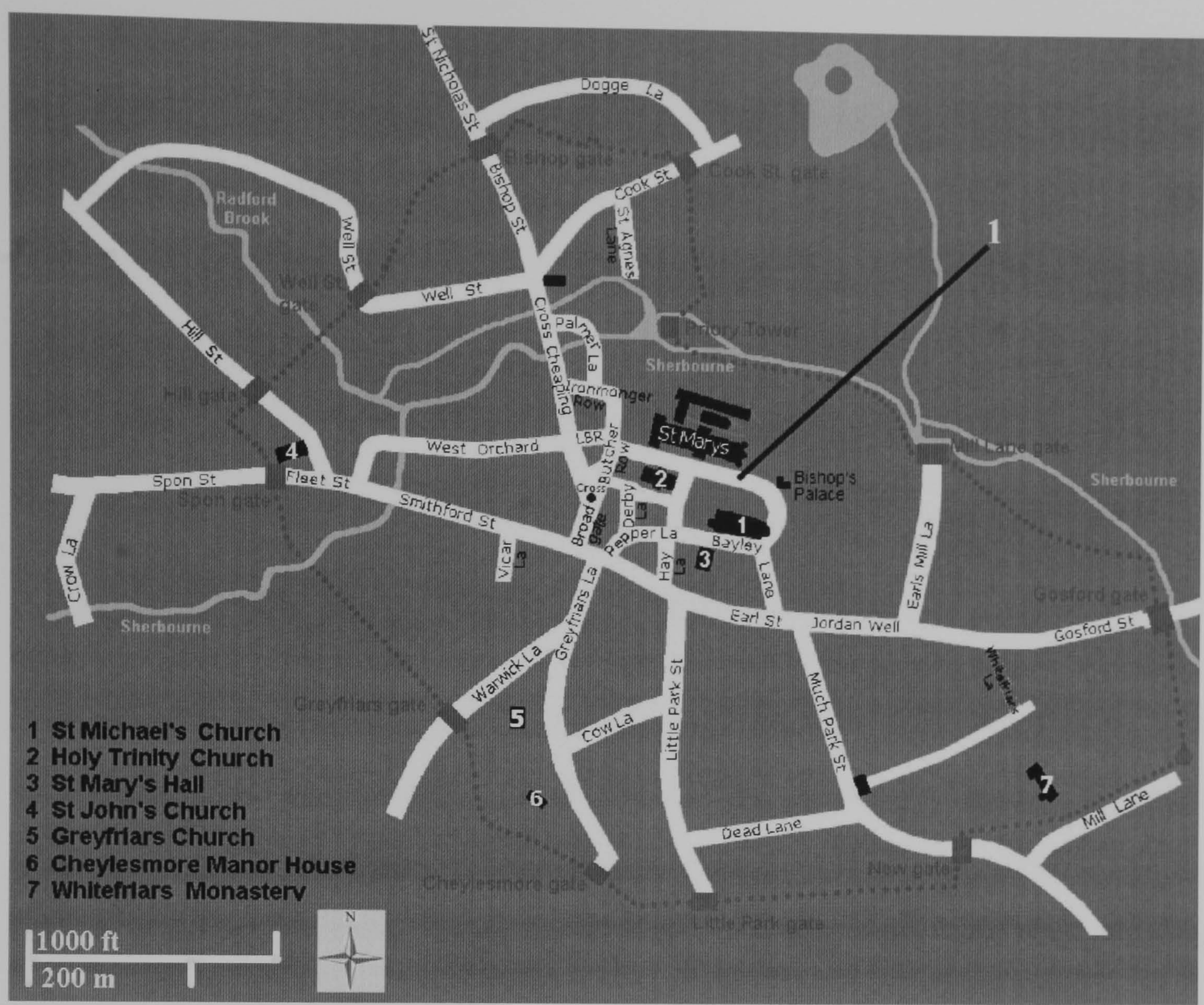


Figure 9: Schematic of Coventry in 1400 showing the position of St. Mary's Cathedral. (1) indicates the position of the road that would subsequently be called Priory Row. (Source: Rob Orland, "Historic Coventry" URL.)

Damage to the site occurred at various points in history, from the truncation of graves during the construction of a bell-tower in the 1850s, to the excavations of Hobley in the 1960s, to both the development and destruction of the Holy Trinity Church Centre in 1975 and 1999, respectively (Hobley 1971; Rylatt and Mason 2003). Excavation and historical documentation reveal that, when the cemetery was in use, it was bounded on two sides (east and west) by buildings, and dividing walls in the north and the south where, in the latter case, it joined with Priory Row (Rylatt and Mason 2003).

The 1999 excavation entailed the removal of 1,706 articulated human skeletons, including those from eight of thirty-seven brick-lined burial vaults, and a further ca. 100 in watching briefs (Rylatt and Mason 2003). *In situ* preservation in areas that were not to be affected by development were estimated to contain another 200 individuals and no details are given in the literature on the Hobley excavations, i.e. the treatment of post-medieval remains was not a priority (Hobley 1971; Boyle and Keevil 1998; Rylatt and Mason 2003).

3.2 The Archaeology of St Luke's, Chelsea

Excavation of St Luke's proceeded in 2000 under the aegis of the Museum of London Archaeological Service (MoLAS) on the site of 2-4 Old Church Street (London, SW3), adjacent to the two unpublished excavations of contemporary sites: 6-16 Old Church Street and 61-62 Cheyne Walk (Farid 1997; Patridge 1997). The site extended over 2,400m^2 overlaying river terrace gravel (1st River Terrace) with a north to south downwards gradient, overlain by a soil horizon primarily altered during the medieval period (Miles 2001).

3.2.1 Pre-Fifteenth Century Archaeology

The medieval archaeology from the site is dated primarily to the thirteenth and fifteenth centuries, and consisted mostly of randomly distributed pit features. The exception to this is five pits to the north side (Miles 2001).

3.2.2 Sixteenth and Seventeenth Centuries

The material from the sixteenth and seventeenth centuries constituted a more substantial component of the recorded archaeology in the excavations. This was comprised primarily of

rubbish and quarry pits, but also included two brick-lined cesspits and a well, which are dated to the earlier part of this phase and which are thought to be garden features of houses fronting onto Church Lane (Miles 2001). In the southern part of the site, the area subsequently covered by the church and the graveyard, quarry pits into the river terrace were also present, filled with pottery, clay-pipes and building material of the seventeenth century and which were earlier than the burials and probably associated with the construction of the church (Miles 2001).

Figure 10: Modern map indicating the position of St. Luke's, Chelsea (1), Old Church Chelsea (St. Lukes) (2), and approximate locations of excavations in Old Church Street (3) and Cheyne Walk (4). Compare with fig. 2 (chapter 2) for comparison between the nineteenth and modern street layouts. (Source: GMaps.)

A wall separated the northern and southern parts of the site and the burial ground proper, which while "well pointed and had a fair face, as if it was meant to be seen" (Miles 2001: 7) was subsequently hidden with material into which burials were cut (Gomme and Norman 1913). The area within the burial ground, with the exception being in the western portions, had been

extensively quarried down to the river terrace gravels (Sumbler 1996). There was no evidence for burials earlier than the late seventeenth century even though the site had likely been in use in the medieval period and, therefore, that the southern portion represents an expansion of the site following rebuilding (Miles 2001; VCH Middlesex XII In Press).

3.2.3 Eighteenth and Nineteenth Centuries

The eighteenth and nineteenth centuries saw the main phase of burial activity on the site following likely expansion during the late seventeenth century (Miles 2001). A total of 285 skeletons were recovered, the majority of which were interred in wooden coffins though some were in lead coffins, including some of the individuals sampled as a part of this project. The site also included three brick vaults, including the Butler family (not present in the sample), and at least one brick-built tomb. The vaults, coupled with documentary evidence indicating the burial of a pauper and the identification of Nicholas Adams as a 'bricklayer', attest to the multiple layers of socio-economic class present in St Luke's (Miles 2001).

3.2.4 Artefacts

Various artefacts were recovered from the Old Church (St Luke's) excavation along with the human remains. These are discussed briefly, below:

Ceramics. The ceramics recovered from the site include domestic and domestic-industry forms from the late seventeenth through early nineteenth centuries, all of which were common to London during the period and some of which were produced in Southwark and Lambeth. Fabrics and forms that were more 'exotic' for the locale include Chinese export porcelains and examples of pearlware decorated in Chinese styles (Miles 2001).

Textiles. The majority of the textiles recovered from the site were from the high-status burial of Martha Butler (d. 1739) and inside the Butler vault. They included a velvet coffin cover and an inner silk lining, this despite the legislation of the period that was meant to prevent burial in anything other than woollen materials (1660 Burial in Woolen Acts [1660, 1666, 1678, 1680; repealed 1814]). The coffin of Mrs Milborough Maxdwell (CHE792) also contained textile remains, an example of which was found adhering to the mid-diaphysis of the right femur:

> "Wool/cotton/linen: discoloured to a light brown colour; fragments of pleated edging with a cut 'pinked' edge and simple punched decoration. Both of these forms of decoration are typical of post-medieval funerary textiles (Janaway 1993) and can be found on the inner coverings of the coffin, the winding sheet and pillows (if present) and the shroud, cap and other funerary clothing. The present examples were found with plain panel fragments and therefore may come from a pillow or from the inner coverings of the coffin itself." (Miles 2001: 22).

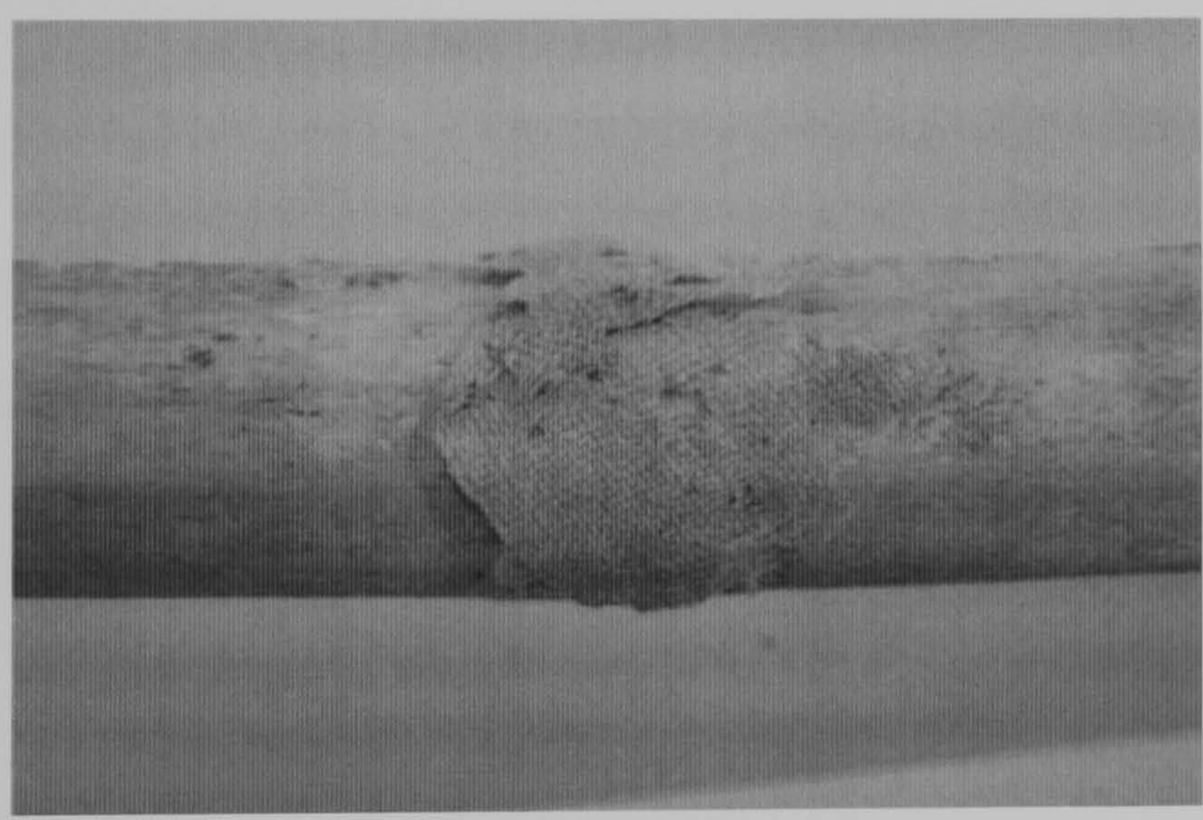


Figure 11: Adhering linen seen on the right femoral mid-diaphysis of Mrs Milborough Maxwell photo: author).

Metals. The majority of metal artefacts recovered from the site consisted of coffin furniture, including the lead coffin plates and in some cases (see below) the lead lining of coffins. A number of other unusual artefacts were recovered, and include copper rings, gold rings potentially from an item of jewellery, and several silver coins. From the grave of Richard

Gideon Hand (CHE622), four copper buttons (18mm with attachment loops on the reverse) were recovered, perhaps suggesting a jacket being worn by the interred individual (Miles 2001).

Lead Coffins. Unfortunately information on the coffin linings or furniture other than the coffin plates and handles was not available, being a part of a separate assessment report. Based upon direct mention in the report, the following individuals were buried within lead coffins: Mr Richard Gideon Hand (CHE622), John Long, Esq. (CHE714), Mr Thomas Long (CHE654), Mrs Milborough Maxwell (CHE792), Mrs Catherine Long (CHE722), and Mr Gideon Richard Hand (CHE35) (Miles 2001). In this and previous periods, burial in a lead coffin was an indicator of social status, a feature confirmed in the documentary evidence recovered in the biographical reconstruction of the interred individuals (Litten 1991; Cox 1996; Cox 1998; Litten 1998).

Other Materials. Building materials, glass, ivory (comb), shell (buttons) and composite materials (namely an iron knife with ivory handle) were also recovered from securely dated post-medieval contexts. One fragments of glass present in the collection may have been from an Italian import (Miles 2001).

3.2.5 Coffin Plates

Individual skeletons identified biographically were done so through, usually, the deciphering of a coffin plate that was either on the outside of the coffin or on an inner lining. Miles (2001: 26-38) discusses each separately. Coffin plates and descriptions are present for those individuals mentioned in section 3.2.4 and the descriptions will not be replicated here.

3.3 Osteoarchaeological Manifestations of Health and Disease

While post-medieval material has been excavated, it remains the smallest fraction of material extent in osteological collections for a number of reasons. Firstly, and perhaps most surprisingly, the material was until recently considered to be relatively 'useless' in the archaeological interpretation of the past (Boyle and Keevil 1998). Secondly, archaeological excavation in the British Isles is arguably fuelled primarily by development of the contemporary economic infrastructure with a tendency of preserving those areas traditionally outside of such endeavours, of which the churchyards of the post-medieval period are one. Furthermore, common historical economic myopia and momentum towards the south tends to place a disproportionate bias towards London with almost 10% of skeletons from this period deriving from this locale (Bell and Lee-Thorpe 1998; Harding 1998). With such an inherent bias, how truly representative can the sample be?

It is also important to remember that only a relatively small fraction of pathologies are manifested on the human skeleton (Roberts and Manchester 1995; Aufderheide and Rodriguez-Martin 1998; Mays 1998; Robert and Cox 2003). Pathologies such as cholera, typhoid and even tuberculosis in its primary stage leave few osteological markers (Wohl 1983). It is, however, to these excavated remains that osteoarchaeologists must return to construct a model of diet and health in the post-medieval period, as manifested through our most obvious and unbiased source, at least in some regards, of evidence.

Roberts and Cox (2003) provide the single most comprehensive report on diet and health in the British Isles and, as such, they have provided an invaluable resource in a field that suffers a marked tendency for reports to remain unpublished. The sites utilised in the analysis of

palaeopathology throughout the Roman, Medieval, etc., periods derive from the following sources:

Site	Location	Publication(s)
Broadgate	London	White 1985
Christchurch Spitalfields	London	Cox 1989; Waldron and Cox 1989; Molleson and Cox 1993; Cox 1996; Stevens 1996; Roberts *et al.* 1998; Mays 2000
Holy Trinity	Coventry	Wakely 2001; Rylatt and Mason 2003
Ennis Friary	Co. Clare	Roberts 2000; Roberts *et al.* 1998
Kingston-upon-Thames	London	Start and Kirk 1998
Mansell Street	London	West 1982
Newcastle Infirmary	Newcastle-upon-Tyne	Roden 1997; Witkin 1997; Boulter *et al.* 1998
Rivenhall	Essex	O'Connor 1993
St Augustine the Less	Bristol	O'Connell 1998
St. Bride's Crypt	London	Harvey 1968; Bowman *et al.* 1992; MacMullen 1998; Scheuer and Bowman 1998; Scheuer 1998
St. Bride's Lower Churchyard	London	Waldron 1997
St. George's Church	Canterbury	Anderson 1991
St. Luke's Chelsea	London	Miles 2001
St. Nicholas' Church, Sevenoaks	Kent	Boyle and Keevil 1998
Upper Penn	Wolverhampton	
Wharram Percy	Yorkshire	Mays 2000

Table 3: Excavated post-medieval cemeteries in the United Kingdom (Roberts and Cox 2003).

An exhaustive discussion of palaeopathology is inappropriate and, instead, the reader is pointed to the various textbooks on this and related topics (Ortner and Putschar 1985; Roberts and Manchester 1995; Larsen 1997; Aufderheide and Rodriguez-Martin 1998; Mays 1998; Roberts and Cox 2003). It is, however, useful to have a broad understanding of the aetiology of the various pathologies and developmental abnormalities that impacted on the population of Coventry and Chelsea specifically and the period of the study in general. These are categorised below.

3.3.1 Dental Disease

Pathologies affecting the dentition, either through disease, the general processes of wear or the features that lead to developmental abnormalities are usually multi-aetiological, that is to say that while they may be ascribed a specific cause more often than not multiple causes can be cited. For example, the development of caries (see below) is often ascribed to a diet rich in sugar, but is exacerbated not only by poor dental hygiene but also by the composition of the tooth itself (e.g., the susceptibility of fluoroapatites to dissolution over other apatite types). In many ways, therefore, one might consider the dental disease as more anecdotal; suggestive rather than defining.

3.3.1.1 Enamel Hypoplasias

Enamel hypoplasias are in essence the result of a sudden and system-wide event within the childhood of an individual, i.e. when the teeth form, thereby affecting proper amelogenesis of dental enamel (Aufderheide and Rodriguez-Martin 1998). This usually acts to create a circumferential linear 'groove' which, given the incremental nature of tooth growth (Hillson 1996) can be attributed to a specific age, though in individuals of advanced age and/or abrasive diets they can disappear with age (Aufderheide and Rodriguez-Martin 1998). Various aetiologies have been attributed to the formation of enamel hypoplasias, from premature birth to endocrine or metabolic diseases, to poor nutrition, or the increased susceptibility to acute, episodic insults caused as a result of this, and are considered to be the primary causes of this pathology (Ortner and Putschar 1985; Larsen 1997; Aufderheide and Rodriguez-Martin 1998; Wakely 2001).

The pathology seems to be rarely recorded in the past, beyond a purely anecdotal reference, with only two of the sites mentioned in Table 3.1 recording its presence (St. Brides Crypt and Upper Penn). In these sites 3 out of 528 recorded individuals were affected, or 0.57% of the population (Roberts and Cox 2003). However, given what is understood historically about the nature of childhood mortality and diseases and, therefore, the potential causes of enamel hypoplasias, this suggests an inherent bias in the data resulting from both the small sample and the nature of the sample itself, i.e. crypts having fewer children or being of higher socio-economic class (Roberts and Cox 2003).

3.3.1.2 Caries

Caries, even in the modern world, remains a chronic disorder affecting all socio-economic classes, although overall prevalence may be reduced in earlier periods with lesser dental hygiene (Aufderheide and Rodriguez-Martin 1998). Dental caries is the result of multi-bacterial and, once again, multi-factorial demineralisation of the bioapatite and subsequent destruction of the dentine-pulp complex (Ortner and Putschar 1985; Larsen 1997; Aufderheide and Rodriguez-Martin 1998). Dissolution of the bioapatite matrix results in increased localised concentration of organic acids and proteases which, as a result of tooth morphology, more generally affects teeth with fissures, e.g. molars and premolars. This does not, however, preclude carie formation on incisors and canines (Aufderheide and Rodriguez-Martin 1998).

Continuing necrosis of the dentine-pulp complex may allow extension of the bacterial infection to the root and, from there, the trabecular of the alveolum to form a periapical abscess. This can be halted through the reaction of odontoblasts in the dentine-pulp complex and the formation of secondary dentine. This latter feature can be seen in CHE841:

Figure 12: Secondary dentine formation on left second mandibular premolar (CHE841), possibly as a result of carie; note the continuing striae moving through the altered surface and with the underlying dentine (photo: author).

Caries on the root can also form, though as they are covered by the gingival tissue and alveolum in life, the roots must be exposed to infection through other means than with a crown carie. This may result from a periapical abscess or as a result of recession of the oral tissues from periodontitis, the latter of which tends to create a senescence-bias into root carie prevalence (Aufderheide and Rodriguez-Martin 1998).

Within the post-medieval period, caries and abscess prevalence rates fell from the medieval period suggesting an improvement in dental health, though both health and hygiene remained poor (Roberts and Cox 2003). Out of the 12,933 teeth analysed from this period, 1,451 (11.2%) were affected by caries. A total of 14 out of 318 individuals (13.8%) were affected by one or more dental abscesses while ante-mortem tooth loss, itself multi-aetiological, affects 60.6% of the individuals (n=365) (Roberts and Cox 2003).

3.3.1.3 Calculus

As with caries, calculus is the result of bacterial activity in the oral environment and is, in essence, mineralised tartar. Within the post-medieval cemeteries it affected 21.4% of individuals (102 of 476 individuals), a decline from 54.0% in the later medieval period, seeming to confirm that while dental health remained poor, still it was a significant improvement on the previous centuries (Roberts and Cox 2003).

3.3.1.4 Periodontitis

Periodontitis is caused by the continued inflammation of the gingival tissue with a chronic affect of causing a gradual resorption of periodontal tissue (periodontal ligament, cementum and alveolar bone), either generalised over the entire dentition or specific to individual teeth (Aufderheide and Rodriguez-Martin 1998). Most commonly caused by a loss of interproximal (tooth-tooth) contact, such as from food debris and plaque invasion, in contemporary populations it affects 75% of the population with the prevalence increasing with age (Aufderheide and Rodriguez-Martin 1998).

Within the post-medieval period the prevalence of periodontitis was 12.9% (70/835), a significant decline from the value of 37.5% in the later medieval period (Roberts and Cox 2003).

3.3.2 Traumatic Conditions

This refers to fractures and exostoses, discontinuities/cracks in the skeletal tissue and ossification of non-skeletal tissue both of which result from a catastrophic event or continued stress or pathology. The resultant fracture usually causes sub-periosteal haematoma with the

subsequent formation of a 'callus' that produces a distortion to the bone. Over time the callus is remodelled but may also persist depending on the nature of the fracture itself, e.g., comminuted fractures or those with significant displacement and the lack of repositioning of the elements in subsequent treatment. While trauma, accidental or as a result of interpersonal violence, remains an obvious aetiology it may also result from established pathology, e.g. neoplasms, cysts, osteoporosis, Paget's disease etc. (Aufderheide and Rodriguez-Martin 1998).

While fractures may result from either a traumatic event or continued stress, they may also result in secondary pathology. These include: delayed healing, pseudoarthrosis, mal-alignment, bone shortening, osteomyletis, avascular necrosis, neuropathy and articular changes, e.g. secondary osteoarthritis or even ankylosis of joints (Ortner and Putschar 1985; Roberts and Manchester 1995; Aufderheide and Rodriguez-Martin 1998). Osteomyelitis is discussed in greater detail in section 3.3.6.2.

The event of traumatic damage or use of the bone/joint subsequent to trauma may also result in damage to the soft tissue, e.g. at the ligaments acting as origin and insertion of the skeletal muscle (*myositis ossificans traumatica*). These exostoses form the same general process as fracture healing, i.e. haematoma subsequent to proliferation of cells and subsequent formation of fibrous and then mature bone (Aufderheide and Rodriguez-Martin 1998). Continued and sudden stress to soft tissue can also result in the ossification of said tissue (Ortner and Putschar 1985; Roberts and Manchester 1995; Aufderheide and Rodriguez-Martin 1998; Roberts and Cox 2003). Ligament and muscle ossification may also result from progressive pathologies, e.g. *myositis ossificans progressiva*, diffuse idiopathic skeletal hyperostosis (DISH), etc. (Aufderheide and Rodriguez-Martin 1998).

One further traumatic condition deserves mention though it is rarely reported in the osteoarchaeological literature: dislocation. This results from a traumatic event that alters the correct alignment of bones within the joint either through accident or interpersonal violence. While reduction (relocation) of a dislocated joint may leave little skeletal evidence, an unreduced dislocation can result in the formation of a pseudoarthrosis. Similarly, *myositis ossificans traumatica*/exostoses may form in or around the dislocated joint.

Trauma can occur throughout the life-cycle of an individual, occurring as a result of activity taken in the home or the work place. Within the post-medieval period with its concomitant focus on industrialisation, occupational trauma in terms of fracture or exostoses becomes an obvious point of interest. Determining the aetiology of said traumatic conditions is, however, difficult at best. Indeed, the London Bills of Mortality show a rise in 'fracture' related deaths that may be attributable to a significant rise in occupational-related trauma or, as pointed out by Roberts and Cox, be representative of changes in the reporting practice or the ascription of the meaning of 'fracture related death' (Roberts and Cox 2003).

The prevalence of fractures varies depending upon the skeletal element affected. Within the post-medieval period the prevalence of fractures varies within the range of 0.15% (fracture of the forearm) to 4.23% (fractured ribs). The humerus and the femur are the next most common bones to be fractured with prevalence in the osteoarchaeological record of 1.09% and 1.25% respectively. All other bones have a prevalence of less than 1%, with an average of 0.53%. Within the later medieval period the average prevalence of fractures within the population was 1.3% and a range of 0.2-11.1%, thus showing a slight rise in trauma with a significantly larger range (Roberts and Cox 2003). The mandible is the most frequently broken (11.1%), with parietal, frontal, occipital, vertebrae, ulna and radius, and ribs all having a prevalence of 1-

3.57%. The decline in trauma prevalence, most especially the cranial and mandibular trauma, may represent a decline in interpersonal violence (Roberts and Cox 2003).

3.3.3 Congenital Abnormalities

Congenital pathologies are a result of non-standard alterations occurring in intrauterine development and which may or may not be affected by intrinsic (genetic) or extrinsic (environmental) factors. The majority of congenital abnormalities that occur within a population do so with a low frequency and, as such, peculiar numbers may impact upon the interpretation of a given site (Aufderheide and Rodriguez-Martin 1998).

3.3.3.1 Craniosynostoses

Craniosynostoses result in the premature fusion of one or more of the cranial sutures resulting in a change in morphology of the cranium, the extent depending upon the order of synostosis in multiple sutures, the age and the aetiology of the pathology (Aufderheide and Rodriguez-Martin 1998). While a familial aetiology is possible and, indeed, one possible interpretation of a high number of like congenital abnormalities, it is too difficult to ascribe a specific aetiology (Aufderheide and Rodriguez-Martin 1998).

One particular craniosynostosis is of interest here: trigonocephaly. This is the premature fusion of the metopic suture, a suture that normally fuses at around 2-3 years and that occasionally remains un-fused (Aufderheide and Rodriguez-Martin 1998). The usually intrauterine fusion of the metopic suture prevents visceral lateral development of the frontal bone creating a 'triangular' shaped skull with the orbits concomitantly closer together (hypotelorism) (Aufderheide and Rodriguez-Martin 1998). As with other craniosynostoses neural function may

be impaired due to a decreased cranial capacity, although the pathology must be severe for this to occur.

Congenital abnormalities are rarely reported in the osteoarchaeological literature and, as a result, no prevalence rates are available. Furthermore, only two cases are reported in the osteoarchaeological record in general (Spitery 1983; Aufderheide and Rodriguez-Martin 1998).

3.3.3.2 Hydrocephaly

Hydrocephalus results from disequilibrium of the secretion and resorption of fluid into the lateral, third and forth ventricles and the subarachnoid space resulting either from congenital development, trauma or infection (Aufderheide and Rodriguez-Martin 1998). It results in expansion of the cranial vault, thinning of the cranial bones, wider sutures, and flattening of the cranial base. Without surgical treatment it has a 50% mortality rate (Ortner and Putschar 1985; Aufderheide and Rodriguez-Martin 1998).

Once again, little information exists in the post-medieval palaeopathological record on the prevalence of hydrocephalus with only thirty suggested cases in the world literature (Ortner and Putschar 1985). One case is reported from Doombury Fort, a later medieval site in County Antrim, Ireland, giving a prevalence of 0.37% (1/234) (Murphy 1996; Roberts and Cox 2003).

3.3.3.3 Spina Bifida

Spina bifida is the most common spinal malformation resulting from the incomplete fusion of the neural arches of the lumbosacral vertebrae, most notably the sacrum (Ortner and Putschar 1985; Roberts and Manchester 1995; Aufderheide and Rodriguez-Martin 1998). It occurs with

varying degrees of severity, from spina bifida occulta with the non-fusion of one or two neural arches and with the meningal/neural structures not protruding, to *spina bifida aperta/cystica* (meningocele, myelomeningocele and myelocele). While the occurrence of *spina bifida occulta* is relatively high (5-25% of the modern population) and does not necessarily have an impact upon the life of an individual, spina bifida aperta without treatment often results in death (Aufderheide and Rodriguez-Martin 1998).

The pathology is not consistently recorded in the palaeopathological literature and as a result no prevalence information is available.

3.3.3.4 Spondylolysis

Spondylolysis is the failure of osseous union of the, usually, lumbar vertebra into a ventral (vertebral body, transverse and superior articular processes) and dorsal (laminae, spinous process and inferior articular processes) (Ortner and Putschar 1985; Roberts and Manchester 1995; Aufderheide and Rodriguez-Martin 1998). It has two potential aetiologies, which are not exclusive of each other (Aufderheide and Rodriguez-Martin 1998): congenial (genetic); or traumatic, relating to age and hyperflexion of the spine with simultaneous extension of the knees.

Spondylolysis has not yet been reported in the palaeopathological literature for the sites mentioned and as such no established prevalence rates exist.

3.3.3.5 Scoliosis

Scoliosis produces a lateral curve in the spine with a rotation of the vertebra such that the spinous processes, normally projecting posteriorly, project towards the concavity of the curve (*cf.* fig.6.24 of Roberts and Cox [2003] and also Ortner and Putschar [1985]). The spine usually curves in such a way that the skull maintains a mid-saggital plane as on a non-affected individual. It can result from congenital factors, but is primarily idiopathic. It also appears in a paralytic form resulting from weakening of the spinal muscles as seen in such conditions as poliomyelitis, cerebral paralysis and muscular dystrophy (Aufderheide and Rodriguez-Martin 1998). Two other forms are also found: kyphosis, where the thoracic curvature is increased; and lordosis, which decreases the curvature of the lumbar spine (Aufderheide and Rodriguez-Martin 1998). These pathologies may occur simultaneously, (i.e., kyphoscoliosis is the pathology that combines features of both kyphosis and scoliosis).

With the post-medieval palaeopathological record it has been shown to affect 0.3% of individuals, with kyphoscoliosis affecting 1.6% of the archaeological population (5/1476 and 10/625 respectively) (Roberts and Cox 2003).

3.3.4 Circulatory Disorders

Circulatory disorders primarily evolve from damage or dysfunction to the peripheral vascular system either resulting in cellular necrosis of the infarcted material or in atrophy in a rapid or gradual process, respectively (Aufderheide and Rodriguez-Martin 1998).

3.3.4.1 Osteochondroses

Osteochondroses are idiopathic, resulting from pathologies or as a result of trauma resulting in collapse of the joint surface and joint fragmentation (Aufderheide and Rodriguez-Martin 1998). It takes a number of forms depending upon the joint affected, e.g., Legg-Calvé-Perthes disease, Osgood-Schlatter's disease, Freiberg's disease, etc. Of interest to this study is Scheuermann's disease, or osteochondrosis of the apophyseal rings of the vertebral bodies (Aufderheide and Rodriguez-Martin 1998). This tends to create a lesion on the anterior vertebral body with subsequent collapse potentially leading to kyphoscoliosis and spondylolysis (Aufderheide and Rodriguez-Martin 1998).

There are no reported ostodeochondroses, particularly Scheuermann's disease, in the post-medieval palaeopathological literature (Roberts and Cox 2003).

3.3.5 Joint Disease

As with the other pathologies, above, 'joint disease' covers a wide range of pathologies but only those that appear within Chelsea and Coventry will be covered here.

3.3.5.1 Degenerative Joint Disease

Otherwise known as osteoarthritis (OA), degenerative joint disease is idiopathic in its primary form but may also be secondary, resulting from changes to biomechanics resulting from another event including amongst others trauma/dislocation, rickets, osteochondritis dissecans, congenital deformities, other forms of arthritis, as well as obesity and occupational stress (Ortner and Putschar 1985; Resnick 1995; Roberts and Manchester 1995; Aufderheide and Rodriguez-

Martin 1998; Roberts and Cox 2003). Osteoarthritis results from the loss of articular cartilage at a joint surface that exposes the bone and, with subsequent movement, allows continued wear upon the bones. Identified archaeologically through numerous means, e.g., the presence of micro- and macro-porosity on the joint surface, subchondral cysts, osteophytosis, it is the *sine qua non* diagnostic criteria of eburnation which is primarily associated with this pathology. While it is more often seen by the fourth decade of life, as mentioned above, it can also be associated with occupational stress, though not as one might imagine through hard labour, but through long inactivity and bad posture (Waldron and Cox 1998; Roberts and Cox 2003).

Degenerative joint disease is commonly identified in the palaeopathological literature (Ortner and Putschar 1985; Aufderheide and Rodriguez-Martin 1998). In post-medieval Britain degenerative joint disease is seen in 11% of the population (57/517) and specifically identified osteoarthritis 24.5% (260/1060), a decrease and increase from that seen in the medieval population (13.6% and 16.8%, respectively) (Roberts and Cox 2003).

3.3.5.2 Degenerative Joint Disease (DJD) of the Spine

Degenerative disease of the spine shares many palaeopathological similarities with non-spinal degenerative joint disease. It is primarily characterised through the formation of vertebral osteophytes and 'lipping' of the vertebral body and, in more advanced cases, potential ankylosis of adjacent vertebra through the osteophytes (Ortner and Putschar 1985; Buikstra and Ubelaker 1994; Roberts and Manchester 1995; Aufderheide and Rodriguez-Martin 1998; Roberts and Cox 2003). Since the osteophytes form as a result of intervertebral contact, DJD of the spine is most commonly seen in the lower cervical (sixth cervical to first thoracic vertebra), upper thoracic (second to fifth thoracic vertebra) and lower lumbar (fourth to fifth lumbar vertebra) regions (Aufderheide and Rodriguez-Martin 1998).

Within the palaeopathological record of post-medieval Britain, degenerative joint disease of the spine affects 13.1% (57/434) of the population, while osteoarthritis affects 13.5% (143/1060) (Roberts and Cox 2003). 'Degenerative disc disease' affected 10.8% (120/1116) of the analysed population (Roberts and Cox 2003). As with non-cranial degenerative joint disease and osteoarthritis, this shows a marked decrease from the later medieval period (20.9% and 27.9% respectively) (Roberts and Cox 2003).

3.3.5.3 Diffuse Idiopathic Skeletal Hyperostosis (DISH)

Also known commonly as Forestier's disease, diffuse idiopathic skeletal hyperostosis (DISH) is characterised by ankylosis of the spine through ossification of the anterolateral spinal ligaments without involvement of the vertebral discs (Ortner and Putschar 1985; Roberts and Manchester 1995; Aufderheide and Rodriguez-Martin 1998). Similarly, ossification of enthesopathies (ligaments/muscle attachments) is also seen throughout the body and may result in ankylosis of joints (Aufderheide and Rodriguez-Martin 1998). It is most commonly seen in males over the age of 40 years and is associated with dietary excess, such as the excess consumption of meats and alcoholic beverages, obesity and the late onset of Type II diabetes mellitus (Aufderheide and Rodriguez-Martin 1998; Roberts and Cox 2003).

In post-medieval Britain the palaeopathological literature reveals a prevalence of 3.3% (73/2216). It is, however, interesting to note that the Christchurch Spitalfields collection has a much higher prevalence of DISH at 5.8% (56/968) compared to the range of 0.8-1.8% witnessed in other collections in which it is identified. This increase is attributed to the increased socio-economic status of the individuals interred at Christchurch Spitalfields (Molleson and Cox 1993; Roberts and Cox 2003). While the prevalence of DISH in the later medieval period is similar to

that in the post-medieval (3.3%), there is more significant variation in the ranges within the earlier period. Most significantly the largest prevalence occurs within monastic populations: with monastic populations contributing six times the number of DISH affected individuals (Roberts and Cox 2003).

3.3.5.4 Ankylosing Spondylitis

Ankylosing spondylitis (AS) is a pathology characterised by the progressive calcification of connective tissue in the sacro-illiac joint, the spine and peripheral major joints (Aufderheide and Rodriguez-Martin 1998). Initiating in the sacro-illiac joint, it progresses to the spine where syndesmophytes or 'bony bridges' form between the vertebra, giving the spine the characteristic 'bamboo' appearance, as well as ossification of spinal ligaments to ankylose the vertebra. Frequently the ribs also become ankylosed to the spine, and other joints are likewise fused giving rise to the differential diagnosis of rheumatoid arthritis in disarticulated material (Ortner and Putschar 1985; Roberts and Manchester 1995; Aufderheide and Rodriguez-Martin 1998). Ankylosing spondylitis is idiopathic although there is strong suggestion of a genetic element (Aufderheide and Rodriguez-Martin 1998).

3.3.6 Infectious Diseases

3.3.6.1 Tuberculosis

Tuberculosis, or consumption as the pulmonary form was known in the post-medieval period, was a significant cause of death during the period (Roberts and Cox 2003). Aufderheide and Rodriguez-Martin (1998) describe the process of infection by tuberculosis: Infection is at first

pulmonary, caused by the inhalation and proliferation of infecting bacteria (*mycobacterium tuberculosis*), and their subsequent spread through the lymph system to the lungs where the body's enzymatic response is incapable of dealing with the bacteria. The primary infective episode, the severity of which is affected by the nutritional and health status of the individual, generally results in a pulmonary fibrocalcific scar as well as some scarring in the hilar lymph nodes. A biphasic infection, the disease often goes into remission until re-infection occurs in subsequent years, either as a result of repeated exposure or as a result of a breakdown in the fibrocalcific scarring and remobilisation of tubercle bacilli. At this point the tubercle bacilli tend to infect the upper lung and create a much larger area of tissue necrosis that can spread to adjacent structures and exacerbate the process of infection, i.e. eroding the bronchial wall and offering another vector by which the infection can be spread outside of the body. This is often associated with haemorrhage of branches of the artery, such that the lumen – the material communicated into the oral environment – is produced; such that the lumen, the material communicated into the oral environment, such that blood is often produced; the process of 'coughing up your lungs', as it has sometimes been described.

Digestion of infected sputem can result in gastrointestinal infection, as well as subsequent infection of the kidneys and internal sex organs amongst others. Spread to the skeletal system occurs through the peripheral vascular system and the morphology of this moderates progression of the disease. Primarily tuberculosis manifests itself in the spine of the infected individual, most likely in the anterior portion of the vertebral body, creating an abscess between the vertebral body and the anterior spinal ligament and, either through infarction or multiple abscesses, collapse of the vertebral body is common. This leads to the pathology commonly called "Potts Spine", commonly affecting three adjacent vertebrae and leads to acute kyphosis of the spine. Haematogenous dissemination of tubercle bacilli can likewise affect extraspinal bones, primarily joints (Aufderheide and Rodriguez-Martin 1998).

Tuberculosis is more likely to affect younger individuals and maintains a mortality rate of 35-40% within five years following diagnosis. An individual infected will most likely be physically impaired due to decreased lung capacity resulting from frequent episodes of pulmonary haemorrhage, alterations to the bone, and so forth (Aufderheide and Rodriguez-Martin 1998).

Historically in the late medieval and early post-medieval period tuberculosis became endemic and, given the high incidence of family infection was at one point thought to be hereditary (Aufderheide and Rodriguez-Martin 1998). It became the largest single-disease killer within the eighteenth and nineteenth centuries, accounting for up to one third of the deaths in the nineteenth century (Wohl 1983). It affected all classes and was particularly associated with the urban-working class in overcrowded districts with poor ventilation, spreading more rapidly with constant exposure to diseased individuals in enclosed quarters (Wohl 1983). Indeed, the prevalence in sailors and other individuals working in enclosed spaces, e.g., potters, miners and hosiers, brought the disease to the attention to the Privy Council. While the deaths attributed to scrofula (lesions associated with lymph infection and tuberculous cervical adenitis) and consumption, or the 'White Plague', decreased by half in Britain during the mid to late nineteenth century, it remained second only to heart disease as the single greatest killer (Wohl 1983; Roberts and Cox 2003).

In the palaeopathological record tuberculosis has been shown to affect 0.5% (8/1690) of the population in the post-medieval period. Rib lesions, an idiopathic pathology sometimes ascribed to tuberculosis although the evidence is tenuous, affected 4.8% (9/189) of the population of Newcastle Infirmary, or a combined prevalence of 0.9% (17/1879) (Roberts and Cox 2003). This shows a reduction from the later medieval period, with positively identified tuberculosis

showing a prevalence of 0.9% (60/6796) with possible tuberculosis accounting for a further 1.9% (111/5873) (Roberts and Cox 2003).

3.3.6.2 Osteomyletis

Osteomyletis is the infection of both bone and the bone marrow caused by pus-producing bacteria resulting from haematogenous dissemination or through direct infection resulting from compound fractures (Ortner and Putschar 1985; Roberts and Cox 1995; Aufderheide and Rodriguez-Martin 1998). In haematogenous dissemination infection is spread to the bone through nutrient artery and spread through the Haversian and Volkmann's canals forming a subperiosteal abscess and resulting in ischemia and subsequent necrosis (Aufderheide and Rodriguez-Martin 1998). This acts to form a sequestrum (necrotic bone surrounding by living bone) while the subperiostal abscess stimulates the production of new bone growth, the involucrum. Cloacae, or drainage channels, can form in the involucrum allowing drainage of the pus out of the bone and, from there, the skin. Traumatic, direct infection, osteomyelitis is rare but proceeds through similar processes of bacterial infection to the marrow cavity (Ortner and Putschar 1985; Aufderheide and Rodriguez-Martin 1998). Osteitis, a related pathology, involves infection of the bone without marrow infection (Aufderheide and Rodriguez-Martin 1998; Roberts and Cox 2003).

The palaeopathological record for the period shows a prevalence of 0.5% (4/795) and 1.4% (4/280) for osteitis and osteomyelitis, respectively (Roberts and Cox 2003). Osteomyelitis within the later medieval period shows an increase over the post-medieval value, with a prevalence of 0.8%, while reported osteitis shows a significant increase with a prevalence of 13.2%. All individuals reported with definitive osteitis do, however, come from a single site –

St. Gregory's Priory, Canterbury – a feature which makes comparison problematic (Roberts and Cox 2003).

3.3.7 Metabolic Diseases

3.3.7.1 Rickets/Osteomalacia

The childhood pathology of rickets – osteomalacia being the adult equivalent of the disease – is, in essence, a vitamin D deficiency that leads to a metabolic defect in endochondral bone mineralisation (Ortner and Putschar 1985; Aufderheide and Rodriguez-Martin 1998). Within the human body vitamin D, produced in the body from the intake of precursor material (e.g., ergosterol from plants and grains) and subsequently hydroxylised in the dermis stimulated by UV radiation, acts in concert with parathyroid hormone to maintain calcium and phosphorus levels required for the production of bioapatite (Ortner and Putschar 1985; Aufderheide and Rodriguez-Martin 1998; Martini 1998). In the absence of vitamin D, proliferation of cartilage cells is not possible with concomitant impact upon the cartilaginous anlage precursor and, therefore, formation of osteoid and the deposition of bioapatite (see chapter 4 for a simplified description of skeletal tissue mineralisation) (Aufderheide and Rodriguez-Martin 1998; Martini 1998; Ten Cate 1998). Coupled with vascular deficiencies, potentially resulting from a lack of support from a properly mineralised matrix, and biomechanical stresses upon the endochondral ossified bone (intramembronous ossification, such a that of the skull, remains unaffected) lead to the typical changes seen in the rachitic skeleton. These are: deformed (flared) metaphyses, shortened and bowed long bones of the thigh, leg and forearm; kyphoscoliosis and lordosis, giving the individual a pot-bellied appearance as well as pushing the acetabulum superiorly and parietally; expansion of the costochondral head of the rib leading to the 'rosemary bead' chest and typical 'pigeon-chest'; and craniotabes, the flattening of the occipital and parietal bones

resulting from the mass of the head (Ortner and Putschar 1985; Aufderheide and Rodriguez-Martin 1998).

Given the predominance of sunlight in the production of vitamin D within the human body, the presence of rickets is a product of non-exposure to sunlight as well as the lack of dietary vitamin D (Wohl 1983; Ortner and Putschar 1985; Aufderheide and Rodriguez-Martin 1998; Roberts and Cox 2003). Following Roberts and Cox (2003) it is rarely seen in the medieval period though becomes increasingly common in the eighteenth and nineteenth centuries, more particularly in the towns as indicated by the Bills of Mortality of the period (Wohl 1983; Roberts and Cox 2003).

Within the cemeteries analysed during the post-medieval period from Britain, 3.7% (93/2545) of the population were affected by rickets, with a range of 0.56-6.76%. This is a significant increase from the prevalence of 0.73% (range 0.19-2.7%) reflected in the later medieval osteoarchaeological material (Roberts and Cox 2003).

3.3.7.2 Osteoporosis

Osteoporosis is the loss of bone density though with the maintenance of the normal ratio of bone mineral to collagenous matrix (Ortner and Putschar 1985; Aufderheide and Rodriguez-Martin 1998). It may be secondary to another pathology, e.g., as a result of sudden immobilisation and/or paralysis, or take one of two idiopathic forms: the first which affects post-menopausal women (normally affecting the spine and forearm; and the second which affects both genders over the age of sixty years (as type 1 but with increased incidence of hip and vertebral fractures) (Aufderheide and Rodriguez-Martin 1998). Osteoporotic bones can suffer traumatic pathology secondary to the reduction in bone density, i.e. pathological fractures resulting from

compression and/or stress that may in themselves lead to traumatic scoliosis or kyphosis (Roberts and Manchester 1995; Aufderheide and Rodriguez-Martin 1998).

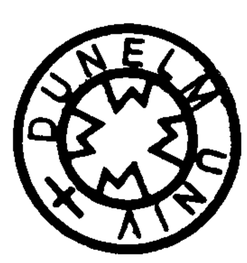
Excavated cemeteries in the post-medieval period reveal a prevalence of 1.2% (18/1501) and range of 1.0-1.5%, a decline from the 2.6% indicated in the later medieval period (Roberts and Cox 2003).

3.3.8 Haematological Disorders

3.3.8.1 Cribra Orbitalia

Cribra orbitalia is characterised by expansion of the diploe of the skull and resorption of the outer cortex allowing, in the dry skeleton, viewing of the cancellous bone (Roberts and Manchester 1995; Aufderheide and Rodriguez-Martin 1998). Located in the superior anterior portion of the orbits, and normally bilateral, advanced cases may lead to protusion of the eyes from the sockets (*exopthalmus*). Clinically *cribra orbitalia*, and the related pathology of porotic hyperostosis (same manifestation though located on the outer table of the cranium), is associated with haematological conditions such as anaemia including both genetic (e.g. thalassemia) and iron-deficiency anaemia. As *cribra orbitalia* is more common than porotic hyperostosis it is seen as a more sensitive marker of haematological dysfunction (Aufderheide and Rodriguez-Martin 1998).

Within the excavated post-medieval cemeteries *cribra orbitalia* had a prevalence of 9% (238/2660) and a range of 0.3-24.9% (Roberts and Cox 2003). Both Christchurch Spitalfields and Newcastle Infirmary have a significant prevalence of *cribra orbitalia* (14.6% and 24.9% respectively) with a median prevalence of 3.3% (50/1503) when these sites are removed



(Molleson and Cox 12993; Boulter *et al.* 1998; Roberts and Cox 2003). This prevalence rate shows a fall from the later medieval period, where it affected 10.8% (640/5752) of the excavated population (Roberts and Cox 2003).

3.3.10 Stature

Stature is often used as an overall representation of the 'health' of a population. The statures of skeletons in the British Isles from the Mesolithic to the post-medieval period can be plotted on a chart:

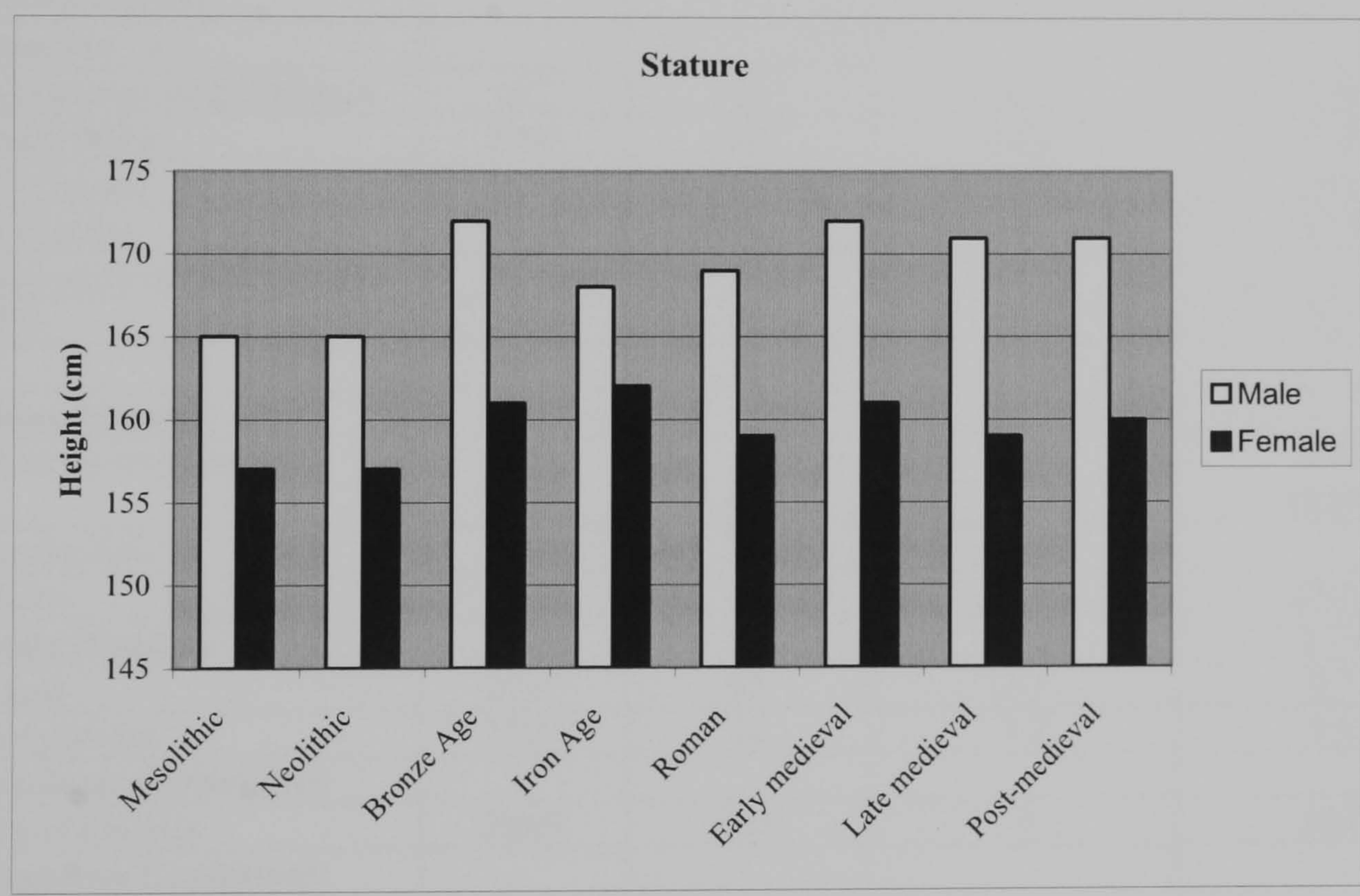


Figure 13: Stature of males/females from the Mesolithic to the Post-medieval period (Roberts and Cox 2003)

While we can see that stature varied considerably over the time period covered by Roberts and Cox (2003), there are only minor differences between the late medieval and post-medieval periods, (e.g., an increase of 1cm in the mean height of females during the period), tending to imply that nutritional and/or environmental considerations affecting stature did not materially shift between the two periods.

Pathology	*n*	Affected	Post-medieval Prevalence (%)	Late medieval Prevalence (%)
Dental Disease				
Enamel hypoplasia	528	3	0.6	35.4
Caries (teeth)	12933	1451	11.2	5.6
Abscesses	18167	399	2.2	3.1
Antemortem tooth loss	13991	3275	23.4	19.4
Calculus	476	102	21.4	54.0
Periodontitis	835	70	12.9	37.5
Traumatic Conditions				
Fractures	-	-	0.2-4.2	0.2-11.1
Exostoses/dislocations	-	-	-	-/0.7
Congenital Abnormalities				-
Craniosynostoses	-	-	-	-
Hydrocephalus	-	-	-	0.37
Spina Bifida	-	-	-	-
Spondylolysis	-	-	-	0.31
Scoliosis	1476	5	0.3-1.9	-
Circulatory Disorders				
Osteochondroses	-	-	-	-
Joint Disease				
Degenerative Joint Disease	517	57	11	13.6
Osteoarthritis	1060	260	25.4	16.8
DJD (Spine)	434	57	13.1	20.9
OA (Spine)	1060	143	13.5	27.9
'Degenerative Disc Disease'	1116	120	10.8	-
DISH	2216	73	3.3	3.3
AS	-	-	-	-
Infectious Diseases				
Tuberculosis (Possible)	1690 (189)	8 (9)	0.5 (4.8)	0.88 (1.89)
Osteomyletis	795	4	0.5	
Osteitis	280	4	1.4	13.19
Metabolic Diseases				2.71
Rickets	2545	93	3.7	0.7
Osteoporosis	1507	18	1.2	2.6
Haematological Disorders				
Cribra Orbitalia	2660	238	9	10.8
Miscellaneous Conditions				
Harris Lines	-	-	-	-

Table 4: Summary of prevalence rates of pathologies from analysed post-medieval cemeteries (Roberts and Cox 2003). Section 6.3 contains prevalence rates for Holy Trinity (Coventry) and St. Luke's (Chelsea).

4. Biogeochemistry

The biogeochemical study of archaeological human remains offers a means by which it is possible to access cultural and biological information that would otherwise be absent from the archaeological record except through inference based upon material culture. Through their use it is arguably possible to determine the type of foods that a past population (or individual) was eating (carbon, nitrogen, strontium), where the individual resided at various intervals during their life (strontium, oxygen, lead) and their exposure to heavy metal pollution (lead). These isotopes, and their respective elemental concentrations, can also be used to determine cultural questions such as weaning (carbon, nitrogen, oxygen and strontium), environmental change (oxygen), and so on.

This chapter aims to introduce, insofar as possible within the constraints of a thesis, the biogeochemistry of the five elements and respective isotopes utilised to determine characteristics of diet, health and migration in the sites of Holy Trinity (Coventry) and St. Luke's (Chelsea). As mentioned above, while each of the elements have multiple uses within bone archaeochemistry, only those that relate to the concepts that form a part of this study will be discussed.

4.1 The Biogeochemistry of Strontium

Strontium (Sr) is, perhaps, one of the most well known elements used within the field of bone archaeochemistry and has received considerable attention since its introduction by Comar *et al.* (1957). While original emphasis on the study of Sr derived from the concern with the atmospheric introduction of the anthropogenic radioactive isotope ^{90}Sr into the food-web from

nuclear testing (Comar *et al.* 1957; Williams *et al.* 1962), it is application to palaeobiological studies became quickly evident (Toots and Voorhies 1965; Ezzo 1992). Subsequently it has been used in both human and environmental studies to address the issues of: palaeodiet through both trace element analysis of Sr and stable isotopic study (Price *et al.* 1985; Brätter *et al.* 1989; Francalacci 1989; Horwood 1989; Price *et al.*1992 ; Ezzo *et al.*1995; Baraybar and de la Rua 1997; Larsen 1997; Arnay-de-la-Rosa *et al.*1998); inferences on palaeodiet through stable isotope analysis (Smith 1984; Parkington 1987; Smith 1987: Parkington *et al.* 1988; Sealy *et al.* 1991); reconstruction of foodwebs (Runia 1987; Sealy and Sillen 1988; Iregren 1992; Sillen 1992; Burton and Wright 1995; Thackery 1995; Sillen 1996); weaning (Underwood 1977; Sillen and Smith 1984; Iregren 1992; Thackery 1995); physiological variability within early hominids and modern humans (Sillen and Kavannagh 1982; Price *et al.* 1985; Sillen 1992; Thackery 1995; Sillen 1996); and migration as determined through stable isotope analysis (Koch *et al.* 1992; Johnson *et al.*1994; Sealy *et al.* 1995; Chamberlain *et al.* 1997; Ezzo, *et al.* 1997; Grupe *et al.* 1997; Price *et al.* 1998; Hoppe *et al.* 1999; Beard and Johnson 2000; Kennedy *et al.* 2000; Price *et al.* 2000; Blum *et al.* 2001). While Sr showed much promise in archaeochemical applications the problems of diagenesis – including, amongst other aspects, the post-mortem modification of human skeletal material and environmental variability in Sr distribution – tempered the initial optimism (Sillen 1981; Price, *et al.* 1992; Price, *et al.* 2002). The introduction of 'solubility profiling' (Sillen 1981, 1986), sequential washing in a weak acidic buffer solution to remove diagenetic contamination, re-established Sr as a viable trace element/stable isotope. Once again, however, the use of post-excavation cleaning techniques have been thrown into doubt, as have many of the methods of migration and life-way reconstruction utilising Sr (Hoppe *et al.* 2003; Trickett *et al.* 2003).

The various aspects of the application of Sr as both a trace element and stable isotope will be discussed in greater detail below, including both general comments on the biogeochemical

significance of Sr but also the archaeochemical applications. Diagenesis of human skeletal material will be discussed in a separate section below.

4.1.1. The Geochemistry and Mineralogy of Strontium

4.1.1.1. General

Strontium, an alkaline earth metal (Group II) and 12th most-abundant element (average 375 μg g^{-1} in the terrestrial crust), occurs in the lithosphere in four naturally-occurring stable isotopes: ^{88}Sr, ^{87}Sr, ^{86}Sr and ^{84}Sr with respective abundances of 82.53%, 7.04%, 9.87% and 0.56%, respectively (Greenwood and Earnshaw 1984; Faure 1986; Nesse 2000). Of these isotopes, the abundances of ^{88}Sr, ^{86}Sr and ^{84}Sr remain fixed from the original accretion of Terra (Greenwood and Earnshaw 1984; Faure 1986; Krauskopf and Bird 1995). ^{87}Sr is radiogenic and, as such, its abundance gradually increases throughout time from the radioactive decay of the naturally occurring isotope of rubidium, ^{87}Rb ($T_{1/2} = 4.88 \times 10^{10}$ yr) (Faure 1986). The Sr composition of a given mineral or ideal soil, i.e. not one subject to drift or mixing phenomena resulting from natural processes, is there dependent on two features: (1) the original Rb-Sr composition of the mineral; and (2) the length of time that has passed since the initial formation of the mineral (Greenwood and Earnshaw 1984; Faure 1986). Alterations to the original Rb-Sr and subsequent ^{87}Sr evolution are not idealised, however, and may change through subsequent metamorphic activity or even migration through general heating (Faure 1986; Krauskopf and Bird 1995). 'Primordial' $^{87}Sr/^{86}Sr$ has been calculated at 0.699 (the 'hypothetical uniform reservoir,' or UR), though modern figures for the initial Sr isotope ratio ($^{87}Sr_O/^{86}Sr$), allowing for the evolution of ^{87}Sr in the mantle are closer to 0.704 (range 0.702-0.706) (Krauskopf and Bird 1995).

4.1.1.2. Ocean

The composition of oceanic $^{87}Sr/^{86}Sr$ is broadly determined from mid-ocean volcanism, with long-term variation keyed to sea-level changes, major tectonic events, climatic change, fluvial contribution and, potentially, the alteration in the character of chemical weathering and rates of erosion on the continents (Capo *et al.* 1998). The Sr composition of the oceans fluctuates over several million years ($2\text{-}3\times10^6$ y), though for the purposes of archaeological studies this can be considered to be constant, varying only between the values of $^{87}Sr/^{86}Sr \approx 0.707\text{-}0.709$ (Holland 1984; Faure 1986; Capo *et al.* 1998; Montgomery 2002). Low sea-water Rb results in an Rb-derived contribution of ^{87}Sr which may be considered negligible within the Holocene, i.e. including the historical period that is the focus of the study (DePaolo and Ingram 1985). While long-term variation in oceanic Sr may not affect archaeometric studies in, for example, determination of the marine *versus* terrestrial diets, it can affect the chemical compositition of biogenic and precipitate sedimentary rocks, (i.e. limestones, chalks, halites, gypsum, etc.), and therefore the strontium isotope composition of such minerals.

Rainwater derives ultimately from the ocean and, as such, will have an $^{87}Sr/^{86}Sr$ signal determined by that of the marine environment, i.e. $\approx 0.707\text{-}0.709$, though with a significantly lesser concentration, i.e. <1 ppb compared to that of ~7.7 ppm in seawater (Faure 1986).

4.1.1.3. Soil

"Soils are the ultimate product of rock weathering" (Krauskopf and Bird 1995). The weathering of mineral structures (both uni- and polymineralic) occurs through a combination of physical (mechanical) - water action (freezing, etc.), root action, differential hydration of minerals, and so forth – and chemical processes (ionic disassociation, addition of water/carbon dioxide,

hydrolysis, oxidation, adsorption and ion exchange) (Faure 1986; Krauskopf and Bird 1995; vanLoon and Duffy 2000). The soils themselves are the result of the differential action of the atmosphere, percolation of groundwater through the material, mechanical infiltration by root structures as conduits for further groundwater percolation, bacterial action as a catalyst for organic and inorganic reactions, bioturbation by larger fauna, and so forth (Krauskopf and Bird 1995). The resistance of a given mineral structure, especially polymineralic structures, to these chemical and physical processes therefore determines the composition of soils derived from the source and, equally, the probability that derived material will be present in any quantity at a given point from said source under given conditions (Nesse 2000). In terms of the Sr composition it adds an additional level of complexity other than the often assumed association of 'geology to soils', as Rb-bearing minerals tend to be more resistant to weathering than Sr-bearing minerals (i.e. plagioclase, carbonates, etc.), and therefore tend to be more radiogenic with higher $^{87}Sr/^{86}Sr$ (Faure 1986; Nesse 2000). In latitudes that would have been subjected to glaciations and blurring of soil, isotope ratios present a potential limit to the interpretation of 'local' or 'non-local' strontium. However, Budd *et al.* (2004*b*) asserts that drift is unlikely to affect strontium isotope ratios beyond the 'local' level, though once again this can be variable.

Variability between Sr in the soil and the underlying bedrock may also be introduced by a number of other phenomena, including river transportation of non-local soils and subsequent alluviation (Capo *et al.* 1998), gradual deposition of wind-blown particles, and to a lesser extent precipitation and contribution of sea spray in coastal environments (Andersson *et al.* 1990; Capo *et al.* 1998; vanLoon and Duffy 2000). While the blurring of $^{87}Sr/^{86}Sr$ from fluvial systems might have a significant localised effect, for example the presence of alluvial plains, the relative contribution of precipitation to soil Sr is questionable, seemingly dependent largely upon the physical and chemical characteristics of the soils into which the 'marine' Sr mixes as well as the

significantly decreased concentrations of Sr in rain (Krauskopf and Bird 1995; Capo *et al.* 1998; vanLoon and Duffy 2000).

4.1.2. The Biochemistry of Strontium

Interest over the introduction of Sr into the food web ultimately derives from concerns over ^{90}Sr, a fallout product of atmospheric nuclear explosions, of great concern during the 1960s when atmospheric nuclear testing peaked (Comar *et al.* 1957; Williams *et al.* 1962). While ^{90}Sr ultimately relates to an anthropogenic event, its action in the foodweb is essentially the same as that of naturally occurring Sr. The utilisation of Sr in such a manner is predicated upon one core feature: Sr has no known biochemical or physiological function within an organism (Underwood 1977; Priest and Van der Vyver 1990; Wallach and Chausmer 1990), although that does not preclude a minor biochemical function in trace quantities. Furthermore, given the proportionately low mass differences between the isotopes of Sr, biological fractionation such as evidenced in lighter isotopes ($\delta^{18}O$, $\delta^{13}C$ and $\delta^{15}N$ for example) is not present (Price *et al.* 1985).

4.1.2.1. Incorporation of Sr into Plants

Sr in both plants and animals is thought to act much like it does in minerals, i.e. Sr^{2+} substitutes for Ca^{2+}. The Sr incorporated into plant tissue has been shown to have an $^{87}Sr/^{86}Sr$ correspondent to the surrounding soil exchange complex and within a given environment (Capo *et al.* 1998; Sillen *et al.* 1998). While Sr might be present in concentrations ranging from 2-20 $\mu g\ g^{-1}$ biochemical processes – 'biopurification' – favour the incorporation of Ca^{2+} against that of Sr^{2+}, although there is no direct correlation between the levels in plant tissue and that of the soil matrix, falling to as little as 0.2% in some woods (Elias *et al.* 1982; Gosz *et al.* 1983; Capo *et al.* 1998). Sr levels may also vary from plant-part to plant-part, (i.e. between roots and

leaves), due to atmospheric deposition in a similar process to that found with Pb deposition, as well as being broadly age-dependent (Elias *et al.* 1982; Gosz *et al.* 1983; Capo *et al.* 1998; Aberg *et al.* 2001). Indeed, as has become increasingly apparent in the study of Sr, each ecosystem must be considered separately (Gosz *et al.* 1983; Schoeninger 1985; Runia 1987; Nadelhoffer and Fry 1994; Capo *et al.* 1998).

The lack of fractionation of Sr isotopes in biological systems means that, while Sr concentrations in plant tissues do not correlate with labile Sr in the soil exchange complex, the $^{87}Sr/^{86}Sr$ of the soil correlates with that of the measured plant tissue (Gosz *et al.* 1983; Price *et al.* 1985; Capo *et al.* 1998; Sillen *et al.* 1998). Thus, while one might not directly infer the Sr concentration of a plant and, therefore, of a plant-eater (Radosevich 1993), both the plant and the plant-eater will have $^{87}Sr/^{86}Sr$ values that are representative of the local soil conditions.

4.1.2.2. Incorporation of Sr into Animals

Sr is incorporated into animal tissues in a similar manner to that of plants, (i.e. substitution of Ca^{2+} by Sr^{2+}), from environmental Sr but primarily from the diet. Internal distribution of Sr occurs through the same physiological pathways as Ca^{2+}, hence its use as a radiological tracer in clinical studies (Bowen 1979; Boivin *et al.* 1996). As a non-nutrient trace element there are no homeostatic controls to moderate levels of Sr within the body (Parker and Toots 1980) and, as such, levels within the diet have a direct if not necessarily linear relationship with the levels within bone (Price *et al.* 1986; Burton and Wright 1995; Boivin *et al.* 1996).

As a 'bone seeking' element, 99% of the Sr in the body lies within the skeletal system (Underwood 1977). It is incorporated into the 4-coordinate Ca^{2+} site of calcium phosphate hydroxyapatite (Ca_{10} $(PO_4)_6(OH)_2$), or through surface adsorption (Parker and Toots 1980;

Greenwood and Earnshaw 1984; Price *et al.* 1985; Vulkovic *et al.* 1998). Physiological distribution of Sr is fairly homogenous with variation potentially resulting from differences between endochondral and membranal ossification of skeletal elements (Tanaka *et al.* 1981; Martini 1998). There may also be some variation in the incorporation of Sr into the differing skeletal tissues, (i.e. enamel, dentine and bone), with enamel usually having the lowest concentrations (Underwood 1977). There are a number of reasons why this phenomenon might be observed. Firstly, dentine and bone show comparable tissue histology and characteristics, e.g. similar crystal size of biogenic hydroxyapatite (~50 nm), comparable organic *versus* inorganic composition, etc. The smaller hydroxyapatite size compared to that of enamel (200-600nm) allows for a proportionately greater surface area for surface adsorption (Underwood 1977; Parker and Toots 1980; Warshawsky 1983; Price *et al.* 1985; Hilson 1996; Chadwick and Cardew 1997). Subsequent incorporation into the hydroxyapatite lattice through the deposition of secondary dentine as well as remodelling evidenced in bone may also contribute to measured differences (Underwood 1977).

The concentrations of Sr *in vivo* also show significant variation between different geographical regions and population/cultural groups (Underwood 1977). Indeed, as mentioned above, the concentration of Sr will vary depending on a wide range of factors including, but not limited to, both solid and drift geology, proximity to the coast and/or other substantial natural phenomena. Furthermore, the subsistence choices made by a given cultural group can also effect *in vivo* Sr concentrations, (e.g. the relative contribution of plant or meat to the diet (Aberg *et al.* 1998)). Reported Sr concentrations in human skeletal and dental tissues for modern populations ranges from 50.3-300 $\mu g\ g^{-1}$ (Underwood 1977; Montgomery 2002). In comparison of specific ecosystems herbivores will tend to have a higher Sr concentration than those of carnivores and omnivores given the latter dietary choices include at least a proportion of meat/flesh, of which Sr contributes only a small fraction to the Sr load.

Sr biochemistry suffers from a number of synergistic and antagonistic effects with other elements, trace and otherwise. First and foremost is the concept of 'biopurification'. the discrimination of Sr in favour of Ca in increasing trophic levels, (i.e. plant to 'super-predator') or, indeed, mother to infant (Comar *et al.* 1957; Sillen and Smith 1984; Burton and Price 1999). However, the relationship between diet, the primary method of incorporation of Sr into the mammalian physiology, and tissue Sr levels is complex. While there is a broad correlation between single-component diets and Sr levels (Price *et al.* 1986), multiple-component diets do not have such a simple relationship (Price *et al.* 1985; Blumenthal 1990; Burton and Wright 1995). Indeed, feeding studies, such as those performed on laboratory rats, indicate that the situation is not only complex in terms of diet but is also related to the age of the individual, sex, and so forth (Lambert and Weydert-Homeyer 1983; Price *et al.* 1986).

It is, however, important to note that, while Sr concentrations in a tissue vary tremendously by metabolic factors, diet, etc., the $^{87}Sr/^{86}Sr$ ratio is fixed by the geochemical source of the Sr. As such the theoretical composition of osseous tissues is determined by the geological provenance of a mammal, (i.e. the source of their diet).

4.1.2.3. Biochemical Effects of Sr in Animals and Humans

The effect of strontium on the biochemistry and skeletal biology of the mammalian physiology is at best poorly understood. While studies of laboratory rats have indicated that elevated dietary strontium can result in malformation of the osteoid, (i.e. hypomineralisation resulting in brittle bones), there is no suggestion as to what proportion of strontium is required to cause this effect (Price *et al.* 1986). At low levels, however, Sr may serve a biochemical role although, once again, there is little information on this subject (Underwood 1977).

4.1.2.4. Anthropogenic Contribution to Sr Variation/Load in Animals and Humans

The situation is arguably further complicated in anthropogenic systems. While the lack of biological fractionation of $^{87}Sr/^{86}Sr$ is often used to show the resistance of the isotopic system to anthropogenic alteration, there are some systems which may present difficulty. Arguably the most obvious of these are large urban agglomerations, although any system that effectively increases the catchment or procurement area of the sample population (Aberg *et al.* 1998). Although limited in scope, Aberg's *et al* (1998) study of Sr and Pb in medieval and modern teeth from Norway begins to show the potential complexity of urban isotope systematics. Here, the data seems to indicate that the individuals in medieval Norway were utilising local food resources, while those of the modern period had a Pb and Sr isotope ratios that lay between that of seawater and common milk sources (Aberg *et al.* 1998). While many researchers propose the use of small mammals with restricted territories to properly indicate the nature of the local Sr environment (Price *et al.* 2002), this is once again problematic in the urban environment both in terms of the animal selected and the contribution of 'local' resources to the diet, both in terms of catchment area and food availability (White *et al.* 2001).

4.1.3. Archaeological Applications of Sr and 87Sr/86Sr Analysis

The use of Sr in archaeological research falls broadly into two categories: elemental analysis, which focuses upon the concentration of Sr in a biological tissue usually in ratio to another element, (e.g. the commonly used Sr/Ca ratio; and isotopic analyses which utilise the relative abundance of Sr isotopes), usually with reference to their proposed geological distinction. While each method has its own strengths and merits, both have been used to cover the same archaeological problems, namely: palaeodiet, various social and physiological phenomena, environmental reconstruction and migration (Sealy and Sillen 1998; Thackery 1995; Price *et al.*

1998; Price *et al.* 2002). Given the nature of this project only palaeodietary analysis and migration will be briefly discussed here.

4.1.3.1. Palaeodietary Analysis

As mentioned previously, Sr is incorporated into the foodweb from the uptake of labile Sr from soils by plants and, from there, into mammalian physiology by consumption of those plants. Not only do organisms biopurify Sr^{2+} in preference for Ca^{2+}, but as primarily a bone-seeking ion it will be incorporated into higher-level organisms, (i.e. predators), in decreasing amounts (Underwood 1977; Papworth and Vennart 1984; Blumenthal 1990). Simply put, carnivores contain less Sr relative to Ca then their prey-animals, which contain less than herbivores, and the herbivores less than the plants they consume (Comar *et al.* 1957; Runia 1987; Sealy and Sillen 1988). This is problematic for a number of reasons: firstly Sr is not homogenously distributed through the tissues of a planet may also contain surface contamination from precipitation or fall-out (Corrin and Natusch 1978; Tornabene *et al.* 1978; Zimdahl and Koeppe 1978; Gosz, *et al.* 1983; Andersson *et al.* 1990; Capo *et al.* 1998; Aberg 2001; White *et al.* 2001. Secondly, many studies of food-webs consider the relationship between diet and the chemical composition of studied remains to be linear. The assumption is that, in a given environment, if herbivores have a Sr/Ca of 'x' and carnivore's one of 'y' a measured value of 'z' which lies in between 'x' and 'y' translates to an omnivore. Indeed, the relative separation between the three values has occasionally been used to indicate the relative contribution of each food resource to the diet of the individual. Thus if 'z' lies closer to 'x' than 'y' then, self-evidently, individual 'z' must consume proportionately greater plant than meat resources. Not only do such assumptions ignore the potential variation introduced by plant type, foraging strategy and area, but ignores the complexities introduced by multi-component diets including elemental synergy and antagonism. Furthermore, individual culinary practices including component selection in plants

and animals, preparation techniques, etc., can have a disproportionate effect on the Sr/Ca of an individual even while in calorific terms providing a relatively minor contribution to the diet as a whole (Burton and Wright 1995).

While offering a great deal of potential, elemental Sr studies of diet are remarkably specific to a given time and environment and, with humans, cultures. Uniformitarian assumptions with regards to prehistoric cultures and diet may therefore be particularly unpalatable to the individual archaeologist.

The use of Sr isotopes for dietary reconstruction is relatively simple compared to that of a consideration of elemental concentrations, in essence, the archaeological application is reduced to a simple hypothesis of 'marine or not marine' (Sealy *et al.* 1991). Trophism within a specific environment or prey-hunter network is ameliorated given the homogenous nature of oceanic Sr (Holland 1984; Faure 1986; Sealy and Sillen 1988; Capo *et al.* 1998). Furthermore, with the lack of fractionation of Sr the problem regarding diet non-linearity becomes more defined, working as a complex mixing problem (Faure 1986). Even then, however, the situation is as complex as sourcing pollution with Pb, especially one when begins to consider extended resource procurement areas.

While Comar *et al.*'s (1957) study essentially started the use of Sr in palaeodietary studies, further enhanced by the work of Brown (1973), and Toots and Vorhies (1965), it was not until the late 1970s and early 1980s that Sr studies came into their own. While theoretical studies of Sr incorporation into the human body continued in parallel with the archaeological application (LeGeros *et al.* 1980), they were by far quieter voice in the literature. Sillen's (1981) work on Hayonim cave in many ways typifies the palaeodietary studies of period, identifying herbivore and carnivore Sr/Ca values and placing humans on the continuum between the two values.

Echoing the caveat of Toots and Voorhies (1965), preliminary studies were wary of drawing conclusions on the substance of palaeodiet without specific reference to a particular niche ecosystem, a consideration which disappeared in many subsequent works. Intriguingly both with elemental and isotopic studies the necessity of using faunal remains distinct from soil values to characterise the local Sr environment is once again becoming prominent in the literature (Budd pers.comm.; Budd *et al.* 2004*a, b*; Evans pers. comm.).

4.1.3.2. Migration

Migration is a more complex phenomenon and, as a result, also one of the most problematic to reconstruct. While primarily based upon the premise of geological distinctiveness of $^{87}Sr/^{86}Sr$, the problems highlighted with palaeodietary analysis continue to dog studies of migration. They have, however, been prominently used to identify immigrants in a number of cases throughout the world.

Sealy, *et al.* (1991, 1995) utilised human and faunal remains from the Cape of South Africa to determine the nature of ancient diet and address issues of residential mobility. Though many of the earlier studies, including the study of South African immigration and ecozones, utilised bone and were therefore subject to the problems of diagenesis, Sealy *et al.* (1991, 1995) was able to distinguish between coastal and inland or terrestrial diets.

Similarly, Price *et al.* (1994) utilised strontium isotopes in the reconstruction of prehistoric migration at the Grasshopper Pueblo and Walnut Creek sites of White Mountain in east-central Arizona (Ezzo *et al.* 1997). Price *et al.* (1994) measured not only the strontium isotope ratios of bones but also those of teeth and thereby side-stepping the issue of diagenesis. Variability in the

strontium isotope ratios of the teeth over those of the bone were used to suggest that a substantial portion of the population were migrants.

As with previous studies, the Price *et al.* (1997, 1998, and 1999) study of Bell Beaker-period skeletons in central Europe was also predicated upon the difference of strontium isotope ratios in bone and tooth enamel. Based upon what the authors considered a reasonable 'cut off' point in determining the significance of difference between the isotope ratios, approximately 25% of the individuals were immigrants (Price *et al.* 1998). Bone strontium isotope ratios were used to determine locality, (e.g. similar bone isotope ratios with those of the local geology were taken as a 'local'), a feature that has subsequently been shown to problematic (Trickett 1999; Trickett *et al.* 2003). Indeed, in many regards a measurement of bone strontium isotope ratios, more particularly those treated for diagenetic contamination is a measurement of the burial soil strontium isotope ratio.

Bone strontium isotope ratios were similarly used by Price *et al.* (2000) in addressing the issue of immigration in Epiclassic and early Postclassical Teotihuacán. As with previous studies, above, the differences in bone and enamel lead were used to suggest an extremely high degree of immigration into the city as well as long-term residence. As with the previous study (Grupe *et al.* 1997; Price *et al.* 1998; Grupe *et al.* 1999) the assumption in the successful removal of diagenetic strontium for bone has been subsequently indicated to be potentially erroneous (Trickett *et al.* 2003).

More recently, studies utilising strontium isotope ratios have become increasingly aware of the limitations of the singular use of strontium and have incorporated other isotopes, more commonly oxygen but also lead (Montgomery 2002; Müller *et al.* 2003; Budd *et al.* 2004*a, b*). With the variation between geological strontium isotope ratios and the labile, and therefore

bioavailable, strontium it provides an unreliable determinant of the expected range of food strontium isotope ratios for a given locality (Sillen *et al.* 1998; Price, Burton *et al.* 2002; Budd *et al.* 2000*b*).

While a method still in development, the combined use of isotopes presents a method by which the limitations of strontium, (i.e. variability in the strontium isotopes within a given locality), may be ameliorated. Furthermore, most strontium isotope studies dealing with migration have done so with pre-industrial societies. An increasing communication which improved the availability of food resources also extended the catchment area for resources. In London, for example, the dominant source for grain-based products would have been the southern agrarian counties, but would have also included marine resources, local meat resources driven into the town, etc. While the grain-signal would have been dominant, all would have contributed to the strontium isotope load in determining diet and migration (Budd *et al.* 2004*b*).

4.2. The Biogeochemistry of Lead

The chemical applications of lead (Pb) and its isotopes has seen wide use through the geological sciences, used generally as an indicator and tracer of pollution in the atmosphere and living organisms, and as an indicator of the presence of valuable minerals in sulphide deposits, (i.e. silver). Within the archaeological sciences the utilisation of Pb is more restricted, primarily of use for the geochemical provenance of metal artefacts, in the studies of the health and exposure to pollutants in past populations and, more recently, the provenance of human osteoarchaeological material in pre-metallurgical societies.

4.2.1. The Geochemistry and Mineralogy of Lead

4.2.1.1. General

Lead occurs naturally in a number of stable isotopes: ^{208}Pb, ^{207}Pb, ^{206}Pb and ^{204}Pb in the approximate proportions 52.3%, 22.6%, 23.6% and 1.46% respectively (Faure 1986). While there are a number of artificially-produced Pb isotopes, i.e. ^{205}Pb and ^{202}Pb, as well as one naturally occurred low-level radioactive isotope (^{210}Pb), it is the stable isotopes that are of the greatest use to those interested in the reconstruction of lead mobility in the geochemical environment, the atmosphere and, ultimately, biological organisms.

Pb is found in minerals containing uranium (U) and thorium (Th) where it is the end-product of a series of radioactive decay processes which form the different isotopes of Pb: ^{238}U decays to form ^{206}Pb; ^{235}U decays to form ^{207}Pb; and ^{232}Th decays to form ^{208}Pb (Faure 1986). It also forms several distinct minerals, the principle of which is galena (PbS), from which U and Th are excluded (Faure 1986; Nesse 2000). The similarity of U and Th chemistry, (i.e. similar electronic configurations and ionic radii (1.05 Å and 1.10 Å respectively)), allow for the elements to readily substitute with each other. However, in the geochemical environment U forms the uranyl ion (UO_2^{2+}), which is soluble in water, while Th is present only as the tetravalent Th^{4+}, which is insoluble under oxidising conditions (Faure 1986). This differential solubility combined with the genesis of the minerals allows for the differing inclusion of U and Th into various rocks types. Granites, granitic gneiss, shale and sandstones, on the other hand, have increasing proportions of U (>3.2ppm) and Th (>11.7ppm) and, subsequently, Pb (>13.7ppm) (Faure 1986).

The radioactive nature of U and Th, and the resultant Pb isotope end-products, forms the basis of both geological dating systems and geochemical provenance of Pb ores utilised for pollution studies, archaeological provenance in pre-metallurgical societies, etc. ^{204}Pb is non-radiogenic and, therefore, its abundance remains unchanged. The proportions of ^{208}Pb, ^{207}Pb and ^{206}Pb are gradually increasing through time based upon the half-lives of U and Th: $T_{1/2}$ $^{232}Th = 14.010 \times 10^9$ y; $T_{1/2}$ $^{235}U = 0.7038 \times 10^9$ y; and $T_{1/2}$ $^{238}U = 4.467 \times 10^9$ y. The Pb of a mineral will therefore result from the differing U/Pb and Th/Pb ratios – which vary as a result of magma generation, fractionation, hydrothermal and metamorphic processes, as well as by weathering and other low-temperature processes (Faure 1986) – and the inclusion of 'primeval' Pb, which may derive from multiple sources (Faure 1986). Lead-bearing minerals that have remained 'closed' to subsequent addition *or* removal of U or Th are ordinary, or conformable, Pb; their isotopic ratios lie on a growth curve that can be plotted for any two ratios (Faure 1986: Kersten *et al.* 1994). Material that does not plot on the growth curve – anomalous Pb – does so for the inclusion or exclusive of U and Th at some point in the formation history of the mineral in question (Faure 1986).

4.2.1.2. Ocean

Within the ocean, Pb has a short residence time due to its low solubility and, therefore, rapid precipitation and subsequent incorporation into marine sediments and organisms (Fergusson 1990; Libes 1992; Kersten, *et al.* 1994). As a result of this rapid precipitation the distribution of Pb through the marine environment is heterogeneous, deriving from terrestrial run-off and atmospheric deposition. Furthermore, the settlement of precipitated Pb compounds results in concentration-depth phenomena, such that Pb concentration is inversely proportional to the depth of the water at any given point (Libes 1992). As such the pre-metallurgic Pb isotope ratio of coastal waters would have had a composite ratio reflective of the proximal land-mass (Von

Blanckenburg *et al.* 1996), with estimated Pb concentrations of 0.5 ngl^{-1} (Fergusson 1990). Similarly, precipitation during the pre-metallurgical period would have most likely been derived locally. These values are much lower than their terrestrial counterparts, i.e. 12-50 $\mu g\ g^{-1}$ in rocks and sediments (Fergusson 1990).

Ocean Pb isotope composition and concentration has, however, become more complex in the post-metallurgical world. Long-range transportation of Pb in pollutant aerosols, such as alkyl-Pb derived from automotive use, can significantly affect the local, 'natural', isotopic signature (Tatsumoto and Patterson 1963; Patterson 1965; Boggess 1978; Schaule *et al.* 1981; Aberg *et al.* 1998; Hong *et al.* 1996; Dunlap *et al.* 1999; Chiaradia and Cupelin 2000; Aberg 2001; Bindler *et al.* 2001; Brännvall *et al.* 2001). Such transmission predominantly takes the form of particulate suspension from not only alkyl-Pb but also material scavenged from surface soils and the weathered components of rock (Corrin and Natusch 1978; Bacon and Bain 1995).

4.2.1.3. Soil

Soil Pb, like the soil itself, ultimately derives from the underlying geology through natural weathering processes (chemical, hydrological, aeolian, etc.). Given that there is no detectable fractionation at low-temperatures of Pb isotopes (Faure 1986; Fergusson 1990) the soil will reflect the isotopic composition of the substrate. However, as seen with Sr, one might imagine seeing a 'blurring effect' due to drift (Budd, pers. comm). Local variations may exist due to the preferential weathering of one mineral over another (e.g. mudstone over limestone), or from local variations within the substrate and/or ore field. Subsequently it is thought that over an area that is isotopically similar, though not necessarily homogenous, substrate the overlying soil will have a homogenous isotopic character (Erel *et al.* 1994).

Within the soil itself, Pb tends to be concentrated in the organic/humic fraction, although its lability is determined by numerous features including pH, inorganic colloids, phosphorus fertility and the levels of Pb in the soil initially (Zimdahl and Hassett 1978: Zimdahl and Koeppe 1978; Fergusson 1990). In general, mobility increases with acidity – such as those in ombotrophic bogs or acidic peats – and the presence of dissolved organic matter, even in neutral or basic conditions in the latter case (Urban *et al.* 1990; Steinmann and Stille 1997). However, it remains relatively immobile in the upper 15-20 cm (Adriano 1986; Sheppard and Thibault 1992). It is interesting to note that in soils, Pb^{2+} when in competition with Ca^{2+} is more strongly absorbed and may further replace K^{+} in organic matter (Adriano 1986; Fergusson 1990).

Modern soils may also have a variable component added from the use of pesticides, addition of sewage sludge, automobile aerosols, smelter and incinerator fallout, coal combustion, etc. (Fergusson 1990). Surface Pb levels vary from 17-142 μg g^{-1} in fluvisols (24-96 μg g^{-1}; mean 63 μg g^{-1}), gleysols (17-63 μg g^{-1}; mean 40 μg g^{-1}) and histosols (26-142 μg g^{-1}; mean 84 μg g^{-1}), though addition of Pb through automobile aerosol from 1946 has been shown to add 3-10 μg g^{-1} (Chamberlain 1983; Fergusson 1990). Concentrations of Pb in the soil, however, can decrease markedly with depth in soils (Erel *et al.* 1997). Furthermore, natural and anthropogenic lead tend to be separately compartmentalised, (i.e. natural Pb being primarily associated with aluminosilicates and not with carbonates and organic matter), while the reverse situation applies with anthropogenic lead (Teutsch *et al.*2001).

Contaminated soils can show much higher Pb levels, from built-up areas (inner city, urban gardens) showing ranges from 56 to 12,420 μg g^{-1} in comparison to values of 115 to 72,000 μg g^{-1} in mining areas (Fergusson 1990).

4.2.2. The Biochemistry of Lead

Lead is found as a trace element in both plants and animals, and is generally considered non-essential, though it is possible that in low concentrations it may perform some function (Underwood 1977).

4.2.2.1. Incorporation of Pb into Plants

Within plants, root and folial uptake remain the two main sources by which Pb can be absorbed. Root uptake is dependent upon the labile Pb within the soil i.e. is that maintained in soil solution, and occurs by either passive diffusion through cell membranes or active transfer (Fergusson 1990). The exact mechanism of membrane diffusion is poorly understood, but may be linked to a complexing agent which transports the metal ion across the membrane and disassociates leaving the ion bioavailable to the plant (Fergusson 1990). Folial uptake occurs through either the stomata or leaf cuticle, and obviously becomes more significant in systems where Pb aerosols are present, though this can be through topical coating as well as metabolic/non-metabolic uptake (Zimdahl and Koeppe 1978; Fergusson 1990).

Once Pb has been incorporated into the plants it becomes bioavailable to the plant and may be transported through the xylem. However, studies have indicated that the majority of Pb remains concentrated in the roots, indeed often exceeding the labile levels in the soil through concentration in dictyosome vesicles (Zimdahl and Koeppe 1978; Fergusson 1990). Translocation to other parts of the plant is therefore limited. This lack of mobility has been attributed to the formation of a lead-phosphate complex concentrated in the cell walls and most likely explains the more significant contribution of aerosol than soil Pb found in Norwegian crops (Zimdahl and Koeppe 1978; Fergusson 1990; Aberg *et al.* 1998).

4.2.2.2. Incorporation of Pb into Animals

Similarly to plants, Pb is taken into animals – including humans, which will form the focus of this discussion – through a number of paths: inhalation of air (and particulates) into the lungs; ingestion of food, water and non-food items into the gastrointestinal system; and transfer through the skin (Underwood 1977; Fergusson 1990). Of these ingestion and inhalation provide the most significant potential for Pb incorporation, with skin incorporation requiring lipid-soluble substances such as organometallic compounds and certain solutions with organic solvents (Fergusson 1990).

4.2.2.3. Gastrointestinal Absorption of Lead

Ingested food and non-food material is digested through enzyme hydrolysis to break the matter into absorbable molecules, where it then moves to duodenum and small intestine. Materials that are on the surface of the digestive tract may therefore be absorbed into the walls and, from there, into the blood stream by diffusion/osmosis or consumption of energy (Fergusson 1990). The absorption is quantitatively greater in infants than in adults, with a mean absorption factor across the gastrointestinal tract to the blood of 5-15% in adults compared to 40-53% in infants (Underwood 1977; WHO 1977; Fergusson 1990). As can be expected, absorption is dependent in numerous factors relating both to the metabolism of the individual as well as their diet, (i.e. quantity of food containing Pb that is ingested, presence of antagonistic metals, etc). (Underwood 1977; Adriano 1986; Fergusson 1990). In fasting individuals absorption in adults may increase to 45% (Putnam 1986).

4.2.2.4. Inhalation of Lead

Inhalation of Pb is a complex process that can be broadly divided into a number of phases. First there is the inhalation of the Pb-bearing aerosol into the lungs, which is dependent upon the individual and which will vary significantly between adult and child (i.e. due to different lung capacities, stroke volume, and so forth). Secondly is the amount and composition of aerosol that is deposited into the lungs, with particulate sizes of >2 μm being trapped in the mucus of the upper respiratory system and then removed by ciliary activity. As with absorption through the gastrointestinal tract, Pb-bearing material that enters the respiratory system may be absorbed into the blood stream, providing the third mechanism by which Pb may be incorporated into the organism. Such absorption is generally orders of magnitude more efficient than gastrointestinal absorption with 50-70% of inhaled particles that reach the respiratory tract are absorbed (Putnam 1986; Budavari 1989; Fergusson 1990; Gilman *et al.* 1990).

4.2.2.5. Incorporation of Lead into Biological Tissues

Once within the blood Pb is swiftly incorporated into the various tissues and organs of the body, though the skeleton is by far the greatest repository of the body's Pb burden. Pb^{2+} is believed to substitute for Ca^{2+} within the hydroxyapatite lattice (Wallach and Chausmer 1990), a thermodynamically favourable situation given the increased stability of lead-phosphates when compared to calcium-phosphates (Verbeeck *et al.* 1981).

Lead is heterogeneously distributed through the human skeletal system, varying substantially between not only the various tissues (soft, hard) but also the different skeletal elements (Aufderheide 1989). The levels within these tissues varies dramatically depending socio-physical circumstances (e.g. urban, rural, proximity to mining/smelting operations, etc.) and

historical period (pre- and post-metallurgy). Modern studies indicate Pb levels in tooth enamel from 4.1-5.8 μg g^{-1} (Britain), 9.12 μg g^{-1} (Scotland) to 19.6 μg g^{-1} (USA) (Fergusson and Purchase 1987; Fergusson 1990). Comparison is, however, problematic due to sample selection, (e.g. permanent *versus* deciduous, enamel *versus* dentine, etc). (Fergusson and Purchase 1987).

Once Pb has been incorporated into the biological system, it does not remain there indefinitely. Bone is a dynamic tissue, constantly modelling and remodelling during the lifetime of an organism. The processes of formation and turnover occur at different rates and times throughout the human skeleton (Larsen 1997; Mays 1998). As such the incorporation of Pb has been shown to be not only dependent upon the skeletal element and formation processes, (i.e. endochondral *versus* membranal ossification), but also with the age (Erkkilä *et al.* 1992; Grynpas 1993). Numerous rates of turnover and removal of Pb have been cited in the literature and, as such, must be considered as suspicious. A period of 20+ years has been cited by Fergusson (1990), while Priest and Van der Vyver (1990) indicate a 3% turnover in cortical bone and a 22% turnover in trabecular bone. In children turnover rates can be 100% during periods of rapid growth. Studies on Australian immigrants by Gulson (1997), however, indicate turnover rates – the exchange of non-Australian to Australian lead – in dentine of approximately 1% per annum, while trabecular bone of the jaw exchanged at approximately 6% per annum, or 15 years for total exchange of the lead (Gulson 1996; Gulson *et al.* 2004). These rates are likely higher in pregnant and breastfeeding females (Sowers *et al.* 2002; Téllez-Rojo *et al.* 2002).

4.2.2.6. Biochemical effects on Humans/Animals

While the incorporation of Pb into an individual is at best poorly understood, the biochemical and medical effects of Pb toxicosis is well documented. The primary effect of Pb is in the forming complexes with oxo-groups in enzymes with a subsequent effect on the process of

haeme synthesis and porphyrin metabolism (Greenwood and Earnshaw 1984). Pb also serves to inhibit important biochemical reactions, including: acetylcholine-esterase, acid phosphatase, ATPase, carbonic anyhdrase as well as protein synthesis through modification of transfer-RNA (Greenwood and Earnshaw 1984; Rose 1991; Hames and Hooper 2000). Furthermore, it inhibits sulfhydryl enzymes in a similar, but lesser, fashion to cadmium and mercury through interaction with proteinaceous cysteine residues (Greenwood and Earnshaw 1984).

4.2.2.7. Clinical Effects of Lead Toxicosis (Plumbism)

While the biochemical effects of Pb in the organism are fairly well documented, even if the results are ambiguous and often contradictory, the relationship between the biochemistry and the actual health effects are poorly understood despite correlation between blood Pb and alteration of ALAD (Aminolevulinic acid dehydrase) levels (Boggess 1978; Hammond 1978; Tornabene, Gale *et al.* 1978; Orlov *et al.* 1994). Diagnostic criteria for Pb poisoning can have multiple aetiologies, but include: nausea; vomiting; abdominal pains; anorexia; constipation; anaemia; irritability; mood disturbance; coordination loss; hyperactivity; and mnemonic difficulties (Hammond 1978; Tonabene *et al.* 1978; Fergusson 1990; Orlov *et al.* 1994; Büsselberg *et al.* 1998).

Upon entering the human body the effects of lead vary depending on the amount and duration of exposure, as well as the age of the individual exposed, with children having the greatest susceptibility to lead poisoning (Putnum 1986; Garrettson 1990):

- *Acute poisoning.* Acute lead poisoning is rare, and usually related to the ingestion of soluble lead salts, leading to gastrointestinal discomfort (irritation, vomiting),

appendicular pain, haemolytic anaemia and renal dysfunction. Without chelation, coma and/or death usually occur within one or two days.

1. *Chronic poisoning.* Acute symptoms may be the result of chronic, long-term exposure to lead, and which may cause gastrointestinal irritation, anorexia, anaemia, blue-lines on the gum-margins, peripheral neuropathy (wrist-drop), convulsions and encephalopathy (i.e. neural dysfunction). Chronic exposure in adults can similarly lead to impairment of visuospatial/visual motor functioning, short-term memory, and confusion and fatigue (Weisskopf *et al.* 2004). It has also been associated with gout due to impairment of the renal system (Matte *et al.* 1992).

- *Asymptopmatic poisoning.* Most common in childhood, lead poisoning may be presented with elevated levels of lead in the blood but my otherwise not present symptoms. This may lead to 'development syndrome,' resulting in developmental and behavioural symptoms, including reduced mental acuity (Lanphear *et al.* 2000; Dietrich *et al.* 2001; Needleman 2004). This includes the reduction in measured IQ (Canfield *et al.* 2003), reading ability, etc. (Needleman 2004), and tendency towards behavioural abnormality (Dietrich *et al.* 2001).

Lead has also been implicated in: Sudden Infant Death Syndrome; increase in the potential for hypertension in pregnant women and the presence of birth defects; and reduced fertility (Fergusson 1990). Once more, the literature on the subject is extensive and beyond the specific purview of this project.

Studies have indicated an association between chronic blood lead levels (PbB) and certain health effects, as indicated in Table 5 (Tornabene *et al.* 1978; Environment 1980; Piotrowski and O'Brien 1980; Adriano 1986; Boeck 1986; Moore 1988; Nriagu 1988; Nriagu and Pacyna 1988; Rabinowitz 1988; Fergusson 1990).

PbB μg dl^{-1}	Effect
4-6	Inhibits Delta-Aminolevulinic Acid Dehydratase
15	Elevation of Electrolyte Panel in blood
2-25	Chromosomal abnormalities
25	Anaemia in children
30	Toxicity to fetus
30-40	Reduced fertility in women
30-40	Altered spermatogenesis for men
40	Reduced peripheral nerve conduction
40	Reduced haemoglobin synthesis
40-60	Psychological sensory and behaviour changes
50	Impaired kidney function
>50	Anaemia
63	Anaemia in adults
50-60	Peripheral neuropathy
100-120	Encephalopathy

Table 5: Health Effects of Pb at Different Blood Lead Levels

Lead, as mentioned previously, also acts antagonistically and synergistically with other metals (Sandstead 1977; Underwood 1977; Luckey and Venugopal 1978; Bremner and Mills 1979; Adriano 1986):

Element	Effect of lead
Fe	Lead competes with iron in the intestine, inhibits the incorporation of iron into protoporphyrin IX, gives the effect of iron deficiency and anaemia
Ca	Lead increases calcium deficiency, on the other hand calcium can alleviate lead toxicity
Zn	Lead interferes with zinc enzymes and added zinc can alleviate the effects of lead
Cu	Lead increases copper deficiency

Table 6: Interaction of Lead and Other Elements in Biological Systems

4.2.2.8. Osteological Impact of Lead Toxicity

Determining *plumbism* through macroscopic analysis of human skeletal remains is problematic due to the broad ranging impact of the pathology on the individual. A number of skeletal manifestations may be found resulting from exposure to various levels of lead. As mentioned above, anaemia can be brought on by the reduction of iron in the diet which itself can be brought about by sufficiently high lead levels in blood (PbB) (Aufderheide and Rodriguez-Martin 1998).

A radio-opaque line may similar form in cases of lead poisoning, a result of the incomplete mineralisation osteoid at the physis (Aufderheide and Rodriguez-Martin 1998). Such radiological techniques are, however, outside of the province of this study and identification of lead poisoning must be identified biogeochemically.

4.2.3. Archaeological Applications of Lead Studies in Human Remains

Lead isotope studies have been used extensively throughout environmental science as a means of tracing pollution sources, identifying modern *versus* ancient pollution sources, etc. (Chamberlain 1983; Fergusson and Purchase 1987; Kersten *et al.* 1994; Chamberlain *et al.* 1997; Chiaradia *et al.* 1997; Erel *et al.* 1997; Aberg *et al.* 1998; Anderson *et al.* 2000; Aberg *et al.* 2001; Aberg 2001; Budd *et al.* 2001). The literature is both extensive and diverse and, while of continuing interest, only the application to human remains will be reviewed at this juncture.

Studies on human remains have focussed around both bone and dental analysis. While bone records a lifetime dietary signal (Wittmers Jr. *et al.* 2002) dental enamel records childhood exposures over the period of mineralisation of a particular tooth (Gulson 1996; Gulson and Gillings 1997; Budd *et al.* 1998; Budd *et al.* 2000*b*; Budd *et al.* 2004*a, b*; Gulston *et al.* 2004). Various authors have analysed lead exposure at various periods in history showing a general trend of low lead exposures in the prehistoric period (Patterson 1965; Patterson *et al.* 1991; Budd *et al.* 2004), with concentrations in the medieval period increasing by an order or two orders of magnitude (Jaworowski 1990; Budd *et al.* 2004*c*). Comparison of prehistoric and modern skeletal material shows overall conformance with lead levels in the 0.5-6ppm in tooth enamel levels dependent on the study region (Delves *et al.* 1982; Nriagu 1983; Nriagu 1998; Alexander *et al.* 1993; Budd *et al.* 2004*c*).

Similarly, focussed studies around geographical locations or periods have been produced in the literature; working variously from dental and bone lead tissue studies. Wittmers *et al.* produced a particular insightful look into lead during the eighteenth century, more so because of the possible association of Milborough Maxwell and the Caribbean (see chapter 6) (Handle *et al.* 1986; Witmers Jr. *et al.* 2002). Here, the association between high lead level in bones compared between that of the 'elite' and the 'slaves' was well established, show that an increasing lead burden is associated with increasing socio-economic status. Variation from 'slaves' to 'elites' in terms of lead was reported from 28.9 to 79.5 $\mu g\ g^{-1}$ (ppm) (Handler *et al.* 1986; Wittmers Jr. *et al.* 2002). Similar values were reported in the bone lead of Roman populations of the early first millennium, though in both cases the biogenic signal may be interfered with by diagenetic alteration of the bone samples (Wittmers Jr. *et al.* 2002). Sourcing of lead exposure is a common part of the environmental literature (*cf.* Gulson *et al.* 1995), but has also been engaged as part of archaeological studies, such as with the Franklin Expedition (Kowal *et al.* 1992), Native Americans of the eighteenth century (Reinhard and Ghazi 1992), Romans of Poundbury (Molleson *et al.* 1986), as well as more generally to various periods in the United Kingdom (Budd *et al.* 2004*b*).

4.2.4. Lead in the Nineteenth Century

It is at this point worthwhile reminding ourselves of the historical sources of lead exposure during the nineteenth century (*cf.* section 2.1.5). Lead was involved in a wide number of activities, including the storage of water, food colouration (especially confectionary), contamination of lower quality cider and wines, etc., where it was used to counteract acidity (Mitchell 1848; DHHS 1980; Farrer 1993). Even beer and tea leaves have been shown to have a substantial lead burden (Monier-Williams 1949; Weeden 1984; Farrer 1993; Richards 1999).

Lead burden during the nineteenth century, as above, was considerable and much higher than that recorded in any previous period (Budd *et al.* 2004*c*). Just how and why it varied from earlier periods remains a question deserving further study.

4.3. The Biogeochemistry of Light Stable Isotopes

The stable isotopes with low atomic mass have been covered in a single section due to similarities in isotope biokinetics.

4.3.1. Fractionation: A Common Feature of the Light Stable Isotopes

The project concerns three elements and their respective stable isotopes:

Element	Stable Isotopes	Natural Abundance (%)
Carbon (C)	^{12}C	98.93
	^{13}C	1.07
Nitrogen (N)	^{14}N	99.64
	^{15}N	0.36
Oxygen (O)	^{16}O	99.76
	^{17}O	0.038
	^{18}O	0.205

Table 7: Stable isotopes and their natural abundance for C, N and O (Hoefs 2004).

These three elements have been grouped together for the purposes of discussion since, unlike lead and strontium, are subjected to fractionation in biological systems (Greenwood and Earnshaw 1984; Faure 1986; Krauskopf and Bird 1995; Hoefs 2004). That is, given that the isotopes of each element varies in mass they will have differing kinetic energies at the same velocity and, therefore, react at different rates in given systems. Thus, the lighter isotope of water, ^{16}O, will preferentially vapourise over its heavier isotopes, and ^{12}C will be more likely to react than ^{13}C. Indeed, if one considers the series of reactions occurring during photosynthesis,

each represents a point at which kinetic fractionation can occur (Hames and Hooper 2000; Hayes 2001).

Fractionation of the light stable isotopes can be expressed mathematically in the generic form of (Faure 1986; Krauskopf and Bird 1995):

$$\delta_{heavy}(‰) = \left[\frac{R_{sample} - R_{std}}{R_{std}} \right] \times 10^3$$

Equation 1: General equation for isotopic fractionation, where: R_{sample} = heavy:light stable isotope ratio of the sample, and R_{std} = the heavy:light ratio for the standard; units of ‰ or 'parts per mil'. R is the ratio of the heavy to light stable isotope in question, i.e. $^{18}O/^{16}O$, $^{15}N/^{14}N$ and $^{13}C/^{12}C$.

Three methods of isotopic fraction of light stable isotopes may be broadly defined (Krauskopf and Bird 1995):

- **Physical Fractionation:** Any physical process, such as evaporation, condensation, precipitation, etc., will tend to favour the light or heavy isotope as appropriate. Thus, 'evaporation' of seawater tends to favour ^{16}O in the rain water while, similarly, precipitation will tend to be relatively enriched in ^{18}O.
- **Exchange Equilibrium:** Is involved in reactions where two or more substances with different isotopic compositions are mixed until equilibrium has been achieved between the different species (Hayes 2001).
- **Reaction separation:** This, as mentioned above, is separation due to the reaction of the species involved. It is common at low temperatures, such as those found in human physiology, for equilibrium isotope fraction not to occur resulting in a concentration of certain isotopes (heavy, light) in given locations (Krauskopf and Bird 1995).

Fractionation between the species mentioned above occurs through a number of different processes, though with carbon/nitrogen they are ultimately related. In its simplest form, oxygen isotope fractionation is essentially temperature controlled (Luz *et al.* 1984; Alley and Cuffey 2001; Darling and Talbot 2003*a*, 2003*b*; Petsch 2004). Carbon and nitrogen isotopes while also involved in low-temperature fractionation, are primarily determined by exchange equilibrium and reaction separation (Hames and Hooper 2000; Matthews *et al.* 2000; Hays 2001).

4.3.2. The Geochemistry and Mineralogy of Carbon

While the importance of strontium and lead to the project derives from the distribution and release of the isotopes from the geological context, the primary interest for carbon isotopes, and similarly for both nitrogen and oxygen, lies within the biosphere and atmosphere. As such greater emphasis will be placed upon these aspects and subsequently less upon the mineralogy.

4.3.2.1. General

Carbon, one of the most important elements formed through the stellar evolution (i.e. carbon fusion subsequent to hydrogen fusion), is found in the terrestrial environment in four primary reservoirs: the atmosphere, oceans, land and fossil fuels (Faure 1986; Houghton 2004). It is, fundamentally, one of the primary bases for 'life' – along with nitrogen, oxygen, sulphur and phosphorus – and comprises some 50% of the dry weight of terrestrial organisms (Frieden 1972; Sanford 1993; Houghton 2004).

Existing in a number of allotropes within the world (α- and β-graphite, diamond, Lonsdaleite, chaoite and carbon (VI) it is distributed widely throughout the world, including as carbonates of electropositive elements (Greenwood and Earnshaw 1984). The $\delta^{13}C$ composition of

mineralogical deposits bearing carbon varies significantly, from +60 $^0/_{00}$ found in extraterrestrial carbonaceous chondrites to –80 $^0/_{00}$ in methane-derived quaternary deposits; marine-sediments with a range of ±3 $^0/_{00}$; and organically-derived materials such as fossil fuels varying from ~ -20-30 $^0/_{00}$ (Degens 1989). It is within this last category that the greater bulk of terrestrial carbon is immobilised, with release occurring through means similar to those found with strontium, (i.e. chemical and physical weathering, etc). (Greenwood and Earnshaw 1983; Krauskopf and Bird 1995). Estimates suggest that such immobilised carbon comprises approximately an order of magnitude greater carbon than the atmosphere (5-10,000 Pg C) and is only rivalled by the marine organic and inorganic carbon reservoir (Houghton 2004). With the significant reliance upon fossil fuels from the mid-eighteenth century, and more particularly from the mid-nineteenth century onwards, the carbon dioxide (CO_2) proportion of the atmosphere has steadily increased, both altering the inputs of the carbon cycle while lowering the $\delta^{13}C$ content of the atmosphere in the 'Seuss Effect' (Faure 1986; Houghton 2004). The use of fossil fuels – coal, natural gas and, later, petroleum – is paralleled by limestone calcinations for the production of cement (Greenwood and Earnshaw 1984). The concerns raised about this, the potential decline in pH of marine waters and resultant impact on aquatic species and the arguments against obfuscation through interglaciation are not directly relevant here (Greenwood and Earnshaw 1984; Houghton 2004).

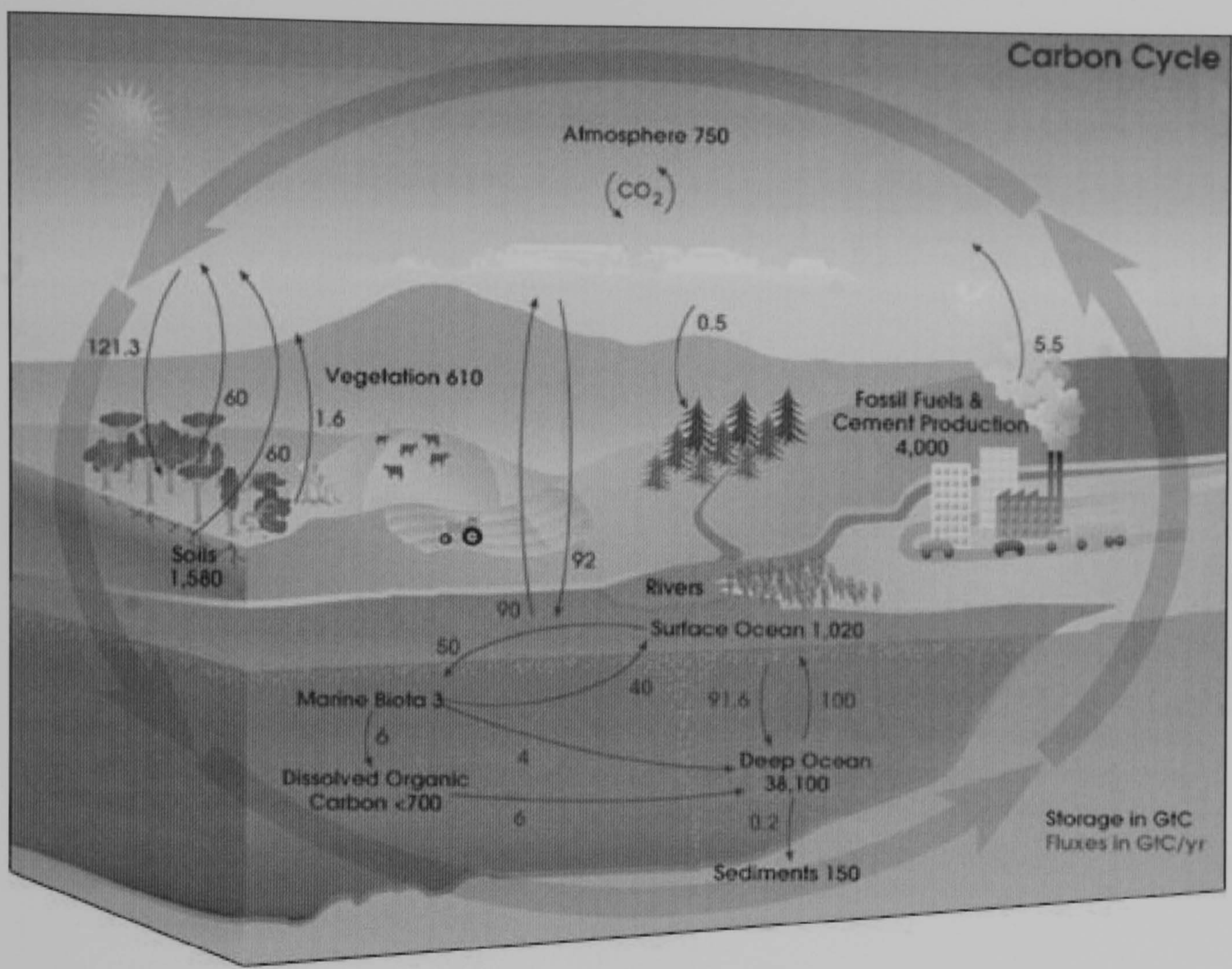


Figure 14: Schematic representation of the global carbon cycle. (Source: NASA.) Reservoir sizes are indicated next to their identity, with fluxes and their direction represented by the arrows.

4.3.2.2. Ocean

The marine carbon reservoir comprises ~90% of carbon on Earth (~3.7×10^4 Pg), primarily in the form of dissolved inorganic carbon (particulate suspension, cells, accumulating sediments), constituting some 50 and 70 times the carbon reservoir present in the atmosphere and terrestrial vegetation, respectively (Hedges and Keil 1995; Freemand 2001; Houghton 2004). Marine sediments, like fossil fuels, are generally not a part of the active (short-term) carbon cycle and, unlike the anthropogenic effects of fossil fuel use, have little bearing at this point beyond noting their presence (Houghton 2004).

4.2.3.2. Soil and Terrestrial

Distribution of carbon throughout the crust and minerals aside, living material is by far the greatest source of terrestrial/soil carbon, containing ~550 Pg C compared to that of 3 Pg in the marine environment . The majority of this carbon is stored in arboreal environments, both in the trees and the enriched surface material contained within the forests/woods/etc, constituting ~50% of the terrestrial carbon reservoir. Of the remaining fraction the majority is stored in the soils of agricultural lands, woodlands, etc. and only a relatively small fraction resides within fauna (Houghton 2004).

4.3.3. The Biochemistry of Carbon

As mentioned previously, carbon is one of the most significant elements for terrestrial and marine life along with oxygen, hydrogen, sulphur and phosphorus (i.e. phosphates) (Sanford 1993). In both the marine and terrestrial environments the primary means of introduction of carbon to the biosphere is through the fixation of plants through photosynthesis of variable stages depending on *taxa*, and through consumption and integration into tissues of fauna. These are discussed individually, below.

4.3.3.1. Incorporation of Carbon into Plants

The primary method by which carbon is introduced into autotrophic entities (i.e. marine and terrestrial flora) is primarily through photosynthesis, the fixation of carbon from the atmospheric reservoir in the form of CO_2 (Hayes 2001). This occurs through the fixation of CO_2 by the plant where it subsequently reacts with water to produce a photosynthate (C_3- or C_6 carbohydrates), which are then used in the biosynthetic production of more complex molecules, including proteins, further carbohydrates, lipids and nucleic acids (Hames and Hooper 2000; Hayes 2001).

The process is made more complex by the presence of three separate photosynthetic pathways – C_3, C_4 or CAM – dependent upon the environment and, therefore, the physiology of the plant in question. For the purposes of this thesis, only C_3 and C_4 photosynthesis will be discussed.

C_3, or Calvin-Benson, photosynthesis is broadly split into two types of reaction: the 'harvesting of light' by chlorophyll to produce adenosine triphosphate (ATP) and nicotine adenine dinucleotide phosphate (NADP) that fix CO_2; and light-independent reactions that form the covalent bonds of carbohydrates (Hames and Hooper 2000; Hayes 2001). The initial photophosphorylation acts to cause a water molecule to be stripped of an electron and separate into its respective ions, with oxygen being emitted as a result, and through two separate series of redox reactions to form NADPH (Hames and Hooper 2000). It is this "energy carrier" molecule, along with ATP, that powers the light-independent, or dark, reactions.

With the introduction of CO_2 through the stomata, and is captured by ribulose biphosphate (RiBP) to produce 3-phosphoglyceric acid (PGA). The PGA reacts with NADPH to add phosphates to the molecule (phosphorylation) to produce glyceraldehyde phosphate, two of which produce glucose (Hames and Hopper 2000; Mathews *et al.* 2000; Petsch 2004). These reactions are summarised by the chemical formula:

$$6\ CO_2 + 12\ H_2O + ATP + NADPH \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

Or schematically, below:

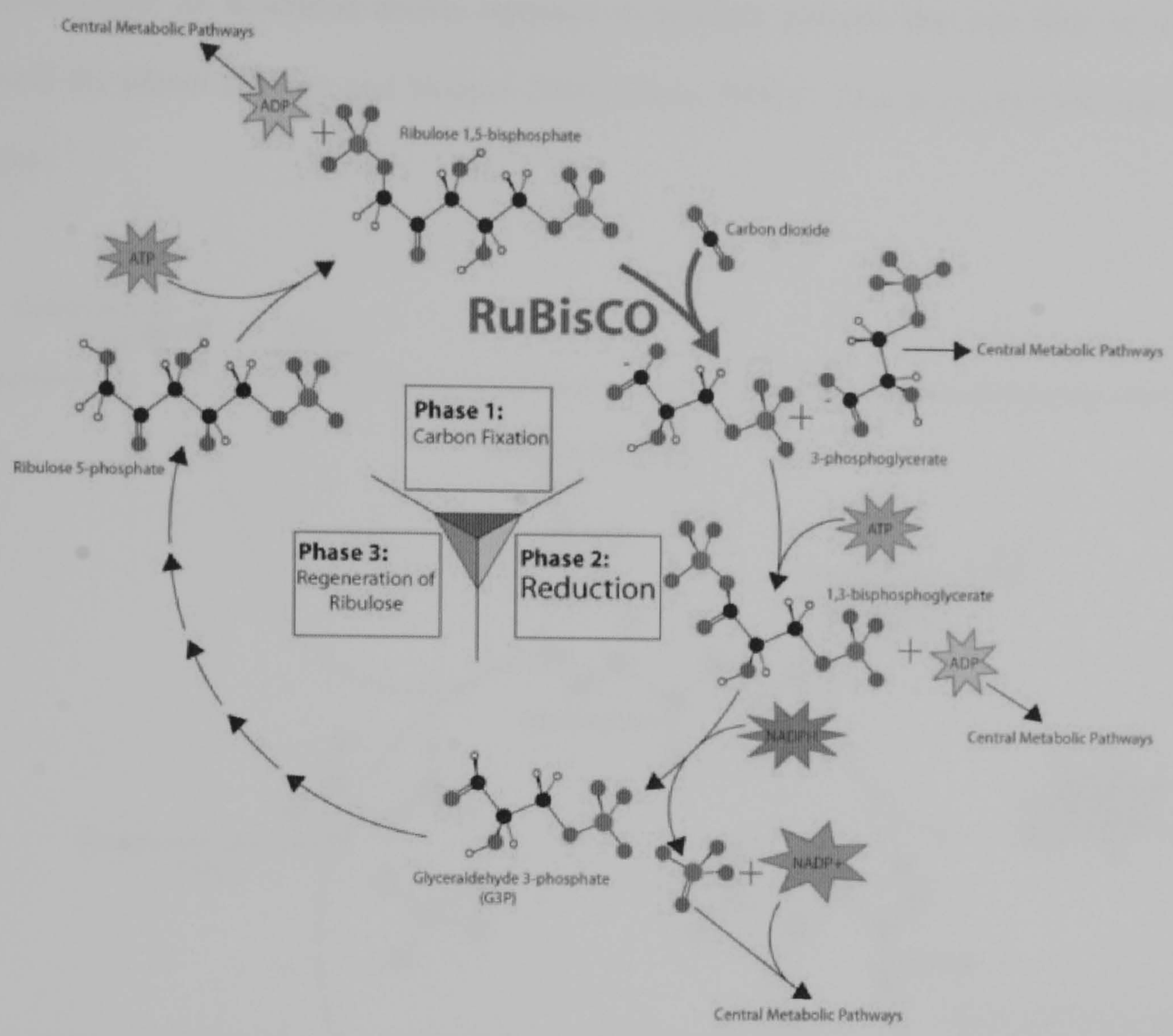


Figure 15: Schematic representation of C_3 photosynthesis. (Author: Mike Jones, Creative Commons ShareAlike license.)

The Hatch-Slack photosynthetical pathway, or C_4, introduces a fourth step in the process that acts to separate carbon (CO_2) fixation and carbohydrate synthesis in space and time. This pathway is ultimately a developmental addition for 'tropical' plants where water conservation is a prime consideration to the plants physiology and, as a result, they close their stomata thereby causing a reduction in the CO_2 partial pressure. Unfortunately, at low CO_2 partial pressures, RuBP catalyses with oxygen to produce neither ATP nor ADPH and therefore breaks the photosynthesis cycle. As such, C_4 plants use phosphoenolpyruvate (PEP) rather than RuBP. C_4 plants therefore act to concentrate CO_2 by the combining it with PEP to produce oxaloacetic acid (OAA). This is then converted to malic acid and transported from mesophyll cells into the bundle-sheat cell, where it is broken down into PEP and CO_2. From this point the Calvin-

Benson cycle, as described above, operates to produce glucose that can then be transported around the planet (Hames and Hooper 2000; Hayes 2001). This is represented schematically, below:

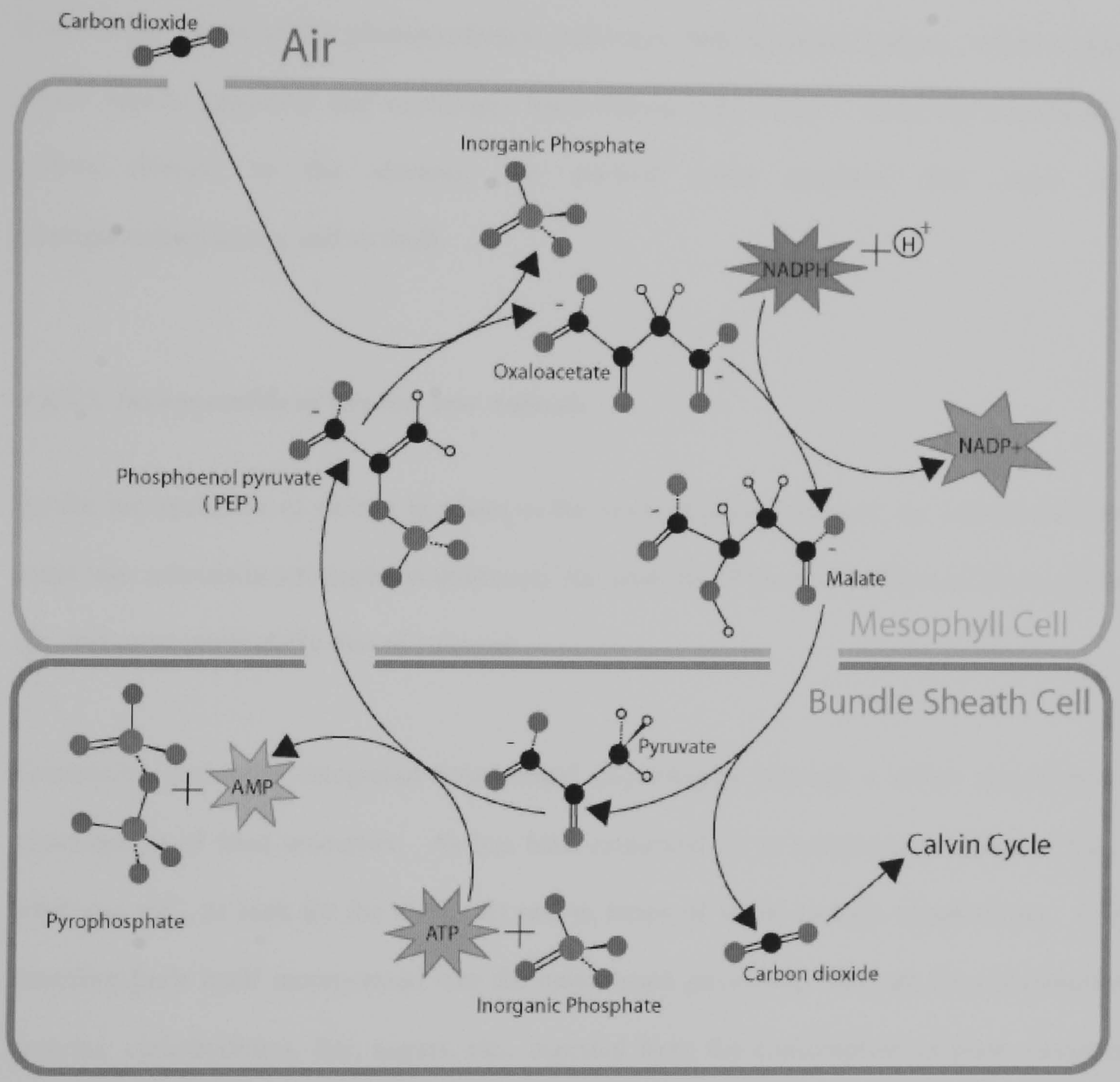


Figure 16: Schematic representation of C_4 photosynthesis. (Author: Mike Jones, Creative Commons ShareAlike license.)

The third form of photosynthesis – CAM, or Crassulacean Acid Metabolism – deserves mention, though isotopic differentiation between C_4 and CAM plants on isotopic grounds requires the utilisation of hydrogen isotopes. The process of carbon fixation occurs along similar lines to C_4

photosynthesis, with CAM plants opening stomata at night (thereby reducing water loss) to take in CO_2. During the day the stomata are closed and malate produced in the bundle-sheath cells as in C_4 plants, although diffuse loss of CO_2 is greater (Hayes 2001).

Each of the stages of the photosynthetical pathways, both C_3 and C_4 above, offers a point at which kinetic (physical and exchange) fractionation may occur – from the introduction of carbon dioxide to the stomata, the stacked redox reactions that occur during photophosphorylation, and so forth.

4.3.3.2. Incorporation of Carbon into Animals

As the incorporation of carbon in plants is the story of photosynthesis, the introduction of the same into animals/heterotrophs is ultimately the analysis of the biosynthesis of lipids, proteins, etc., but most particularly that of collagen.

Essentially, carbon is integrated into animal physiologies through a rather simple process: consumption of food resources. As has been remarked on at numerous occasions, "You are what you eat", at least for the most part and in terms of stable isotope compositions. Carbon therefore finds itself incorporated into the heterotroph physiology through the consumption of proteins, carbohydrates, fats, sugars, etc., ingested from the consumption of plant and/or meat resources depending upon species and individual preference. Digestion of these components follows the physical break-down of food within the digestive system, with the larger molecules broken down to provide energy for the synthesis of ATP or into proteins, carbohydrates and lipids. Enzymatic activity of carbohydrases, proteases and lipases serve to hydrolyse ingested organic material within the digestive tract, e.g. enzymes are released by the salivary glands,

tongue, stomach and pancreas, into these smaller molecules (i.e. mono/di/trisaccharides, short peptides and amino acids, etc.) (Martini 1998).

Although the physical and biochemical specifics of digestion and food transport are an interesting aside, it is useful at this point to mention the differences between carbohydrate and protein metabolism given the suggested compartmentalisation of food sources between collagen and apatite (Lee-Thorp *et al.* 1989; Lee-Thorp and van der Merwe 1991; Martini 1998; Lee-Thorp 2000; Van Klinken *et al.* 2000; Jim *et al.* 2004).

Carbohydrate metabolism is initiated in the oral environment through the release of salivary amylase and, later, pancreatic alpha-amylase to break down complex carbohydrates (starches) into di- and trisaccharides. Both salivary and pancreatic alpha-amylase ignore the simple monosaccharide form such that 'brush enzymes' (maltase, sucrose and lactase) are required to further break down the di- and trisaccharides which are then subsequently absorbed through facilitated diffusion or cotransport mechanisms (Martini 1998). Protein metabolism, on the other hand, is a physiologically far more demanding process and, unlike the digestion of starches, does not initiate through enzymatic activity in the oral environment but rather through mastication to physically break down the structure of the food. Following passing through the esophagus, the proteoytic enzyme pepsin, breaks the peptide bond of polypeptides into shorter polypeptides or constituent amino-acids (Martini *et al.* 1985). Once the protein has been digested sufficiently, movement into the intestine allows the action of endopeptidases to further fragment the polypeptides into smaller molecules, while carboxypeptidase acts to remove the last amino acid in a polypeptide chain and, therefore, produce simple amino acids. Once again, the product of these biochemical reactions are absorbed through facilitated transport and cotransport mechanisms into the cell and, from there, into the intestinal capillaries for transportation to the liver (Martini *et al.* 1985).

While it is incorporated into all tissues of the body, its greatest concentration is in the connective and fibrous tissues of which collagen are the dominant structural component. The specific composition of collagen is variable but, in its various forms (type I-V) it is found in skin and bone, cartilage, blood vessels, in the placenta, etc. (Hames and Hooper 2000). The chemical and structural properties of collagen will be discussed in a later section. Within animal physiology approximately one-third of the weight of proteins in the body are tied up in collagen (including glycine, proline, hydroxyproline, lysine, etc.), one of the major structural components of the endoskeleton (White 1991; Martini 1998; Mays 1998; Hames and Hooper 2000; Matthews *et al.* 2000).

Fish, meats and dairy products provide good sources of dietary proteins, containing all the essentially amino-acids required for balance with proteins synthesised by the body from glucose and lipids (Matthews *et al.* 2000). Eggs and milk generally provide ~6-8 g of protein, compared to 15-30g (for every ~85g consumed) for meats and 1-7g for plant sources. Balanced diets generally require 170-250g of meat sources to supply the correct amount of dietary protein and, therefore, essential amino-acids.

The incorporation of carbon into the food chain ultimately is a chain of biochemical reactions with various stages of kinetic fractionation (Krueger and Sullivan 1984; Lee-Thorp and van der Merwe 1991; Ambrose 1993). Studies reveal that, for C_3 plants $\delta^{13}C$ generally have ranges of –27‰ to –26‰ which, when fractionationed through the incorporation into an herbivore has a measured collagen value of approximately 5‰ higher i.e., –22‰ to –21‰ (Bender 1968; Tieszen *et al.* 1983). A carnivore feeding upon the flesh of such an herbivore, (e.g. a human consuming an ungulate), shows a fractionation of ~+1‰, resulting in a variation of approximately –26.5‰ to –20‰ for omnivorous diets for terrestrial resources (Van Klinken *et*

al. 2000). Aquatic resources tend to be $\delta^{13}C$ enriched compared to their terrestrial counterparts, with a 'flesh' value of –18‰ to –17‰ that given the trophic effect of consumption. results in a collagen value for marine consumers of –13‰ to –14‰ (Chisholm *et al.* 1982; Tauber 1986; Mays 1997; Coltrain *et al.* 2004).

The expected diet of an individual in the post-medieval period is, therefore, omnivorous with an approximate $\delta^{13}C$ of –26.5‰ to –20‰, with enrichment resulting from either a contribution from aquatic resources or as a result of C_4 diets (Van Klinken *et al.* 2000).

4.3.4. The Geochemistry and Mineralogy of Nitrogen

Nitrogen biogeochemistry shares a number of similarities with that of carbon, indeed more particularly the biochemistry than geochemistry, and as such reference between the two systems is inescapable.

4.3.4.1. General

Nitrogen is the most abundant uncombined terrestrial element, providing 78.1% of atmosphere (Greenwood and Earnshaw 1984). Despite this abundance and the importance of nitrogen in contemporary agricultural and commercial industry the solubility of nitrogen compounds or existence as gaseous forms result in a relative rarity in crustal rocks (Greenwood and Earnshaw 1994; Faure 1986). Nitrogen has two stable isotopes: ^{14}N (relative abundance 99.634%) and ^{15}N (0.366%) (Greenwood and Earnshaw 1984).

As with carbon, nitrogen enjoys a global cycle with an interchange from a number of reservoirs including the atmosphere (79.5%), sedimentary rocks (20.1%), the ocean (0.4%), soil organics,

with land and marine biota offering only a minor contribution (Schlesinger 1997; Mackenzie 1998; Galloway 2004). Exchange between the reservoirs occurs in a number of processes dependent upon the reservoir. Between the land and the atmosphere, low/high temperature volitisation through combustion of fossil fuels, outgassing from soils as a result of microbial activity or the ejection of particulate matter directly into the atmosphere. Similarly, nitrogen is removed from the ocean through out gassing of dissolved nitrogen, ammonia and through aerosol introduction from wave activity. The final part of the cycle is transmission from the atmosphere to the surface through either wet (rain, snow) or dries (gases and aerosols, primarily NH_3 and HNO_3) (Greenwood and Earnshaw 1984; Galloway 2004). This can be seen represented in the diagram, below:

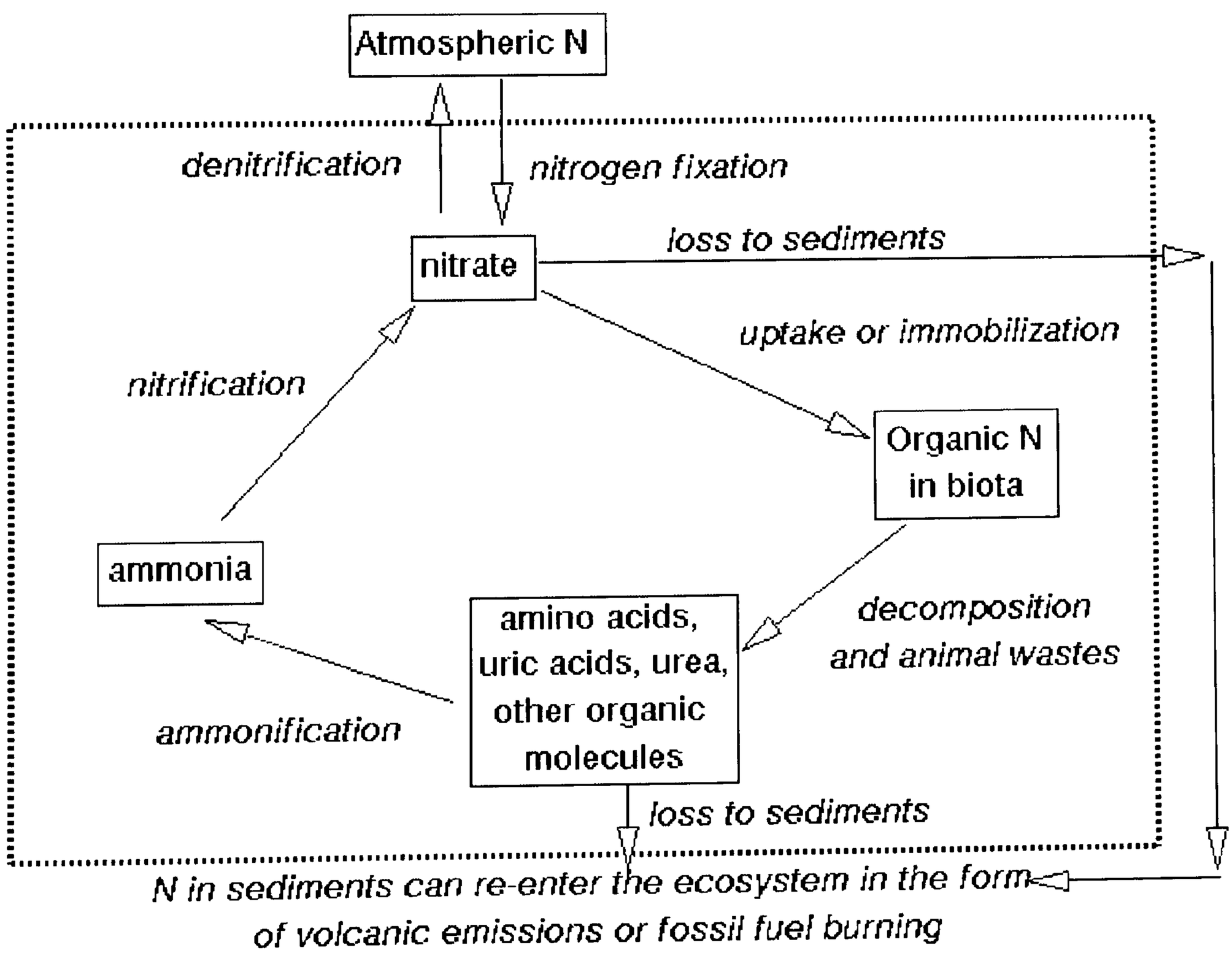


Figure 17: Schematic representation of the nitrogen cycle. (Modified from Environmental Protection Agency diagram of the nitrogen cycle.)

4.3.4.2. Non-Atmospheric Nitrogen

Nitrogen within the ocean is primarily composed of diffused N_2, with remaining components present both in the form of soluble nitrogen compounds (i.e. NO_3^-) and particulate matter, as well as deep marine sediments (Faure 1986; Galloway 2004). Diffused nitrogen remains in equilibrium with atmospheric pressure, with variation caused by temperature allowing outgassing as mentioned previously. Variation in other nitrogen compounds, including ammonium, nitrates and nitrites varies as a function of locality, pH, season, depth and local conditions (i.e. upwelling in pelagic areas upon coastal shelf, etc.) (Galloway 2004).

4.3.5. The Biochemistry of Nitrogen

4.3.5.1. Incorporation of Nitrogen in Plants

Nitrogen is primarily incorporated in plants primarily through biological nitrogen fixation (BNF), as well as additional biochemical reactions including ammonia assimilation, nitrification, and assimilatory nitrate reduction (vanLoon and Duffy 2000; Galloway 2004). Denitrification is the process in which ammonia is removed from biomass in a process of bioremediation, protecting autotrophs from the toxic effects of ammonia (Matthews *et al.* 2000; Galloway 2004). BNF occurs in a number of soil bacteria, cyanobacteria and as a symbiotic nodule in the form of leguminous plants, but can also form 'bacteroids' in the cells of certain tree species (Matthews *et al* 2000). Following the formation of the nitrate, a further sequence of enzymatic reactions utilising nitrate reductase creates NH_3 (Matthews *et al.* 2000; Galloway 2004).

It is through NH_3 that the majority of auto- and heterotrophs introduce nitrogen to their biomass in the form proteins (glutamate, glutamine, asparagine, and carbomoyl phosphate with particular emphasis on glutamate and glutamine) (Matthews *et al.* 2000). At this point the specific reactions become complex and it is sufficient to understand that the proteins are incorporated into the structure of plants and, from there, enter the food-chain.

Within terrestrial environments the variation in nitrogen are significant, dependent upon the soil and mineral matrix, climate, water, etc. (Ambrose 1993). While moist and temperate soils, such as those in forests, tend to have high nitrogen fixation and, as a result, low $\delta^{15}N$ while the opposite applies for hot and dry soils such as those in deserts. Similarly, soils which are highly fertilised also tend to have high $\delta^{15}N$. In 'average conditions', nitrogen variation in nitrogen fixers tends to range from 0‰ to 5‰, with C_3 and C_4 plants having greater enrichment at around 5‰ to 10‰. Marine nitrogen isotopes tend to be enriched over their terrestrial counterparts by approximately 4‰ (Ambrose 1993).

4.3.5.2. Incorporation of Nitrogen into Animals

Once again, the phrase "You are what you eat" crops up in terms of nitrogen introduction into animals and humans. The requirement for the introduction of nitrogen in the form of amino acids that cannot be biosynthesised in sufficient quantities in mammalian physiology and must therefore be acquired from plant and animal sources (who themselves either directly or indirectly consume plant resources as part of dietary preferences) (Hames and Hopper 2000; Matthews *et al.* 2000; Galloway 2004). These are: arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine; arginine and histidine are considered to be essential only in the growth of juveniles and periods of catabolic stress

(Matthews *et al.* 2000). Insufficient intake of proteins requires a remobilisation of integrated protein sources (i.e. muscle proteins, etc.) since no reservoirs are maintained, unlike carbohydrates with glycogen and simple fat storage (Martini 1998; Hames and Hooper 2000; Matthews *et al.* 2000).

As with carbon, nitrogen isotopes fractionate in foodwebs such that each level is enriched in nitrogen by approximately 3‰ (Ambrose 1993; Fogel *et al.* 1997). Thus, herbivores will have an approximately $\delta^{15}N$ of +3‰ over that of consumed plants, carnivores one of approximately +3‰ over herbivores ($\delta^{15}N$+7‰), with omnivores having an intermediate level of $\delta^{15}N$+4.5‰ (Lajtha and Marshall 1994; Lajtha and Michener 1994; Fogel *et al.* 1997).

4.3.6. Archaeological Applications of $\delta^{13}C$, $\delta^{15}N$ and Combined C/N Studies

The studies of the stable isotopes of carbon and nitrogen have a long history in archaeochemical investigations. Hall (1967) realised that maize and other tropical (C_4) grasses produced a high ^{13}C content that interfered with radiocarbon dating, producing much younger results (Ambrose 1993). Following Vogel and van der Merwe's (1978) analysis of prehistoric Woodland skeletons in North American, other articles from the period began to address the issue of the late adoption of maize agriculture (Price and Cavanagh 1982; Schwarcz 1985; Buikstra *et al.* 1987). Parallel with the measured studies were feeding studies determined to analyse the specific contribution of different food resources to the detected carbon/nitrogen values present in analysed material (DeNiro and Epstein 1978; DeNiro and Epstein 1981). This would subsequently have a bearing upon the dietary routing of food resources, (i.e. collagen for protein), apatite for whole dietary analysis (Schwarcz 1985; Lajtha and Marshall 1994; Lajtha and Michener 1994; Fogel *et al.* 1997; Jim *et al.* 2004).

Extension of carbon/nitrogen studies to marine systems was initiated by studies of Danish Mesolithic hunter-fisher-gatherers, with subsequent extension from carbon to nitrogen isotope systematics (Tauber 1981; Schoeninger and DeNiro 1983; Schoeninger and DeNiro 1984). As with the terrestrial models, numerous studies have confirmed some of the basic assumptions while introducing greater complexities. It is therefore useful at this point to discuss specific applications.

4.3.6.1. Differentiation of C3 and C4 Plants in the Diet: Maize Agriculture

Given the complexities of diet with terrestrial *versus* marine inputs, trophic level effects, etc., the use of carbon and nitrogen requires the exclusion of certain variables. With specific reference to Coventry and Chelsea, while C_4 plants in the form of maize, millet and sugar cane, were used in Europe, as mentioned previously these plants only have a minimal impact upon the diets of Britons in the eighteenth and nineteenth centuries. A similar situation can be seen with the adoption of maize agriculture in the New World where generally speaking, the influence of marine isotopes is considered negligible. Studies of prehistoric Ontario indicated carbon isotope ratios of –20.5‰ pre-700 AD, a value consistent with a predominantly C_3 diet (see above and chapter 6), which post-700 rises to –15‰ (van der Merwe and Vogel 1978; van der Merwe 1982; Schwarcz 1985; Katzenburg 1993a; Katzenberg *et al.* 1995. A similar pattern is reflected in North America (Buikstra 1992; Schurr and Schoeninger 1995; Larsen 1997). Larsen (1997) details the complexities of maize uptake in prehistoric North America. Similar methods were employed to show the adoption of maize by Euro American settlers, as both fodder for animals and as a component of diet.

Social status and variation of access to maize between the sexes has also been discussed in the literature (White and Schwarcz 1989; White, Healy *et al.* 1993; Reed 1994).

4.3.6.2. Marine Diets and Weaning

In areas where there is no significant consumption of C_4 plants that would otherwise allow for an enrichment of $\delta^{13}C$, carbon isotopes can be utilised to distinguish terrestrial and marine resources. Carbon isotopes have been used to show the transition from a predominantly marine diet (-11‰ to –15‰) (Tauger 1981; Tauber 1986; Coltrain *et al.* 2004) to an increasing reliance on terrestrial foods as bone collagen shifts from the marine signal to –18‰ to –23‰, or a C_3 signal (Lidén 1995). Similarly, greater reliance upon marine or aquatic resources has been shown in populations from the Roman period (Prowse *et al.* 2004), as well as variation in the access to marine resources between medieval inland and coastal populations, as well as between monastic and lay communities (Mays 1997; Richards *et al.* 2003).

Intermediate signals between marine and terrestrial carbon isotopes have also been used to infer the reliance upon non-marine aquatic resources in the Jomon period of Japan (Yoenda *et al.* 2004).

Both nitrogen and carbon isotopes shed light on the phenomenon of weaning in sub-adult skeletons (Larsen 1997). Changes in nitrogen ratios of 2-3‰ consistent with tropism, (i.e. the child is 'predating' and feeding from the mother), have been reported in the literature from various sites and settings (Katzenberg 1993b; Reed 1994; Katzenburg and Pfeiffer 1995; Sealy *et al.* 1995; Fogel *et al.* 1997; Schurr 1998; Wright and Schwarcz 1998; Richards *et al.* 2002; Fuller *et al.* 2003). The process of weaning and the concomitant effects on diet is reflected in this study with the selection of dental tissues. In many populations, weaning occurs around the

age of two to three years (Iregren 1992) and as such dentition that is not formed during this time has been selected, (e.g. preferentially the second premolar or molar) both of which mineralise between three and six years of age (Hillson 1996) (see Chapter 5 for more information on sampling procedures).

4.3.6.3. Coventry and Chelsea

Coventry and Chelsea represent two different socio-economic communities and localities. While Chelsea enjoys a high socio-economic status and ready access to marine resources via the River Thames, Coventry is land-locked with no navigable rivers in ready proximity and is also representative of a lower socio-economic or working-class population. As such it is expected that Coventry will have less of a marine signal than that represented by Chelsea with its more ready access to those resources. Yet, as indicated in Chapter 2, freshwater ("terrestrial") fish were a popular and common component in eighteenth and nineteenth century diet. Access to protein resources increased with socio-economic status, so one would expect the Chelsea diet to be elevated with respect to ^{15}N than that of the Coventry sample, to represent a proportionately greater contribution of protein resources to the higher-status diet.

4.3.7. The Geochemistry and Mineralogy of Oxygen

Oxygen is important in a number of ways, not only forming another of the 'life molecules' but also forms a vital component to the sustenance of that life (i.e. free oxygen), in numerous organic and inorganic compounds and, as such, provides the dominant contribution to the elemental composition of the lithosphere and hydrosphere (Greenwood and Earnshaw 1984; Faure 1985; Petsch 2004).

4.3.7.1. General

While the elements we have been dealing with previously have had a radical importance to life, still they have remained as relatively 'low' importance of crustal rocks (Greenwood and Earnshaw 1984). With the large number of molecular forms of oxygen, including both organic and inorganic, as well as different allotropic forms (i.e. free molecular O_2 and its allotrope O_3, ozone) a detailed discussion of the biogeochemistry of oxygen is not possible within this thesis (Greenwood and Earnshaw 1984; Faure 1986; Nesse 2000; Petsch 2004).

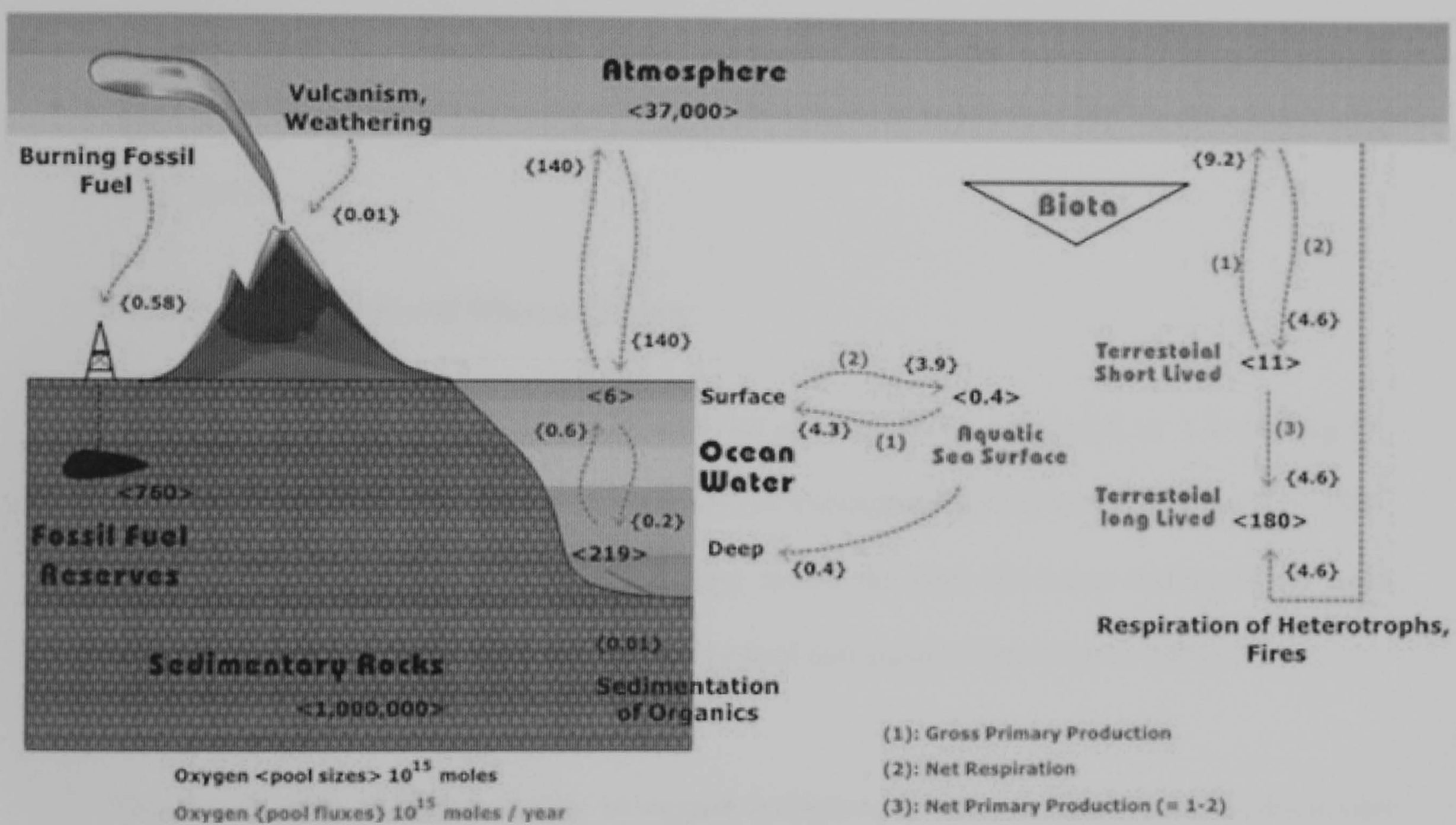


Figure 18: Schematic representation of global oxygen cycle (source: Warwick Hillier, Research School of Biological Sciences, Australian National University.) Values in < > represent estimated reservoir sizes, while rates of flux are in { }. Data from Keeling *et al.* (1993).

Once again oxygen exchanges readily between the three reservoirs, each of which is straddled by the biosphere: the atmosphere, hydrosphere and land surface or, more appropriately, water associated with the land masses (vanLoon and Duffy 2000; Darling and Talbot 2003*a*; Darling

and Talbot 2003*b*; Petsch 2004). This can be seen with a schematic representation of the oxygen cycle (see fig.18 above).

The isotopic compositions of the various reservoirs are not equivalent, but vary from the Standard Mean for Ocean Water (SMOW). Atmospheric oxygen is relatively enriched in ^{18}O, as is oxygen dissolved in seawater (23.5 ± 0.3 ‰ and 0.85 ‰ at 0°C, respectively) with oxygen solubility varying as a function of temperature ($\varepsilon = 0.85 - 0.01$ T, where T = temperature [°C]) (Kroopnick and Craig 1972). Variation is similarly seen *within* reservoirs. The atmosphere, for example, while on average being relatively enriched in ^{18}O, the enrichment decreases in the more northerly latitudes as a result of vegetation/biota respiration (i.e. beyond 70°N) (Farquhar *et al.* 1993).

4.3.7.2. Atmospheric and Mineral Oxygen

Atmospheric oxygen provides ~21-23% of the atmosphere by weight of, or 1.4×10^{18} kg O_2, much of which is concentrated in the first 5km of atmosphere (Greenwood and Earnshaw 1984; Petsch 2004). Production of oxygen can vary across the land and water surface of the earth depending on the presence and density of terrestrial and aquatic biota (Petsch 2004).

The complexities and wide variety of oxygen inclusions in mineral forms makes a discussion inappropriate at this point, and the reader is pointed to more appropriate sources (Faure 1986; Degens 1989; Duff 1993; Nesse 2000; Hoefs 2004). It can, however, be found as a significant structural component in silicates (including framework (i.e. feldspars), sheet, chain, orthosilicates), carbonates, sulphates, phosphates, etc. Indeed, oxygen is present, for the most part, in the greater majority of composite minerals (Nesse 2000).

4.3.7.3. Ocean

Oxygen finds its way into the marine environment in numerous ways, including biomineralised skeletons, oxygen-bearing minerals from fluvial influx and, of course, in the form of water (H_2O), with oceanic water comprising ~97%, while polar water and ground water (land surface) comprise ~2.65% (Greenwood and Earnshaw 1984). Other sources, including lakes, soil moisture, water aerosol, etc., provide a diminishingly small water resource (Greenwood and Earnshaw 1984). While oxygen also finds its way into water through saturation, with solubility ultimately increasing as a function of cool, high latitude waters (Petsch 2004).

While evaporation occurs on bodies of water across the surface of the Earth, the majority occurs from low-latitude oceans tending to homogenise differential source effects on $\delta^{18}O$ in precipitation (Alley and Cuffey 2001).

4.3.7.4. The Importance of Precipitation (Evaporation and Condensation)

Precipitation is the dominant means by which water, and therefore oxygen, is exchanged between the reservoirs of the water cycle (Berner and Berner 1987; vanLoon and Duffy 2000). This process is dominated by the twin process of evaporation/transpiration and condensation. That is, moisture evaporates from the ocean, condenses into clouds and ultimately falls back to the ground either over the ocean or ultimately making its way back to the ocean by streams and rivers.

Ultimately the oxygen isotope composition of sea-water is dependent upon temperature, and this remains the basis of palaeothermometric studies (Jouzel *et al.* 1994; Alley and Cuffey 2001). Physical fractionation effects resulting from the varying vapour pressure between $H_2{}^{18}O$ and

$H_2{}^{16}O$ serve to cause an isotopic depletion in the transpiration/vaporisation of $\delta^{18}O$ (Krauskopf and Bird 1995; Alley and Cuffey 2001; Darling and Talbot 2003a). That is, $H_2{}^{16}O$ evaporates more readily than $H_2{}^{18}O$, and $H_2{}^{18}O$ condenses more readily than $H_2{}^{16}O$. As air rises, or moves towards the poles, the temperature decreases and thereby preferentially results in the condensation of ^{18}O, which falls as rain. As the moisture continues to rise, or move towards the poles, an increasing proportion of ^{16}O falls and which then becomes trapped in the polar ice (Bradley 1999). Thus, glacial periods are associated with oceanic waters enriched in ^{18}O. On the other hand, as temperature increases, polar ice melts and thereby liberates ^{16}O and decreases the relative contribution of ^{18}O to the oxygen isotope composition of sea water (Jouzel *et al.* 1994; Bradley 1999).

While the palaeoclimate model offers two extreme situations that are applicable to glacial and interglacial periods, i.e. the Pleistocene and the Holocene, with a single climatic period the same processes of evaporation and condensation apply. Within a single epoch, though, the preferential depletion of ^{18}O can be tied to the "continental effect", such that as one moves further into a land-mass the rain will have an increasingly negative $\delta^{18}O$ signal:

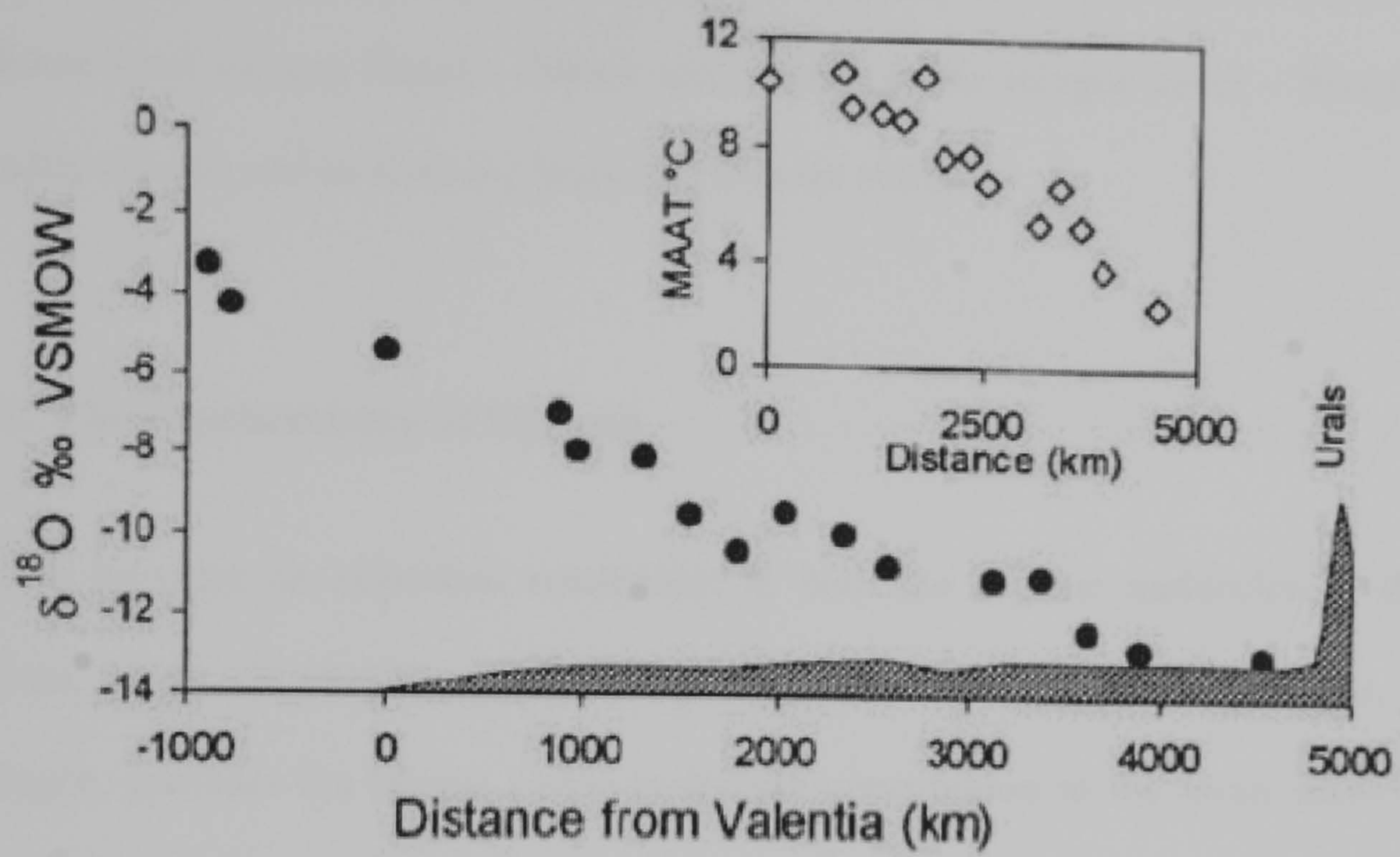


Figure 19: The "continental effect" showing increasing depletion of ^{18}O in rain as a functional of distance from the ocean, with the drop in means annual air temperature as inset (Clark and Fritz 1997).

Thus as one increases distance from the ocean, and the more the air temperature drops, the more negative the value for $\delta^{18}O$ (Alley and Cuffey 2001; Darling and Talbot 2003*a*; Darling and Talbot 2003*b*). As one might imagine, precipitation also varies as a function of season, atmospheric pressure, etc. (Fricke *et al.* 1998; Alley and Cuffey 2001; Darling and Talbot 2003*b*; Welp *et al.* 2004).

As mentioned previously, the precipitation driven hydrological system ultimately returns water to the ocean via streams and rivers that, along with ground water accessed through wells, offer the primary drinking water for humans. It has been shown that there is an overall good correspondence between rainwater and this groundwater (Fricke *et al.* 1995; Fricke and O'Neil 1996; Fricke and O'Neil 1999; Alley and Cuffey 2001; Darling and Talbot 2003*a*; Darling and Talbot 2003*b*). However, local conditions can complicate the situation. For example, standing bodies of water are subject to enrichment in ^{18}O over a local river system as there is no flow of

water to moderate vapour effects (Darling and Talbot 2003*b*). Similarly, the environment can moderate local oxygen fluxes – inputs and outputs to the oxygen cycle – through local flora, humidity effects, and so forth (*cf.* Burk and Stuvier 1981).

4.3.8. The Biochemistry of Oxygen

Oxygen provides an important constituent in both the organic molecules of the body (e.g. proteins, lipids, carbohydrates, alkaline phosphatase, etc.) but most significant, coupled with hydrogen, provides the largest single molecular contribution to the mean mass of the human body (Hames and Hooper 2000; Matthews *et al.* 2000). The greater majority of these compounds are, unfortunately, beyond the scope of the specific investigation.

4.3.8.1. Incorporation of Oxygen into Auto/Heterotrophs

The integration of oxygen into mammalian physiology through the precipitation of phosphate – more specifically enamel phosphate – is moderated by the body's core temperature (37°C). With a constant low temperature that is independent of the environment, precipitated phosphate takes on a $\delta^{18}O$ value that is related to the body water $\delta^{18}O$ by a fixed offset (Longinelli 1984; Luz *et al.* 1984; Levinson *et al.* 1987).

While oxygen enters the body through respiration and as dietary material, it also can be introduced into the body through a number of means, all of which can affect the ultimate recorded oxygen signal in biophosphates. Lajtha and Michener (1994) summarise the fluxes to oxygen isotope incorporation into bio phosphates:

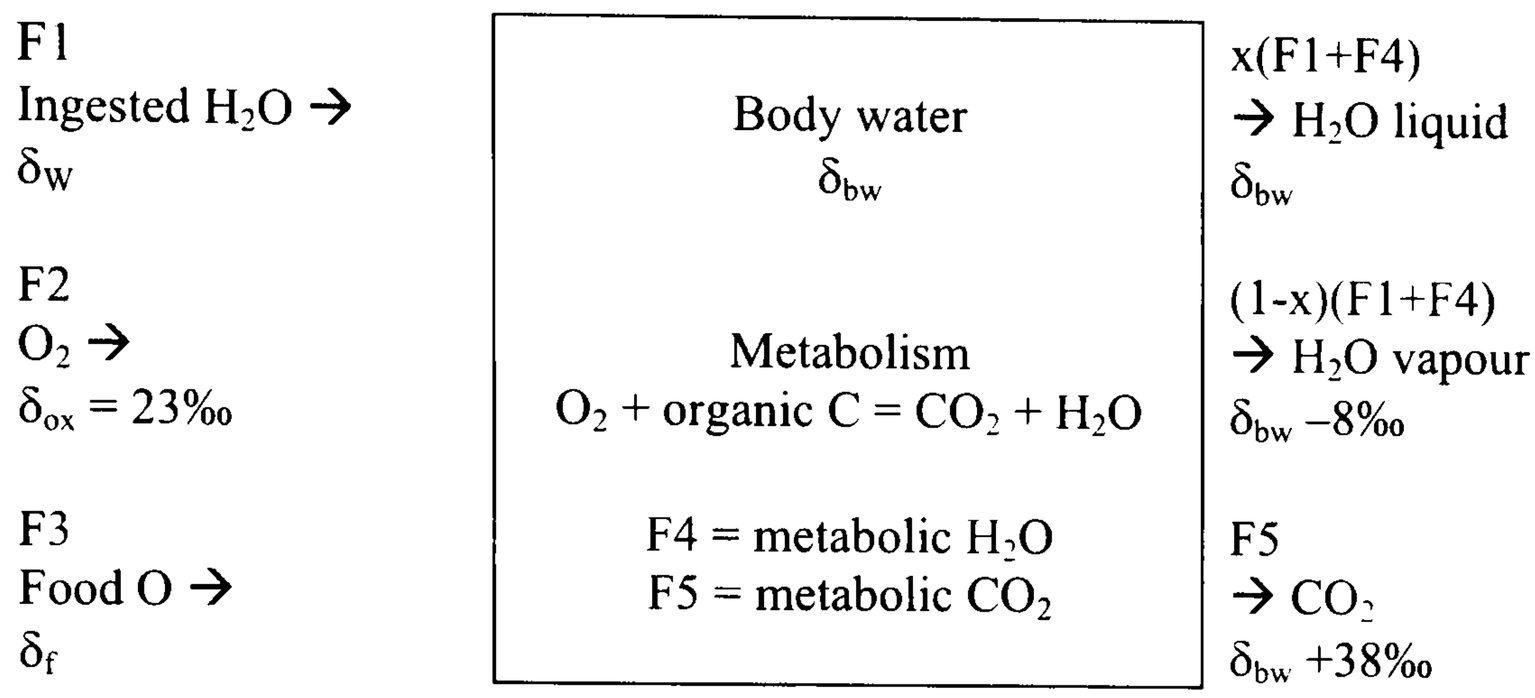


Figure 20: Oxygen fluxes entering and leaving the body of an autotroph/heterotroph (Lajtha and Michener 1994).

Thus, as one can see from the above figure, the primary inputs of water into the body are from drinking water (F1), respiratory oxygen (F2) and oxygen ingested as part of the diet (F3). This is then incorporated into the bodies oxygen load (body water, metabolic components such as carbohydrates as well as water and carbon dioxide held within cells, etc.), until it is eventually excreted in a number of forms: excreted liquid (sweat, faeces, urine) and respired carbon dioxide (Longinelli 1984; Luz and Kolodny 1985; Luz *et al.* 1987; Lajtha and Michener 1994; Langlois *et al.* 2003). Furthermore, the reaction to the body to the local environment will likewise affect oxygen fluxes. For example, humid environments decrease the ability of oxygen to be removed by sweating than dry environments. Similarly, evaporative transpiration in plants allows for ^{18}O enrichment and, therefore, incorporation in diets (though dietary oxygen has a lower contribution to bio phosphate oxygen than ingested or respired oxygen); variation in plant incorporation of oxygen, etc. (Lajtha and Marshall 1994).

4.3.9. Archaeological Application Applications of $\delta^{18}0$ Studies

The aforementioned conformity of body water with bio phosphate at tissue formation therefore provides a record of the oxygen isotopes and, therefore, past climate (Kolodny *et al.* 1983; Luz *et al.* 1990; Fricke *et al.* 1995; Larsen 1997). In a climate that is considered broadly uniform in base mean temperature or dominant weather patterns and therefore variation in oxygen isotopes, they have also been used to determine migration (Schwarcz *et al.* 1991; White *et al.* 1991, 2000; Dupras and Schwarcz 2001; Budd *et al.* 2004*a, b*). Similarly to carbon and nitrogen, oxygen also shows variation brought about by weaning (Wright and Schwarcz 1998; Longstaffe *et al.* 2000).

4.4. Diagenesis and Archaeochemical Studies

Diagenesis is the processes by which biogenic apatite becomes chemically and physically altered in the post-depositional environment. It is defined as "a general term for any kind of alteration or change subsequent to the original definition of the material matrix... [and includes] the processes of dissolution, precipitation, adsorption, mineral replacement and recrystallisation" (Elliot and Grime 1993).

The alteration of the biogenic lattice with the incorporation of diagenetic strontium may proceed along a number of pathways, many of which are essentially similar to incorporation *in vivo*. For the purposes of this study, the most important of these is the dissolution of the biogenic apatite and its subsequent recrystallisation as diagenetic apatite, by a process referred to as *Ostwald ripening* (Koch *et al.* 1992; Person, Bocherens *et al.* 1995). That is, in the burial environment the biogenic apatite interacts with the local groundwater and creating a mixed solution containing *both* 'biogenic ions' and 'diagenetic ions.' These ions may then reprecipitate from

the solution and reform a calcium phosphate hydroxyapatite. This diagenetic apatite is differentiated from biogenic apatite in its increased crystallinity (increased crystal size) and decreased lattice strain, (i.e. the reprecipitated crystals have a "lower energy" (Bonar *et al.* 1983; Tuross *et al.* 1989; Hedges and Millard; 1995; Person *et al.* 1995; Sillen and Parkington 1996)). Dissolution and precipitation of compounds are dependent upon the local conditions of the burial matrix: alterations in water acidity, temperature, concentration of certain materials, etc., may initiate an alteration to the system. This reprecipitation is not limited to diagenetic apatite, however, and may include salts of elements incorporated into the biogenic apatite such as calcite ($CaCO_3$) or strontianite ($SrCO_3$). Furthermore, these additional salts may become associated with either biogenic or diagenetic apatite through surface adsorption (biogenic apatite crystals are small and therefore offer a large surface area for this to take place) (Koch *et al.* 1992). Of greatest importance to this consideration, however, is that reprecipitated materials may contain both biogenic and diagenetic material.

The diagenesis of skeletal tissue is not simply a process of dissolution and precipitation, however. Tissue in the burial environment equilibrates over time with the local soil conditions. As such, *in vivo* levels may be enriched or depleted as the tissue reaches equilibrium with these local conditions (Lambert *et al.* 1985; Klepinger *et al* 1986; Tuross *et al.* 1989; Dauphin and Denys 1992; Sillen and Sealy 1995). Ultimately, this equilibration with the local conditions may lead to the complete fossilisation of the tissue. Part of this homogenisation with the burial environment includes the deposition of exogenous materials into the structure and/or micro-composition of the skeletal tissue. This deposition does not require the dissolution of the existing mineral of the bone. The precipitation of groundwater material into bone is a well-studied phenomenon (Plate and Brown 1985; Klepinger *et al* 1986; Krueger 1991; Lambert *et al.* 1991; Price *et al.* 1992; Elliot and Grime 1993; Hedges and Millard 1995; Hedges *et al.* 1995; Hillson 1996; Kohn *et al.* 1999). Common precipitates include calcite, quartz, iron and

zinc salts. These salts may become incorporated into the histological structure of the tissue (i.e. Haversian canals, dentinal tubules or at the dentine-enamel junction) or become associated with biogenic or diagenetic apatite through surface adsorption or incorporation into a surrounding hydration layer (Neuman and Mulryan 1967; Termine and Lundry 1973; Lambert *et al.* 1991; Elliot and Grime 1993; Hillson 1996; Kohn *et al.* 1999).

The exact process of diagenesis and how it affects the skeletal tissues, including the interaction between the organic and mineral phases, is not fully understood. However, it is the *effects* of diagenesis that concern the archaeologist and palaeontologist. In general, it may be stated that diagenesis homogenises the skeletal tissue with the burial environment. As such the equilibration of the bone with the soil may obliterate trophic level distinctions. Sillen (1981) found that while trophic distinction was maintained in Natufian material, both the carnivores and herbivores of the older Aurignacian material had Sr/Ca ratios that were markedly decreased markedly from their Natufian material and were paralleled by a similar increase in the ratios of the carnivores. These two features argue against an artefact of the particular diet of the carnivores or herbivores in question.

Similarly to the inorganic 'phase' of bone, the organic component – collagen – also suffers from diagenetic alteration (Nelson *et al.* 1986; Millard 1998; Millard 2001). While there is some evidence for the alteration of collagen in the depositional environment that can have an effect upon the measured isotope ratios (DeNiro and Weiner 1988), in light of sufficient recovery of collagen from human material the affect is likely ameliorated (Nelson *et al.* 1986).

While the utilisation of bone for strontium and oxygen isotope studies is questionable, dental enamel has been effectively shown to be a reliable reservoir of biogenic, *in vivo* isotopes (Budd *et al.* 2000; Budd *et al.* 2000*b*; Hoppe *et al.* 2003; Trickett *et al.* 2003). Although dental material

has been shown to contain elevated levels of lead on an order of magnitude greater than previously recorded lead levels, mechanical removal of both the internal and external surfaces of the tooth have allowed the recovery of lead at low levels (40 ppb) and which is isotopically distinct from modern pollution levels (Molleson 1987; Budd *et al.* 1998; Budd *et al.* 2004*c*).

In application to the analysis of material from Coventry and Chelsea, the recovery of biogenic isotope signals in terms of carbon, nitrogen, strontium, oxygen and lead is therefore possible given the following caveats:

- Isotopes which are most subject to diagenetic alteration in the depositional environment be restricted to analysis from dental material, previously identified in the literature as more resistant to diagenesis. Thus, strontium, oxygen and lead should only be recovered from dental enamel.
- Bone collagen, if suitably mechanically prepared, offers a record for carbon and nitrogen isotopes that is diagenetically secure given the time-scales involved in the population (i.e. within the last three centuries).

4.5. Biomineralisation and Sampling

The mineralisation of the various skeletal tissues, as well as the formation of collagen, has been covered extensively elsewhere and as such will not be addressed here (Warshawsky 1983; Chadwick and Cardew 1997; Martini 1998; Mays 1998; Ten Cate 1998; Hames and Hooper 2000; Matthews *et al.* 2000). Weaning, however, presents a problem with the recovery of a signal representative of the isotope being analysed, (e.g. diet or locality). However, this is easily moderated by the appropriate selection of material.

4.5.1. Bone

While collagen has been shown to be affected by weaning, creating enrichment in both $\delta^{13}C$ and $\delta^{15}N$, this is notable only in sub-adult remains. Adult remains were therefore preferentially selected, although a single example of sub-adult remains (CHE-1051) was selected for analysis. Similarly, bone samples were selected from locations with significant quantities of trabecular bone were present, thereby increasing the probability that the sample would represent the most recent dietary experience, (i.e. a result of bone turnover as explained in earlier chapters).

4.5.2. Dental Enamel

While bone constantly remodels throughout life, enamel once mineralised remains unaltered except through surface enrichment, etc (Ten Cate 1998). The mineralisation of teeth occurs throughout childhood and, as previously mentioned, weaning normally occurs between the ages of one and two years. While in the case of strontium and lead isotope analysis weaning does not play a significant factor,

	Mineralisation	
Tooth	**Initiated (years)**	**Completed (years)**
First premolar	1.5-2.0	5-6
Second premolar	2.0-2.5	6-7
First molar	0	2.5-3.0
Second molar	2.5-3.0	7-8

Table 8: Initiation and completion of mineralisation for selected dentition in humans. Values reported for both mandibular and maxillary dentition (Hillson 1996)

The second premolar and second molar therefore allow the secure recovery of a signal that is unaffected by weaning. Furthermore, the first premolar in the absence of the second premolar or molar may preserve a non-weaning signal, while the first molar should be avoided as it mineralises during weaning (Hillson 1996).

4.6. Geology of Coventry and Chelsea

Detailed descriptions of the geology of Coventry and Chelsea can be found in Bridge *et al.* (1998) and Sumbler (1996), respectively, as well as in the respective Victoria County Histories (VCH 1904, 1969, In Press). The following information primarily represents a summary of both the bedrock and superficial deposits of the immediate areas around Chelsea and Coventry and not the geological evolution of these deposits.

Furthermore, biogeochemical results for one individual from Chelsea, Milborough Maxwell (CHE792), suggest a possible childhood residence in the British Caribbean. In the absence of supporting historical information that ties Milborough Maxwell to a specific island with the British Caribbean, beyond the historical ties mentioned in Chapter 2, means that any specific overview of the geology in the region would be so broad as to be practically meaningless. Of greater interest, however, are examples of Caribbean volcanic rocks, whose conformance with the strontium isotope results from Milborough Maxwell are particularly striking.

4.6.1. Coventry

The superficial and solid geology is represented in the following two figures:

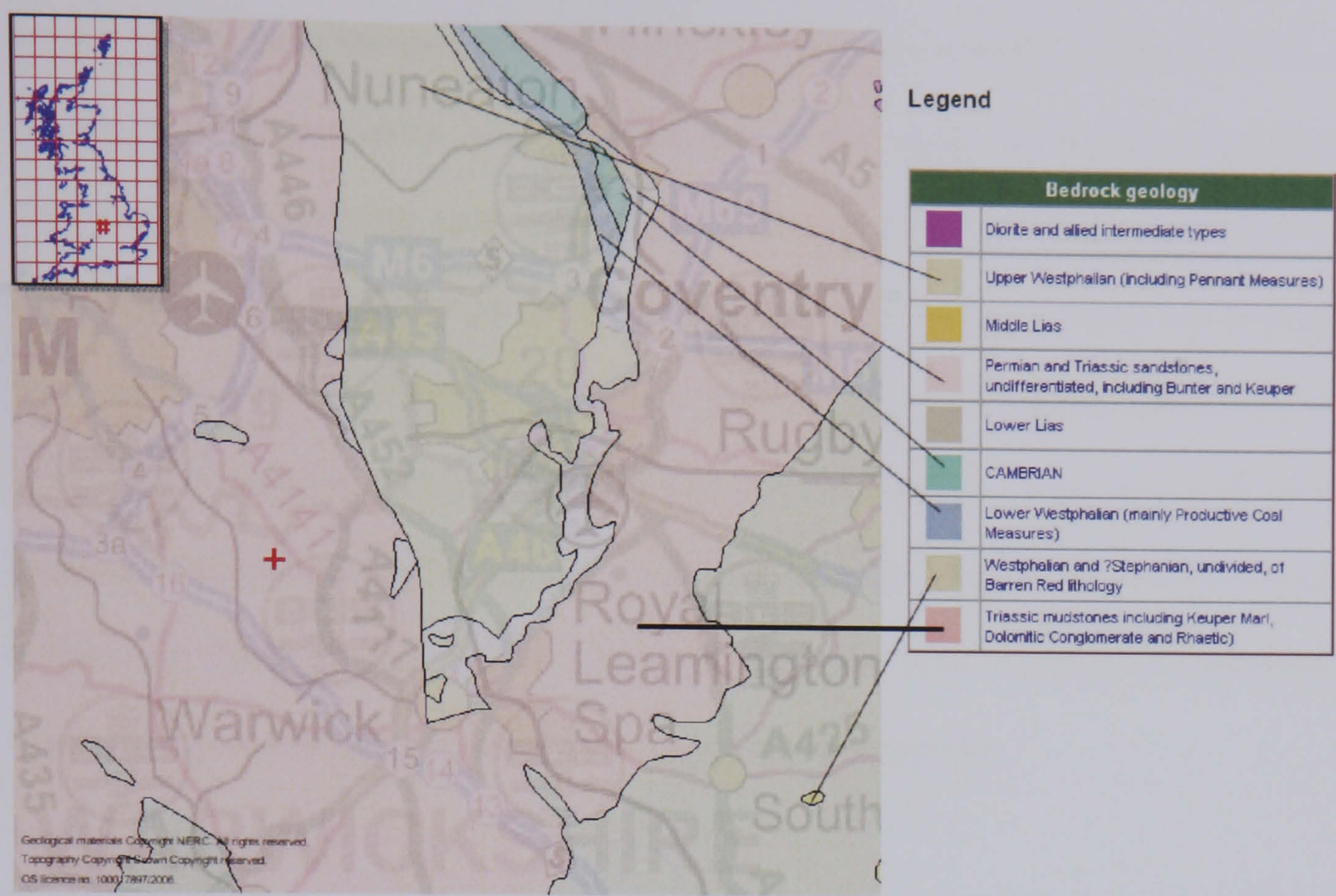


Figure 21: Bedrock geology of Coventry and environs (source: British Geological Survey).

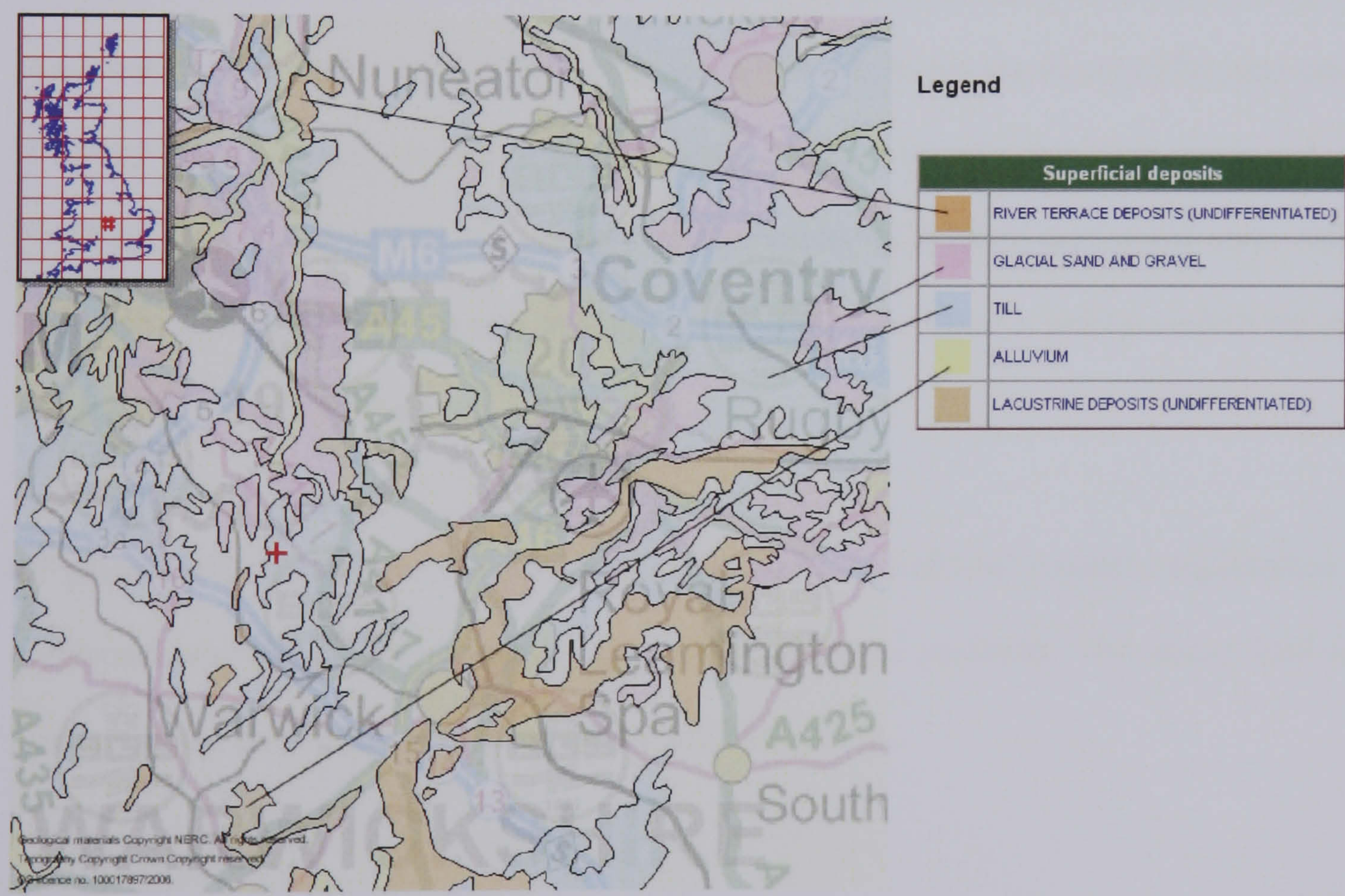


Figure 22: Superficial geology of Coventry and environs (source: British Geological Survey).

As can be see from the two figures, above, Coventry lies broadly upon the interface of three lithologies, with interaction with a further two to the north. In terms of geological age of formation, the underlying rock strata are of a far more diverse range than those of Chelsea, described below. Dominant strata in the area are, to the west, Westphalian (?Stephanian) or "Barren Red Lithology" sedimentary rocks (Paleozoic, carboniferous), surrounded by Triassic mudstone (Keuper Marl, Dolomitic Conglomerate and Rhaetic). These two strata are divided by Permian and Triassic undifferentiated sandstones (including Bunter and Kepler formations) and, to the north, Cambrian and Permian/Triassic sedimentary rock. In terms of superficial deposits, Coventry is primarily comprised of glacial sand, gravels and tills.

With specific reference to James Brown (COV978) and John Chattaway, two individuals from Coventry who were known to have migrated, the lithologies and superficial deposits are broadly comparable. Warwick, one time home for James Brown, shares the Permian/Triassic sandstone lithology of Coventry, though with overlying deposits of till and river sand and gravel. Similarly, James Chattaway was resident in the hamlet of Radford during his early childhood (two miles east of the modern city centre), would also have shared a similar underlying geology to the inhabitants of Coventry.

Of particularly significance for the study, at least in terms of coal resource exploitation in the eighteenth and nineteenth centuries, is the Warwickshire coalfield. No direct lead isotope measurements are present upon this formation (Rohl 1995).

4.6.2. Chelsea

The superficial and solid geology is represented in the following two figures:

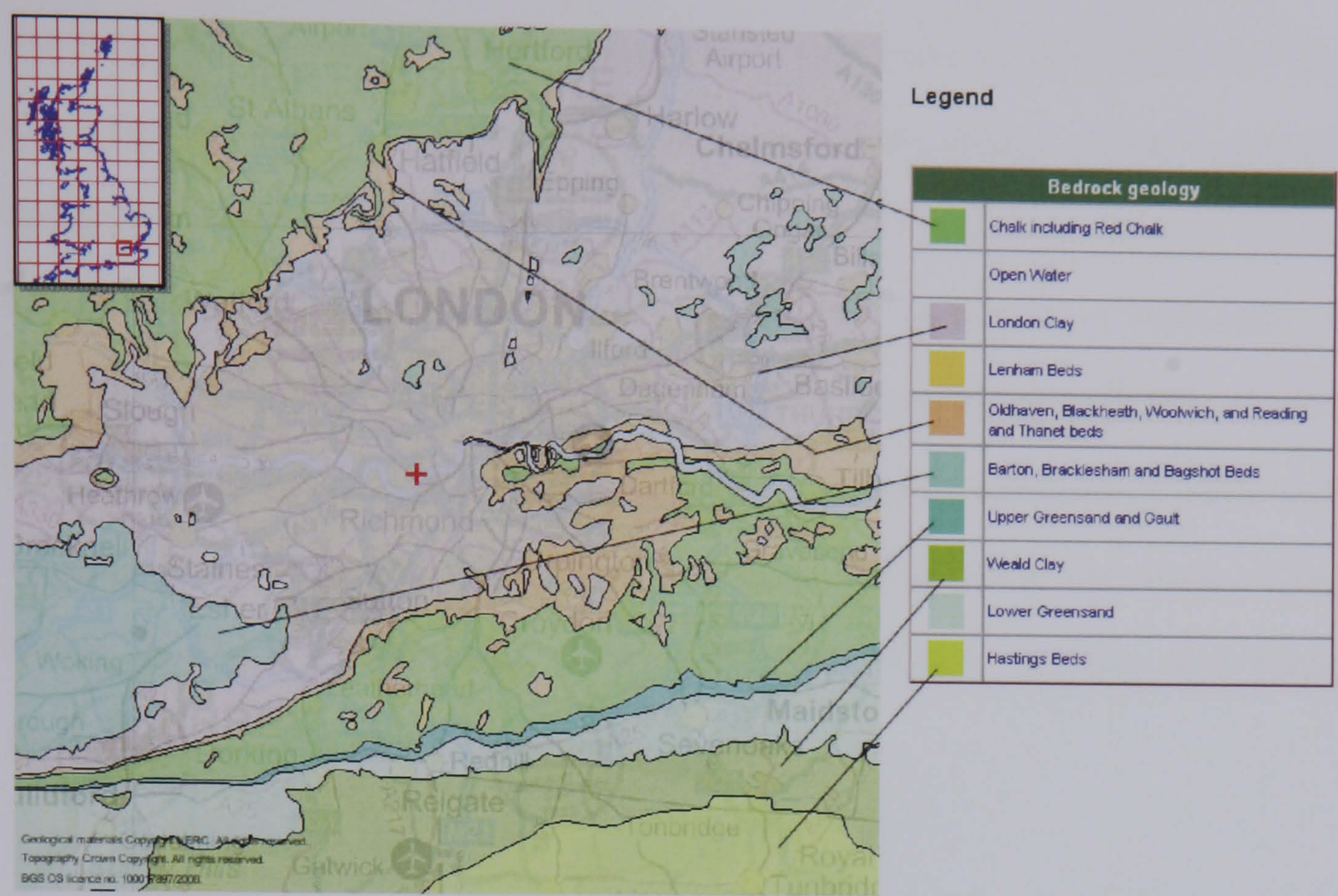


Figure 23: Bedrock geology of London and environs (source: British Geological Survey).

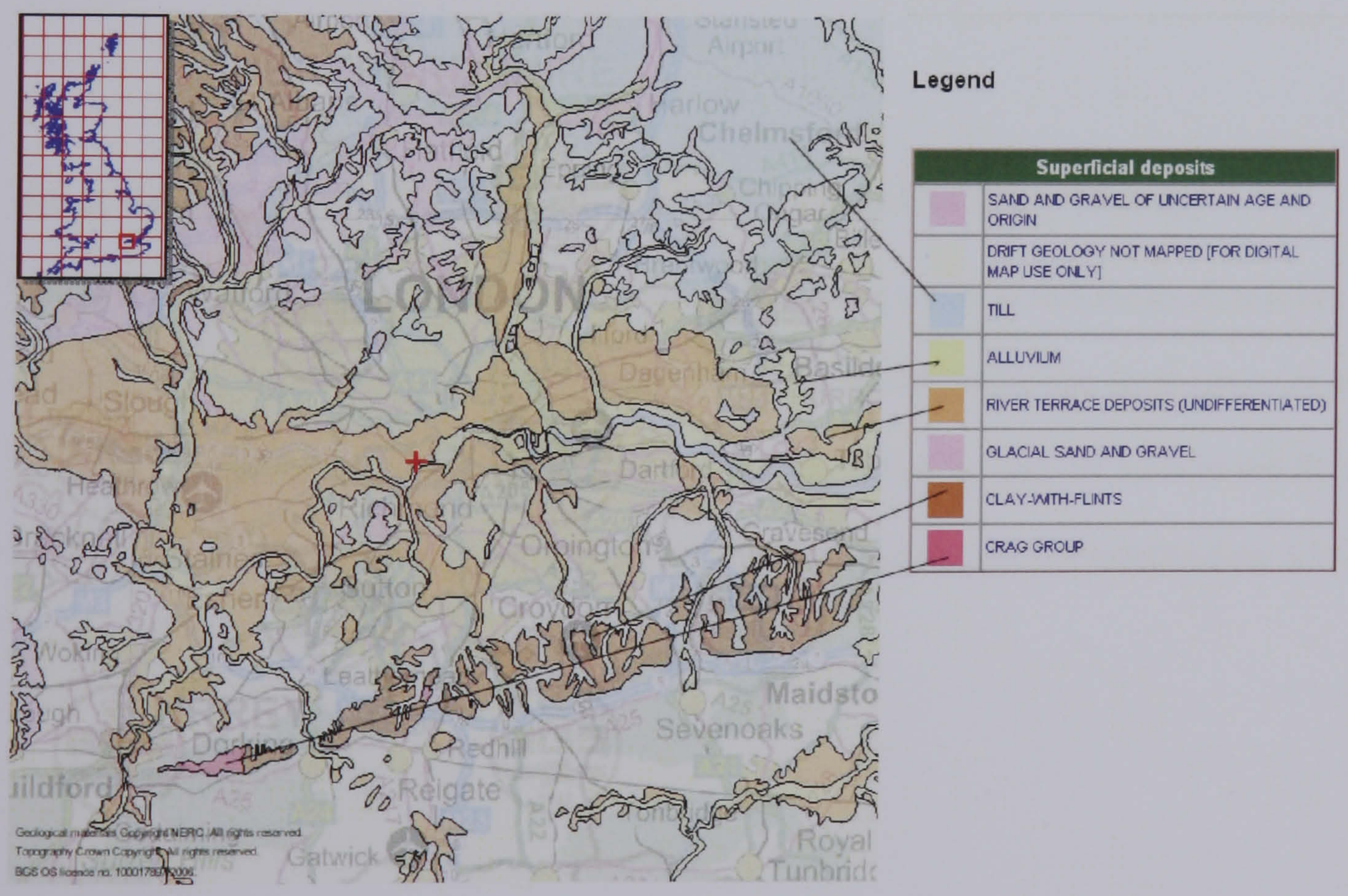


Figure 24: Superficial geology of London and environs (source: British Geological Survey).

Far more complex than the bedrock geology of Coventry and environs, as we can see from the above figure, London's geology is primarily comprised of Cenozoic and surrounding Mesozoic (cretaceous) sedimentary rocks. Within the study area of Chelsea, located near the cross on the figures above, the dominating geological stratum are the London clays ("brickearths"; Cenozoic – Palaeocene/Eocene). Within several miles of Chelsea are deposits of Oldhaven, Blackheath, Woolwich and Reading and Thanet (Cenozoic, paleogene) sedimentary rocks, surrounding Hastings Beds (Mesozoic, cretaceous). Dominating to the north and south of the Thames Valley, however, are Mesozoic (cretaceous) chalks (Chalk including Red Chalk, Upper Greensand and Gault, Lower Greensand).

The superficial deposits are more variable, primarily consistent of undifferentiated and Crag Group river sand and gravels. As one might expect, alluvial deposits are present along the Thames.

4.6.3. Expected $^{87}Sr/^{86}Sr$ Range from Chelsea and Coventry Geology

Given the relatively large number of samples analysed as a part of this thesis, it was not possible to take soil or local faunal samples, commonly used to determine the local range of strontium isotopes. However, in an extensive and as of yet unpublished study of soils in the British Isles by Paul Budd, the following isotope ranges for geological features surrounding Chelsea and Coventry.

Site	Geological Epoch	Lithology	$^{87}Sr/^{86}Sr$ (n)
Chelsea	Eocene (Tertiary)	"London Clay" range	0.710-0.7115
	Carboniferous	"Dination"	0.70907 (2)
	Late Cretaceous	Gault/Lower Greensand	0.70833 (6)
	Upper Cretaceous	Chalk	0.70743 (5)
	Upper Jurassic	Clay	0.70935
	Lower Cretaceous	Gault/Greensand	0.70933 (3)
Coventry	Triassic		0.710-0.7115
		Westphalian	~0.714

Table 9: Measured and expected $^{87}Sr/^{86}Sr$ for geological deposits at Coventry and Chelsea (Paul Budd pers.comm.).

Jane Evans (pers. comm.) has represented gross expected strontium isotope values over the British mainland:

Figure 25: Expected $^{87}Sr/^{86}Sr$ values for the British Mainland (Evans pers. comm.).

Thus, in terms of $^{87}Sr/^{86}Sr$, the ranges covered by Chelsea and Coventry (lying approximately 40-50 miles north-north-west of Oxford in the map above) are broadly similar, falling with the

range of 0.7084-0.7100. Coventry, however, should have an elevated $^{87}Sr/^{86}Sr$ than Chelsea, though no soil samples were taken from this area at the time of writing to quantify this.

4.6.4. Expected $^{87}Sr/^{86}Sr$ Range from Caribbean Volcanic Rocks

The Caribbean becomes significant to the project as a result of the measured strontium isotope value of CHE792, or Milborough Maxwell, which was sufficiently low to suggest a volcanic origin in the Caribbean or, alternatively, in north-western Scotland (Isle of Skye, i.e. $^{87}Sr/^{86}Sr < 0.7073$). The oxygen isotope ratio would, however, seem to indicate the Scottish birthplace as being only a remote possibility. Isotopic analysis of volcanic rock in the Caribbean, more specifically in the islands of the Lesser Antilles (i.e. St. Kitts, St. Lucia, etc.) have recovered $^{87}Sr/^{86}Sr$ values in the range of ~0.7030 (Redonda) to ~0.7045 (Martinique), with islands such as Montserrat and St. Kitts taking intermediate values (Davidson *et al.* 1993). Values derived from the "Quill", a volcano on the south-west of St. Eustatius are comparable to the Davidson *et al.* (1993) $^{87}Sr/^{86}Sr$ isotopes in terms of the range presented (Roobol and Smith In Press). While lower than the value recovered for Milborough Maxwell ($^{87}Sr/^{86}Sr$ 0.7064), sedimentary mixing may offer one possible explanation for such variation (Davidson *et al.* 1993; Roobol and Smith In Press).

5. Materials and Methods

This section details the osteological samples and the biogeochemical processes through which the isotopic compositions and concentrations were determined. Also discussed are the osteological methods applied in the limited osteoarchaeological study employed on the Chelsea sample, as well as the prosopographic research techniques and sources for identifying the 'named' individuals.

5.1. Selection of Osteoarchaeological Material

From each individual both cranial (dental) and post-cranial material was sampled as follows:

5.1.1. Dental Sample Selection

Given the noted effects of weaning on the isotope composition of the early forming permanent dentition and skeleton as a whole, the mandibular second premolar (P_2) or the mandibular second molar (M_2) were selected as being safely outside of the age of weaning in post-medieval British samples (Sillen and Smith 1984, Iregren 1992, Hillson 1996, Larsen 1997, Polishchuk *et al.* 2001). The left antimere was preferentially selected in all circumstances, as were teeth that did not show significant destructive pathological lesions, i.e. carious lesions, although other types of pathology, enamel hypoplasia, calculus, etc., did not affect selection (Ortner and Putschar 1985; Aufderheide and Rodriguez-Martin 1998).

In the case of certain individuals, i.e. Coventry, if post-cranial material survived and P_2 or M_2 was absent, maxillary equivalents were selected and, only then, material of a more debateable

integrity in terms of the mineralisation/weaning phenomenon. Again, given the paucity of the material, certain individuals from a number of sites, dental material was sampled regardless of the presence of post-cranial material. This material is necessarily highlighted, more so in those cases where an outlying situation is noted.

5.1.2. Post-Cranial Bone Sample Selection

As post-cranial material is primarily of use for the collection of collagen for $\delta^{13}C$ and $\delta^{15}N$ analyses, and the accepted preservation of collagen in relatively young archaeological material is likely to be good (Millard 2001), rib was preferentially selected. This bone is often fragmentary and, in terms of gross osteoarchaeological examination, seen as less important thereby reducing the impact of the sampling upon the integrity of the skeletal collection. In one case from Coventry (COV50) the sample derives from the *inominae*, while a number of samples from Chelsea derive from sources other than the rib: CHE687 (right phalange) and CHE1051 (diaphyseal fragment, unidentifiable). In all possible cases, only material that showed good cortical integrity was selected (Buikstra and Ubelaker 1994).

5.1.3. Sub-sampling of Skeletal Collections

Material from St. Mary's (Coventry, see section 5.6) consisted of a small number of named individuals, i.e. 11 adult skeletons of approximately 100 individuals, and as such a total sample was collected for those adults that could be sampled for both post-cranial and dental material even if it did not comprise the full sample for biographically identified individuals. In limited cases, e.g. COV-1119 (John Ballard), single samples were taken from those individuals whose initial historical survey revealed potentially interesting information. In a second round of sampling occurring simultaneously with sampling of the Chelsea collection (see below), the

Coventry collection could not be further sampled for un-named individuals to address the sample size discrepancy between the two sites.

Selection of material from Chelsea was more complex. While the initial project outline detailed a total sample of named individuals it was not possible to produce these using the two selected sites either a result of a lack of dental material (i.e. edentulism) in the named sample or the adult/non-adult composition of the named sample. As such, it was determined to use un-named individuals from the Chelsea sample selected with the *provisio* that they could be dated from associated coffin furniture (i.e. coffin handles). As such, the preliminary osteoarchaeological report was consulted and individuals selected based upon the following criteria: (1) adult; (2) both bone and dental material present; and (3) presence of a dateable coffin handle. This sub-sample was then totally sampled, including those handles of 'type 1' which are only loosely identified so as to include a more 'random' element (Miles 2001).

5.1.4. Sample Descriptions

For a list of the samples utilised in the study and any pathologies present, see *Appendix 1*. This information is summarised in table, below.

Site	Sample	Tooth	Bone	Site	Sample	Tooth	Bone
Chelsea	CHE-18	35	Rib	Coventry	COV-13	-	Rib
	CHE-19	35	Rib		COV-16	-	Rib
	CHE-31	16	Rib		COV-50	14	Rib
	CHE-35	45	Rib		COV-77	25	Rib
	CHE-39	35	Rib		COV-147	-	Rib
	CHE-104	37	Rib		COV-417	44	-
	CHE-143	-	Rib		COV-434	35	Rib
	CHE-147	44	Rib		COV-516	37	Rib
	CHE-161	35	Rib		COV-672	47	Rib
	CHE-218	-	Rib		COV-808	44	Rib
	CHE-285	37	Rib		COV-866	47	Dentine
	CHE-392	35	Rib		COV978	44	Rib
	CHE-432	-	Rib		COV-1119	-	Rib
	CHE-502	-	Rib		COV-1248	37	Rib
	CHE-552	17	Rib				
	CHE-622	-	Rib				
	CHE-654	17	Rib				
	CHE-697	15	R. phal.				
	CHE-713	18	Rib				
	CHE-722	-	Rib				
	CHE-744	1/25	Rib				
	CHE-750	1/25	Rib				
	CHE-792	25	Rib				
	CHE-841	37	Rib				
	CHE-856	25	Rib				
	CHE-918	37	Rib				
	CHE-980	35	Dentine				
	CHE-990	37	Dentine				
	CHE-994	35	Rib				
	CHE-1021	-	Rib				
	CHE-1051	3/46	Diaphysis				

Table 10: Summary of samples used (tooth sample using terminology employed by Brothwell 1981 and Van Beek 1983).

5.2. Mechanical Preparation of Samples

5.2.1. Dental Samples

Each tooth was then half-sectioned along the mesio-distal line using a diamond cutting-disc on a Kavo-4 dental drill (Prestige Dental, Manchester, UK) operating at speeds <15,000 rpm to moderate any potential thermal effects. One-half of each tooth was left intact without any

further treatment to allow for replicate analysis or re-run upon sample failure. Individual half-teeth where then clamped around the root and the dentine drilled with tungsten carbide burrs (Prestige Dental, UK). Particular care was taken at the enamel-dentine junction to remove an opalescent layer of enamel-like material that was present in all the teeth. This layer, while absent from histological and osteoarchaeological texts on dental anatomy, produced substantial quantities of organics which served to obstruct the molecular sieve in the $\delta^{18}O$ analysis by laser fluorination. While silver phosphate preparation techniques are less sensitive to this organic layer, it was removed in all dental samples.

Once the dentine had been fully removed the enamel cap was removed from the root and the external and inner surface of the enamel burred to remove the uppermost 200-300μm, the layer most likely to be contaminated with post-mineralisation material (Molleson 1987; Budd *et al.* 1998). Surfaces which were affected by the diamond cutting disc were similarly burred (i.e. the plane resulting from the original mesio-distal sectioning). Additional care was taken in those teeth with prominent inter-cuspal fissures so as to ensure the removal of any surface enamel.

In the cases of some teeth from both Coventry and Chelsea, primary crown dentine was removed with the burring process and subsequently saved for limited analysis.

5.2.2. Bone Samples

All bone samples were mechanically cleaned of soil (etc.) to minimise non-collagenous carbon/nitrogen contamination with soil or soil microbes as well as to mitigate preparation time for sample demineralisation and/or preconditioning.

5.3. Preparation of Collagen for $\delta^{13}C$ and $\delta^{15}N$

Collagen preparation followed the method proposed by Richards (ref.), a modified version being utilised at NIGL.

5.3.1. Preparation of Osteological Material

Bone samples were prepared as outlined in section 5.2.2 and fragmented so as to increase the surface area for the effect of the demineralising acid. As mentioned previously, samples were preferentially selected from ribs except in those circumstances where a securely identified rib was unavailable.

5.3.2. Demineralisation and Gelatinisation of Bone Samples

Samples (0.5-1g) were placed in individual test-tubes and 10ml of 0.5M HCl added. Each sample was agitated in the test-tube twice per day with the acid exchanged every two days. Demineralisation was terminated when the samples were soft, (i.e. complete demineralisation), and the demineralising acid decanted. Samples were then washed three times in H_2O (MilliQ) and placed into pre-weighed and cleaned storage beakers.

Gelatinisation was achieved through heating of the collagen in pH 3.0 water and the drop-wise addition of HCl. Samples were then heated at 75°C for 24-48 hours. The sample was then centrifuged and the gelatin-rich supernatant decanted and freeze-dried overnight.

5.3.3. Analysis of Samples

Samples were analysed by Continuous Flow Isotope Ratio Mass Spectrometry (CFIRMS) through coupling a high temperature elemental analyser (TC/EA) with a Delta Plus XL isotope ratio mass spectrometer through a ConFlo III interface (Thermo Finnigan). Instrument reproducibility was determined as ±0.017 ‰ $\delta^{13}C$ on CO_2 reference gas, and ±0.018 ‰ on N_2 reference gas.

All samples (~68 mg) were analysed in duplicate along with C3 (x5 batch-1 and x6 batch-2) an in-house collagen control (expected values: $\delta^{13}C$ = -19.49±0.03 ‰, $\delta^{15}N$ = +11.07±0.38 ‰ each to 1σ). Four additional samples duplicate samples – CHE-750, CHE-841, CHE-918 and COV-13 – were also analysed in each analytical batch (1, 2) to act as mass spectrometry controls. These were randomised and interspersed within the batch at approximately one duplicate per five samples with in-house reference samples M1360 gelatine to correct for ratio drift during analysis.

Sample C3 was also analysed by conventional elemental analysis to determine the elemental carbon and nitrogen abundance and elemental ratio. C3 was further used to in the analysis as a reference to calculate the percentage mass of carbon and nitrogen. Samples were once again drift corrected against M1360 with the mean and reproducibility for mass spectrometer control being $\delta^{13}C$ –19.16±0.03 ‰ and $\delta^{15}N$ +10.52±0.24 ‰ (expected value $\delta^{13}C$ –19.49±0.03 ‰, 1σ). This is represented in tabular format below:

Identifier	Mean Corrected $\delta^{13}C$ ($^0/_{00}$)	1σ	Mean Corrected $\delta^{15}N$ ($^0/_{00}$)	1σ	Number (n)
Expected	-19.49	0.03	11.07	0.38	
C3 Batch-1	-19.63	0.02	10.52	0.24	5
C3 Batch-2	-19.59	0.03			6
Combined	-19.61	0.03			11

Table 11: Mean and corrected $\delta^{13}C$ and $\delta^{15}N$ for analytical batches (Chenery 2004).

The mean and reproducibility of duplicate samples analysed as mass spectrometer controls is shown in the table below. The average reproducibility for these samples was for $\delta^{13}C$ ±0.02‰ and for $\delta^{15}N$ ±0.20‰.

The average reproducibility for all sample duplicates (excluding M1360) within and between batches was $\delta^{13}C$ = ±0.03‰ and $\delta^{15}N$ = ±0.15‰ to 1σ in each case.

Identifier	Mean Corrected $\delta^{13}C$ ($^0/_{00}$)	1σ	Mean Corrected $\delta^{15}N$ ($^0/_{00}$)	1σ	Number (n)
CHE-750 Batch 1	-18.42	0.02	12.78	0.02	2
CHE-0750 Batch 2	-18.44	0.03			3
CHE-0750 Batches 1&2	-18.43	0.03			5
CHE-0841 Batch 1	-19.30	0.01	12.61	0.48	2
CHE-0841 Batch 2	-19.27	0.02			2
CHE-0841 Batches 1&2	-19.29	0.02			4
CHE-0918 Batch 1	-19.41	0.00	12.17	0.04	2
CHE-0918 Batch 2	-19.45	0.05			2
CHE-0918 Batches 1&2	-19.43	0.04			4
COV-0013 Batch 1	-18.41	0.00	12.58	0.26	2
COV-0013 Batch 2	-18.46	0.02			2
COV-0013 Batches 1&2	-18.44	0.03			4

Table 12: Reproducibility between analytical batches in terms of $\delta^{13}C$ and $\delta^{15}N$ (Chenery 2004).

5.4. Sr/Pb by Ion-Exchange Column Chemistry

5.4.1. Sample Preparation

Enamel samples were prepared as in section 5.2.1, above. Additionally each sample was ultrasonicated in water (MilliQ) three times before a final acetone wash to remove any potentially adhering grease/oils from manual handling. Each sample (~50-100mg) was then individually weighed (Sartorious) into acid-leached (6M HCl, Teflon-distilled (TD)) Savillex beakers. Upon transfer to class 100 HEPA-filtered flow hoods, 1ml of nitric acid (6M HNO_3, Teflon-distilled) and evaporated down to dryness overnight. To these dried samples 1ml of hydrogen bromide (1M HBr, TD) was added.

5.4.2. Isotope Dilution

Determination of the elemental concentration of Pb/Sr in the samples required the addition of a measured "spike", a material enriched in an appropriate isotope (i.e. ^{84}Sr or ^{208}Pb), to the sample with known mass. The spikes added were for Sr and Pb, respectively: Oak Ridge and a ^{208}Pb trace material.

Material spiked with ^{84}Sr was then split and a 200ml aliquot placed in the ^{208}Pb spiked beakers.

5.4.3. Ion-Exchange Column Preparation and Preconditioning

Ion-Exchange columns were individually prepared using Dowex 1×8, 200-400 mesh anion exchange resin for Pb elution, with pre-measured Dowex AG50W×12 cation exchange resin for the elution of strontium. The individual preparation of the Pb columns required the drop-wise

addition of agitated exchange resin into a pipette tip. Each column was then washed three times in first 6M HCl (TD) and then H_2O (MilliQ) until and, if left to stand, a further wash of H_2O. Prior to sample loading columns were pre-conditioned in 1 column volume of HBr.

5.4.4. Sample Collection (Sr)

The samples were individually loaded onto the prepared columns using separate pipette tips, each pre-conditioned in HBr. The spiked beakers (^{84}Sr) were placed underneath the columns and the Sr eluted with 1.25 column volumes of The sample (Pb) was recovered from each column through the addition of 1 column volume of HCl (6M) and, to this solution, HNO_3 was added and the sample dried down over night.

5.4.5. Sample Collection (Pb)

A separate set of columns were prepared and pre-conditioned as described in section 5.4.3. The dried sample was taken up in 1ml of HBr and separately loaded onto the preconditioned columns. Each sample was then eluted with 1.25 column volumes of HBr into spiked beakers. To the final solution, 2-3 drops of HNO_3 and 2.2μl of phosphoric acid (H_3PO_4; TD) and the resultant left to dry down overnight.

5.4.6. Ion-Exchange Columns (Sr)

Recovery of Sr required additional processing through cation exchange resin (see section 5.4.3). Exchange columns were prepared through sequential washes: 50ml of 6M HCl (Quartz Distilled, QD) to remove any adhering anions; 50ml of H_2O (MilliQ); 50ml of 6M HCl (QD);

and finally 2.5M HCl (QD) to pre-condition columns for the addition of the sample/chloride solution.

Samples were loaded onto individual columns and flushed into the resin through the addition of two separate washes of 1ml 2.5M HCl (QD). Upon draining of the matrix from the columns, a further 38ml of 2.5M HCl was added to further remove contaminants (i.e. calcium, phosphorous) that would interfere with subsequent analysis. Finally, Sr was eluted from the columns with a final wash of 2.5M HCl (QD) and allowed to dry down overnight.

5.4.7. Sample Analysis

The Pb isotope concentrations were determined by Thermal Ionisation Mass spectroscopy (TIMS) using a Finnigan Mat 262 multi-collector mass spectrometer and the lead isotope composition were determined by solution using a VG Elemental Axiom MC-ICPMS. Data were corrected exponentially for mass discrimination using a 100ppb Pb solution doped with 10ppb of Tl according to the method of Longerich *et al.* (1987). The data are normalised to the NBS 981 values of Thirlwall (Thirwall 2002). The reproducibility and the normalising factors for the Pb isotope compositions are given in the table 18 at the end of this chapter.

Sr isotope composition and concentrations were determined using a Finnigan Mat 262 multi-collector mass spectrometer in static mode using a TaF activator (after the method of Birck 1986) on single Re filaments (Birck 1986).

The international standard for $^{87}Sr/^{86}Sr$, NBS987, gave values of 0.710221 ± 17 (n=32, 2σ). All strontium ratios were run to an internal precision of ± 0.000010 2SE or better and have been

correct to an accepted value for the standard of 0.710240. Lead and strontium blanks were approximately 150 pg, with concentrations with a precision better than 10%.

5.5. $\delta^{18}O$ by Silver Phosphate

Silver phosphate analysis was the primary means by which $\delta^{18}O$ was analysed from enamel phosphates and, in a small number of individuals, bone phosphate. The original process of fluorination of bismuth phosphate from a solution of phosphatic material developed by Tudge (Tudge 1960) was subsequently refined by Kolodny *et al.*(Kolodny, Luz et al. 1983), Karu and Epstein (Karhu and Epstein 1986) and Shemesh *et al.* (Shemesh and Kolodny 1988) and then into the current simpler form utilising silver phosphate by Crowson *et al.* (Crowson, Showers et al. 1991) and O'Neil (O'Neil, Roe et al. 1994). The procedure may be represented schematically as follows (Chenery 2004):

	Powdered Phosphate Material	
Step 1	↓	Oxidise in H_2O_2
	Dry Sample	
Step 2	↓	Dissolve in 2m HNO_3
	Solution	
Step 3	↓	Raise pH to ~5 with 2 ml KOH. Add 2 ml HF to precipitate CaF_2
	Solution + CaF_2	
Step 4a	↓	Centrifuge, separate and rinse
	Solution of H^+; $H_2PO_4.NO_3$	
Step 4b	↓	Add 15ml buffered silver amine solution and heat at 50°C
	$NH_{3\,(g)}$ + $Ag_3PO_{4\,(s)}$ + Solution	
Step 4c	↓	Collect on filter paper, rinse, and dry at 110°C
	Ag_3PO_4 crystals	
Step 4d	↓	Grind Ag_3PO_4 crystals to fine powder
	Ag_3PO_4 powder	

Figure 26: Schematic diagram of procedure for precipitation of silver phosphate

5.5.1. Preparation of Silver Amine Buffer Solution

The buffered silver amine solution (0.2M $AgNO_3$; 0.35M NH_4NO_3; 0.74M NH_4OH) was created through the addition of 13.2g of ammonium nitrate (NH_4NO_3; Solumetrics, Pure) dissolved in a little distilled water (Milli-Q) to a volumetric flask containing 50-100 ml of H_2O. Into this solution one ampoule of silver phosphate (Ag_3PO_4; BDH) was added to the volumetric flask and then rinsed through with H_2O. To this 57.5ml of concentrated ammonium solution (NH_4OH) was added and H_2O added to the resultant to make up to 500ml.

5.5.2. Preparation of Hydrogen Potassium Hydroxide Solution

114g of potassium hydroxide pellets (KOH; Merck) were added to a 1l volumetric flask, then 300ml of H_2O. The endothermic reaction of the dissolution of the KOH required the cooling of the solution in a water bath in between the piecemeal addition of H_2O to bring up to 1l.

5.5.3. Sample Preparation/Cleaning

Samples were weighed into 100-200ml beakers with watch-glass covers, to which 15-50ml of hydrogen peroxide (H_2O_2; 33%, purity grade unimportant) was slowly added to the beaker. Following slow agitation, the watch glass-covered beakers were transferred to an ultrasonic bath for 5-10 minutes before placing on a hot plate (~50°C; temperature could be raised to ~80°C but lowered once the volume of H_2O_2 was small to prevent explosion of the sample). Samples were left overnight until all H_2O_2 had evaporated.

5.5.4. Dissolution of Phosphate and Precipitation of Calcium Fluoride

The dry and cleaned sample was taken from the hotplate and 2ml of 2M nitric acid (HNO_3; Volumetrics, 69% Ultrapure) was added to the beaker, with careful agitation ensuring that any sample adhering to the side of the beaker was taken up in solution. This resultant solution was transferred to a 15ml polypropylene test tube and the beaker fluxed with 1ml H_2O to ensure maximal recovery of the dissolved sample.

To this solution 2 ml of 2M KOH was added and, after several minutes, a white colloid was seen to precipitate near the top of the resultant solution. Each polypropylene test tube was then gently agitated until the colloid dissolved and then left for 5-10 minutes. Following this, 2ml 2M hydrofluoric acid (HF; Solumetrics, 40% Ultrapure) was added to the test tube and left overnight so as to cause the precipitation of calcium fluoride (CaF_2).

5.5.5. Precipitation and Recovery of Silver Phosphate

Precipitated CaF_2 was concentrated at the base of the polypropylene tube by centrifuging for 10 minutes at 40,000 rpm. 15ml of silver amine solution was added to clean and dry 200ml beakers and the sample phosphate solution carefully added so as to prevent the concreted CaF_2 from entering the solution. The sides of the test tube were rinsed with 1ml H_2O and the resultant decanted into the 200ml beakers with phosphate/silver amine solution, the process repeated a total of three times.

The resultant solution was placed on a hotplate (50-75°C). At this point the approximately pH of the solution was ~pH 10. Gradual heating serves to drive of the ammonia (NH_3) and, in so doing, increasing the acidity of the solution. Precipitation of Ag_3PO_4 occurs between pH 8.5-6.8, with the low temperature aimed at slow precipitation and concomitantly larger crystal size to minimise sample loss following subsequent centrifuging.

Once precipitation was complete as monitored through continual observation of the pH of the solution, the 200ml beakers were placed in an ultrasonic bath and agitated for 5-10 minutes so as to dislodge any Ag_3PO_4 crystals adhering to the bottom or sides of the beaker. This solution was then passed through a 2μm HVLP type Millipore filter and the filtrate rinsed several times with H_2O in a vacuum pump aided process. The filter paper was then placed on a clean watch glass and placed within a covered drying oven at moderate temperature.

5.5.6. Ag3PO4 Crystal Homogenisation and Sample Preparation

Once dried over night, the watch glass/filter paper were removed from the drying oven and percussion used to remove the Ag_3PO_4 crystals into a cleaned mortar. The Ag_3PO_4 crystals were

then ground with a cleaned pestle until a fine consistency was formed. This was then deposited into plastic storage capsules. Individual samples were weighed (~26mg) and loaded into silver capsules ready for analysis.

5.5.7. Analysis of Samples

As with carbon/nitrogen analysis, above (section 5.3.3), samples were analysed by Continuous Flow Isotope Ratio Mass Spectrometry (CFIRMS) through coupling a high temperature elemental analyser (TC/EA) with a Delta Plus XL isotope ratio mass spectrometer through a ConFlo III interface (Thermo Finnigan). Internal reproducibility of $\delta^{18}O$ of the Delta Plus XL and ConFlo III on a carbon monoxide (CO) reference gas was ±0.03 $^{0}/_{00}$ (1σ). Reproducibility of analysis of the barium sulphate ($BaSO_4$) NBS127 on commissioning of the analytical equipment was ±0.2 $^{0}/_{00}$ (1σ, n=10), while ACC1-9 analysed as a control (triplicate measurements in each analytical run) over a seven-month period gave a mean reproducibility of 13.9±0.27 $^{0}/_{00}$ (1σ, n=80).

All samples were analysed in triplicate with ACC1-9 mass spectrometry and ACC1-MT1 and NBS120C-MT sample preparation batch controls. All samples and controls were distributed randomly throughout the batch and interspersed at, approximately, every eight samples with in-house reference material NBS120C to correct for isotope ratio drift during analysis. Samples were therefore drift corrected against NBS120C.

Each mass spectrometer analytical run, as mentioned above, contained three ACC1-9 mass spectrometry controls with the following results indicating no statistical difference from the expected value:

ACC1-9 (Control)	Mean ($^0/_{00}$)	Standard Deviation (1σ)	Number (n)
Expected	13.9	0.27	80
Batch-1	13.9	0.11	3
Batch-2	13.6	0.05	3
Rpts-1	14.0	0.08	3
All Batches	13.8	0.21	9

Table 13: Mass spectrometer controls through CFIRMS (Keyworth, UK). (Expected value for ACC1-9 = 14.0 $^0/_{00}$ (Chenery 2004).)

Each precipitation batch contained a single in-house reference standard (NBS120C) and Batch-1 contained a single ACC1, which were analysed in triplicate as a precipitation batch control giving the results, below. No statistically significant variation from the expected value was noted.

Batch Control	Batch	Mean ($^0/_{00}$)	Standard Deviation (1σ)	Number (n)
ACC1		13.9	0.27	80
ACC1-MT	Batch-1	13.9	0.17	3
	Batch-2	13.8	0.18	3
	All Batches	13.8	0.16	6
NBS120C		21.7	0.36	81
NBS120C-MT1	Batch-1	21.6	0.20	3
NBS120C-MT2	Batch-2	21.5	0.20	3
	All Batches	21.5	0.19	6

Table 14: Batch controls through observation of NBS120C and ACC1 for CFIRMS (Keyworth, UK). (Expected value of NBS120C = 21.7 $^0/_{00}$ (Chenergy 2004).)

Average reproducibility on all samples analysed by CFIRMS at Keyworth (UK) was ±0.13 $^0/_{00}$ (1σ, n=6).

5.6. Osteoarchaeological Methods

A preliminary report detailing the osteoarchaeology and palaeopathology of the St. Mary's material from which the samples were taken remains unpublished (Wakely 2001), though can be accessed at the archive of the University of Leicester (UK). It does, however, only detail the sub-sample collected by Dr. Wakely prior to the rapid reburial of the collection. Selection of the material was based upon observed preservation of the material and/or the presence of pathological specimens and, as such, any palaeodemographic and palaeopathological inferences must be viewed with a healthy degree of scepticism. Very limited osteological information can be found in the Phoenix Project's publication of the archaeological excavation, essentially discussing the osteology of a small number of individuals (Rylatt and Mason 2003).

At present, the Chelsea material has only a preliminary analysis performed by Brian Connelly of the Museum of London Specialist Service (MoLSS), identifying overall preservation, age status of the individual (adult/non-adult), and significant noted pathologies. As such, while no osteoarchaeological analysis was foreseen as being included as a part of the project, a limited study was undertaken to provide the maximum amount of information given the time available for the study. Unfortunately, analysis could be performed on only those individuals that had been sampled as part of the biogeochemical study. For these individuals the selection criteria detailed below was undertaken.

5.6.1. Post-cranial Skeleton

Initial analysis by MoLSS identified dominant pathological lesions on the skeletons and, as such, this part of the skeleton would receive the briefest attention so as to confirm the identity of the lesion in question or to catalogue lesions not previously identified. Two features were

determined from the post-cranial skeleton: age of the skeleton determined from a surviving element (preferentially pubic symphysis, then the auricular surface) and stature estimations based upon a complete long-bone, usually the femur. In those cases where the femur was fragmentary, frequently the distal epiphysis, a secondary complete bone was selected.

5.6.2. Cranium

The cranium provided the focus of the brief osteoarchaeological analysis of the Chelsea material. A full dental analysis was performed, identifying the presence, number and distribution of carious lesions, calculus and enamel hypoplasias (see section 4). While detailed systems of recording are available (Hillson 1996) their application to the analysis of material from Chelsea was not considered worthwhile given only partial analysis of the material. Furthermore, given the multiple aetiology of dental pathology analysis of the Chelsea data becomes primarily *ad hoc* and, in many regards, similar to the historical analysis.

5.7. Methods of Biographical Reconstruction

Documentary sources offers archaeology a potentially invaluable source for the interpretation of the archaeological record and, in the case of isotope biogeochemistry, a means of estimating expected values against those provided for theoretical models. As mentioned in the introductory chapter, identifying an individual in the documentary evidence allows for the definition of one or more of the critical axes of archaeological interpretation, namely the identity of the individual in question and the origins of that individual. Thus, with an individual identified by name and date of death on the surviving coffin plate, there existed the potential to determine the specific life history of an individual rather than implying one from either the archaeological, including osteoarchaeological, record or an interpretation of biogeochemical analysis.

Biographical reconstruction is therefore dependent upon the ability to identify and link up the various documentary sources of the period, including in the first regard the register of burials in the parish and from that point additional materials. The nature of such material is highly variable, including other parish registers (births/christenings and marriages), will or entries in the Prerogative Court of Canterbury (PCC), apprenticeship enrolment registers, insurance documentation, journals and newspaper clippings, etc. There are, however, a number of limitations on the extent and nature of the historical archive. Firstly and most importantly, the quantity and quality of historical documentation varies significantly over the United Kingdom (Tate 1983), dependent not only on the specific interest of the individuals that generated the records but also on the socio-economic status of the individual; the greater the wealth of the individual the more likely they are to leave a documentary 'fingerprint'. Indeed, one can contrast the level of information obtainable between the Hand family of Chelsea and that of, say, the Chattaway family of Coventry. The Chattaway family and specifically John the younger, are identified in the burial register, the 1841 census of Coventry and apprentice enrolment registers. The Hand family with their much higher social and economic status are referenced not only in the burial register, but also numerous contemporary commentaries of the period (see section 2), newspaper clippings and insurance documents.

Secondly, the quantity of extent material, the quality of the archive in terms of material available for research, and the availability of indices varies tremendously. For example, the Chelsea Local Archive and the Chelsea and Kensington archive was undergoing research, with many of the documentary sources split between the two locations, in storage or transit or otherwise unavailable. One must also remember that the Coventry archive, and the records themselves, were damaged during the Second World War.

The following sections present sources of information used to aid in the biographical reconstruction of the named individuals in the Coventry and Chelsea samples. It does not exhaustively detail all sources utilised in this reconstruction, rather those sources within which information appropriate to the named individuals was recovered.

With regards the reconstruction of the history of the cities themselves, while source material at the respective local archive (Chelsea Library and Coventry Archive) was available information was replicated in the Victoria County Histories and, as such, those were predominantly used as reference material.

5.7.1. Coventry

Institutional sources of information on Coventry included the Coventry Main Library, the library of the University of Coventry, and the Coventry Archive. As the first site in which biographical reconstruction was attempted, a "total approach" was taken to the available material. That is to say that all sources of extant information were looked at with regards to identifying each of the named samples.

5.7.1.1. Burial Register

The names and dates of death were determined from surviving coffin plates recovered in the Saint Mary Cathedral (SMC) excavations of 1999 (Rylatt and Mason 2003). All individuals that formed the Coventry named sample were identified in the burial register in microfiches (MF) 1273/18 (1813-24+) and 1273/19 (1829-1908). Thomas Thomson (SMC99 SK13, or COV13) was identified by name, but unspecified damage to the coffin plate prevented a determination of the date of burial other than "pre-1837" (Wakely 2001). Burial registers to ca. 1750 extant in

the Coventry Archive did not reveal any individual that was buried in the parish of Holy Trinity by this name (e.g. MF 1273/12, 1809-12). Similarly, the individual recorded as "MH" (SMC99 SK1195) was not recorded as being buried in 1856 (MF 1273/19).

5.7.1.2. Baptismal Records

The year of birth was estimated from the recorded age of burial on the coffin plate, giving a likely age of birth. The baptismal records for Holy Trinity were then consulted to this year ±10 years to allow for misreporting or rounding of ages recorded on the coffin plate and burial register. Surviving baptismal records for Coventry were identified on MF 1273/12.

No individual identified in the burial register was securely identified in the baptismal record, a feature that might not be considered unsurprising given that if the individual had at some point married the named recorded in the burial register would not have been their maiden name.

5.7.1.3. Marriage Records

The marriage index for Coventry was, at the time of biographic reconstruction, unavailable for consultation. All information pertaining to the marriage of any of the individuals from Coventry was identified from "FamilySearch", the Internet-based webpage produced by the Church of Jesus Christ and Latter-day Saints (LDS). Record numbers are mentioned in the section 6 in the descriptions of the biographies of specific individuals, recorded as "IGI" followed by a reference number.

5.7.1.4. International Genealogical Index (IGI, LDS)

The IGI/LDS was consulted for all individuals in the Coventry sample and aided in the identification, variously, of birth, marriage or death. "IGI" refers to the microfiche International Genealogical Index maintained at the Coventry Main Library, while IGI/LDS refers to the internet "FamilySearch" site: William Wagstaffe (birth, IGI/LDS C021412); James Brown (birth, IGI MF p2156; marriage IGI/LDS 447923, 72977; IGI MF p1447, apprenticeship enrolment register); John Ballard (marriage to spouse IGI/LDS C133561, 1067410; birth of spouse, IGI/LDS M041925, 1067413); and John Chattaway (IGI MF p7790, apprenticeship enrolment register).

5.7.1.5. Wills and Prerogative Court of Canterbury (PCC)

Although both wills and PCC records were available in Coventry, no individuals were identified as having prepared a will prior to their death. James Brown (COV978) was potentially mentioned in the Index available at Coventry archive: Wills 139, Ref.PA55/29/3 ("Administration with the Will (10 March 1801) Annexed by Thomas (I) Smith – 17 March 1801").

5.7.1.6. Trade Directories

Trade directories were held at both the Family Research Centre (London) and the Coventry Main Library. Only two individuals were directly associated with trade information found in these directories: Richard Ballard and Mary Ballard, respective brother and wife of John Ballard (COV 1119) were identified as owners of the Golden Cross Tavern (Pigot 1835); and Charles Read, watchmaker of Harnall Place and listed master to John Chattaway (Pigot 1841).

5.7.1.7. 1841 Census of Coventry

Two individuals were securely identified in the Census of Coventry (Coventry 1841): James Brown, listed as living in Harnall Place (district 22); and John Chattaway and family, listed as living in Tower Street (district 12). No other individuals were listed as resident in Holy Trinity and none were identified from the parish of St. Michael or St. John.

5.7.1.8. Additional Sources

The internet resource "Cyndi's List" was consulted for parallel information, identifying "CovKid", the source of the Voter's List identifying James Brown and Richard Ballard as individuals of high socio-economic status.

No other records were identified that pertained to the individuals that form the Coventry named sample. Given the low socio-economic status of the site the paucity of the evidence is not surprising. Identification of the marriage records for the named sample would potentially allow identification of occupation of a wider number of the individuals, as well as the maiden name of the female named individuals allowing a more detailed interpretative framework of the socio-economic class of the Coventry sample as a whole.

5.7.2. Chelsea

Extensive research was performed subsequent to the preparation of the post-excavation assessment report for the "2-4 Old Church Street OCU00" excavation identifying the major sources of information on the named sample from Chelsea (Miles 2001). While additional

historical research on the biographically-identified individuals of Chelsea was performed, the previous work worked as a desk-based and post-excavation analysis of the Chelsea material greatly facilitated the interpretation of the Chelsea collection. Additional research was performed at the London Metropolitan Archive (LMA), Family Research Centre (FRC, London) and the Guildhall Library (London), as well as utilising online resources (IGI/LDS, etc.).

The generally increased socio-economic status of the Chelsea sample provided a greater variation in the nature of the records available, including Prerogative Court of Canterbury wills, newspaper clippings, and so forth.

5.7.2.1. London Metropolitan Archive

Miles (2001) identifies archival sources utilised in the records of baptisms, marriages and burials in the parish of St. Luke's and is given in the table 15. The results of the analysis is summarised in section 6.2 and Miles (2001).

5.7.2.2. Family Research Centre

The FRC provided a valuable source of many of the documents significant to the biographic reconstruction of individuals from Chelsea, more particularly Thomas Langfield (CHE147), the Hand family (CHE35 and CHE622) and the Long family (CHE654, CHE722, CHE713 and CHE744). These included the Death Duty Registers for Gideon Richard Hand (IR 27/46) and Thomas Long (IR 27/202); Administration for Richard Hand (PROB 6/213/4 (Middx) folio 192-292); Index of Administration for Richard Hand (PROB 12 Middx April 136); PCC will for Thomas Langfield (PROB 11/1486, sig 814); PCC will for John Long Esquire (PROB 11/1664 sig 643 p370-371); and PCC will for Thomas Long (PROB 11/1733 sig 653).

No other extent wills, PCC or otherwise, were identified in the Chelsea named sample.

5.7.2.3. Guildhall Library

The Guildhall Library maintained a Sun Fire Office Policy (no. 439073) for Margaret Hand of the Royal Bun House, near the Five Fields, Chelsea (ms 11936/289). Mrs Hand is identified as a "pastry maker".

5.7.2.4. Other Sources

The Chelsea Local Library contained a number of contemporary sources and commentaries on the Chelsea Bun House, most significantly, including identification of individuals as 'subscribers' to the Faulkner, e.g. Thomas Long (Faulkner 1829). These sources are discussed in the second chapter and include: (Chambers 1816; Faulkner 1929; Bryan 1869; L'Estrange 1880*a*, *b*; Martin 1889; Anonymous 1899; Davies 1904; Gomme and Norman 1913; Blunt 1918, 1921, 1928; Godfrey 1921; James 1950; Edmonds 1956; Pocock 1970; Holme 1972; Cathcart-Borer 1973; Grant 1975; Marsh 1984; Farid 1997; Patridge 1997; Richardson 2003).

5.7.3. Other Sources

A number of electronic sources were consulted in attempting to determine biographical details of individuals from Chelsea and Coventry. These include:

- London and Middlesex Genealogy Society on-line list, though most "look up" information concentrated on the mid- to late-19th century outside of the scope of this project.
- Caribbean Mailing and Name Lists, more specifically for the name "Maxwell". No additional information was available online and original Caribbean archives were not consulted.
- *Cyndi's List*, an extensive host for online genealogical research including sites that cover London/Middlesex and Coventry ("Cov Kid"), and including online map resources.
- The Middlesex Past electronic archive for their online publication of the Victoria County History for Chelsea, a resource that was invaluable in building up a contextual history of Chelsea (http://www.middlesexpast.net/).

Reference	date	Register	Microfilm no.
P74/LUK/161	Feb 1559 – Mar 1654 Oct 1559 – Aug 1652 May 1559 – May 1652	Baptisms Marriages Burials	X026/012
P74/LUK/162	Jun 1653 – Mar 1703 Aug 1653 – Feb 1703 Mar 1653 – Mar 1703	Baptisms Marriages Burials	X026/012
P74/LUK/163	Mar 1704 – Mar 1747 May 1704 – Jan 1748 Mar 1704 – Mar 1748	Baptisms Marriages Burials	X026/012
P74/LUK/164	Mar 1748 – Dec 1777 May 1748 – Feb 1754 Mar 1748 – Dec 1777	Baptisms Marriages Burials	X026/012
P74/LUK/271	Jan 1756 – Dec 1759	Burials	X026/021
P74/LUK/272	Jan 1771 – Dec 1780	Burials	X026/021
P74/LUK/255	Jan 1778 – Dec 1812	Burials	X026/016
P74/LUK/273	Jan 1781 – Dec 1789	Burials	X026/021
P74/LUK/275	Mar 1795 – Feb 1863	Burials	X026/022 (unfit)
P74/LUK/256	Jan 1813 – Jul 1817	Burials	X026/017
P74/LUK/276	Jan 1813 – Sep 1826	Burials	X026/022
P74/LUK/257	Jul 1817 – Jun 1821	Burials	X026/017
P74/LUK/280	Jul 1819 – Dec 1820	Burials	X026/023
P74/LUK/258	Jun 1821 – Oct 1824	Burials	X026/017
P74/LUK/281	Aug 1821– Dec 1824	Burials	X026/023
P74/LUK/259	Nov 1824 – Sep 1827	Burials	X026/017
P74/LUK/282	Jan 1825 – Dec 1827	Burials	X026/023
P74/LUK/277	Sep 1826 – Sep 1836	Burials	X026/036
P74/LUK/260	Sep 1827 – Aug 1830	Burials	X026/018
P74/LUK/283	Jan 1828 – Aug 1828	Burials	X026/023
P74/LUK/285	Sep 1828 – Sep 1834	Burials	X026/023
P74/LUK/284	Sep 1828 – Jan 1840	Burials	X026/023
P74/LUK/261	Aug 1830 – May 1833	Burials	X026/018
P74/LUK/262	May 1833 – Jan 1836	Burials	X026/018
P74/LUK/263	Jan 1836 – 1838	Burials	X026/018
P74/LUK/278	Oct 1836 – Sep 1848	Burials	X026/036
P74/LUK/264	Sep 1838 – Aug 1841	Burials	X026/019
P74/LUK/265	Jan 1841 – Sep 1841	Burials	X026/019
P74/LUK/266	Aug 1841 – Sept 1844	Burials	X026/019
P74/LUK/267	Sept 1844 – Jul 1847	Burials	X026/019
P74/LUK/268	Jul 1847 – Sep 1849	Burials	X026/020
P74/LUK/279	Sep 1848 – 1860	Burials	X026/037
P74/LUK/269	Sep 1849 – Apr 1852	Burials	X026/020
P74/LUK/270	Apr 1852 – Jan 1883	Burials	X026/020

Table 15: LMA archives consulted by Miles (2001) and in follow-up biographical research (author); table derived from Miles (2001).

Site	Sample	Name	Birth	Death	Age	Biographical Details
Coventry	COV-13	Thomas Thomson		<1837		No details recovered.
	COV-16	Ann Kimberly	1770	1847	77	Last resident on Spon Street (parish of St. Michaels).
	COV-50	...ein...	1797	1840	43	No details recovered.
	COV-77	Eliza Burton	1797	1820	30	Last residence in "Agnes Street".
	COV-417	Sarah Green	1787	1847	60	Last residence in "Much Park Street".
	COV-434	Hannah Denney	1803	1825	23	Last residence on "Gran Street".
	COV-516	... Cooper	1780	1845	65	No details recovered.
	COV-672	Eliza Sparkes	1814	1844	30	Last residence in Palmer's Lane; not listed in 1841 Census.
	COV-808	William Wagstaffe	1798	1846	48	Last residence in "Eswith Street".
	COV-866	Harriet Parsons	1821	1846	25	Last residence in King Street. Possibly Harriet Ashby (15) living in a house with Joseph Goode on the north side of King Street.
	COV-978	James Brown	1785	1846	61	Ward of the parish of St. Michaels. Apprenticed to James Price (weaver) on 28-10-1797. Last residence Far Gosforth Street. May have been resident in Harnall Place with wife Hannah and children Charles, Ann, Mariah, Charlotte and Mary (1841 Census). Contradictory information on location of birth: possibly born in Warwick or Coventry, though more likely the former (marriage with Hannah). Listed in the Voter's List for the period.
	COV-1119	James Ballard	1760	1823	60	Lost residence in St. John's Bridge. Brother to Richard Ballard and possibly trade directory references to being a brewer. Richard Ballard listed as the owner of the Golden Cross Tavern, subsequently run by Mary Ballard (?wife).
	COV-1248	John Chattaway	1823	1842	19	Apprenticed to Charles Read (watch and clock maker; Harnall Place) through charitable support. Father, John, was a labourer in nearby hamlet of Radford, then later in Coventry (Tower Street). Mother Ann, brothers Timothy (journeyman weaver), Job (apprentice), John and sister Phoebe. Died of typhus?

Table 16: Summary of biographical details from Coventry sample.

Site	Sample	Name	Birth	Death	Age	Biographical Details
Chelsea	CHE-35	Gideon Richard Hand	1761	1821	60	Last residence Pimlico Row, known address of the Chelsea Bun House.
	CHE-147	Thomas Langfield	1741	1808	67	Last residence in Danvers Street. Gentleman of means and property. See *Appendix 2*.
	CHE-432	John M?	?	?	?	No details recovered. Miles (2001) reports a "John Mann" in Paradise Row (Faulkner 1829).
	CHE-622	Richard Gideon Hand	1752	1836	84	Last address Grosvenor Row, listed as the location of the Chelsea Bun House. Described as a "poor Knight of Windsor" upon his death, worth $3,000.
	CHE-654	Thomas Long	1749	1827	78	Last address Beaufort Row. Married to Catherine (CHE-722). Property-owner. See *Appendix 2*.
	CHE-713	John Long Esquire	1754	1822	68	Last address Beaufort Row, subsequently bequeathed to his brother, Thomas Long (CHE-654). Part of an extended family not sampled, including Esther, Harriet Elizabeth and Matilda.
	CHE-722	Catherine Long	1766	1822	56	Wife of Thomas Long (CHE-654). Last residence in Sloane Street, of which a property is listed in PCC records (see *Appendix 2*). Mother of ten children.
	CHE-744	John Long	1723	1793	70	Resident of Little Chelsea. Husband of Esther, most likely the Sister of John Long Esquire (CHE-713) and Thomas Long (CHE-654). Part of the Long family.
	CHE-792	Milborough Maxwell	1739	1807	68	Possibly related to Elizabeth Maxwell. Otherwise no information recovered.
	CHE-980	Sarah Adams	1752	1806	52	Maiden name Young. Married Nicholas Adams (bricklayer) 1782. Second wife.
	CHE-990	Charity Adams	1749	1781	32	First wife of Nicholas Adams (bricklayer).
	CHE-1051	?Collon	?	?	?	No details recovered.

Table 17: Summary of biographical details from Chelsea sample.

Date	$^{206}Pb/^{204}Pb$	1σ	$^{207}Pb/^{204}Pb$	1σ	$^{208}Pb/^{204}Pb$	1σ	$^{207}Pb/^{206}Pb$	1σ	$^{208}Pb/^{206}Pb$	1σ
13/05/2004	16.9372	0.0022	15.4934	0.0027	36.7039	0.003	0.914769	0.0008	2.16706	0.0011
	16.9348	0.0019	15.4908	0.0022	36.671	0.0026	0.914737	0.0007	2.16696	0.0012
	16.9353	0.0019	15.4919	0.0022	36.701	0.0027	0.914767	0.0008	2.16710	0.0012
	16.935	0.002	15.4918	0.0022	36.7009	0.0026	0.914750	0.0007	2.16712	0.0011
	16.9353	0.002	15.4914	0.0026	36.6983	0.0029	0.914736	0.0009	2.16698	0.0013
	16.9339	0.0023	15.49	0.0029	36.6953	0.0035	0.914755	0.0008	2.16698	0.0014
Average	**16.9352**		**15.4916**		**36.6994**		**0.914752**		**2.16703**	
1s	**0.0011**		**0.0012**		**0.0031**		**0.00001**		**0.00007**	
RSD	**0.0064**		**0.0074**		**0.0085**		**0.0016**		**0.0032**	
Normalisation Factor	**0.9996**		**0.9995**		**0.9993**		**0.9999**		**0.9997**	
12/05/04	16.9339	0.0019	15.4907	0.0024	36.6990	0.0029	0.91478	0.0008	2.16722	0.0014
	16.9341	0.0025	15.4913	0.003	36.6985	0.0034	0.91478	0.001	2.16714	0.0015
	16.9335	0.0018	15.4898	0.0024	36.6950	0.0028	0.91474	0.0008	2.16693	0.0012
	16.9334	0.002	15.4898	0.0026	36.6945	0.003	0.91475	0.0008	2.16700	0.0013
	16.9341	0.0024	15.4904	0.0028	36.6967	0.0035	0.91475	0.0008	2.16702	0.0014
	16.9347	0.002	15.4914	0.0026	36.6998	0.0031	0.91476	0.0009	2.16713	0.0016
Average	**16.9340**		**15.4906**		**36.6973**		**0.91476**		**2.16707**	
SD	**0.0005**		**0.0007**		**0.0022**		**0.00002**		**0.00011**	
RSD	**0.0027**		**0.0045**		**0.0060**		**0.0019**		**0.0049**	
Normalisation Factor	**0.9995**		**0.9994**		**0.9993**		**0.9999**		**0.9997**	

Table 18: NBS 981 corrected standards for two PIMMS runs at NIGL, Keyworth.

6. Results and Discussion

The following chapter presents the results of thesis, dividing into three broad sections.

1. For the named individuals in the Coventry and Chelsea samples, a synthesis of the historical and osteological record is presented and interpreted.
2. A summary of the osteoarchaeology from Coventry and Chelsea, and comparison between the two sites and the broader osteoarchaeological record of post-medieval England.
3. The presentation and discussion of the results from each of the isotopes used in this study.

6.1. Biography and Osteology of the Individuals from Coventry

While section 6.2 focuses purely upon the interpretation of the sites of Coventry and Chelsea in terms of the osteology of the period, this section aims to integrate the historical record with that of the biology, or more specifically pathology, of the named individuals. Similarly, the pathologies of the un-named sample are briefly described. How do the expectations of the historical literature mesh with that of the osteological record, and what inferences can be derived from consideration of both sources of data?

6.1.1. COV13 (Thomas Thomson)

The coffin plate used to identify Thomas Thomson, unfortunately, was so degraded that all that could be deciphered was the name of the individual and the indication that the individual was of pre-1837 origin (the specific reason is not mentioned in the archaeological archive or subsequent publications). A search of the archives revealed no individual by this name, or a sufficiently similar alternative (i.e. Thomas Thompson, Tomas

Thompson/Thomson), recorded as being interred in Holy Trinity. There are a number of references to both "Thompson" and "Thomson" within extent trade directories but, once again, there is insufficient information to link the individuals mentioned securely to COV13.

While the lack of historical information is frustrating, based upon the pathology from the Coventry sub-sample it is possible to make some inferences about the life experience of the individual as recorded on their musculoskeletal physiology. Osteological analysis revealed that Thomas suffered not only from osteoarthritis of the spine, but also of the clavicle (i.e. part of the shoulder girdle including the scapula). The age of Thomas, interpreted through osteological means as "60+ years", prevents an identification of spinal osteoarthritis with occupational stress as it is increasingly found in patients over the age of 60-70 years, i.e. it is idiopathic and results from multiple aetiologies (Aufderheide and Rodriguez-Martin 1998). The osteoarthritis of the clavicle/shoulder is, however, usually secondary to occupational stress suggesting that Thomas was engaged in unilateral activity involving the shoulder and upper arm (Aufderheide and Rodriguez-Martin 1998). In comparison with the pathologies in the named individuals, osteoarthritis of the arm and shoulder is remarkably common, suggesting a population suffering in general from occupational stress that, when taken into account the period, might be attributable to weaving and the many other industries of Coventry.

6.1.2. COV516 (? Cooper)

"Cooper" was buried in Holy Trinity in 1845 though again no record of the burial could be found in the Holy Trinity burial register. Although this might be thought unusual, this is not the case. Burials within inner-city graveyards were becoming increasingly rare during the period, both generally and in Holy Trinity where 1849 marks a rapid decline in the number of burials per year, dropping to one in 1856 with the final burial (CovMF 1273/19). As a result of a movement towards non-denominational 'garden cemeteries', e.g. the 1832 Act for

the creation of the Kensal Green Cemetery (London), but also from an increasing awareness of the potential health implications of corpses left exposed to view, burial increasingly moved away from the urban burial grounds (Wohl 1983; Cox 1998; Rugg 1998). Indeed, the last burial mentioned in 1856 was a "JB", interred by Frances Dreeson, with no mention of another of the Coventry samples "MH" also said to be buried in this year. Further, continued burials by the 'wealthy' continued within urban cemeteries despite fines held in place against such activity by, for example, the 1852 Burial Act (15&16 Vict c85) (Wohl 1983). While the interment of "Cooper" occurred at a time when legisislative force was being brought to bear, including the civil registration of deaths required by the 1864 Registration of Burials Act (27&28 Vict c97) and the 1874 Births and Deaths Registration Act (37&38 Vict c88), the lack of archival record of his burial cannot be considered unusual for the period (Wohl 1983).

As in the care of Thomas Thomson, the original osteological analysis revealed potential indicators of occupational activity, more specifically recorded in bilateral variation in the leg. That is to say the right leg – tibia and fibula – showed a significant increase in size and shape indicative of continued and stressful activity. While it is difficult to ascribe such activity to a specific activity, one can quite readily imagine a similar alteration to the morphology of the bones of the leg resulting from the operation of, say, a peddle press. Any specific assignment of occupation is, however, impossible without further analysis of cross-sectional geometry, mulsculoskeletal markers (MSM) in the population as a whole (Larsen 1997). Similarly, "Cooper" suffered from enamel hypoplasia, indicating childhood stress, as well as the presence of two abscesses and ante-mortem tooth loss.

The osteology of "Cooper" is characteristic of the Coventry population, generally: poor dental health, including indications of childhood sickness or deprivation, and occupational stress which continued into the later decades of life.

6.1.3. COV808 (William Wagstaffe)

William Wagstaffe, son of William and Sarah Wagstaffe, was born on the 19th February 1798 in the parish of St. Michael, Coventry (International Genealogical Index (IGI) C021412). While there is no specific occupation for this individual, in terms of his osteology William shows similar characteristics to others within the Coventry sub-sample. On the 16th August 1846 William, last resident in Jewth Street (CovMF 1273/19, burial 1530) died of "phthisis" and was finally interred in Holy Trinity by J.B. Winkworth (Wakely 2001). The name 'Wagstaffe' is also associated with a number of trades in Coventry, but there is no mention in the various extant trade directories to indicate the presence of a 'William Wagstaffe' (Bailey 1783; Extracts 1783-1817; Bailey 1784; Universal 1793; Holden 1805; Golden 1814-15; Holden 1816-17; Pigot 1822-3, 1828-9, 1835, 1841). This, of course, does not mean that William was not present in Coventry. Rather, it likely means that he was not sufficiently advanced in his 'trade' to be highlighted as a separate individual.

Other than what appears to be the 'norm' for Coventry in terms of dental hygiene, e.g. the presence of mild calculus and several dental abscesses, the osteoarthritis present in other individuals is absent. While there is a non-specific infection of the periosteum of the tibia (periostitis), this could have resulted from either infection or trauma, for instance via an impact to the left shin. Seemingly, in whatever function William played within the society of Coventry, his body had not been subjected to the same level of stress evident in the rest of the sample.

6.1.4. COV978 (James Brown)

In the case of James Brown, several strands of historical information can be drawn together to provide a comparatively comprehensive picture of his life. Born in 1785 (IGI, p2156) in the parish of St. Mary, Warwick, he at some point travelled to Coventry where at the age of

4 years he was christened on the 10th March 1789 (IGI, p2156). By his twelfth year (11-13 years), James was a ward of the parish of St. Michael and had been sponsored to an apprenticeship with James Price, weaver (Apprentice Enrolment Register, 1447).

James had not only lived outside of Coventry but, through his lifetime, at several places within the city. There is a tentative link to a sixteen-year-old James on the 17th March 1801:

> "... of Holy Trinity Parish, Coventry, ribbon-and-velvet manufacturer, the testator bequeathes to his wife Martha his personalty, looms, the lease of the adjacent house which William Wallis inhabits and two tenements on the southern side of New St. (sic) (occupied by Widow James and James Brown); thereafter the property will pass to his children Thomas (II), Jacob, John, William, Hannah ("Peeters"), Elizabeth and Joseph or by default to their children, with right of survivorship." *(Wills 139, Ref.PA55/29/3; "Administration with the Will (10 March 1801) Annexed by Thomas (I) Smith – 17 March 1801")*

The circumstances in which he met his wife, Hannah, remain unknown though they married in St. Mary, Warwick, on the 26th January 1812 (IGI 447923, 72977). James seemingly remained in both his and his wife's home parish of St. Mary for at least five years where, in 1817, Hannah gave birth to their first child, Caroline. Following Caroline's birth, the Browns returned to Coventry where in 1841 they were resident at Harnall Place in the parish of St. Michael (district 22). James and Hannah's first daughter, Caroline, is not listed in the residents of the house in the census though it is not known whether she had previously died or married and moved into the house of her husband (Coventry 1841). Five other children are mentioned in the census: Ann (25 years), Maria (20 years), Charlotte (18 years), Charles (15 years) and Mary (14 years).

While James is recorded as an apprentice to a weaver and, presumably, became one himself in time, his exact socio-economic status is not known. James could have been anything from a secondary-class weaver, a manufacturer or indeed manufacturer/trader. Some indication is given in 1826 where several "James Browns" are mentioned in the 1826 Voters' List as "town voters") and in 1834, including both the £5 and £10 level

(http://www.covkid.org.uk/). While there is at present no definitive link between COV978 and the James Brown's mentioned on this Voters' List, it does suggest that there is at least the potential for him to have been a moderately wealthy individual.

In the following five years from the taking of the census, the Browns seem to have moved into Far Gosford Street – a residential area in Coventry from as early as the thirteenth century – where, at the age of 61 years, he died. J.B. Winkworth, curate at the time, inters James on the 7th January 1846 (CovMF 1273/19).

The osteological archive reveals James to have a very robust skeleton, although suffering from a range of dental diseases not unusual to the period (see Chapter 3), including an abscess of the canine, ante-mortem tooth loss, enamel hypoplasia (see above, approximate age of affect 1.6-4.4 years) and severe periodontitis (Wakely 2001). Distortion to the nasal bones may indicate a fracture either through interpersonal violence or from industrial accident, although the exact cause cannot be determined. Once more we see osteoarthritis in the right shoulder and, as previously mentioned, this is usually secondary to occupational activity. It would therefore seem reasonable to suggest that his occupation as a 'weaver' resulted in this osteoarthropathy. Other pathologies present would have little effect on James, more specifically a slight craniosynostosis of the saggital suture (Aufderheide and Rodgriguez-Martin 1998; Wakely 2001) and, potentially related, a midline diastema of the palate (Wakely 2001).

While James seems to have had suffered from common childhood diseases, such as enamel hypoplasia, he seems to have been broadly unaffected in the long term. Although the parish supported him in his apprenticeship to James Price, notably in a period of relative success for the weaving industry in Coventry, it is possible that he became a successful businessman, as reflected in the mention of a James Brown in the Voter's List and final place of residence.

6.1.5. COV1119 (John Ballard)

John Ballard resided on St. John's Bridge at his death on the 25th December 1823 (CovMF 1273/18, burial 1565). At 60 years of age when he died, he is the earliest sample from Coventry, being born in 1763. John married Mary Allen, born to William and Mary on the 23rd May 1762 in the parish of Holy Trinity (C133561, 1067410), on the 12th April 1784 (M041925, 1067413). Mary Ballard is subsequently listed as the proprietor of the Golden Cross tavern in 1835, taking over from Richard Ballard (Pigot 1835). While John is not specifically mentioned in reference to this public house, a John Ballard is mentioned as a 'victualler' of the "Unicorn" in 1793 (Universal 1793). Further, after his death a John Ballard is also mentioned in the 1835 trade directory as a 'Maltster' in Burgess – this being one of the names for St. John's Bridge being "bitwene the brugges" (VCH 1969) –and it is possible that this was his son (Pigot 1835).

Following John's death on the 25th December 1823 (CovMF 1273/18, burial 1565), his brother Richard, mentioned in the 1834 Voters' List with several other John Ballard's continues to run the Golden Cross tavern until Mary Ballard, John's wife came into the proprietorship (Pigot 1841). In the decades following John's death, his son, brother and wife continued within either the production and transport of ale or its sale.

Given his links to the Golden Cross tavern, the osteology of John Ballard is especially interesting in terms of occupational stress. While osteoarthritis of the spine is idiopathic and increasing in frequency with age, John suffered not only from degenerative joint disease of the spine (e.g. osteophytosis) but also a significant number of osteochondroses of the vertebral bodies, extending from the seventh thoracic to the third lumbar vertebra consistent with an aggressive case of Scheuermann's disease, or extreme kyphoses of the spine (Aufderheide and Rodriguez-Martin 1998). While there is genetic transmission of this

condition it also has a traumatic aetiology. Furthermore, John also suffered from osteoarthritis of the knees.

John's life, seemingly, was one of continued stress to his body resulting in gradual degeneration of his knees and spine, more than likely related to continued bending and straightening of these joints with massive objects. Despite this, however, as a 'maltster' or 'victualler' associated with the Golden Cross tavern, itself an established public house and the listing of Richard Ballard as a town voter would strongly suggest that John was a wealthy and, presumably, respected and prominent individual.

6.1.6. COV1248 (John Chattaway)

As in the care of James Brown (COV978), John Chattaway is an individual where a number of strands of evidence combine to provide a more comprehensive view of his life history. Aged nineteen years when he died, John was born on the 27th February 1823 in the parish of Holy Trinity, Coventry (Coventry 1841, district 12; IGI, p7,790; CovMF 1273/19 burial 575). While born in Holy Trinity, the Apprentice Enrolment Records for John's older brother, Job, reveal that at some point in their life the family lived in the small village of Radford, to the east of Coventry where they remained until at least 1835 (Apprentice Enrolment Register 1391). Indeed, John's father, also called John, is listed in the registry entry dealing with Job as a 'labourer', consistent with the economy in and around the village of Radford (sees Chapter 2).

The Chattaway family returned to Coventry by 1841, when they are listed as living in Tower Street where they remained until John's death on 1st March 1842 (Coventry 1841, district 12; CovMF 1273/19 burial 575). The family, composed in 1841 of John senior's wife Ann (not born in Holy Trinity, 50 years), Timothy (25 years, journeyman weaver), Job (20 years, apprentice weaver), John (15 years, apprentice weaver) and Phoebe (9 years), was

presumably not particularly wealthy. For it was only with the charitable support of "Baker, Billings and Crow" of Coventry that John was apprenticed to Charles Read, a watchmaker of Harnall Place on 9th September 1836 (Pigot 1841). While John's father was a labourer and his elder brothers were weavers, John is apprenticed as a watchmaker at the cusp of transition from the dominance of the weaving trade to the rise of the local watch-making trade (see Chapter 2).

Osteologically, the archaeological record suggests that John's life was one of hardship, if not necessarily deprivation. Not only did John have poor dental health allowing the incidence of caries, ante-mortem tooth loss even at this young age as well as diffuse periodontitis, but also enamel hypoplasia of the canine indicating a childhood (3-5 years) period of stress (Wakely 2001). Spina bifida occulta was also present, as well as cribra orbitalia. Interestingly enough John also evidences Schmorl's nodes in the lower thoracic spine (T10, T12) linked to intervertebral disc disease potentially resulting from continued flexion and extension of the spine, and therefore probably occupational. It should also be noted that one of the ageing methods employed in ageing John, (i.e. epiphyseal fusion), suggested a much lower age than the chronological age indicated in the burial register and baptismal record (White 1991; Buikstra and Ubelaker 1994; Bass 1995).

John's early life seems to have been one of hardship and childhood illness, though John would certainly not have stood out as unusual in this regard (Wrigley and Schofield 1981; Daunton 1995; King and Timmins 2001). Indeed, contrary to the osteological record for the post-medieval period, it would seem that many of the individuals formed of the Coventry showed indications of enamel hypoplasia (Roberts and Cox 2003). Although an agricultural labourer, his father was capable of sponsoring at least his eldest children into the weaving trade in the hope of bettering their future, a hope that would be defeated in the long-term by the changing economy of Coventry itself. Moving away from the village of Radford, John needed charitable support to take up his position as an apprentice watch-maker in Harnall

Place, "Baker, Billings and Crow" recognising the rising prominence of the watch-making trade. Indeed, one wonders whether at some point in their lives the young John Chattaway came into contact with the elder James Brown or, at least, whether James Brown and John's master ever had course to engage in business. Short-lived as the burgeoning watch-making trade would be in the face of competition from both London and Birmingham, John would never see these developments because he died of some unknown pathology in 1842 (Allen 1929; Duggan 1985).

6.1.7. COV 16 (Ann Kimberly)

At the time of her death on the 11th of February 1847, Ann Kimberly aged 77 years, was last resident on Spon Street (CovMF 1273/19). While there are numerous mentions of a 'Kimberly' in the trade directories, including one 'Charles Kimberly' a 'Boot/Shoe Maker' (Pigot 1841) no definite link can be established.

In terms of the osteological record, Ann was, by the time of her death, suffering from osteoarthritis in her hip, shoulder, spine and hands. Of average height for the period (1.59m), she nonetheless suffered from a mild, medio-lateral bowing of the bones of the leg indicating a case of rickets. Furthermore, one rib had been fractured earlier in her life and subsequently healed. A death certificate recorded for Ann Kimberly suggests that she died of bronchitis (Wakely 2001).

The osteological record presents a picture of Ann consistent with the Coventians mentioned previously. During her childhood Ann suffered from childhood rickets, at least impacting on her legs, to give her the typical 'bowed legs' of a rachitic individual. Despite this her dental hygiene was good for the Coventry sample and, indeed, for the population generally during the post-medieval period (Roberts and Cox 2003). Ann also suffered from the same types and distributions of osteoarthropathies seen in others among the Coventry sample,

namely osteoarthritis of the upper appendicular skeleton, e.g. shoulder and arms. While these may be related to occupational stress, the osteoarthritis of the spine and hip are idiopathic, increasing in proportion with age and sex (female) (Aufderheide and Rodriguez-Martin 1998). One can only wonder as to the occupation that engendered these osteoarthropathies: was she too involved in the weaving trade so prominent in Coventry? Or perhaps she was involved with the boot and shoe-making trade, helping her husband?

6.1.8. COV76/77 (Eliza(beth) Burton)

The burial register reveals that an Elizabeth Burton at 30 years of age died on the 20th March 1827 and was interred by John Davies, curator of Holy Trinity at this time (CovMF 1273/18, burial 2186). While she was last resident in Agnes Street, the only Burton mentioned in the Trade Directories for this period was a John Burton, a builder living in Butts Lane (West 1830).

Elizabeth was a petite woman at 1.50m (1.58m is the median value for the period), she suffered not only from osteoarthritis of the elbow but also tuberculosis of the lower spine (first and second lumbar vertebra). She also seems to have been interred with COV77 (SMC99 SK77), a child whose age is estimated at just over one year of age (1 year ± 4 months) (Wakely 2001).

Elizabeth had advanced secondary tuberculosis that had moved away from the likely primary site of infection (e.g the lungs) that, given the cramped conditions in the lower-status housing of Coventry during the period, would likely have had an impact on both Elizabeth and those surrounding her. The osteoarthritis of the arm (elbow) at such a young age is once against suggestive of stress secondary to occupational activity. While the direct relationship between Elizabeth and the child interred with, or near, her cannot be directly established, a familial relationship is likely, possibly even directly as the child's mother.

6.1.9. COV417 (Sarah Green)

Sarah Green was buried in Holy Trinity on the 20th November 1847 at the age of 60 years (CovMF 1273/19, burial 1849). As there are no 'Sarah Greens' present in the Holy Trinity baptismal records it is highly likely that Sarah was married, though the common presence of the surname 'Green' make tracing a marriage record problematic. While the IGI provides a number of potential possibilities for the marriage of Sarah, each indicates a particularly late age of marriage that is not consistent with the Coventry named sample. Furthermore, only two individuals of the name 'Green' are encountered in the extant trade directories: Thomas Green, a 'barrister at law' of Bishop Street (Bailey 1783); and Thomas Green, 'surgeon and apothecary' (Universal 1793). Neither would seem obviously linked to Sarah, either based on her last residence in Maid Paste Street, or as an obvious similarity in period.

Osteologically, as with much of the Coventry sample, Sarah had a degenerative joint disease of the spine, though given her advanced age it is not possible to suggest occupational stress over senescence (Aufderheide and Rodriguez-Martin 1998). Sarah also suffered from a dislocated jaw that had not been reduced back into the joint allowing the formation of a pseudoarthrosis. One can only imagine the continued pain of mastication and even talking. As with the other individuals from Coventry, Sarah also suffered from ante-mortem tooth loss, more notably of the mandibular molars, periodontitis and extensive calculus. She also has the same form of craniosynostosis present in James Brown, i.e. a 'mild' early fusion of the saggital suture. Given the genetic component in the formation of these pathologies, they are often linked to kin-based structures and a larger, focussed study of Coventry material in terms of non-metric traits, commonly used to determine biological affinities within a skeletal population, would be useful to suggest the nature of familial diversity within the Coventry sample (Larsen 1997).

Sarah's life is therefore historically opaque. While she shares the same broad pathology as the other Coventry individuals, the lack of non-spinal osteoarthopathies and her advanced age mean that it is difficult to suggest occupation as a cause. Despite this, her dental hygiene seems broadly consistent with the remaining Coventians, though this is not surprising given the period and, indeed, one can draw parallels with her pathologies and those in the Chelsea sample below.

6.1.10. COV433/4 (Hannah Denney)

Hannah Denney was last resident in Spon Street before she died on the 17th July 1847 at the age of 22 years (CovMF 1273/18, burial 1857). The surname 'Denney' is rare in extant trade directories for Coventry, appearing in 1830 as a 'turner' in Gosford Street (West 1830).

While the historical record tells us little about Hannah Denney, the osteological record reveals a picture of occupational strain to Hannah's young body. She suffered from Schmorl's nodes to the eighth and tenth thoracic vertebrae, as well as osteophytes from the tenth to twelfth thoracic vertebrae. While degenerative joint disease of the spine is related to age, at 22 years such degeneration is most likely to be related to occupational activity. Further, she had osteoarthritis of the metacarpal-phalangeal joints (knuckles) suggestive of continued stress to the hands. Hannah's dental health is amongst the poorest in the Coventry sample, with extensive ante-mortem tooth loss, caries and a periapical abscess.

Hannah's life was seemingly one of hardship, with continued strain to the spine leading to intervertebral herniation and, one would imagine, continued back pain. Her access to any form of dental hygiene seems extremely limited and these two features taken together make it reasonable to infer that Hannah came from the lower socio-economic classes of Coventry.

6.1.11. COV672 (Eliza Sparkes)

Eliza Sparkes, last resident in Palmer's Lane, was buried on the 31st July 1844 at the age of 30 years (CovMF 1273/19, burial 1077). No mention of an Eliza Sparkes is found in the 1841 census of Coventry for Holy Trinity, and only two mentions of a similar name are found in the Trade Directories, namely: Mrs Spark, widow and ribbon-dresser; and Thomas Spark, huckster (Bailey 1783). Both individuals were born far earlier than Eliza (b. 1814, d.1844).

Once more Eliza has pathologies that are consistent with what appears to be an occupationally dominated Coventry palaeopathology. Osteoarthritis of the jaw and elbow are again present, the former suggesting stress secondary to occupational activity. Furthermore, Eliza is also rachitic, with medio-lateral bowing in both the arms and the legs. While the bowing of the legs is common in those individuals who are motive, the presence in the arms suggests either an early period of impact, e.g. early childhood, or the use of walking aids.

Eliza is representative of continued hardship in Coventry, at least on the individual level. While she suffered from rickets as a child, resulting in extensive morphological changes to her skeleton, she continued to work in such a manner as to suffer from the same occupational pathology (osteoarthritis of the elbow/shoulder) that is common in the Coventry sample. One can quite readily imagine a rachitic individual, perhaps using crutches, continuing to work in the same occupations as many of the others (e.g. weaving) despite initial and continuing hardship.

6.1.12. COV866 (Harriet Parsons)

Harriet Parsons died on the 6th September 1846 at the age of 25 years (CovMF 1273/19, burial 1578). Last resident in King Street she moved to this address in the last years of her life as the census of 1841 indicates that she did not live on King Street in that year (Coventry 1841). Daughter of William and Sarah Sisserson of Well Street and baptised on the 15th May 1821 (COV MF 1273/12 1819-23, baptism 1710), she was raised into a weaving family. There is only a single mention of a 'Parsons' in the trade director: Joseph Parsons, a 'straw hat maker' of Smithsford Street Pigot (1822-3).

A young woman, buried with an artefact identified as a 'hair pin', she did not suffer from the associated pathologies found in the rest of the Coventry sample (e.g. osteoarthritis). Evident pathologies were primarily dental, including enamel hypoplasia throughout the dentition (indicating widespread health impact in or around the age of 5-6 years), periodontitis and ante-mortem tooth loss. Harriet also suffered from the same mid-line deviation in the palate as mentioned for COV978 (James Brown, section 6.1.4).

While born into a 'weaving' family, the exact socio-economic level of the family is not mentioned. Given the lack of occupationally related pathology, e.g. osteoarthropathies of the upper appendicular skeleton, the presence of periodontitis and ante-mortem tooth loss make given her an osteological character more similar to that of Chelsea than Coventry. While this may hint at a higher socio-economic status, the presence of enamel hypoplasia indicates that if she were from a wealthier family then childhood disease did not respect social status (Wohl 1983; Roberts and Cox 2003).

6.1.13. Un-named Individuals

One individual from the Coventry sample was analysed despite the lack of biographical information discernable in the historical record: COV50. Other than she was born most likely in 1787 and died 43 years later in 1840, the only name information that could be deciphered from the coffin plate was "...ein..." No similar letter combination was found in the burial registers, baptismal records or marriage bonds for Coventry.

6.1.14. Brief Summary of Historical and Osteological Data from Coventry

The Coventry males were by far the easiest individuals to reconstruct with a limited biography. Where occupation is listed, either from the individual sampled or as a result of the occupation of a relation (e.g. parental occupation or apprenticeship of siblings), it is perhaps not unusual to see that 'weavers' are commonly represented. As we saw in Chapter 2, the weaving industry was of significance throughout the history of Coventry until external competition saw a decline in the industry and in that of the socio-economic status of many of its practitioners. The common presence of occupational osteoarthritis in the Coventry sample, including those individuals recognised as weavers, does allow reasonable inference as to the socio-economic status of those individuals without defined occupations. That is to say that they are representative of a working class, industrial population.

The Chattaway family, however, provides an interesting example of what may be seen as a changing perception of the relative importance of weaving in the industry of Coventry and one that may also be marked. While the ages reported in the 1841 census are suspiciously neat and appear rounded to the nearest decade of half-decade, approximately one decade and one-half decade separate John from his elder brothers, respectively Timothy and Job both of whom are mentioned as 'weavers'. When John was to come to his apprenticeship, one that was charitably supported by "Baker, Billings and Crow", however, it was to the watch-

making trade that he would be placed. John therefore seems to straddle the economic gap between the waning of the weaving trade, one in which his brothers seem to have been caught up in, and the waxing of the watch-making trade. It is unfortunate that in 1842, in his nineteenth year, he died just before the watch-making trade began to truly rise to significance within Coventry, causing much change to the social fabric (see Chapter 22).

If one now turns to a consideration of the osteological data of the named sample, it is interesting to note some intriguing similarities. Almost all of the sample except the youngest individuals, and even then not exclusively, show some degenerative changes to the post-cranial skeleton. Most notably in the named sample is the axial and appendicular skeleton, e.g. spine, shoulder, elbow and joints. Given the nominally advanced age of the individuals that form the sample (45.2±19.8 years, 1σ) it is difficult to ascribe the pathology to specific occupation. With that said, however, the example of a non-weaver in the sample, namely John Ballard, the distribution, type and extent of the pathologies seem markedly different. While one might point out the upper appendicular osteoarthritis on the 'weavers', John Ballard's pathologies are focussed primarily on the spine, but also on the lower appendicular skeleton suggesting a different biomechanical use, or abuse, in life.

The osteology of the Coventry sample therefore would seem to conform to a working class sample, one in which a predominant industry, probably weaving, is dominant. The presence of individual's resident on the Voter's List for Coventry indicates that the sample covers a spectrum of socio-economic activity, from the 'poor' agricultural labouring families to the wealthier individuals.

6.2. Biography and Osteology of the Individuals from Chelsea

While the details of the Coventry sample are scarce, in part a result of the limited documentation available for those of lower socio-economic status, those of the Chelsea sample are more promising. While continued research may establish more detailed information on these individuals, the identification of wills of the Prerogative Court of Canterbury allow a more detailed picture to be constructed of at least some of the individuals from this cemetery and allow confirmation or otherwise of familial relationships (Miles 2001). Each individual recovered with a coffin plate is covered separately below, regardless of the specific information that could be determined from the historical record. As with section 6.1, the osteology of each individual is mentioned to provide parallel evidence about his or her life experience and history.

6.2.1. CHE 35 (Gideon Richard Hand)

Gideon Richard Hand was the youngest child of Richard 'Captain Bun' Hand and Margaret Hand, owners of the Chelsea Bun House and born in 1760/1. There is little to suggest that his life would have been significantly different from that of his elder brother, Richard Gideon (CHE622) with the exception that as second son his duties might not have been as onerous. As with Richard Gideon, Gideon Richard was last resident in 10 Grosvenor Road (the location of the Chelsea Bun House) upon his death on the 13th February 1821.

The preliminary osteological analysis of the St. Luke's material revealed no obvious pathologies (Miles 2001), though a secondary and focused study by the author revealed some minor dental abnormalities and pathologies. Gideon Richard, despite his wealth and greater access to dental hygiene, suffered from extreme periodontitis, the presence of calculus and a potential periapical abscess of the right maxillary second molar. His secondary incisors, both upper and lower, were congenitally absent and his left mandibular

canine was mesially orientated and rotated, likely causing an alteration to the occlusal characteristics of the jaw (see figure, below). It is, however, unlikely that these pathologies would have seriously impacted upon the life of this individual.

Figure 27: Picture of Gideon Richard Hand's dentition, showing rotated canine and alteration to dental arcade (photo: author).

Gideon Richard, as with his brother, is representative of an individual of high socio-economic status. The absence of any of the occupationally related osteoarthropathies seen in Coventry indicates that, while he may have been directly involved in the running of the Bun House, he was not subject to the same level of stress as those from 'working class' Coventry. While his dental pathologies would have had an obvious visual impact they would not have severely affected his health.

6.2.2. CHE147 – Thomas Langfield

Thomas Langfield, born in 1740/1, was a 'gentleman' who at the time of his death on 5th October 1808 was resident in Danver's Street, Chelsea (Miles 2001). A gentleman of some means, he had property in several locations throughout the United Kingdom:

> "And as to all my freehold, leasehold and personal estate situated and being in the County of Middlesex and the County of Somerset or elsewhere in the Kingdom of Great Britain whatsoever and wheresoever wherewith it may please God to bless me." (Prob 11/1486, Appendix 1).

Along with the various fixed capital assets the PCC will variously confers a not insignificant amount of liquid capital onto a number of individuals, notably:

- Ann Grant (£20) and Mary Grant (£20), both sisters to Mrs Potts of Turnham Green, Middlesex.
- Hannah Lattery (£300).
- Mary and Harriot Lattery (£100 each), daughters of Hannah Lattery "on their severally attaining their respective ages of twenty one years" (Prob 11/1486, Appendix 1).
- Mary Newman (£100), also including household goods.

Excluding fixed capital assets, Thomas Langfield was worth approximately £640 and likely more given the standard requirement that "payment of my funeral expenses and the expenses of proving this my will and all my just debts" be taken into consideration (Prob 11/1486, Appendix 1). Comparison with a random PCC record, such as that presented with the Gideon Richard Hand's 'Index of Administration' indicates that the values sworn under the will vary from £100-600, with occasionally higher values (e.g. Index of Administrations PROB12 Middx April, IR 26/245, p233).

The fixed capital assets are themselves divided between three individuals: Betty Langfield of Stokeunderham[1] (Somerset), Thomas' half-sister; John Langfield of Coalpool in the parish of Stokeunderham (Somerset), Thomas' brother; and Ann Boult, wife of James Boult, gentleman, resident in Taunton (Somerset) (Prob 11/1486, Appendix 1). While one can only speculate on the exact value of the properties owned by Thomas Langfield, they are

[1] Now Stoke-sub-Hamden.

sufficient to enable the payment of £395 4s (with interest at £5 per annum), which includes past debt, on the 1st April of 1809. It is also interesting to note that Mary Newman, described as being resident with Thomas Langfield, was to receive the one-third share of Ann Boult if she died before the will could be enacted.

Some indication of the social status of Thomas Langfield derives from the assignment of the Executors of his will, namely: Mary Newman, said to be resident with Thomas; Richard "Nowiter" Burnard, a surgeon of Crookham (Someset); and James Langfield of Hatfield Broad Oak (Hertfordshire), nephew to Thomas. While the occupations of Mary Newman and James Langfield may not be specifically mentioned, the fact that Richard Burnard is a surgeon, and further that Thomas is in contact with the gentry of Somerset in the form of James Boult and his wife, all attest to moving in the upper echelons of society.

The PCC will offers a somewhat myopic view of Thomas' life in the division of fixed and liquid assets and rarely gives specific insight into the movement or life of Thomas, indeed hinting at more than it defines. That is to say it presents a snapshot of the life of the individual in the moment of his death. Furthermore, the listing of properties and relations in two or three different counties offers the potential of long-distance migration if Thomas was not resident in Chelsea all of his life.

Thomas only had five teeth remaining in his skull (first and second mandibular incisors, both left and right and the right mandibular canine), but of those teeth present all were very heavily affected by both calculus and wear. Despite the ante-mortem loss, Thomas' teeth were otherwise in extremely good condition showing little evidence of caries, calculus or periodontitis. A non-specific infection was present on one tibia.

While the specific status of Thomas Langfield is questionable, both the mention of properties throughout the southern parts of the United Kingdom and his associations with

other 'gentleman' suggest an individual of elevated socio-economic status. While he shows the kind of dental pathology that one is increasingly coming to expect in reading through the palaeopathologies of the individuals of this project, once again the occupationally related osteoarthropathies evident in the Coventry sample are absent. Although it in no way suggests that Thomas lead a life of indolence, it is certain that he was in no way subject to the same level of occupational stress suffered by the Coventry sample.

6.2.3. CHE432 (John M?)

It was not possible to determine biographical information on this individual despite the fact that a fragmentary name could be determined from the coffin plate. While Faulkner mentions a "John Mann" in 1829, the coffin handle form recovered in the excavation (type 3, 1735-9) present a contradictory argument even when one considers the potential of extended residuality of coffin furniture form (Miles 2001).

Osteologically there were no obvious pathologies on CHE432, although a focussed study indicated an osteological age of 21-46 (30-35) years.

6.2.4. CHE 622 (Richard Gideon Hand)

Richard Gideon is likely the single wealthiest individual as well as the most socially prominent in both the Coventry and Chelsea samples. Born into the wealthy Hand family in 1751/2, as the first son, he would have more than likely be involved in all aspects of the family business with an eye to his future inheritance; the Hand's took pride in their occupations, listing themselves as various 'baker' or 'pastry cook' (Sun Fire Policy no. 439073; ms 11936/289). One can imagine a quite varied life, from learning the family trade in its various aspects, to potentially 'rubbing shoulders' with some of the elite members of society, including royalty.

By the time that Richard Gideon was 16/17 he went through the trauma of the death of his father, the infamous "Captain Bun", on the 3rd April 1767 and then, two years later, the death of his younger brother George (21st April 1769) (Miles 2001). Richard's mother, Margaret, took up the running of the family business and it is said that she was the most successful proprietor of this already famous house (James 1950; Cathcart-Borer 1973). When she died some 22 years later on the 13th July 1790, it is likely that both surviving sons – the eldest Richard Gideon as well as Gideon Richard (CHE35; see section 6.2.1 above) – took up running of the Bun House.

The 13th February 1821, was to see another death in the Hand family, namely that of Gideon Richard Hand. Richard Gideon, who had never married as a result presumably of the demands of running of the Bun House, was at some point knighted or is at least, as James asserts, referred to as a 'poor knight of Windsor' (James 1950). With Gideon Richard's own demise some fifteen years later on the 24th February 1836, a time in his life when at least his total liquid assets were worth £3,000, he died without issue and the State was bequeathed his entire legacy (Prob 12 Middx April, IR 26/45, p233). As mentioned in Chapter 2, the Bun House (at 10 Grosvenor Row) – Richard Gideon and Gideon Richard's last residence – then fell into the hands of Robert Loudon who continued to run it until in the summer of 1839 when it was closed to allow the widening of the adjacent road (Wieinreb and Hibbert 1983).

In terms of the osteology of Richard Gideon, no pathologies were evident in the preliminary analysis (Miles 2001) or in subsequent focussed analysis. This in itself is suggestive of a life that while unlikely to have been devoid of stress still did not suffer it to the extent of the Coventry sample.

6.2.5. CHE654 – Thomas Long

Born in 1760/1, Thomas was to spend the majority of his 66 years in and around Chelsea and London. During his life he fathered ten children, five sons (Thomas the Younger, John, Pierre/Peirre, Charles and George) and five daughters (Maria, Eliza, Esther, Emily and Catherine Mary) (Prob 11/1733). Both the PCC will and Death Duty Register (IR27/202) indicate that Thomas was a man of not inconsiderable wealth, owning a number of properties (fixed capital assets) as well as significant liquid assets. The mention of "stock" and references to changes in Parliamentary matters indicates an individual actively participating in the business of London and Chelsea, as well as an awareness of broader political matters.

Last resident in Beaufort Row and subscriber to Faulkner (Faulkner 1829), it is likely that at least some of the property in Thomas' estate derived from his brother, John Long, who died aged 70 years on the 1st April 1793 (Miles 2001). The brothers were seemingly involved in some form of business together in terms of a bond for £700:

> "And whereas there is now due to me from my brother Thomas Long the sum of seven hundred pounds as a security for which I have this bond or writing obligatory under his hand and seal bearing date the twenty eighth day of March one thousand eight hundred and four." (Prob 11/1664)

While the format of the document follows the same format as other PCC wills in terms of the language used in reference to Thomas' estate, one cannot help but wonder as to his character and habits when specific mention is made to certain items:

> "And I bequeath all my household goods and furniture, books, wines and other liquors, plate, linen and china which may be in and about my dwelling house at the time of my decease to my said daughters Eliza, Esther and Catherine Mary equally to be between and amongst them for their respective absolute benefit." (Prob 11/1733, Appendix 2)

The mention of 'books, wines and other liquors' portray a picture of an individual with the resources and, more particularly, the time to engage in social activity.

It is notable that at the time of her death, Thomas' wife Catherine was resident in Sloane Street similarly suggest that the same was true of Thomas (Miles 2001). Thomas' brother, John (CHE713), owned a property in Sloane Street (No. 56) and it is possible that his younger brother was resident with his wife in this tenement although subsequently moved to 18 Beaufort Row when that property was left to him upon the death of John (Prob 11/1733, Prob 11/1664). Both Thomas' wife and brother died within months of each other in 1822 and Thomas and Catherine's former residence was bequeathed to Thomas' eldest children while he moved to his brother's former house.

The preliminary osteological analysis of the material performed by the Museum of London revealed no obvious pathologies (Miles 2001). Subsequent brief analysis substantiated the lack of pathology and suggested that Thomas, at least in terms of his musculoskeletal system, was a remarkably healthy individual. While he may have favoured 'wines and liquors' (Prob 11/1733, IR 26/1137), he was remarkably robust with good dental hygiene. Indeed, both the dentition and degenerative changes used to indicate age in skeletal remains indicated an individual much younger (20-30 years) than we know to be the care from the historical record.

Thomas seems to have been an individual who was actively engaged in both the social and economic life of Chelsea, as well as being politically aware. A physically robust and healthy individual, he certainly was not subject to the same level of physical stress seen in the Coventry samples. Indeed, it would appear that, whatever the specific occupation of Thomas, it did not involve manual labour at all.

6.2.6. CHE713 (John Long Esq.)

John Long Esquire, brother to Thomas Long (CHE654) was born in 1753/4 and, at the age of 68 years, died on the 6th November 1822 (Miles 2001). Interred nine days later, he was last resident in 18 Beaufort Row (Prob 11/1664, below), a property which he subsequently left to his younger brother Thomas. John was a part of an extended family which included several individuals interred in St. Luke's: Catherine (CHE722), Thomas' and John's sister Esther (CHE1133), Harriet Elizabeth (CHE719), John (CHE744), and Matilda (CHE721) (Miles 2001). Those individuals not specifically mentioned in the description of the graveyard inscriptions of St. Luke's include the other children of Thomas Long, mentioned above (Godfrey 1921).

John, along with his brother, seems to have been a man of strong faith and both wills open up by commending their body and souls to a Christian God (Prob 11/1664, Prob 11/1773). It does appear that John felt a responsibility to the poor of the parish of St. Luke, leaving a specific bequeath in his will to them:

> "I give and bequeath unto the churchwardens are overseers of poor for the time being of the Parish of Saint Luke Chelsea aforesaid for the time being shall from time to time on the fourteenth day of January in every year lay out the interests or dividends of the said sum of one hundred pounds in purchasing bread and shall on such day in every year distribute the same amongst such of the poor of the Parish of Saint Luke Chelsea aforesaid as are not wholly supported at the expense of said Parish." (Prob 11/1664, Appendix 2)

In terms of fixed capital assets, John bequeathed two leaseholds: 56 Upper Sloane Street, which included a tenement "at the back thereof in New Road" to "Thomas Long the Younger, Maria Long, Eliza Long, John Long and Pierre Long"; and 18 Beaufort Row "in which I now reside to hold the same unto my brother Thomas Long the Older" (Prob 11/1664, Appendix 2). As mentioned above, it seems like that 56 Upper Sloane Street was the previous residence of both Catherine and Thomas Long before both the death of Catherine and John, in which case the above bequeath comes into effect.

John does seem to have had a special relationship with Sarah Poulter, resident with him in 18 Beaufort row such that he added a codicil within his will stating that Thomas, who would inherit the house and must:

> "...trust nevertheless to permit and suffer the said Sarah Poulter to continue and reside in my said house for the term of six months next after my decease without paying any rent for the same" (Prob 11/1664, Appendix 2)

As Executrix of his will along with John Long, Sarah Poulter was further to receive the not inconsiderable sum of £50 per annum for the performance of this function (Prob 11/1664).

It is not known whether John (Esq.) was married and while Harriet Elizabeth Long (b. June 1818 and dying some 19 month later) was the daughter of "John Long and Sarah Waite" it seems more likely that this would have been a reference to John's nephew more than himself (Chambers 1816; Miles 2001). If John (Esq.) was the father of the child then he would have done so as a sexagenarian, which while not impossible is improbable in the circumstances.

Osteologically John Long (Esq.) evidenced ankylosing spondylitis (AS, see section 3.3.5.4) fusing at least eight vertebrae (6th thoracic to the 2nd lumbar vertebra), a pathology which would have limited flexion, extension, lateral movement and rotation of the spine.

6.2.7. CHE722 (Catherine Long)

Born in 1765/5, Catherine Long died at the age of 56 years on the 11th July 1822 and was interred seven days later (Miles 2001). Wife of Thomas Long (CHE654), she gave birth to ten children (see section 6.2.5). As mentioned above, her last residence was in Sloane Street, and John Long (Esq.) makes specific mention in his will to a tenement in "Upper Sloane Street" (No. 56) which:

> "I give and bequeath unto my five oldest nephews and nieces (that is to say) Thomas Long the Younger, Maria Long, Eliza Long, John Long and Pierre Long all my leasehold messuage or tenemant No. 56 in Upper Sloane Street Chelsea together with the Tenement at the back thereof in New Road both included in one lease together all other the premises and appurtenances included in the same lease. To hold the same unto my said five oldest nephews and nieces for the remainder of the term which shall be then to same therein as tenants in common and not as joint tenants the rents, issues and profits thereof or produce thereof by sale or otherwise to be equally divided between and amongst them share and share alike subject nevertheless to the payment of the ground rent reserved by the lease and to the Covenants therein contained." (Prob 11/1664, Appendix 2)

While no specific number is given in the burial record (Miles 2001), one might speculate that both Thomas and Catherine were resident in "No.56", with John upon his death bequeathing the leasehold to his eldest nephews and nieces. As Catherine was to die in the same year, Thomas would then subsequently move to 18 Beaufort Row, also bequeathed to him by his brother (Prob 11/1664, Appendix 2; section 6.2.5).

No specific osteology is associated with Catherine Long, though only the left and right mandibular canine was present both from post-mortem and ante-mortem tooth loss (Miles 2001).

Given the Long family's seeming involvement in both the business and social life of Chelsea, Catherine would have been equally involved. With an extended family it is reasonable to infer a life predicated around the care of the children, even though the Long's wealth would have allowed the hiring of domestic and service staff which were such a burgeoning part of the local economy (VCH In Press). While only on a preliminary analysis, there were no obvious signs of osteoarthropathies present in the Coventry sample and that are, for the most part, absent from the Chelsea sample. As with those individuals it is unlikely that Catherine suffered from the musculoskeletal stress associated with the industrial activity of the period, though that does not mean that her life was without periods

of poor health or non-occupational stress. One need only look at the large family that she gave birth to, to see the truth in this.

6.2.8. CHE744 (John Long)

A member of the large Long family resident in Chelsea, John was born in 1722/3 and was to live for 70 years before his death on the 1st April 1793 (Miles 2001). Described as a resident of "Little Chelsea", he at some point in his life married Esther Long, though it is not known whether they had children. The will of John Long (Esq.) mentions a sister, Esther, and given the size of Thomas and Catherine Long's family, it would not be unreasonable to surmise that Thomas' own sibling group was just as large.

While no specific pathologies were identified for John Long in the preliminary analysis, it is reasonable to assume that the quality of his life would have been similar to that of the other Longs. As with the other Longs, and indeed Chelsea sample, that is not to say that his life was free of the disease and stress. Wealth and money could not distance any individual from the realities of this period of industrialisation, though it could certainly ameliorate some of the specific circumstances and the resultant impact upon the body (Wohl 1983).

6.2.9. CHE792 (Milborough Maxwell)

Milborough Maxwell, as mentioned above, is perhaps an example of one of the most frustrating of the named individuals from Chelsea. As can be seen from the isotope biogeochemistry results, below (section 6.4 onwards), there is convincing evidence to suggest that Milborough was, at least in her early childhood, resident in the Caribbean. Use of "FamilySearch" (Church of the Latter Day Saints) indicates that the name 'Milborough' is commonly associated with the Caribbean and, further, 'Maxwell' was a name present in the area at the time, e.g. a Maxwell was positioned as temporary governor of Jamaica in

1790, a "Charles William Maxwell" was the governor of Dominica 1816-19, etc. (website derived: http://www.enclopoedia.thefreedictionary.com on "1816 British Incumbents"). Unfortunately, no specific historical records could be identified for Milborough Maxwell.

Biographical information for Milborough is therefore limited to her recorded death at the age of 68 years on 10th September 1803 with her interment following swiftly some five days later (Miles 2001). Milborough is specifically recorded as a "Mrs" so it is obvious that she at some point married a Maxwell, a feature which makes her historic identification problematic as outlined above. Miles suggests that Milborough may have been related to Elizabeth Maxwell (b. 1753, d.1790) and who subsequently married Captain Leonard Brookes in 1753 (Miles 2001). While the possibility is intriguing, more especially given the suggested non-UK origin and the link to what appears to be a merchant sailor (no 'Leonard Brookes' is mentioned in UK military historical archives). Further research needs be performed on Milborough Maxwell, though archived information in the Caribbean is primarily kept in the form of hard copies requiring personal access.

No specific pathologies were identified with Milborough Maxwell, although the skeleton was both gracile and had little mass. It was not, however, possible to X-ray to identify potential osteoporosis in this individual.

6.2.10. CHE980 and CHE990 (Sarah and Charity Adams)

Sarah and Charity Adams were, separately, both the wives of Nicholas Adams, a bricklayer also interred in St. Luke's (Miles 2001). They are discussed together for both this reason and the limited biographical data that could be determined for them.

Charity Adams was born in 1749 and lived for 32 years before her death on 1st August 1787 (Miles 2001). She married Nicholas Adams, a bricklayer, presumably before 1774 and the

birth on the 11th December of their daughter Sarah Elizabeth. Nicholas himself was born in 1748/9 and lived for 78 years before his death on the 7th June 1827 (Miles 2001). He was last resident in Milmann's Row, Chelsea (Miles 2001).

Sarah Adams, Nicholas's second wife and formerly Sarah Young, was born in 1751/2 and died at the age of 54/55 years January 26th 1806 (Miles 2001). Though the specific circumstances of Charity's death are unknown, Nicholas rapidly remarried some nine months later on the 16th May, 1782 (Miles 2001). It is not known whether the 24 years of marriage produced any issue.

Osteologically both Charity and Sarah, though more particularly Charity, have a number of evident pathologies that are unusual in the sample thus far described. Charity seems to have fractured her left femur (distal epiphysis). The fracture subsequently healed, though with indication of rotation and resultant alteration to the morphology of the acetabulum that would have affected her gait. Likewise, Charity suffered from enamel hypoplasia indicating childhood stress and also from both ante-mortem tooth loss and caries, the latter of which all but destroyed her left mandibular third molar. Sarah, on the other hand, shows no obvious pathologies other than caries on her right second mandibular molar and one affecting a premolar sufficiently to make identification problematic.

Charity provides one obvious point of divergence from the rest of the Chelsea sample with the presence of a severe fracture of the hip that, given her age, was more likely to have occurred through trauma than secondary to pathology. While this does not define her socio-economic status since trauma is obviously not planned, i.e. accidental, it provides the single divergence from an osteological sample that is primarily defined in terms of dental pathology.

6.2.11. CHE392 (John ?Mann) and CHE1051 (?Collon)

These individuals are mentioned separately because they are associated with limited biographical information. Given the fragmentary coffin plate they are counted as not having a name and are therefore included in section 6.2.12, below.

6.2.12. Un-named Individuals

Given the difficulty in acquiring a sample composed entirely of named individuals, a number of un-named individuals were utilised in the project. These, and any identified pathologies, are listed below:

Skeleton (CHE)	Pathology (Miles 2001)
18	No obvious pathology
19	No obvious pathology
31	No obvious pathology
39	No obvious pathology
104	No obvious pathology
143	Diffuse Idiopathic Hyperostosis (DISH)
161	Intra-uterine death[2]
218	No obvious pathology
285	Fused vertebrae (pathology? trauma?)
392	Cribra orbitalia
502	No obvious pathology
552	No obvious pathology
697	No obvious pathology
750	No obvious pathology
841	No obvious pathology
856	No obvious pathology
918	HFI, ankylosed talocrural joint
994	DISH
1021	DISH
1051	No obvious pathology

Table 19: Un-named individuals from Chelsea, including noted pathologies (Miles 2001)

[2] Intra-uterine death (IUD) is the death of the fetus within the uterus. After 18 weeks of pregnancy IUD usually results in a stillbirth after approximately 4 weeks, though there is an increasing chance of catastrophic bleeding and/or death of the mother for the longer the dead fetus remains in the uterus.

6.2.13. Brief Summary of Historical and Osteological Data from Chelsea

Although the different levels of analysis undertaken between Coventry and Chelsea makes comparison of the pathologies difficult, even a superficial comparison of the osteology of the named samples indicates a totally different character. While dental hygiene and therefore dental health is a feature that runs through the full social spectrum, it is in the absence of occupational osteoarthropathies that is most significant in the Chelsea sample (Roberts and Cox 2003). Indeed the incidence of DISH, a pathology associated with the 'wealthy' and 'elite', is significant at higher than the analysed post-medieval period (3.8%: see sections 6.3 and 3.3.5.3), when coupled with the absence of those pathologies associated with stress, poverty and poor housing, e.g. brucellosis and tuberculosis.

The osteological evidence is further substantiated by the recovered biographical data. With the exception of the Adams', the majority of the named sample is 'high status' (either 'middle class' or higher), listed as 'gentlemen', their wives, siblings and children. Indeed, Chelsea was the 'village of palaces' and of completely different social fabric to Coventry, only beginning to become significant urbanised in the nineteenth century, a feature which seems to be born out in the osteology (L'Estrange 1880, Cathcart-Borer 1973; Richardson 2003; VCH In Press).

6.3. Osteology of Coventry and Chelsea

While the pathologies relating to specific individuals are covered in section 6.1 and section 6.2, above, the following section renews the osteoarchaeology of the two sites of Coventry and Chelsea within the wider context of the post-medieval period. It must once again be noted that both sites are in the process of continued analysis or awaiting the assignation of

funding for focussed post-excavation analysis and, thus, the osteoarchaeological information is sometimes lacking.

To facilitate comparison within the period and between the sites the osteoarchaeology of Chelsea and Coventry will be discussed simultaneously.

6.3.1. Size of Collections and Sub-samples

While the excavation of St. Luke's cemetery allowed for the material in its entirety to be curated by the Museum of London, the greater majority of the Holy Trinity material was reburied subsequent to excavation. Of the Holy Trinity material, only a small sub-sample was retained with each skeleton selected either for quality of preservation or for the presence of interesting pathologies. As such, pathologies within the Holy Trinity sample used within the project may not be reflective of the population of Coventry as a whole.

Individuals utilised within this project were selected on criteria discussed in chapter 5, consisting of both 'named' individuals (those identified through stratigraphic and/or the presence of a coffin plate) and 'un-named' individuals, those who could not be attributed an identity within either the archaeological or burial record.

		Selected Sub-sample				
Collection	**Size (*n*)**	**Named**	**Un-named**	**Male**	**Female**	**Total**
St. Luke's	286	10	21	12	19	31
Holy Trinity	60†	11	3	6	7	14

Table 20: Size of curated collections and sub-samples from St. Luke's and Holy Trinity († <10% of excavated burials (Wakely 2001)).

6.3.2. Preservation of Material from the Cemeteries

As mentioned above, the material from Holy Trinity was selected for completeness of the skeleton and the quality of preservation, as well as the extent of any 'interesting' pathologies

(Wakely 2001). No estimates are given as to the 'completeness' of skeletons, nor reference to any system of determining preservation (Wakely 2001). Visual inspection by the author on sampling the material for biogeochemical study did indicate that on the individuals examined, i.e. the sub-sample but also other observed skeletons, the material was 'well preserved' both in terms of cortical integrity and completeness of the skeletons.

Following the system presented by Conheeney (1997), of the 286 skeletons curated in the St Luke's collection 228 (80%) were 'very well preserved', 36 (13%) had 'moderate preservation' and 22 (7%) were 'very poorly preserved'. This is, however, a synthetic statistic with cortical integrity varying considerably within the sample (Miles 2001).

6.3.3. Demography

The interim osteological report from Holy Trinity presents demographic details for the analysed material (Wakely 2001), while the preliminary nature of the St Luke's analysis only allows gross inferences to be made with regards to the age structure.

	Holy Trinity (*n=60*)		**St Luke's (*n=286*)**	
Age Range (yrs)	***N***	**%**	**n**	**%**
Perinatal	3	5	10	3.5
Post-neonatal	0	0	5	1.8
>1	2	3.3	9	3.2
1-2	4	6.7		
3-5	5	8.3		
6-10	2	3.3	12	4.2
11-15	3	5	6	2.1
16-18	1	1.7		
18-24	3	5	244	85.3
25-29	2	3.3		
30-34	0	0		
35-39	2	3.3		
40-44	5	8.3		
45-49	4	6.7		
50-60	9	15		
60+	12	20		
Indeterminate	3	5	0	

Table 21: Age of Holy Trinity and St Luke's (Miles 2001; Wakely 2001).

While age estimates were acquired for the individuals within the Chelsea sample, the relative size of sub-sample against the excavated population is such that the utilisation of this data for the reconstruction of a mortality profile would be statistically meaningless. The number of adult males/females in each site is given below (percentage does not include sub-adult skeletons):

	Male		Female		Unsexed	
Site	***N***	**%**	***n***	**%**	***n***	**%**
Holy Trinity (40)	18	45	22	55	0	-
St Luke's (244)	71	29.1	78	32.0	95	38.9

Table 22: Proportion of male/females in Holy Trinity and St Luke's (Miles 2001; Wakely 2001).

6.3.4. Stature Estimations

Wakely (2001) primarily utilised the femur for stature estimations for Holy Trinity (n=40) and, for consistency, the same calculations were used in stature estimations for the St Luke's named collection (n=21). In those individuals were the femur was damaged or absent no stature estimation was attempted.

	Male			Female		
Site	**Mean**	**S.D.(1σ)**	**Range**	**Mean**	**S.D.(1σ)**	**Range**
Holy Trinity (n=40)	1.72m	-	1.54-1.82	1.58m	-	1.48-1.65
St Luke's (n=21)	1.65m	0.10m	1.55-182	1.59m	0.6m	1.52-1.63

Table 23: Stature estimations for Holy Trinity and St Luke's.

While the stature estimations for the Holy Trinity sample are approximately consistent with those found in the post-medieval period (see fig. 3.2), as are the females from St Luke's, the mean height of males is greatly diminished. While this may be a product of the smaller sample size (n=7 in males, n=14 in females) Roberts and Cox do not note variation in stature by socio-economic class (Roberts and Cox 2003).

6.3.5. Dental Disease

The dental health of the analysed material from Chelse and Coventry is summarised in the table, below.

	Holy Trinity (*N*=60)		St. Luke's (*N*=286)	
Pathology (*N*=60)	n	%	n	%
Enamel Hypoplasia	**(5)**	(8)	(2)	(1)
Caries	**13**	22	(12)	(4)
Abscesses	**9**	15	(1)	(0.5)
Ante-mortem tooth loss	**14**	23	(2)	(1)
Calculus	**14**	23	(5)	(2)
Periodontitis	**13**	22	(28)	(10)
Edentulism	**4**	7	7	2

Table 24: Individuals affected by dental pathologies from Holy Trinity (Coventry) and St. Luke's (Chelsea). Values in parentheses indicate a pathology not mentioned in a preliminary report and/or were noted either in the archive or in focussed analysis (Coventry, *n*=13; Chelsea, *n*=28).

It is not possible to make direct comparisons between the dental health of the two populations, nor relate it to the wider post-medieval period nor the proceeding later medieval. Certain pathologies are not mentioned in the broader report (i.e. enamel hypoplasia) while they are mentioned in the skeletal archive, and the nature of the St. Luke's report did not allow for a detailed analysis of dental pathology. What is certain, however, is that dental hygiene is comparatively poor for all the individuals analysed. Caries, ante-mortem tooth loss, calculus and periodontitis seem to have afflicted the populations in a similar fashion, regardless of socio-economic status. In many ways it was a great leveller: as is commonly held in contemporary America, the British quite simply have 'bad teeth' and this seems born out in the dental health of both Coventry and Chelsea.

6.3.6. Traumatic Conditions

Traumatic conditions, fractures etc., are only rarely mentioned in the osteological record for Coventry and Chelsea. In the Chelsea sample, only one individual in the sample (Charity Adams, CHE990) is noted as having a traumatic pathology, i.e. fracture to the proximal

femur and subsequent alterations to the hip itself. Within the rest of the Chelsea population there are a number of individuals where traumatic pathologies are evident:

Skeleton	Trauma
152	Ankylosed tibia/fibula
188	Ankylosed tibia/fibula
281	Fused vertebra
453	Dislocation in tarso-metatarsal joints
587	Colles fracture
668	Fractured radius (right), fractured pelvis
782	Fractured ulna
918	Ankylosed talocrural joint
948	Fractured metatarsal, fractured humerus (right)
990	Fractured proximal femur
1068	Fractured tibia

Table 25: Traumatic conditions evident in the St. Luke's (Chelsea) collection (Miles 2001).

Thus, approximately 3.9% (n=11) of the population of Chelsea evidenced pathologies consistent with trauma, well within the 4.2% upper limit within the post-medieval period (Roberts and Cox 2003).

Approximately 25% (n=15) of the Coventry sample have evident traumatic pathologies. While this is much higher than both Chelsea and the proportion expressed through analysis of post-medieval cemeteries, one must also note the smaller sample size. However, it is clear that the individuals from Holy Trinity were exposed to greater physical trauma than those from Chelsea, although the range of traumatic conditions are broadly analogous.

Skeleton	Trauma
123	Fractured nasal septum
249	Dislocated hip
283	Lumbar exostoses with secondary lordosis
417	Dislocated jaw
584	Compression fracture (vertebra)
856	Compression fracture (vertebra), 2 rib fractures, bilateral and multiple fractures to the tarsals and metatarsals
902	Compression fracture (vertebra) with secondary kyphosis, fracture of right femur
978	Fractured nasal septum
1118	Compression fracture (vertebra) with secondary scoliosis, dislocation of right shoulder
1147	Fracture of right radius
1180	Compression fracture (vertebra)
1413	Ankylosis of right knee
?	Depressed skull fracture (healed), female skeleton

Table 26: Traumatic conditions evident in the Holy Trinity (Coventry) collection (Wakely 2001).

6.3.7. Congenital Abnormalities

Five individuals (1.8%) express congenital abnormalities are evident in the St. Luke's (Chelsea) collection: CHE951 with a congenital malformation of the thorax; severe congenital scoliosis in CHE407; and spondylolysis in CHE701, CHE 754 and CHE1023 (Miles 2001). Scoliosis, also included in congenital abnormalities, is present secondary to trauma (i.e. compression fracture of the vertebral bodies) and is not included here. Congenital abnormalities in the Coventry population include: spina bifida occulta and spondylolysis (COV249); congenital scoliosis (COV1165); and trigoncephaly (COV400, COV978). This accounts for 6.7% of the analysed population.

6.3.8. Circulatory Disorders

Osteochondroses are only found in the Coventry collection, and then in two (~3%) male individuals: COV77 and COV1119 (John Ballard). In the latter case it is possible that the pathology is secondary to occupational stress, e.g. constant flexion and extension of the spine.

6.3.9. Joint Disease

Within the Chelsea sample, joint disease is a rare condition (see above) and seen as indicative of the differing character of the two sites or, at least, the samples themselves. Joint disease is, however, present in both sites. Within Coventry twelve individuals have osteoarthritis in the spine, four in the knee, three in the hip, two in the shoulder and one in the temporomandibular joint (secondary to dislocation of the jaw). Chelsea evidences a similar distribution, with osteoarthritis reported in seven individuals (2.5%), most commonly in the elbow (3 individuals), though it is also present in the knee (1 individual), coccyx (1 individual) and metacarpophalangeal joint (1 individual). Degenerative joint disease of the spine is not mentioned in the preliminary Chelsea report (Miles 2001), though it is noted in eleven adult skeletons in Coventry (18.3%). Furthermore, Schmorl's Nodes were identified in twelve individuals (20%), including two juveniles.

Diffuse idiopathic skeletal hyperostosis (DISH) is not evident in the Coventry sample, but is present in eleven (3.9%) individuals from Chelsea, a value higher than the post-medieval prevalence (3.3%) although not as high as from the 'high status' Christchurch Spitalfields sample (~5.8%). Similarly, ankylosing spondylitis (AS) is absent in Coventry but found in one individual (0.4%) from Chelsea.

While joint disease is present in both samples, the distribution and nature of these pathologies suggest different characters. Simply, while the population of Holy Trinity suffered from degenerative osteoarthropathies indicative of continued physical stress in both the adult and sub-adult populations, the same degree of stress is not present in Chelsea. The abundance of DISH, higher than the post-medieval prevalence, would similarly argue for a 'high status' character to Chelsea. That is not to say that stress, occupational or otherwise, was absent from Chelsea.

6.3.10. Infectious Disease

Tuberculosis, a major cause of death in the post-medieval period, was present in two individuals from both Coventry (3.3%) and Chelsea (0.7%). Although we are once again dealing with a low sample size, both Coventry and Chelsea have a prevalence rate higher than that witnessed in analysed post-medieval material (0.5%).

Osteomyeletis is found in one individual (1.7%) from Coventry, while three individuals (1.1%) have non-specific infections described as 'secondary infection', periostitis or osteitis (Miles 2001).

6.3.11. Metabolic Disease

Defined rachitic changes are noted in five individuals (8.3%) from Coventry, two sub-adult (COV105, COV272) and three adult (COV1118, 1165 and COV1288), a proportion that is much higher than that witnessed in analysed material from the post-medieval period (3.7%). Four individuals (1.4%) from Chelsea show evidence of rachitic changes: CHE265 (sub-adult), CHE910, CHE951 and CHE701, an adult showing evidence of 'adult rickets' (osteomalacia) (Miles 2001).

Osteoporosis is noted in both sites, though restricted to one individual per site: COV516 ("...ein...") evidenced the typical porosity and low density of osteoporosis, and also CHE586 (1.7% and 0.4%, respectively). This is approximately consistent with that reported in the post-medieval period (~1.2%) (Roberts and Cox 2003).

6.3.12. Haematological Disorders

Ten individuals (seven sub-adults, three adults) from Coventry showed evidence of cribra orbitalia, or 16.7%, while only three individuals (1.1%) were mentioned from the Chelsea analysis (Miles 2001). Compared to the average prevalence rate in the post-medieval period (9%), this suggests that dietary stress was far more common in Coventry than Chelsea again supportive of the differing socio-economic status of the two cemeteries.

6.3.13. Coventry and Chelsea

While the many pathologies mentioned above are present, for the most part, in both sites the degree and character of pathologies argues for distinction between the two sites. The analysed population of Coventry show a relatively high rate of osteoarthritis and degenerative changes to the skeleton in both adult and sub-adult skeletons, indicating continued stress from childhood and throughout the lifetime of an individual. Indeed, dietary stress as represented in *cribra orbitalia* – associated with 'anaemia', either congenital or through deficient iron intake – is particularly prevalent. Furthermore, fully one quarter of the analysed material showed evidence of trauma, a much higher rate than that reported in the period. Chelsea, on the other hand, seems a population defined less by stress and more by excess. Trauma, dietary deficiency, infectious diseases, etc., all have a lower prevalence than found in Coventry. DISH, commonly associated with late-onset diabetes and obesity, has a higher prevalence than the average for the period, although not has high as that reported from Christchurch Spitalfields (Cox 1998; Roberts and Cox 1993).

The osteology is broadly consistent with the historical record: Coventry appears to be, broadly, a working-class population while Chelsea represents middle to upper class individuals with increased socio-economic status.

6.4. Carbon and Nitrogen Stable Isotopes ($\delta^{13}N/\delta^{15}N$)

The $\delta^{13}C$ and $\delta^{15}N$ results obtained are presented along with the name of the individual if known, the sex and the site code and skeleton number in tables 27-29.

Sample	Sex	Name	ID	$\delta^{13}C$	1σ	$\delta^{15}N$	1σ
COV13	M	Thomas Thomson	1	-18.44	0.03	12.58	0.26
COV516	M	? Cooper	2	-19.49	0.01	11.59	0.15
COV808	M	William Wagstaffe	3	-19.74	0.05	11.28	0.27
COV978	M	James Brown	4	-19.50	0.06	13.00	0.03
COV1119	M	John Ballard	5	-19.30	0.01	12.98	0.01
COV1248	M	John Chattaway	6	-19.93	0.03	12.21	0.08
COV16	F	Ann Kimberly	7	-19.56	0.00	12.06	0.04
COV50	F	"…ein…"	8	-19.93	0.03	12.06	0.09
COV77	F	Elizabeth Burton	9	-19.61	0.04	11.55	0.06
COV417	F	Sarah Green	10	-19.57	0.02	11.79	0.03
COV434	F	Hannah Denney	11	-19.65	0.02	12.05	0.28
COV672	F	Eliza Sparkes	12	-19.47	0.00	12.09	0.08
COV866	F	Harriet Parsons	13	-19.86	0.06	12.11	0.12

Table 27: $\delta^{13}C$ and $\delta^{15}N$ results for analysis of osteological material from Coventry.

Sample	Sex	Name	ID	$\delta^{13}C$	1σ	$\delta^{15}N$	1σ
CHE35	M	Gideon Richard Hand	14	-19.46	0.01	13.62	0.02
CHE143	M		15	-19.36	0.00	12.20	0.09
CHE147	M	Thomas Langfield	16	-19.09	0.00	13.16	0.16
CHE285	M		17	-19.11	0.02	13.31	0.08
CHE432	M	John M?	18	-19.12	0.01	13.14	0.04
CHE622	M	Richard Gideon Hand	19	-18.45	0.02	12.91	0.18
CHE654	M	Thomas Long	20	-18.40	0.04	12.85	0.42
CHE713	M	John Long (Esq.)	21	-18.95	0.00	12.47	0.03
CHE744	M	John Long	22	-19.20	0.01	12.59	0.00
CHE856	M		23	-19.16	0.02	11.95	0.19
CHE994	M		24	-18.95	0.02	12.95	0.26
CHE1021	M		25	-18.74	0.02	12.52	0.16

Table 28: $\delta^{13}C$ and $\delta^{15}N$ results for analysis of male osteological material from Chelsea.

Sample	Sex	Name	ID	$\delta^{13}C$	1σ	$\delta^{15}N$	1σ
CHE18	F		26	-15.00	0.01	13.09	0.23
CHE19	F		27	-18.99	0.02	12.41	0.04
CHE31	F		28	-18.76	0.00	12.81	0.21
CHE39	F		29	-18.88	0.02	13.07	0.05
CHE104	F		30	-19.01	0.00	13.02	0.19
CHE161	F		31	-19.62	0.01	12.45	0.54
CHE218	F		32	-19.22	0.01	12.72	0.04
CHE392	F		33	-19.39	0.03	12.60	0.20
CHE502	F		34	-19.67	0.02	12.19	0.23
CHE552	F		35	-18.89	0.01	12.62	0.03
CHE697	F		36	-19.37	0.04	11.78	0.17
CHE722	F	Catherine Long	37	-18.65	0.00	13.21	0.04
CHE750	F		38	-18.43	0.03	12.77	0.15
CHE792	F	Milborough Maxwell	39	-16.38	0.18	13.26	0.26
CHE841	F		40	-19.29	0.02	12.61	0.48
CHE918	F		41	-19.43	0.04	12.11	0.29
CHE918T	F		42	-19.43	0.02	12.17	0.04
CHE980	F	Sarah Adams	43	-19.31	0.03	10.98	0.20
CHE990	F	Charity Adams	44	-19.15	0.07	11.80	0.21
CHE1051	F	?Collon	45	-19.49	0.00	13.46	0.11

Table 29: $\delta^{13}C$ and $\delta^{15}N$ results for analysis of male osteological material from Chelsea. (CHE918T represents analysis of a root fragment from said individual.)

6.4.1. Bivariate Interpretation of Diet between Coventry and Chelsea

This data in tables 27-29 represented graphically in fig 28. As can be seen from the bivariate plot of $\delta^{13}C$ and $\delta^{15}N$ the centroids there is a determined difference between the average dietary C/N between the two sites as indicated in the table, below.

		$\delta^{13}C$	$\delta^{15}N$
Coventry	Mean	-19.54	12.10
	Standard Deviation (1σ)	0.38	0.51
	Mean Error	0.03	0.12
	Variance	0.15	0.25
Chelsea	Mean	-18.89	12.65
	Standard Deviation (1σ)	0.93	0.56
	Mean Error	0.02	0.18
	Variance	0.84	0.32

Table 30: Mean, standard deviation, average error and variance of Coventry and Chelsea.

The mean values for both $\delta^{13}C$ and $\delta^{15}N$ show a significant variation of approximately 0.5-0.6‰, with Coventry showing a tighter distribution then Chelsea (variance 0.15/0.25 and 0.84/0.32 respectively for $\delta^{13}C$ and $\delta^{15}N$). While this may be a product of the small sample size from Coventry, a consideration of univariate significance (section 6.4.3) suggests an asymptotic significance of less than 1% giving statistical validation to this semi-quantitative observation.

Interpretation of human diet from C/N isotopes is problematic since 'simple' resource-prey-hunter relationships do not exist. Humans select from a wide variety of food resources dependent upon, amongst other things, preference and differential access resulting from geographical position, variation in socio-economic class, and so forth.

Analysis of various grains by Bender determined that the average $\delta^{13}C$ for C_3 plants varies between –27‰ and –26‰ with a further fractionation effect between diet and animal tissue of +1‰ (Bender 1968; Tieszen *et al.* 1983). Variation in mammals between diet and collagen are approximately 4-6‰, with 5‰ commonly used such that based upon a primarily C_3 diet, UK individuals should show a $\delta^{13}C$ value of ~21.5‰ (Ambrose 1993; Mays 1997; Yoneda *et al.* 2004). Studies of the terrestrial species from various European archaeological sites offer further confirmation of this with a $\delta^{13}C$ of –21.5‰ (Burleigh *et al.* 1984). Measure of faunal data, on the other hand, gives a median of 20.98‰, a value consistent with reported values for humans (20.1‰) (van Klinken *et al.* 2000). Given the centroids of both the Coventry and Chelsea samples and the historical information with regards to diet, another component must be contributing to the recorded collagen value, e.g. fish and C_4 plants (Ambrose 1993; Hammond 1993; Roberts and Cox 2003). Diets known to be predominantly composed of aquatic (marine and freshwater fish) resources have been recorded at –13 to –14‰, consistent with the value for fish flesh of –18 to –17‰ (Chisholm *et al.* 1982; Tauber 1986; Mays 1997; Coltrain *et al.* 2004).

The results for the combined carbon/nitrogen analysis, their relationship to terrestrial and marine food-webs as well as to selected medieval sites, are presented in figs. 28-32.

6.4.1.1 Sources of Dietary Protein

As can be seen from fig. 28, two characteristics are readily apparent with regards to both the Coventry and Chelsea populations. First, both populations have very high $\delta^{15}N$ ratios and, second, the $\delta^{13}C$ ratios are significantly shifted towards a C_3 dominated diet.

While elevated $\delta^{15}N$ can be attributed to the consumption of significant quantities of marine faunal resources, one would expect such a diet to have an increasingly enriched $\delta^{13}C$ signal, i.e. shifting to the right on fig. 28. This is not the case for either Chelsea or Coventry and, the implication must be that dietary protein is primarily derived from the terrestrial system. The enrichment of ^{15}N by 3-4 ‰ witnessed with increasing trophic level implies that neither the Chelsea nor Coventry sample acquired a significant portion of their diet from terrestrial herbivores, such as cattle, sheep, domestic fowl (Schoeninger *et al.* 1984; Richards *et al.* 2001; Müldner and Richards 2005). Such elevated $\delta^{15}N$ are, as mentioned above, associated with the consumption of aquatic (marine and freshwater) resources or terrestrial omnivores, e.g. pigs that are fed with faunal material (Grant 1988; Privat *et al.* 2002; Müldner and Richards 2005). While freshwater fish or pig would have contributed to the diet, they were by no means the primary source of dietary protein; Richards *et al.* (2001) suggest that values in the range experienced by Chelsea and Coventry are consistent with 25-50% of the diet coming from freshwater resources, in this case also including pig.

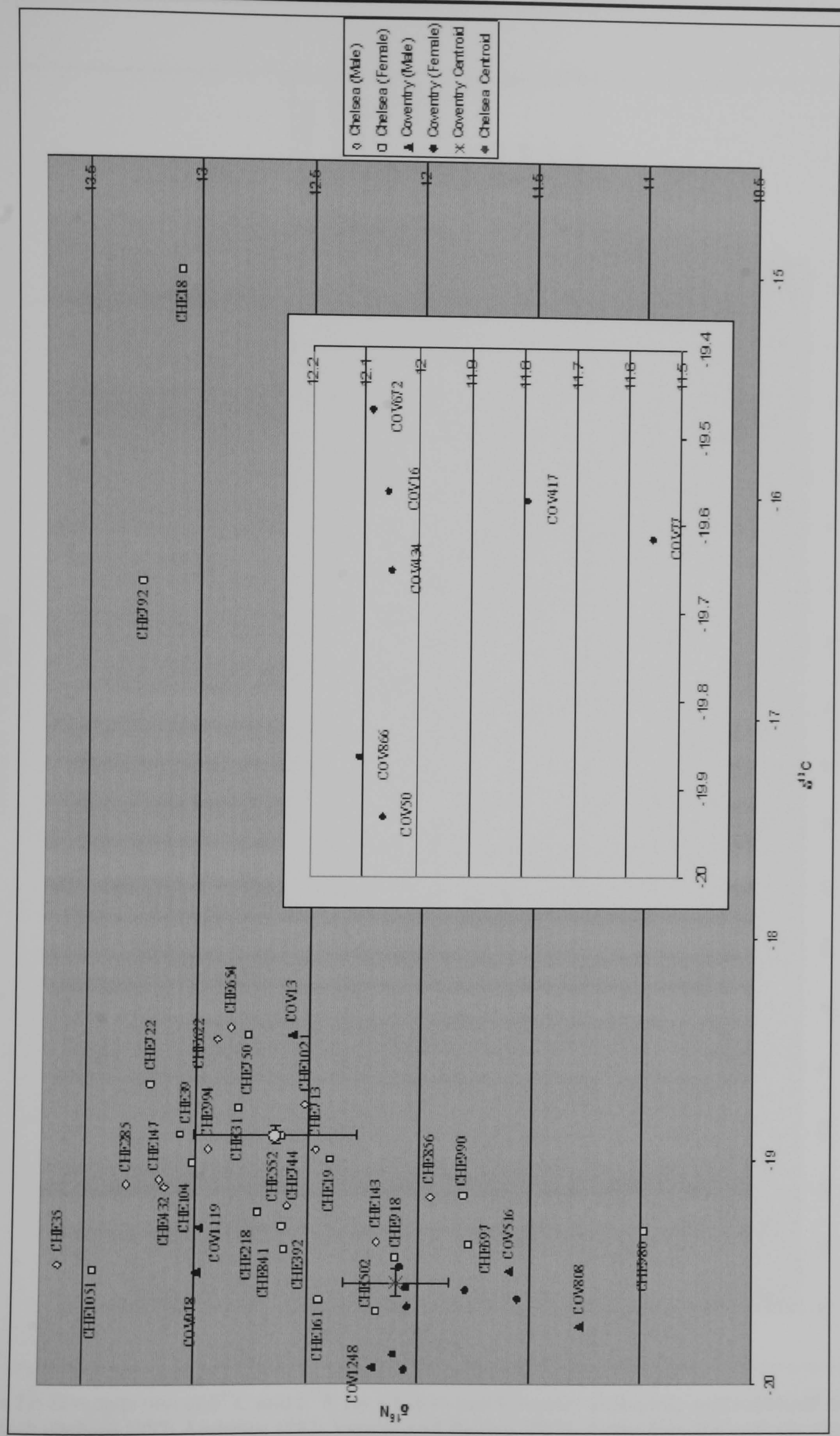


Figure 28: Bivariate plot of $\delta^{13}C$ and $\delta^{15}N$ for Chelsea and Coventry, divided by both site and sex. Centroids represent mean value with error bars indicating average error (2σ).

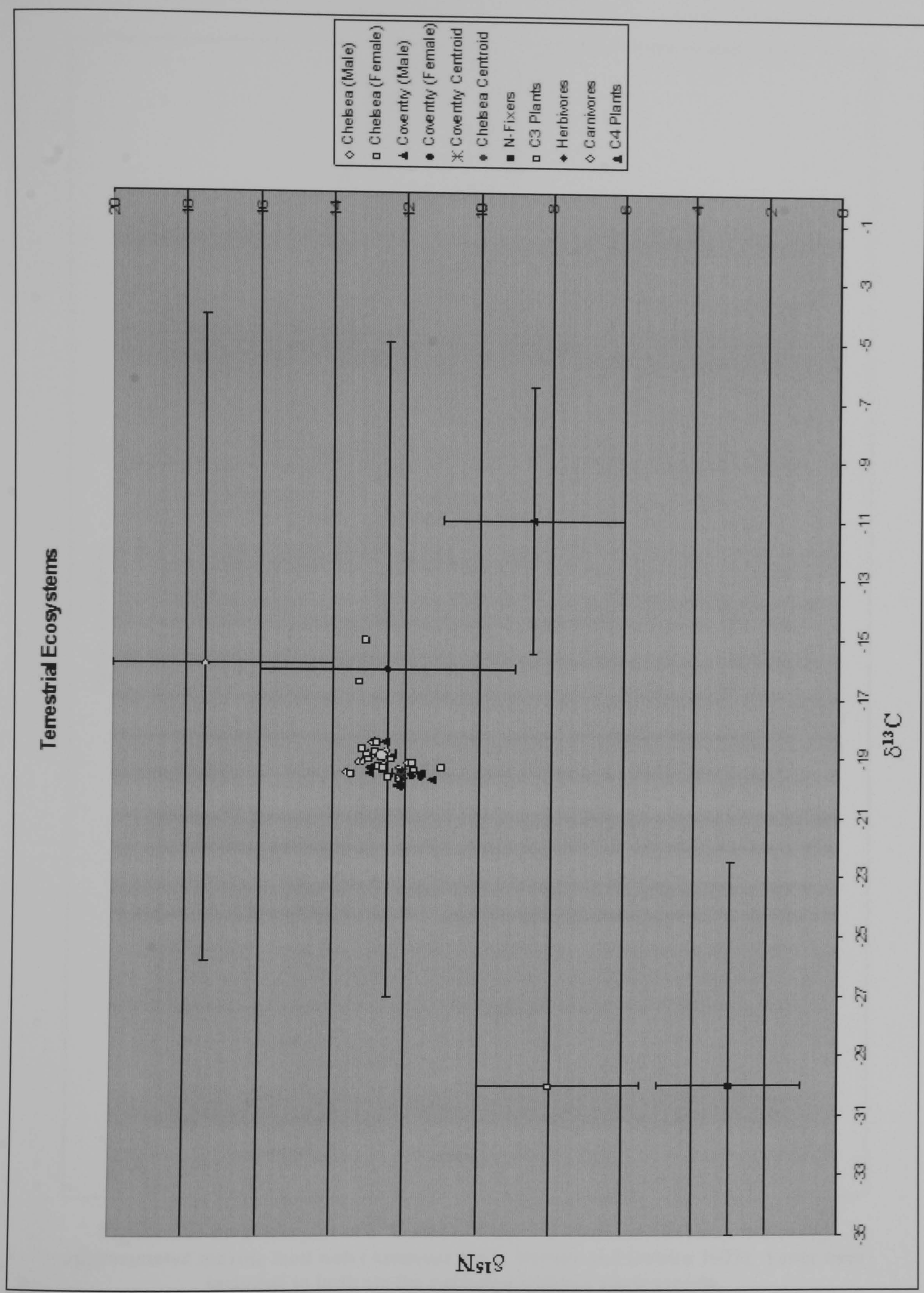


Figure 29: Bivariate plot of $\delta^{13}C$ and $\delta^{15}N$ for Chelsea and Coventry indicating approximated marine food web (DeNiro 1987; Ambrose 1993; Verano and DeNiro 1993). Error bars indicate the range of variation within the sample.

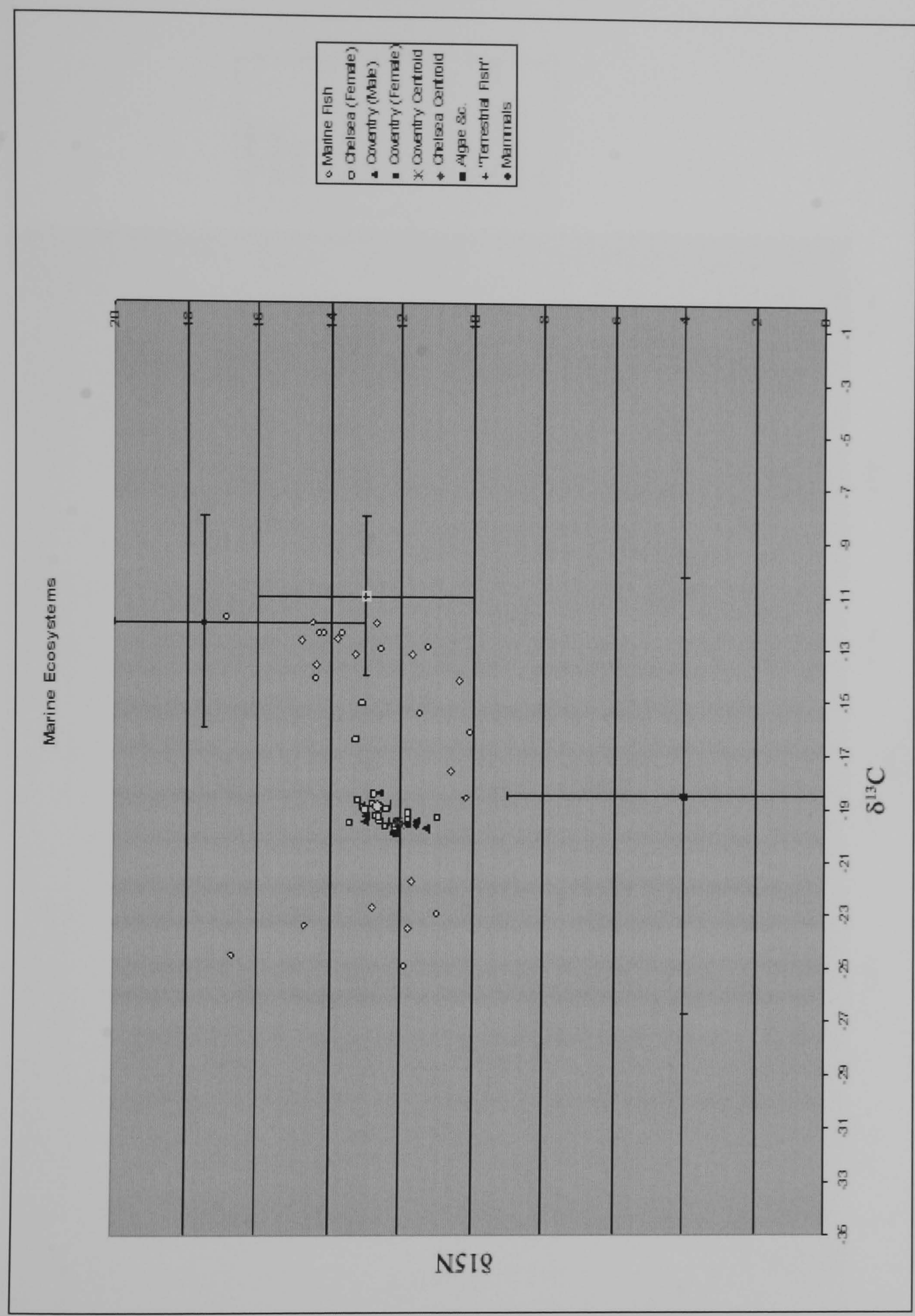


Figure 30: Bivariate plot of $\delta^{13}C$ and $\delta^{15}N$ for Chelsea and Coventry indicating approximated marine food web (Ambrose 1993; Verano and DeNiro 1993). Error bars included to indicate the variation within a given sample.

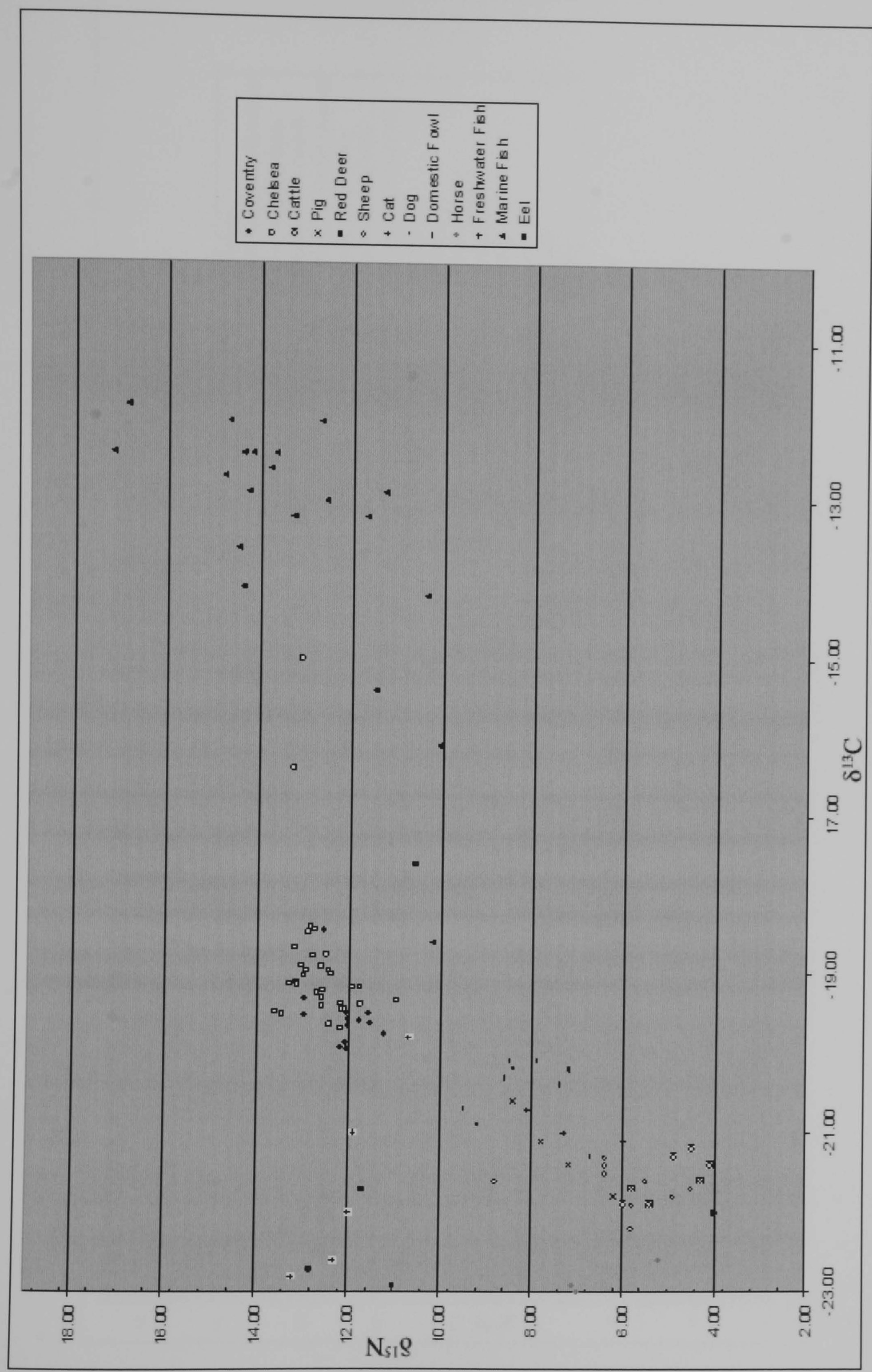


Figure 31: Bivariate plot of $\delta^{13}C$ and $\delta^{15}N$ of Chelsea and Coventry humans plotted against terrestrial fauna, including freshwater fish, and marine fauna (Richards *et al.* 2001; Müldner andRichards 2005). Error bars removed for clarity.

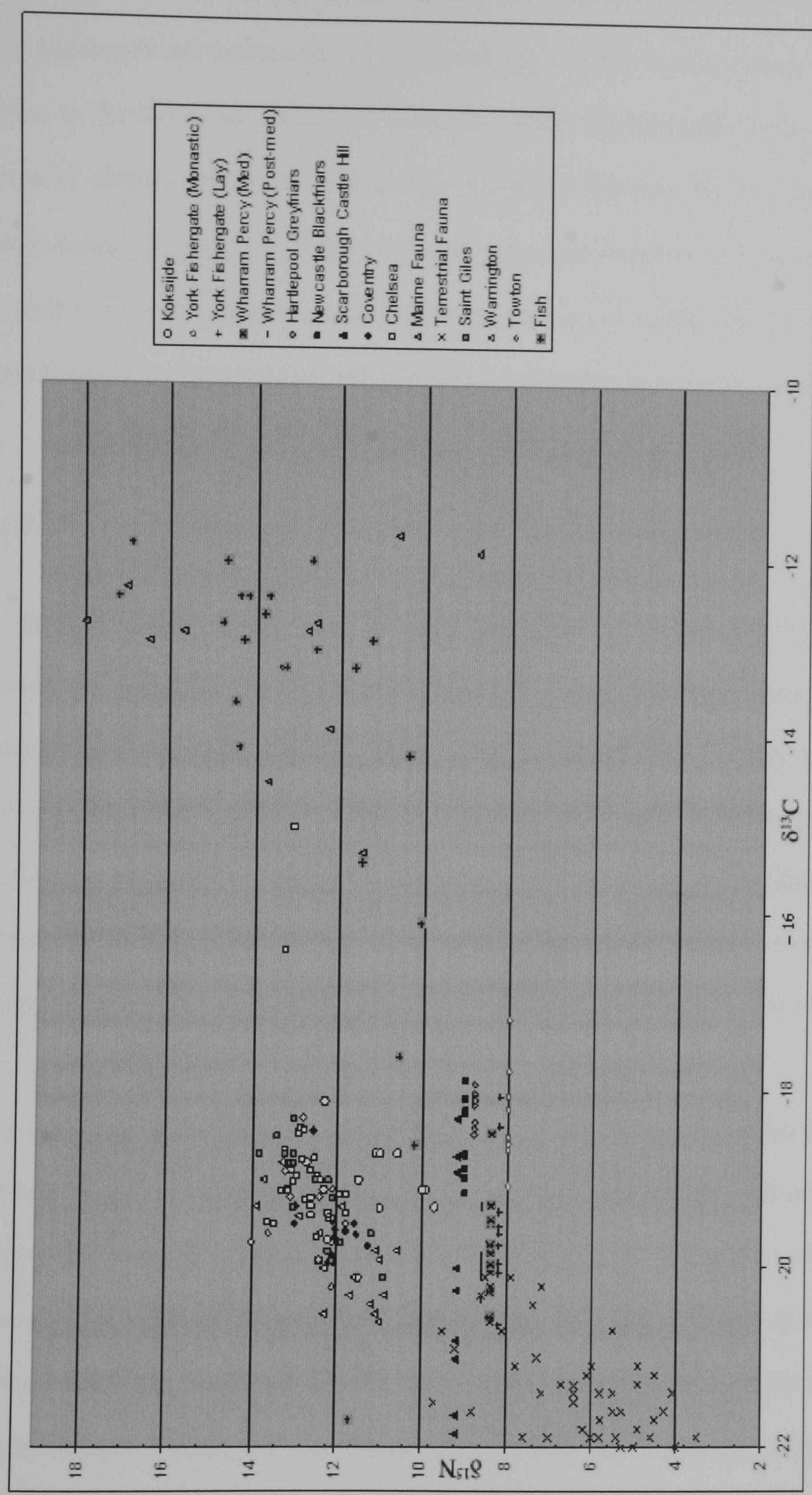


Figure 32: Bivariate $\delta^{13}C/\delta^{15}N$ plot of Coventry and Chelsea with the monastic community of Dunnes abbey, Koksijde (Belgium), and UK medieval populations (Mays 1997; van Klinken *et al.* 2000; Privat *et al.* 2002; Polet and Katzenburg 2003). Error bars removed for clarity.

As has been in shown in Chapter 2, freshwater and other fish were available in the markets of the eighteenth and nineteenth centuries, and pig – in the form of bacon – was a regular addition to the diet of an agricultural labourer. While Chelsea and Coventry share similar sources of dietary protein, there is a clear distinction between the two populations, with Chelsea being relatively enriched in ^{15}N and with a less negative $\delta^{13}C$ signal. This can be the result of several factors, including preferential access to marine resources, differences in animal fodder (i.e., the use of maize), or a greater contribution of these resources to the diet.

6.4.1.2. The Contribution of C_4 Resources to Chelsea and Coventry Diet

The Chelsea and Coventry diet, as indicated above, is dominated by C_3 terrestrial carbon/nitrogen signals. To what degree could a C_4 component contribute to the diet of the eighteenth and nineteenth centuries in the study locations? The primary sources of a C_4 signal are mentioned in Chapter 2 – maize, millet and sugar cane, including products such as rum that are made from sugar cane. However, both maize and millet did not contribute significantly to human diet during eighteenth and nineteenth century, though one might consider the possibility of maize being used as a fodder for terrestrial herbivores.

Sugar cane and its derivatives therefore offer the primary means by which a C_4 diet could have been introduced into the Chelsea or Coventry diet. Indeed, the will of Thomas Long attests to the presence of alcoholic beverages (section 6.2.5). While the average wealth of Chelsea's population seems that much greater than Coventry and may therefore offer an explanation for the small shift towards a C_4 signal, our ability to quantify this is limited. That is, collagen records the contribution of protein to the diet of the individual whereas bone apatite provides a means of analysing the total dietary inputs (Ambrose 1993; Schwarcz 2000). Future analysis of bone apatite on the two samples may therefore offer the means by which the contribution of sugar cane, and other C_4 plants, to the diet of the two samples may be quantified.

6.4.1.3. Milborough Maxwell and CHE18

Two individuals deserve special mention for their significant variation from the Chelsea centroid: CHE792 (Milborough Maxwell) with $\delta^{13}C/\delta^{15}N$ of –16.38‰/13.26‰; and CHE18 (un-named) with $\delta^{13}C/\delta^{15}N$ of –15.00‰/13.09‰. While in terms of other isotopes CHE18 is not unusual (see sections 6.5, 6.6 and 6.7), she has the most divergent diet. Milborough Maxwell is an outlier not only in $\delta^{13}C/\delta^{15}N$, but also $^{87}Sr/^{86}Sr$ and $\delta^{18}O$. The nature of this dietary shift is, as with the contribution to $\delta^{13}C/\delta^{15}N$ of C_4 plants, difficult to explain. Both individuals plot within the range of 'marine invertebrate consumers' (Verano and DeNiro 1993) and show the elevated $\delta^{15}N$ consistent with a significant marine contribution to diet. It is therefore plausible that these individuals consumed a greater proportion of marine resources in their diet, e.g. 60.2% and 76.5% respectively for CHE792 and CHE18, or a diet primarily composed of marine invertebrates (i.e. shellfish).

An alternative hypothesis must be considered with Milborough Maxwell. Consideration of the results of the other isotopic systems analysed for CHE792 give a strong likelihood that this individual was born in the Caribbean and, as such, they would have been exposed to a diet that included C_4 plant material. Furthermore, the timing of the return to the UK of this individual remains unknown, a feature that could further affect any mixing phenomenon through gradual replacement of a tropical dietary signal. Without further information with regards to Milborough Maxwell's residency status, such as historical evidence attesting to birth location, the exact cause of this variation must remain unknown. Further analysis of post-medieval populations from different socio-economic situations and geographic locations, including the use of defined Caribbean and American colonial material, may provide the means by which this question could be addressed.

6.4.2. Test of Significance of Difference in Diet between Coventry and Chelsea

While there is an observed difference between the Coventry and Chelsea samples, a Mann-Whitney test between the two sites is summarised in the table, below:

Isotope	Site	N	Mean Rank	Sum of Ranks
$\delta^{13}C$	Coventry	13	11.04	143.50
	Chelsea	32	27.86	891.50
	Total	*45*		
Mann-Whitney U	52.500			
Wilcoxon W	143.500			
Z	-3.895			
Asymp. Sig. (2-tailed)	0.000			

Table 31:Mann-Whitney test of the asymptotic significance of difference between $\delta^{13}C$ values of Coventry and Chelsea (produced by Statistical Package for Social Sciencies)

A Mann-Whitney test of significance of difference was performed against the nitrogen isotope values of the Coventry and Chelsea samples and is summarised in the table below:

Isotope	Site	N	Mean Rank	Sum of Ranks
$\delta^{15}N$	Coventry	13	13.88	180.50
	Chelsea	32	26.70	854.50
	Total	*45*		
Mann-Whitney U	89.500			
Wilcoxon W	180.5			
Z	-2.968			
Asymp. Sig. (2-tailed)	0.003			

Table 32: Mann-Whitney test of asymptotic significance of difference between $\delta^{15}N$ values of Coventry and Chelsea (produced by Statistical Package for Social Sciences)

As can be seen from the Mann-Whitney tests, above (table 31 and 32), both $\delta^{13}C$ and $\delta^{15}N$ are significantly different between the two sites ($P<0.001$ and $P\leq0.003$ for $\delta^{13}C$ and $\delta^{15}N$, respectively). Section 6.4.1. discusses the nature of the difference in the diet between the two populations (Mays 1997; van Klinken *et al.* 2000; Richards *et al.* 2001; Privat *et al.* 2002; Yoneda *et al.* 2004).

The historical record provides additional information on the individuals sampled, it is useful to define significant outliers to the main groups, either Chelsea or Coventry, through the simple creation of box-plots herein performed separately for $\delta^{13}C$ and $\delta^{15}N$.

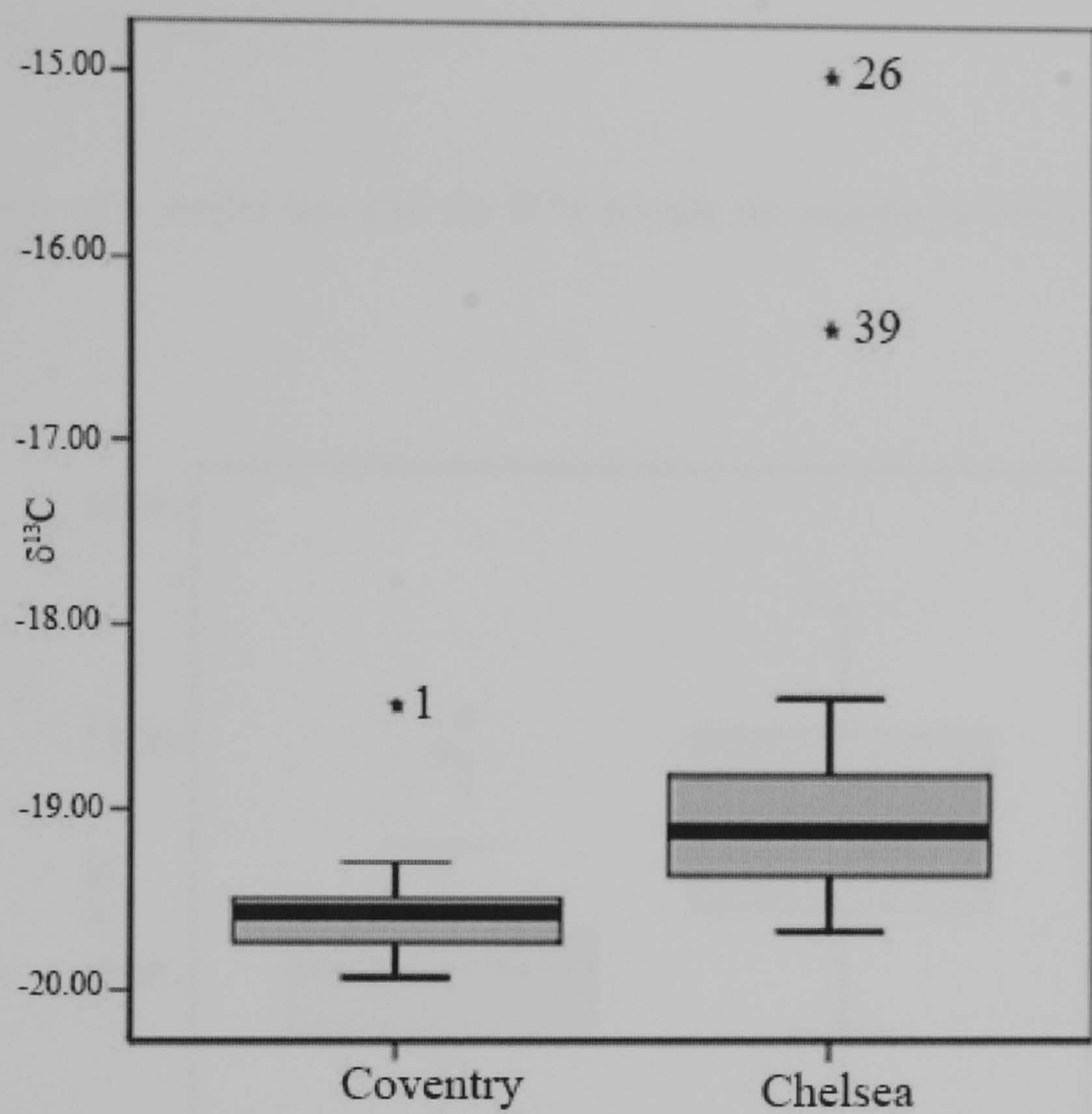


Figure 33: Box-plot of $\delta^{13}C$ for Chelsea and Coventry indicating outlying individuals.

As can be seen from fig. 33, individual "1" (COV13, Thomas Thomson) is an outlier in the Coventry sample in terms of $\delta^{13}C$, while individuals "26" (CHE18) and "39" (CHE792, Milborough Maxwell) are outliers in the Chelsea sample, consistent with the observations made in section 6.4.1. From the previous argument, it can be suggested that Thomas Thomson had a more significant contribution of a C_4 signal to his diet. It should be noted, however, that both James Brown (COV978) and John Ballard (COV1119) have elevated $\delta^{15}N$ suggestive of marine input and a $\delta^{13}C$ that is consistent with the remainder of the

Coventry sample and that there is a tentative link between $\delta^{15}N$ and socio-economic class. Trophism offers one potential explanation, with the nature of the marine resources consumed by James Brown and John Ballard being from a higher trophic level (e.g. freshwater carnivores such as eel or pike) though not necessarily contributing a significant proportion of the diet.

Production of a similar box-plot for $\delta^{15}N$ reveals the significant outliers for this stable isotope:

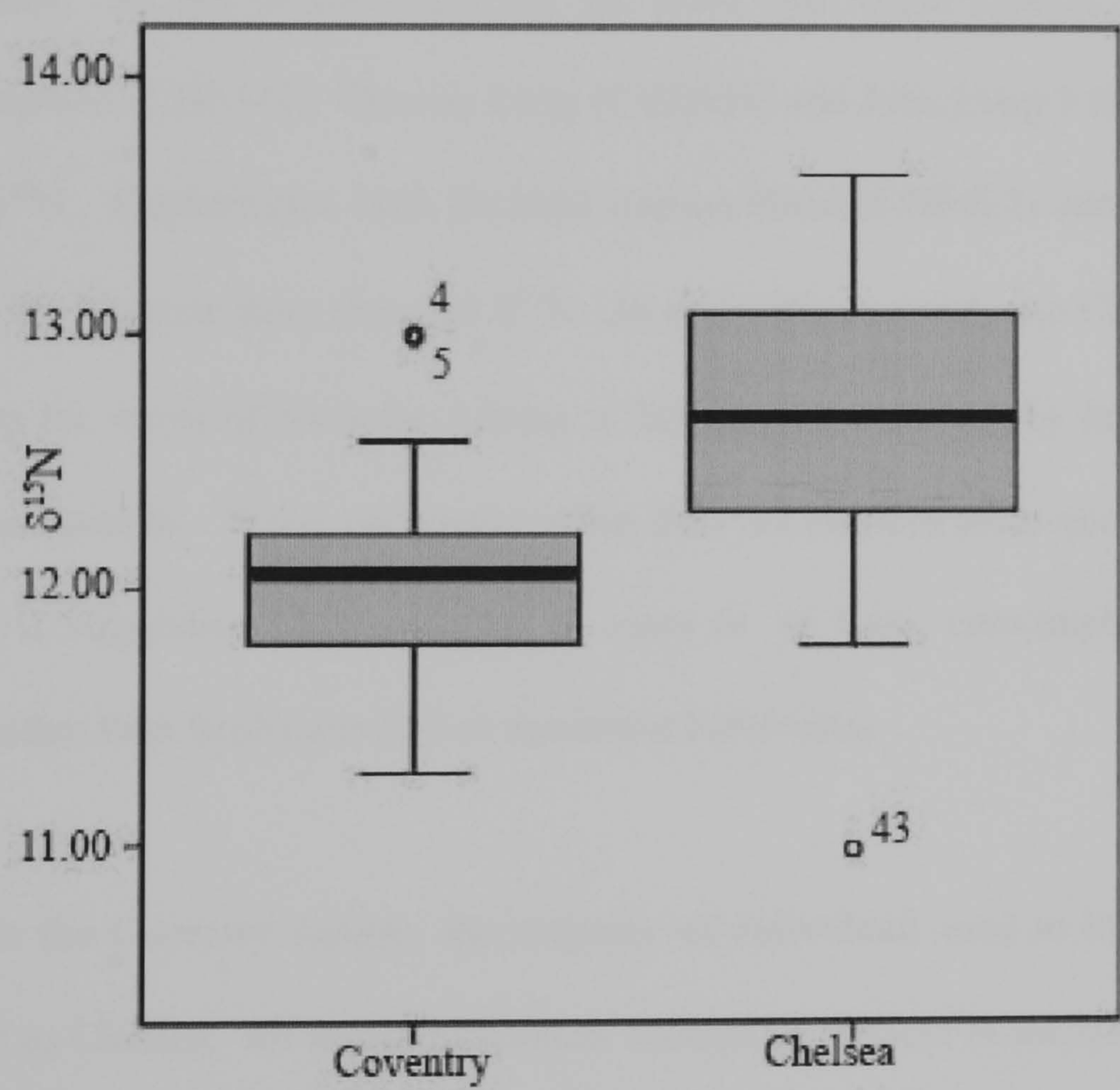


Figure 34: Box-plot of $\delta^{15}N$ for Holy Trinity (Coventry) and St. Luke's (Chelsea) indicating outlying individuals.

Three individuals are represented as outlying the main groups. Within the Coventry sample there are two outliers: individuals "4", or James Brown (COV978); and individual "5", John Ballard (COV1119). Individual "43", or Sarah Adams (CHE980), provides the single outlier in the Chelsea sample. As, above, this would seem to suggest that the diets of these individuals were significantly different from that of the majority of their respective

populations. In the case of James Brown (COV978) and John Ballard (COV1119), this would seem to imply an increased intake of meat and or fish resources in their diet beyond the norm of Coventry, while Sarah Adams (CHE980) seems to have a decreased presence of these components in her diet.

6.4.3. Socio-Economic Status and Dietary Variation in Coventry and Chelsea

The acquisition of biographical information for a number of the individuals from both Coventry and Chelsea provides insight into differential access to food resources by socio-economic class. As can be seen from fig. 28, those individuals defined as 'gentleman' – Thomas Langfield (CHE147), Thomas Long (CHE654) and John Long Esq. (CHE713) – all have high $\delta^{15}N$. Furthermore, both Richard Gideon Hand (CHE622) and Gideon Richard Hand (CHE35) likewise have elevated $\delta^{15}N$. In comparison, Sarah and Charity Adams are mentioned as the wives of Nicholas Adams, a 'bricklayer', and have by far the lowest $\delta^{15}N$ in the Chelsea sample. While occupation often does not confirm socio-economic status, the lower $\delta^{15}N$ is suggestive of less access to meat or, at least, consumption of terrestrial herbivores rather than freshwater fish or terrestrial herbivores.

Similarly for the Coventry sample, the majority of individuals tend to have a lower $\delta^{15}N$ with respect to Chelsea. Of those individuals defined as outliers in the Coventry sample – James Brown and John Ballard – both are listed on the Coventry Voter's list indicating that they were of higher socio-economic class than the remainder of the Coventry sample. John Chattaway is seemingly from a less wealthy agricultural family, and has much lower $\delta^{15}N$ than either James Brown or John Ballard. With the greater wealth there would be, once again, greater access to meat resources. Further, it is reasonable to associate John Ballard with the 'ale' industry, and taverns of the period were a common source of meats, etc. (Hammond 1993; Roberts and Cox 2003).

While the association of higher $\delta^{15}N$ with elevated socio-economic class is intriguing, furthur analysis of biographically-determined post-medieval is required, including individuals from a wide array of social and geographical situations.

It is, however, possible to compare the Coventry and Chelsea material against that which is generally considered to be 'high status' with variable diets consisting of significant contribution by meats and fish: later medieval monastic communities. The majority of studies of monastic communities have focussed solely upon $\delta^{13}C$. Polet and Katzenberg (2003) performed a biviariate ($\delta^{13}C$ and $\delta^{15}N$) study of human skeletal material from the 12th-15th century abbey of Dunnes at Koksijde, Belgium. Individuals from the medieval sites of St. Giles, Towton and Warrington are likewise included on fig.32 (Müldner and Richards 2001).

Mays (1997) offered a univariate ($\delta^{13}C$) study of several medieval sites, including both monastic and lay settlements. These are plotted on fig.32 with the $\delta^{15}N$ being entirely arbitrary (it was not analysed in the cited studies).

Group 1	**Group 2**
Coventry	*Chelsea*
Scarborough Castle Hill	Dunnes Abbey (Belgium)
Wharram Percy (Post-medieval)	Hartlepool Greyfriars
Wharram Percy (Medieval)	York Fishergate (Monastic)
York Fishergate (Lay)	

Table 33: Classifications of 'groups' of diet based upon the current project (post-medieval) and published medieval and post-medieval $\delta^{13}C$ data (Mays 1997; Richards and van Klinken 1997; van Klinken *et al.* 2000; Polet and Katzenberg 2003).

The diet of monks has been discussed in greater detail elsewhere, but following the twelfth century they were permitted to consume meats, often in large quantities (Hammond 1978; Hammond 1993; Mays 1998; Roberts and Cox 2003). Individuals at Bolton Abbey were, for example, recorded as consuming 21/2lb of grain and approximately 1/2 lb of meat per day and 1/2 lb butter and milk per week (Roberts and Cox 2003). Specific eating

restrictions between the various monastic orders varied such that, for example, Cistercians were not permitted to eat fish until the fourteenth century (Hammond 1993; Roberts and Cox 2003). This is at variance to the diet of the 'peasants' of the period consisting, as mentioned above, of predominantly grain-related products (Hammond 1993; Roberts and Cox 2003).

The median values for Group 1, including Coventry, are suggestive of a diet with only minimal marine input although that input may have had a disproportionate effect on the protein component of the diet (Mays 1997). Herrscher *et al.* (2001) suggest that similar values in a sample from the cemetery of Saint-Laurent do not represent a sample with significant contribution of marine/fish protein into the diet. Variation in $\delta^{13}C$ in local fish may explain the proposed load of marine/fish resources in the Coventry diet, though similarly one must question the assumption of linearity of diet when one considers the incorporation of carbon into collagen in times of stress (Mays 1997).

Group 2 shows a median value that is shifted towards a 'marine/fish' $\delta^{13}C$ and that is also consistent with broad analogy between monastic settlements based upon the extant historical record (Hammond 1993; Roberts and Cox 2003). While sugar cane may have contributed to this signal, one might question the relative contribution of what was otherwise an expensive commodity in the period.

6.4.4. Variation of Diet between Sexes (Chelsea)

Visual examination of the results (fig. 28) indicates an apparent difference in diet between males and females, particularly among the Coventry sample. The small sample size of Coventry for males and females (n=6 and 7, respectively) makes quantitative analysis problematic. As a result the tests of significance of diet variability are limited to the Chelsea sample.

Table 34 and 35 present the results of Mann-Whitney tests of significance

Isotope	Sex	N	Mean Rank	Sum of Ranks
$\delta^{13}C$	Male	12	18.17	218.00
	Female	20	15.50	310.00
	Total	*32*		
Mann-Whitney U	100.000			
Wilcoxon W	310.000			
Z	-0.779			
Asymp. Sig. (2-tailed)	0.436			
Exact. Sig. [2×(1-tailed Sig.)]	0.454 [1]			

Table 34: Mann-Whitney test of asymptotic significance of difference between $\delta^{13}C$ values of males and females in Chelsea ([1] not corrected for ties; produced by Statistic Package for Social Scientists).

Isotope	Sex	N	Mean Rank	Sum of Ranks
$\delta^{15}N$	Male	12	18.83	226.00
	Female	20	15.10	302.00
	Total	*32*		
Mann-Whitney U	92.000			
Wilcoxon W	302.000			
Z	-1.090			
Asymp. Sig. (2-tailed)	0.276			
Exact. Sig. [2×(1-tailed Sig.)]	0.289 [1]			

Table 35: Mann-Whitney test of asymptotic significance of difference between $\delta^{15}N$ values of males and females in Chelsea ([1] not corrected for ties; produced by Statistical Package for Social Scientists).

Historically it is commonly assumed that the male in a family household had preferential access to protein-resources over that of the wife and any dependents whose diet would focus on bread and weak tea (Wohl 1983). Within this study there is little statistical indication of difference between males and females in the Chelsea sample (e.g. $0.276 \geq P \leq 0.436$). Despite the poor correlation, it is interesting to note that the significance of variation in diet with $\delta^{15}N$ is greater than that of $\delta^{13}C$ implying that at least to some extent there was differential access to protein resources between the sexes. The median and standard deviation (1σ) for the Chelsea males and females are, respectively: $\delta^{13}C/\delta^{15}N$ of –19.00‰ ± 0.33/12.81‰ ± 0.48 and –18.82‰ ± 1.14/12.56‰ ± 0.60. As such it is difficult to make definitive

assertions in this regard without recourse to further samples, both within Chelsea and in terms of additional sites and periods.

6.4.5. Summary of $\delta^{13}C/\delta^{15}N$ Results for Coventry and Chelsea

The results of the carbon and nitrogen analysis of the two populations suggest that the individuals of Coventry and Chelsea had different dietary experiences. While all individuals had elevated $\delta^{15}N$ consistent with the consumption of meat resources, the significance of this contribution varies between the sites. Chelsea, a higher status population, had greater access to meat in their diet as well as greater variability in that diet than did Coventry.

While there is some indication of status related to enrichment of $\delta^{15}N$, the limited number of cases of individuals with known socio-economic class presents problems of statistical validation and requires additional samples to be analysed from alternative samples. Comparison with the $\delta^{13}C/\delta^{15}N$ results of medieval settlements, including 'high status' monastic sites, indicates that while access to marine resources may be a function of locality, in as much as inland sites have less access than coastal sites, socio-economic status defines preferential access to high protein sources (Mays 1997; Polet and Katzenberg 2003).

In the case of both sites, the relatively elevated $\delta^{15}N$ of both populations shows that marine resources – e.g. fish, eels, etc. – provided a not-insignificant component to the diet of the study population. While there is internal variation within each population, the variation between the two populations can be a product of two factors:

- *Socio-economic class.* The average individual within at least the named sample of Chelsea enjoys a higher socio-economic class than that of Coventry. Thus the discrepancy between the two populations may be the result of status-based access to

meat and marine/fish resources. This may have included such foods as eels – freshwater predators that consume other fish – with their higher trophic level translating to greater enrichment in ^{15}N.

- *Location.* While both sites are situation on rivers, e.g. the Sherbourne (Coventry) and the Thames (Chelsea), Chelsea's proximity to the ocean may have allowed greater access to marine products. As such, these products may have been more prevalent in the many markets of what was otherwise a bustling locale (Chelsea and, more widely, London) and, as a result, cheaper and more accessible to the population.

As with other populations analysed, while the historical evidence suggests that males had preferential access to meat than women or children, there is little evidence of this in the isotopic record (Wohl 1983; Richards *et al.* 2001; Privat *et al.* 2002). What evidence does exist suggests that any differentiation in sex-based access to meat resources is more likely to be a function of socio-economic class. For example, while Thomas and Catherine Long share broadly analogous dietary protein, the wives of Nicholas Adams – Charity and Sarah – had significantly different access to protein.

Milborough Maxwell (CHE792) and CHE18 both had diets that were significantly enriched in $\delta^{13}C$ relative to the average Chelsea diet. The specific combination of food types by which this was achieved is difficult to ascertain, but may represent either the greater contribution of marine-based resources to their diets, or the gradual acclimatisation from a C_4 to a C_3-based diet.

6.5. Strontium Stable Isotopes ($^{87}Sr/^{86}Sr$)

Results for the strontium isotope ($^{87}Sr/^{86}Sr$) are presented in the table below.

Sample	N	Sex	Name	$^{87}Sr/^{86}Sr$	Sr ppm
COV516	1	M	? Cooper	0.709183	351
COV808	2	M	William Wagstaffe	0.709974	107
COV978	3	M	James Brown	0.709151	142
COV1248	4	M	John Chattaway	0.709620	63
COV16	5	F	Ann Kimberly	0.710417	91
COV50	6	F	…ein…	0.709972	95
COV77	7	F	Elizabeth Burton	0.710417	91
COV417	8	F	Sarah Green	0.710436	94
COV434	9	F	Hannah Denney	0.709778	139
COV672	10	F	Eliza Sparkes	0.709940	113
COV672	10	F	Eliza Sparkes (primary dentine)	0.709776	113
COV866	11	F	Harriet Parsons	0.710028	109
CHE35	12	M	Gideon Richard Hand	0.709270	137
CHE147	13	M	Thomas Langfield	0.708765	83
CHE285	14	M		0.708974	111
CHE654	15	M	Thomas Long	0.709449	125
CHE654	15	M	Thomas Long (primary dentine)	0.709227	921
CHE713	16	M	John Long Esquire	0.709468	156
CHE744	17	M	John Long	0.709449	163
CHE856	18	M		0.709190	175
CHE994	19	M		0.709295	197
CHE18	20	F		0.709216	277
CHE19	21	F		0.710898	73
CHE31	22	F		0.708932	128
CHE39	23	F		0.709318	104
CHE104	24	F		0.709087	117
CHE161	25	F		0.709310	198
CHE392	26	F		0.709217	154
CHE552	27	F		0.709880	83
CHE697	28	F		0.709202	76
CHE750	29	F		0.709163	98.1
CHE792	30	F	Milborough Maxwell	0.706361	118
CHE841	31	F		0.710357	175
CHE918	32	F		0.709298	135
CHE980	33	F	Sarah Adams	0.708903	90
CHE990	34	F	Charity Adams	0.709380	39
CHE1050	35	?F	Collon	0.709268	141

Table 36: $^{87}Sr/^{86}Sr$ and concentration (ppm) results from enamel for individuals analysed from Chelsea and Coventry.

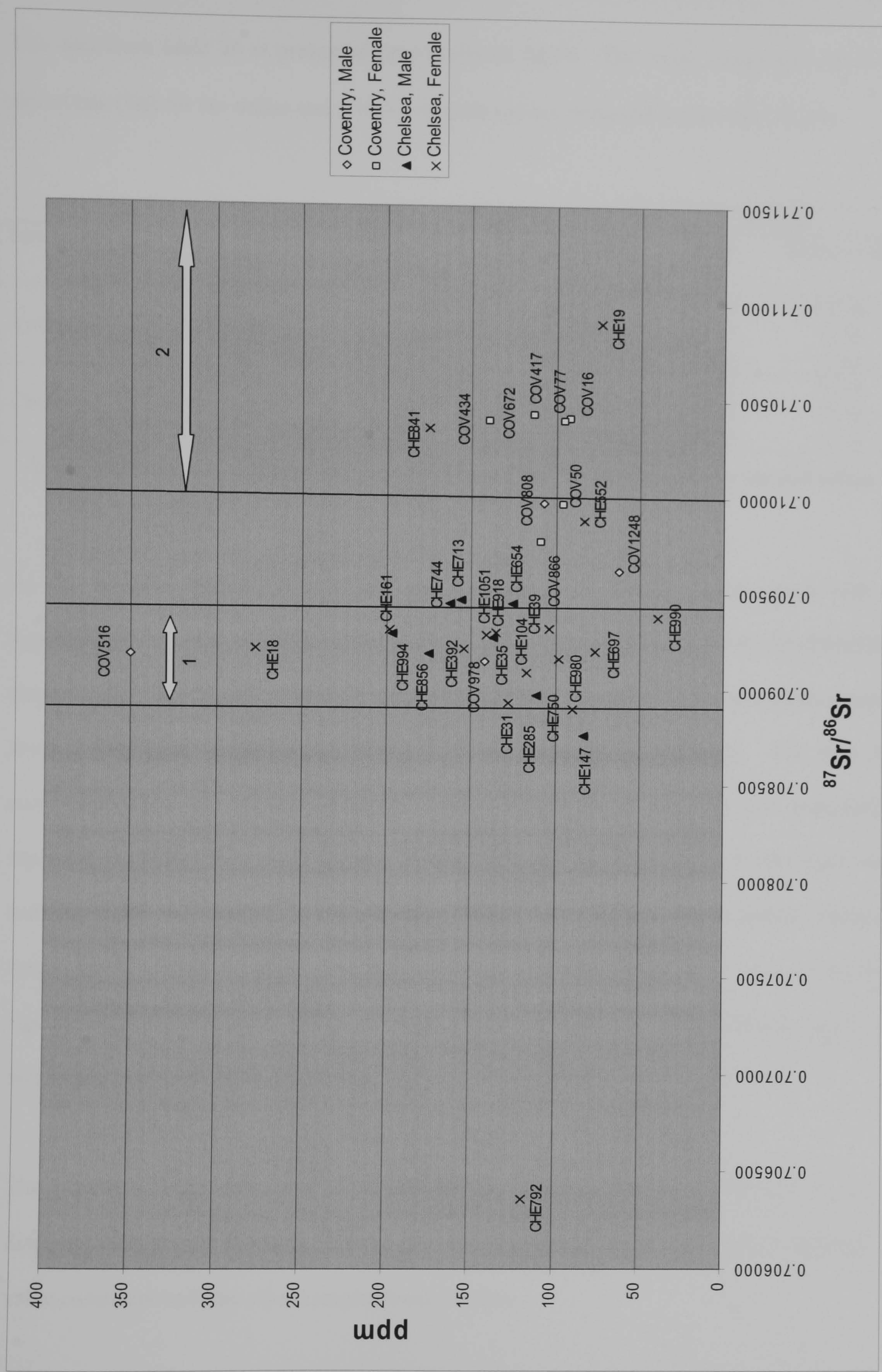


Figure 35: Plot of Sr ppm against $^{87}Sr/^{86}Sr$ for Chelsea and coventry. Range "1" indicates expected range for Thames Valley lithology; range "2" indicates expected range from lithology surrounding Coventry (Paul Budd, Jane Evans pers. comm.) Error bars are smaller than symbols.

The data from table 36 is presented graphically in fig.36. The mean values and standard deviations (1σ) for the males and females of each site are presented in the table, below.

		$^{87}Sr/^{86}Sr$		Sr ppm	
Site	Sex	**Mean**	**St.Dev. (1σ)**	**Mean**	**St.Dev. (1σ)**
Coventry	Male	0.709842	0.000392	165.75	127.66
	Female	0.710141	0.000275	105.57	17.55
	Male + Female	0.709901	0.000449	126.82	77.63
Chelsa	Male	0.709223	0.000251	143.38	36.82
	Female	0.709237	0.000930	125.38	57.10
	Male + Female	0.709235	0.000764	131.38	51.13

Table 37: Mean and standard deviation for sample ($^{87}Sr/^{86}Sr$ and Sr ppm) by site and within site by sex.

As can be seen from fig.36, Chelsea and Coventry form distinct groups, each with a significantly different mean Sr isotope ratio (0.709901±0.000449 and 0.709235±0.000764 respectively). The Sr concentrations are similar to those reported in other strontium isotope studies with three exceptions: COV516, COV654 (dentine) and CHE18. The high Sr concentrations in the enamel of CHE18 and COV654 are of concern, and potentially represent the failure to remove primary dentine from the dental sample. Furthermore, the samples share very similar Sr isotope ratios, which may indicate that diagenetic mineral might be the dominant signal, i.e., representing a soil rather than an *in vivo* Sr isotope signature (*cf.* Trickett *et al.* 2003). As such, they must be viewed with a certain degree of scepticism in the following discussion.

The extremely large concentration in the primary dentine of CHE654 indicates a large diagenetic component to the Sr isotope composition, though the enamel sample presents a value consistent with the other samples from Chelsea.

6.5.1 Provenance Studies and Strontium Isotopes

As mentioned previously, while it is possible to visually determine a separation between the Coventry and Chelsea populations in terms of $^{87}Sr/^{86}Sr$ and Sr concentrations (ppm) a Mann-Whitney test was employed to determine the significance of difference between the two populations:

Isotope	Site	N	Mean Rank	Sum of Ranks
$^{87}Sr/^{86}Sr$	Coventry	11	25.27	278.00
	Chelsea	24	14.67	352.00
	Total	*35*		
Mann-Whitney U	52.000			
Wilcoxon W	352.000			
Z	-2.843			
Asymp. Sig. (2-tailed)	0.004			
Exact Sig. [2×(1-tailed)]	0.004 [1]			

Table 38: Mann-Whitney test indicating significance of difference between the $^{87}Sr/^{86}Sr$ ratios of Chelsea and Coventry ([1] not corrected for ties; produced by STATISTICAL PACKAGE FOR SOCIAL SCIENTISTS).

As can be seen, there is a significant difference (P=0.004) between the Coventry and Chelsea samples in terms of their $^{87}Sr/^{86}Sr$ ratios. Expected strontium isotope ratios, indicated by "Range 1" and "Range 2" on fig.36 are given in chapter 4.

The use of the Sr isotopes to determine the local characteristics within the project is limited by the complexity and variability of strontium geochemistry and, therefore, the ability to define a local Sr isotope signature. In more recent studies, archaeological animal remains have been used to define this local Sr isotope signature. However, the relative expense of such procedures balanced against the large sample size of the human remains prevented such an approach in this project. Despite this, Sr isotopes remain useful in determining when individuals present within a sample do not conform to the local Sr isotope composition, as was the case here with outliers such as Milborough Maxwell (CHE792).

While the Chelsea median value plots within the expected range derived from the solid geology, those of the Coventry do not conform to the expected Sr isotope composition of the Westphalian stratum. However, as one can see from fig.25 (Chapter 4), the surrounding deposits share similar geological ages such that the expected Sr isotope composition are more similar to Chelsea than not. This would therefore affirm the suggestion of non-conformance of labile Sr to the underlying lithology.

Although determination of the 'local' Sr isotope signature is not possible with the current data set, a number of outliers do arise that suggest a completely different source of Sr integrated into the skeleton. These are: CHE792 (Milborough Maxwell); COV978 (James Brown); and CHE19.

Milborough Maxwell represents the clearest case of migration in the combined sample, with a Sr isotope ratio that is beyond the range presented by British lithology, with the possible exception of the geology of the Isle of Skye (*cf.* fig.25). When coupled with the oxygen isotope analysis, however, an origin in the British Isles seems unlikely (section 6.6). Rather, the Sr isotope composition of Milborough Maxwell is consistent with the young isotopic signature of igneous or basaltic rock (Faure 1986; Duff 1993; Sumbler 1996; Bridge *et al.* 1998).

CHE19 has a $^{87}Sr/^{86}Sr$ that plots significantly away from both the median values for both Coventry and Chelsea, implying that the individual migrated during their lifetime.

As with CHE19, the Sr isotope ratio of James Brown (COV978) implies a migratory individual. While the sample derives from the first premolar rather than the second premolar or second molar, for the purposes of determining childhood residence this makes

little difference as strontium isotopes are not affected by biological fractionation (see Chapter 4). Historically, James Brown is attested as having migrated between Coventry and Warwick during his lifetime (section 6.1.4). As can be seen from figs.18 and 20, the bedrock geology of Coventry and Warwick are broadly comparable, once again suggesting that bedrock geology and labile Sr are not directly related.

6.5.2 Summary of $^{87}Sr/^{86}Sr$ Results for Coventry and Chelsea

The results of the analysis indicate that strontium remains a useful tool for characterising archaeological populations and in identifying immigrants into those populations. The correlation between recorded strontium isotope ratios of the human population and the underlying geological strata is not fully understood. Without further sampling of local soils and non-migratory faunal populations to characterise labile strontium in the area, it is only possible to note the wide degree of variation seen in both populations.

While the question of the geological strata and biologically available strontium offers one avenue of complexity in the interpretation of strontium isotope ratios of human populations, the study of remains from a city adds yet another. Namely, biologically available strontium includes not only that derived from local food sources, but also from those imported into the city. With improvements in communications infrastructure, product packaging, etc., this 'blurring phenomenon' – the mixing of biologically available strontium from one or more sources – would theoretically become an increasing contributor to an individuals strontium load. Depending on the food resource in question, it is conceivable that a trend towards homogenisation of strontium isotopes could be observed.

Some of these complexities can be seen in Aberg *et al.*'s (1998) paper detailing a study of medieval Norwegian teeth. Within this study, modern tooth enamel had a strontium isotope ratio similar to Norwegian milk (0.7086), rather than the area-specific values of the

medieval period, where the population was primarily subsisting from local food resources (Aberg *et al.* 1998). Aberg *et al.* (1998: 116) further notes that a significant contribution to the strontium load of an individual from Medieval Norway likely derived from milling stones used to grind grain.

Similar considerations would likely be found in eighteenth and nineteenth century England. As described in chapter 2, in the study period regional specialisation tended to concentrate industrial and agrarian activities into specific areas. Thus, while there was likely a local component to food resources, the increasing tendency was for grain and other food resources to come from an increasingly greater distance from the city. As such, the ability to define a childhood residence to a specific locale will become increasingly more problematic in 'modern' populations, both for strontium isotope rations *and* oxygen isotope ratios.

In application to the study populations, the variability seen in the strontium isotopes ratios may be explained by the importing of food resources into the city and, therefore, a decreasing reliance upon local produce. Individuals such as John Chattaway (COV 1248) who, given the historical details available, are unlikely have moved outside of Coventry may be subsisting on food resources with a predominantly non-local origin. Similarly with "Cooper" (COV516) whose strontium isotope signature is more similar to the Chelsea population than that of Coventry.

While the application of strontium isotopes to provenience studies may be increasingly problematic in modern populations, it is still possible to identify significant outliers and exclude individuals who could not have derived from that locale.

6.6. Oxygen Stable Isotopes ($\delta^{18}O$)

The results for the oxygen isotopic analysis of individuals from Coventry and Chelsea are presented in table 39 and 40.

Sample	N	Sex	Name	$\delta^{18}O$ (SMOW)	St.Dev (1σ)
COV516	1	M	? Cooper	16.8	0.01
COV808	2	M	William Wagstaffe	16.6	0.04
COV978	3	M	James Brown	17.1	0.04
COV1248	4	M	John Chattaway	16.3	0.04
COV50	5	F	…ein…	17.0	0.15
COV77	6	F	Elizabeth Burton	16.1	1.09
COV417	7	F	Sarah Green	16.6	0.12
COV434	8	F	Hannah Denney	16.1	0.21
COV672	9	F	Eliza Sparkes	16.3	0.07
COV866	10	F	Harriet Parsons	17.3	0.11

Table 39: $\delta^{18}O$ ($SMOW_{Phosphate}$) results for Holy Trinity Coventry.

Sample	N	Sex	Name	$\delta^{18}O$ (SMOW)	St.Dev (1σ)
CHE35	11	M	Gideon Richard Hand	17.8	0.02
			Gideon Richard Hand (Bone)	16.7	0.16
CHE147	12	M	Thomas Langfield	17.4	0.14
			Thomas Langfield (Bone)	17.3	0.07
CHE285	13	M		18.8	0.21
CHE654	14	M	Thomas Long	17.2	0.17
			Thomas Long (Bone)	16.9	0.02
CHE713	15	M	John Long Esquire	17.3	0.18
CHE744	16	M	John Long	17.4	0.25
CHE856	17	M		17.6	0.14
CHE994	18	M		17.9	0.19
CHE18	19	F		17.5	0.21
CHE19	20	F		18.6	0.11
CHE31	21	F		17.5	0.25
CHE39	22	F		17.4	0.11
CHE104	23	F		17.7	0.09
CHE161	24	F		17.0	0.13
CHE392	25	F		16.9	0.22
CHE552	26	F		17.3	0.26
CHE697	27	F		17.2	0.19
CHE722	28	F	Catherine Long (Bone)	16.3	0.04
CHE750	29	F		17.6	0.03
CHE792	30	F	Milborough Maxwell	18.9	0.16
CHE841	31	F		16.7	0.29
CHE918	32	F		17.9	0.19
CHE980	33	F	Sarah Adams	17.4	0.21
CHE990	34	F	Charity Adams	16.2	0.02

Table 40: $\delta^{18}O$ ($SMOW_{Phosphate}$) results for Chelsea.

The median, standard deviation for each site and sub-divided by sex is given in the table below.

		$\delta^{18}O$ ($SMOW_{Phosphate}$)		Error
Site	Sex	**Mean**	**St.Dev. (1σ)**	**Mean**
Coventry	Male	16.70	0.37	0.03
	Female	16.57	0.50	0.29
	Male + Female	16.62	0.42	0.19
Chelsea	Male	17.68	0.52	0.16
	Female	17.45	0.68	0.17
	Male + Female	17.53	0.62	0.16

Table 41: Mean and standard deviation for sample ($\delta^{18}O$ $SMOW_{Phosphate}$) by site and within site by sex.

While the sample size for Coventry is too small to allow proper determination of normality, the Chelsea data does have a Gaussian distribution. The mean value from table 41 indicates that the two populations do separate out but, once again, the variation within the sample would make determination of the provenance of an individual analysed in isolation problematic (see section 6.5). Given the static nature of at least the Coventry population, the incorporation of oxygen isotopes into human dental enamel is more complex than originally proposed both in terms of the biochemical incorporation and the human interaction that moderates isotopic values.

6.6.1. Conversion of Enamel $\delta^{18}O$ to Mean Surface/Groundwater Values

A number of commonly utilised regression formulae have been used in an attempt to relate measured $\delta^{18}O$ (SMOW) measured in mammalian skeletal tissues and measured values from surface and/or groundwater. This can be stated generically:

$$Human(\delta^{18}O) = \frac{\left(\left[\delta^{18}O_{SMOW} - K\right] - c\right)}{m}$$

Equation 2: Calibration of human biophosphate to surface/ground water, where: $\delta^{18}O_{SMOW}$ = measured oxygen isotope value for biophosphate, K = correction constant applied as a result of Ag_3PO_4 analysis to laser fluorination processes (1.01‰), c = intercept at $\delta^{18}O_{SMOW}$=0 and m = gradient of regression line through calibration data. Where K = 1.01 and c = 19.4 (Levinson *et al.* 1987), 22.7 (Luz *et al.* 1990) and 22.37 (Longinelli 1984).

The $\delta^{18}O_{SMOW}$ analyses for Coventry and Chelsea have been calibrated using the above formulae to facilitate determination of provenance as based upon the isotopic record. This data is presented in the following two tables:

Sample	Name	$\delta^{18}O$	1σ	Levinson	Luz	Longinelli
COV516	? Cooper	16.76	0.01	-7.93	-8.90	-10.34
COV808	William Wagstaffe	16.64	0.04	-8.21	-9.07	-10.54
COV978	James Brown	17.11	0.04	-7.17	-8.46	-9.79
COV1248	John Chattaway	16.33	0.04	-8.86	-9.46	-11.01
Male Average $\delta^{18}O$		*16.71*	*0.03*	*-8.04*	*-8.97*	*-10.42*
Standard Deviation (1σ)		*0.32*	*0.02*	*0.70*	*0.41*	*0.50*
COV50	…ein…	17.03	0.15	-7.34	-8.56	-9.92
COV77	Elizabeth Burton	16.07	1.09	-9.43	-9.79	-11.42
COV417	Sarah Green	16.63	0.12	-8.22	-9.08	-10.55
COV434	Hannah Denney	16.09	0.21	-9.40	-9.77	-11.39
COV672	Eliza Sparkes	16.28	0.07	-8.98	-9.53	-11.10
COV866	Harriet Parsons	17.26	0.11	-6.85	-8.27	-9.57
Female Average $\delta^{18}O$		*16.56*	*0.29*	*-8.37*	*-9.17*	*-10.56*
Standard Deviation (1σ)		*0.50*	*0.39*	*1.09*	*0.64*	*0.78*
Average $\delta^{18}O$		16.62	0.19	-8.24	-9.09	-10.56
Standard Deviation (1σ)		0.42	0.32	0.92	0.54	0.66

Table 42: $\delta^{18}O$ in human biophosphate from Coventry calibrated to surface/groundwater by methods employed separately by Levinson, Luz and Longinelli (Longinelli 1984; Luz *et al.* 1984; Luz and Kolodny 1985; Levinson *et al.* 1987; Luz *et al.* 1990).

Sample	Name	$\delta^{18}O$	1σ	Levinson	Luz	Longinelli
CHE35	Gideon Richard Hand	17.78	0.02	-5.71	-7.60	-8.74
	Gideon Richard Hand (Bone)	16.65	0.16	-8.16	-9.05	-10.51
CHE147	Thomas Langfield	17.44	0.14	-6.46	-8.04	-9.28
	Thomas Langfield (Bone)	17.29	0.07	-6.77	-8.22	-9.51
CHE285		18.81	0.21	-3.49	-6.29	-7.15
CHE654	Thomas Long	17.18	0.17	-7.01	-8.37	-9.68
	Thomas Long (Bone)	16.85	0.02	-7.74	-8.79	-10.20
CHE713	John Long Esquire	17.25	0.18	-6.86	-8.28	-9.57
CHE744	John Long	17.39	0.25	-6.56	-8.10	-9.35
CHE856		17.58	0.14	-6.15	-7.86	-9.06
CHE994		17.87	0.19	-5.53	-7.49	-8.61
Male Average $\delta^{18}O$		*17.66*	*0.16*	*-5.97*	*-7.75*	*-8.93*
Standard Deviation (1σ)		*0.52*	*0.07*	*1.13*	*0.67*	*0.81*
CHE18		17.45	0.21	-6.43	-8.02	-9.26
CHE19		18.58	0.11	-3.98	-6.58	-7.50
CHE31		17.52	0.25	-6.29	-7.94	-9.16
CHE39		17.40	0.11	-6.55	-8.09	-9.35
CHE104		17.68	0.09	-5.94	-7.73	-8.91
CHE161		17.04	0.13	-7.32	-8.55	-9.90
CHE392		16.87	0.22	-7.69	-8.77	-10.17
CHE552		17.33	0.26	-6.70	-8.18	-9.46
CHE697		17.23	0.19	-6.92	-8.31	-9.61
CHE722	Catherine Long (Bone)	16.32	0.04	-8.88	-9.47	-11.02
CHE750		17.63	0.03	-6.04	-7.80	-8.98
CHE792	Milborough Maxwell	18.92	0.16	-3.23	-6.14	-6.96
CHE841		16.75	0.29	-7.96	-8.92	-10.36
CHE918		17.86	0.19	-5.54	-7.50	-8.62
CHE980	Sarah Adams	17.37	0.21	-6.61	-8.13	-9.39
CHE990	Charity Adams	16.22	0.02	-9.11	-9.60	-11.19
Female Average $\delta^{18}O$		*17.46*	*0.16*	*-6.42*	*-8.02*	*-9.26*
Standard Deviation (1σ)		*0.67*	*0.08*	*1.46*	*0.86*	*1.05*
Average $\delta^{18}O$ (excluding bone)		17.48	0.16	-6.37	-7.99	-11.9
Standard Deviation (1σ)		0.65	0.08	1.42	0.84	1.02
Average $\delta^{18}O$ (bone)		16.78	0.07	-7.89	-8.88	-10.31
Standard Deviation (1σ)		0.41	0.06	0.88	0.52	0.63
Average $\delta^{18}O$ (all)		17.42	0.15	-6.50	-8.07	-9.32
Standard Deviation (1σ)		0.64	0.08	1.40	0.83	1.01

Table 43: $\delta^{18}O$ in human biophosphate fom Chelsea calibrated to surface/groundwater by methods employed separately by Levinson, Luz and Longinelli (Longinelli 1984; Luz *et al.* 1984; Luz and Kolodny 1985; Levinson *et al.* 1987; Luz *et al.* 1990).

Ground/surface water has recently received substantial attention in the geochemical community and, as such, are well measured within the United Kingdom (Darling and Talbot 2003*a, b*; Budd *et al.* 2004*a, b*; Millard 2004). The current $\delta^{18}O$ for surface/ground waters are presented in fig.37.

From fig.37 it is apparently that the $\delta^{18}O$ values for surface/ground water in the two study areas should be $-7.5 \leq \delta^{18}O \leq -8.0$ for Coventry and $-7.0 \leq \delta^{18}O \leq -7.5$ for Chelsea. A comparison between the expected range and the mean values presented in table 39 and 40 can be used to determine the success of the various calibrations:

Site, Sex	Levinson		Luz		Longinelli	
	Value	1σ	Value	1σ	Value	1σ
Coventry, Male	N	Y	N	N	N	N
Coventry, Female	N	Y	N	N	N	N
Coventry, Male & Female	N	Y	N	N	N	N
Chelsea, Male	N	Y	N	Y	N	N
Chelsea, Female	N	Y	N	Y	N	N
Chelsea, Male & Female [1]	N	Y	N	Y	N	N
Chelsea, Male & Female [2]	N	Y	N	N	N	N
Chelsea, Male & Female [3]	N	Y	N	Y	N	N

Table 44: Successful provenance by calibration type, where 'value' represents a successful predication within the expected range, '1σ' when the value is within the expected range when one standard deviation is taken into account. ([1] Excluding bone $\delta^{18}O$, [2] bone $\delta^{18}O$ values, [3] both bone and non-bone $\delta^{18}O$ values.)

The table, above, is a simplistic means by which the success of the various calibrations in application to the population can be determined. As seen historically, with one or two exceptions both the Coventry and Chelsea samples represent a static population, more so Coventry than Chelsea where increased socio-economic status allows for greater recreational transience. As can be seen, none of the calibrations employed successfully determine the 'value' of drinking/precipitation from biophosphate $\delta^{18}O$. The Longinelli calibration is particularly unsuccessful, failing to predict $\delta^{18}O$ value even to within a single standard deviation. Similarly, the Luz calibration is unsuccessful in predicating the expected $\delta^{18}O$ value, though in the case of Chelsea is accurate within one standard deviation in all but one case. The Levinson calculation is likewise incapable of predicting the appropriate value although in each case predicts the range within one standard deviation (Budd *et al.* 2004*b*).

In all cases it is unlikely that single individuals analysed would have been successfully identified as deriving from a $\delta^{18}O$ (surface/groundwater) range consistent with either

Coventry or Chelsea. As with $^{87}Sr/^{86}Sr$ analyses this is concerning with archaeological interpretations and the weight that is placed on the validity of isotopic techniques, but more so especially with the application of isotopic provenance studies to forensic cases.

The variation in $\delta^{18}O$ in the calibrations in converting biophosphate $\delta^{18}O$ to drinking water $\delta^{18}O$ has recently been highlighted as a problem in provenance studies. Calibrations are often predicated around twentieth century samples where 'exotic water', including both bottled mineral waters and that from imported alcoholic beverages, serves to biase the data (Millard 2004). While the Longinelli calibration used material before the extensive use of bottled water, as can be seen above it does not return values consistent with the known locations of the sample population (Longinelli 1984). This introduces a standard error that is a significant fraction of the determined $\delta^{18}O$ for drinking water, e.g. 0.7‰ and 2.4‰ for the Levinson and Longinelli calibrations (Longinelli 1984; Levinson *et al.* 1987; Longinelli 1996; Millard 2004). A median value for the standard error still produces an error range (to 2σ), which is a greater variation than that found in surface/ground waters in the United Kingdom (Millard 2004).

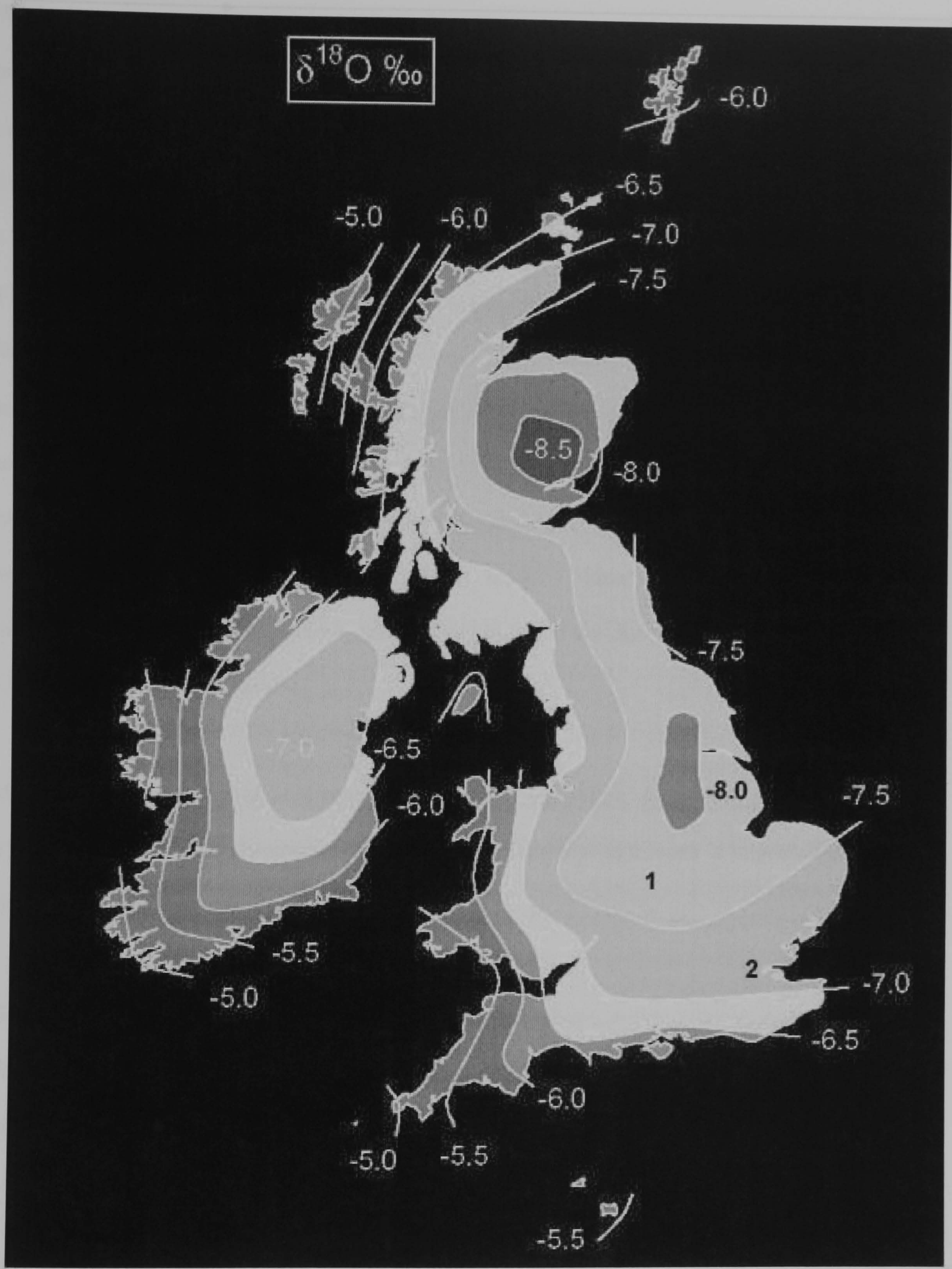


Figure 36: $\delta^{18}O$ in surface ground/waters – '1' marks the approximately location of Coventry and '2' that of Chelsea/London (Darling and Talbot 2003, 2003*a*; Budd *et al.* 2004*a, b*; Millard 2004).

While the consistently ^{18}O enriched signals from the Coventry and Chelsea populations may point towards the limitations of the established calibration formulae, indeed the complications of physiological and environmental contributors to oxygen flux within the human body are well established (Millard pers. comm.), alternative hypotheses might apply.

First, the source of drinking water might have been subjected to significant evaporation. Water supply in the nineteenth century was highly variable, with water commonly transported over distances of a quarter-mile or more, and many individuals were forced to use unfiltered rain butts (Wohl 1983: 62). As these contain water that is exposed, evaporation will enrich the ^{18}O as the lighter ^{16}O tends to be removed. While annually this will tend towards an average value, if the primary source of water is from a pool continually subject to evaporation it is possible that this might create the discrepancy observed in the Coventry and Chelsea data sets.

While the consumption of alcoholic beverages was significant during the period (Wohl 1983), the age of mineralisation of the teeth in the sample would make it improbable that this was a significant source of dietary water.

Second, as mentioned in section 6.5.2 for strontium isotopes, within cities a great deal of food resources are coming from non-local areas, which may contribute to the ^{18}O-enriched signal. While possible, it is unlikely given the oxygen isotope variation experienced in the UK (Darling and Talbot 2003, 2003*a*; Budd *et al.* 2004*a, b*; Millard 2004).

The established calibration formulae, therefore, are of limited us to this archaeological study. Indeed, we might go further and suggest that previous studies should be regarded with some scepticism. While there are individuals within the Chelsea sample who are isotopically consistent with long-distance migration, the primary character is of a local population who, if they migrated all, did so in short migrations in the order of several tens of

miles. These short-distance movements can neither be resolved with accuracy nor can the place of birth be determined using the methods described here.

The next section will consider multiple isotope applications in determining provenance, an analytical technique that has been receiving greater attention in the archaeo- and biogeochemical literature in the past decade.

6.6.2. Combined Strontium and Oxygen Analysis

Within recent the last decade, archaeological isotope studies have begun to recognise the limitations of the application of single isotope systems to provenance studies. The most successful combined isotope studies for analysing the locality of past populations have been combined strontium and oxygen studies: the stronger relationship between ground/surface water and location offers a means by which the variability of the strontium isotopes is tempered (Budd *et al.* 2003; Müller *et al.* 2003).

In this case the picture presented for combined Sr-O isotope studies is similar to that for the consideration of $\delta^{18}O$ in isolation. That is to say both Coventry and Chelsea are identifiable as groups but it would be difficult to assign an individual to one site or another except in extreme circumstances. Furthermore, a combined isotope approach allows the identification of individuals who might be outliers in terms of oxygen – and therefore the climate in which they were raised – but that would otherwise share similar lithologies.

Fig. 38 presents the combined Sr-O for the Coventry and Chelsea sample. The mean and standard deviations for $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{SMOW(Phosphate)}$ are given in tables above. As can be seen from fig.38, the two population groups overlap with respect to both strontium and oxygen as represented by the approximate Sr/O ranges indicated on the figure. What rapidly

becomes obvious, however, are the three main outliers: CHE19, CHE285 and CHE792 (Milborough Maxwell).

Milborough Maxwell (CHE792) records a $^{87}Sr/^{86}Sr$ that in the British Isles can only be found in Scotland, particularly in the Isle of Skye (Faure 1986; Sealy 2001). While this presents an alternative location for childhood residence, when coupled with the oxygen isotope data a British origin is unlikely. Rather, it is in keeping with a sub-oceanic signal ($^{87}Sr/^{86}Sr$ ~ 0.709) that is most likely derivative of an igneous lithology, such as volcanic rock (Faure 1986; Sealy 2001). Secondly, the recovered $\delta^{18}O$ signal is suggestive of a sub-tropical or tropical climate, with values of ~19.0 $\delta^{18}O_{SMOW}$ (biophosphate) reported in precipitation in the Caribbean (Jamaica). Thus, it is likely that Milborough Maxwell was resident in or around the Caribbean, most likely on one of the numerous volcanic islands present in the area, for example, St Lucia. While there is no direct historical reference to this, both the commonness of the 'Milborough' forename as well as a continued association with 'Maxwell' in the Caribbean region further supports this assertion.

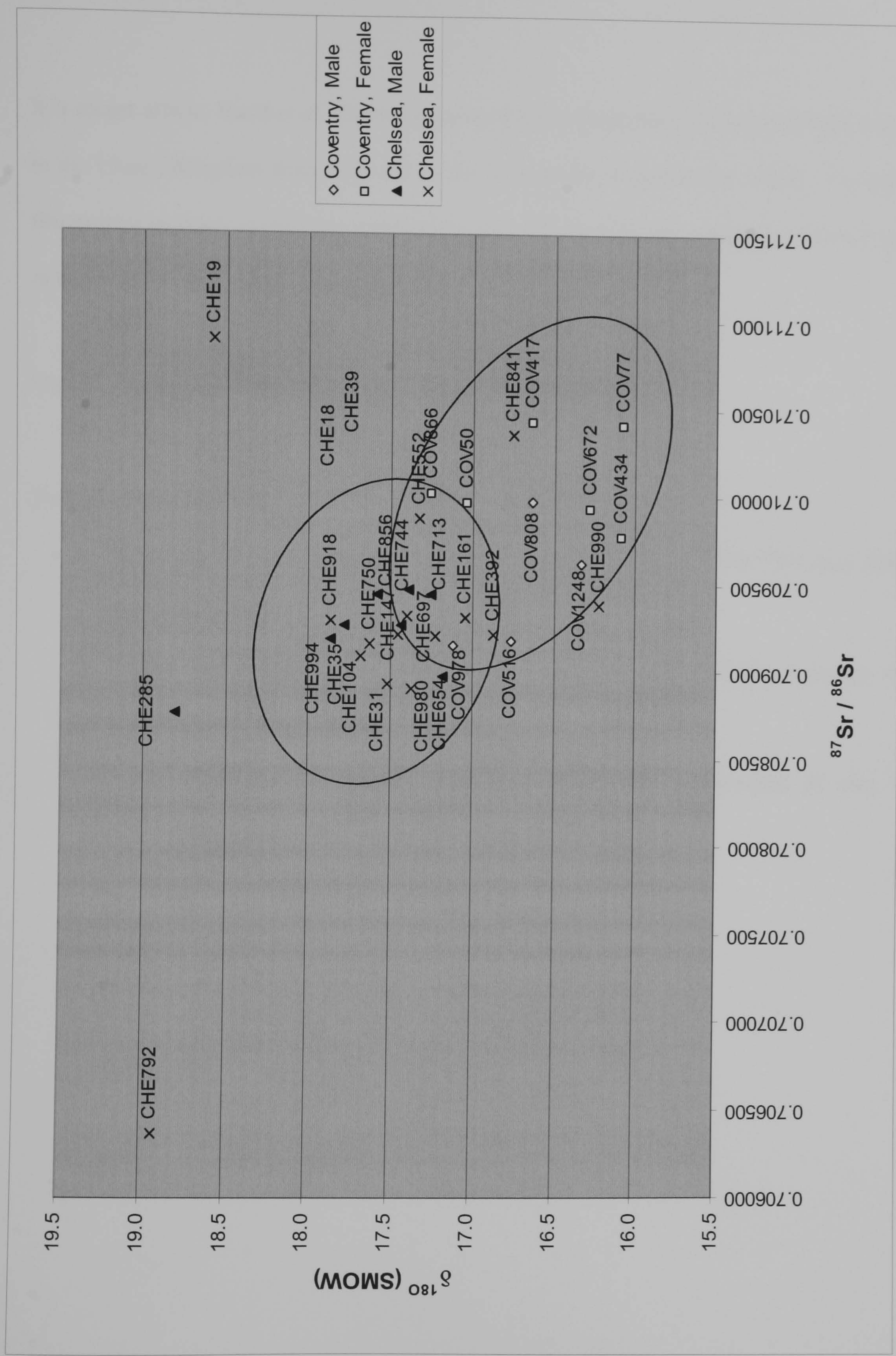


Figure 37: $^{87}Sr/^{86}$ Sr and $\delta^{18}O$ for Chelsea and Coventry. Ovals represent approximate range of population by Sr/O. Errors smaller than symbols.

6.7. Lead Stable Isotopes

In a recent article, Budd *et al.* (2004*c*) undertook a comprehensive synthesis of lead isotopes in the United Kingdom from 5550 BP to the later medieval period (ca. 1600). The data in this project uniquely extend this series to the mid-19th century, the results of which are given in tables 45-46 and graphically in fig. 39.

Visual examination of fig.39 indicates two primary features:

Two groups are evident:

a) Relatively low lead concentrations with wider variation in $^{206}Pb/^{207}Pb$ than seen in the second group.

b) Higher lead concentrations with a smaller variation in $^{206}Pb/^{207}Pb$, consistent with UK Pb-Zn ore fields (Budd *et al.* 2004).

1. That the two groups mentioned in (1) are independent of site, e.g. incorporate analyses from both Chelsea and Coventry.

Sample	*N*	*Sex*	Name	Pb ppm	Pb ppm^{-1}	$^{206}Pb/^{204}Pb$	1σ	$^{207}Pb/^{204}Pb$	1σ	$^{208}Pb/^{204}Pb$	1σ	$^{207}Pb/^{206}Pb$	1σ	$^{208}Pb/^{206}Pb$	1σ
COV516	1	M	? Cooper	0.00*	-	18.4456	0.004	15.6254	0.006	38.4142	0.007	0.84714	0.002	2.08267	0.005
COV808	2	M	William Wagstaffe	26.86	0.03723	18.4360	0.002	15.6253	0.002	38.3944	0.003	0.84756	0.001	2.08264	0.001
COV978	3	M	James Brown	16.96	0.05895	18.4438	0.002	15.6222	0.002	38.3967	0.003	0.84702	0.001	2.08182	0.001
COV1248	4	M	John Chattaway	9.18	0.10894	18.4183	0.002	15.6131	0.003	38.3719	0.004	0.84771	0.001	2.08336	0.002
COV50	5	F	…ein…	29.92	0.03342	18.4995	0.003	15.6286	0.005	38.4143	0.007	0.84710	0.002	2.08215	0.005
COV77	6	F	Elizabeth Burton	9.51	0.10513	18.4218	0.004	15.6309	0.006	38.3971	0.008	0.84849	0.002	2.08447	0.005
COV417	7	F	Sarah Green	7.71	0.12971	18.4014	0.003	15.6083	0.003	38.3301	0.004	0.84820	0.001	2.08330	0.002
COV434	8	F	Hannah Denney	18.40	0.05436	18.4373	0.002	15.6239	0.003	38.4015	0.003	0.84739	0.001	2.08729	0.001
COV672	9	F	Eliza Sparkes	32.04	0.03121	18.4314	0.003	15.6193	0.003	38.3846	0.004	0.84744	0.001	2.08253	0.002
COV866	10	F	Hannah Denney	21.38	0.04676	18.4415	0.007	15.6298	0.008	38.4233	0.009	0.84752	0.002	2.08352	0.003

Table 45: Results for lead isotope analysis of Coventry. (* The concentration of Pb in COV516 could not be measured in the analytical run.)

Sample	N	Sex	Name	Pb ppm	Pb ppm^{-1}	$^{206}Pb/^{204}Pb$	1σ	$^{207}Pb/^{204}Pb$	1σ	$^{208}Pb/^{204}Pb$	1σ	$^{207}Pb/^{206}Pb$	1σ	$^{208}Pb/^{206}Pb$	1σ
CHE35	11	M	Gideon Richard Hand	75.04	0.0133	18.4460	0.007	15.6179	0.009	38.3936	0.012	0.84667	0.001	2.08138	0.004
CHE147	12	M	Thomas Langfield	14.03	0.07127	18.3754	0.005	15.6163	0.006	38.3465	0.008	0.84991	0.002	2.08694	0.003
CHE285	13	M		12.49	0.08009	18.4396	0.005	15.6168	0.006	38.3743	0.009	0.84691	0.001	2.08105	0.003
CHE654	14	M	Thomas Long	40.25	0.02484	18.4520	0.005	15.6277	0.006	38.4290	0.009	0.84692	0.002	2.08627	0.005
CHE713	15	M	John Long Esquire	83.44	0.01198	18.4523	0.004	15.6302	0.004	38.4388	0.006	0.84707	0.002	2.08316	0.004
CHE744	16	M	John Long	12.96	0.07715	18.4441	0.006	15.6291	0.006	38.4221	0.006	0.84739	0.002	2.08314	0.002
CHE856	17	M		37.06	0.02698	18.4524	0.003	15.6286	0.004	38.4157	0.005	0.84696	0.002	2.08192	0.003
CHE994	18	M		19.80	0.05051	18.4495	0.007	15.6260	0.008	38.4163	0.010	0.84699	0.002	2.08230	0.004
CHE18	19	F		82.42	0.01213	18.4232	0.006	15.6197	0.006	38.3792	0.007	0.84782	0.002	2.08411	0.003
CHE19	20	F		9.42	0.10616	18.4286	0.008	15.6142	0.009	38.3759	0.012	0.84727	0.002	2.08232	0.005
CHE31	21	F		4.65	0.21505	18.3766	0.009	15.6168	0.011	38.3471	0.014	0.84987	0.002	2.08686	0.005
CHE39	22	F		44.75	0.02235	18.4206	0.008	15.6118	0.009	38.3731	0.012	0.84751	0.001	2.08307	0.005
CHE104	23	F		50.84	0.01967	18.4398	0.005	15.6153	0.006	38.3829	0.009	0.84683	0.001	2.08415	0.004
CHE161	24	F		70.25	0.01423	18.4188	0.005	15.6173	0.006	38.4069	0.008	0.84790	0.001	2.08517	0.003
CHE392	25	F		42.69	0.02343	18.4369	0.005	15.6264	0.006	38.4388	0.009	0.84758	0.002	2.08496	0.005
CHE552	26	F		19.39	0.05156	18.4445	0.005	15.6271	0.006	38.4101	0.010	0.84730	0.002	2.08262	0.005
CHE697	27	F		5.01	0.19956	18.4357	0.007	15.6286	0.008	38.4212	0.010	0.84774	0.002	2.08420	0.006
CHE750	28	F		28.95	0.03454	18.4402	0.006	15.6285	0.006	38.4174	0.006	0.84752	0.002	2.08332	0.002
CHE792	29	F	Milborough Maxwell	83.42	0.01199	18.4332	0.006	15.6324	0.006	38.4403	0.006	0.84806	0.002	2.08536	0.002
CHE841	30	F		27.88	0.03587	18.4502	0.006	15.6274	0.006	38.4238	0.006	0.84700	0.002	2.08261	0.002
CHE918	31	F		27.46	0.03462	18.4541	0.004	15.6289	0.004	38.4173	0.005	0.84695	0.002	2.08192	0.003
CHE980	32	F	Sarah Adams	6.04	0.16559	18.4058	0.003	15.6293	0.004	38.3932	0.006	0.84914	0.002	2.08594	0.004
CHE990	33	F	Charity Adams	13.29	0.07526	18.4069	0.004	15.6172	0.003	38.3735	0.006	0.84844	0.002	2.08475	0.004
CHE1051	34	F	? Collon	23.60	0.04237	18.4364	0.004	15.6312	0.005	38.4203	0.007	0.84785	0.002	2.08397	0.005

Table 46: Results for lead isotope analysis of Chelsea.

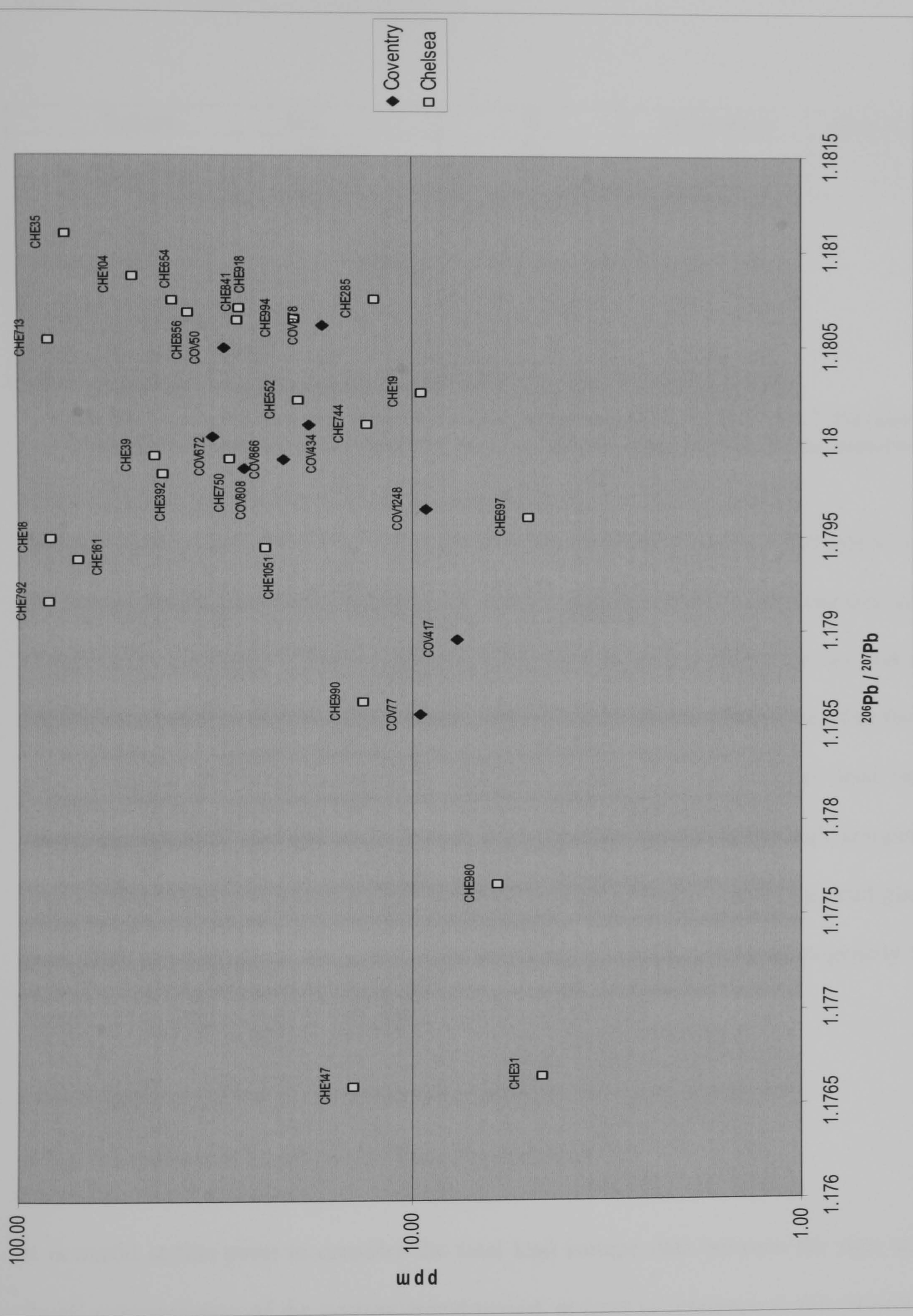


Figure 38: $^{206}Pb/^{207}Pb$ for Holy Trinity Chelsea and Coventry.

A Mann-Whitney test for significance of difference between the sites provides the following result:

Isotope	Sex	N	Mean Rank	Sum of Ranks
$^{206}Pb/^{207}Pb$	Coventry	10	16.10	161.00
	Chelsea	24	18.08	434.00
	Total	*34*		
Mann-Whitney U	106.000			
Wilcoxon W	161.000			
Z	-0.529			
Asymp. Sig. (2-tailed)	0.597			
Exact. Sig. [2×(1-tailed Sig.)]	0.615 [1]			

Table 47: Mann-Whitney test of significance of difference between the $^{206}Pb/^{207}Pb$ ratios for Chelsea and Coventry ([1] not corrected for ties; Statistical Package for Social Scientists).

The test implies that, for $^{206}Pb/^{207}Pb$, there is little statistical significant difference between the isotope results from both Chelsea and Coventry. For the other isotope measured as a part of this study, the Mann-Whitney tests were performed on each to determine any statistically significance between the two sites. These tests revealed a similar picture, i.e., that there was little statistical difference between the two sites in terms of the analysed lead isotopes. Given the nature of lead use in the period, e.g. primarily introduced through inorganic and organic fuel burning and lead-source exposure through domestic items (e.g. lead glazes on pots, joins in water pipes, etc.), this is not surprising given the greater homogeneity in lead isotope ratios used in ores of this period (Budd *et al.* 2004*b*).

6.7.1. Variation of Lead in the Two Populations

It is useful at this point to consider the total lead isotope data between the sites and as a 'total' representation of the post-medieval period, at least in reference to this project. This data is summarised in the table, below.

		Pb ppm	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$
Coventry	Mean	17.20	18.433	15.6227	38.3928	0.8476	2.0829
	St. Dev. (1σ)	10.56	0.0149	0.0073	0.0267	0.00047	0.00075
	Mean Error	-	0.003	0.0041	0.005	0.002	0.003
Chelsea	Mean	34.80	18.432	15.6235	38.4031	0.8476	2.0835
	St. Dev. (1σ)	26.53	0.022	0.0065	0.02729	0.00089	0.00168
	Mean Error	-	0.005	0.0063	0.008	0.002	0.004
Total	Mean	29.62	18.432	15.6233	38.4001	0.8476	2.0834
	St. Dev. (1σ)	24.23	0.020	0.0066	0.02731	0.00079	0.00149
	Mean Error	-	0.005	0.0056	0.007	0.002	0.004

Table 48: Mean value, standard deviation (1σ) and mean error for lead isotopes from Chelsea and Coventry with both sites taken together as representative of a "post-medieval" sample.

The experiences of lead exposure, i.e. total exposure during mineralisation of the tooth in question (generally from ~3-6 years), seems to have differed between the two sites with Coventry having a mean value of approximately one-half that of Chelsea while the variation from the mean value is approximately consistent (Hillson 1996).

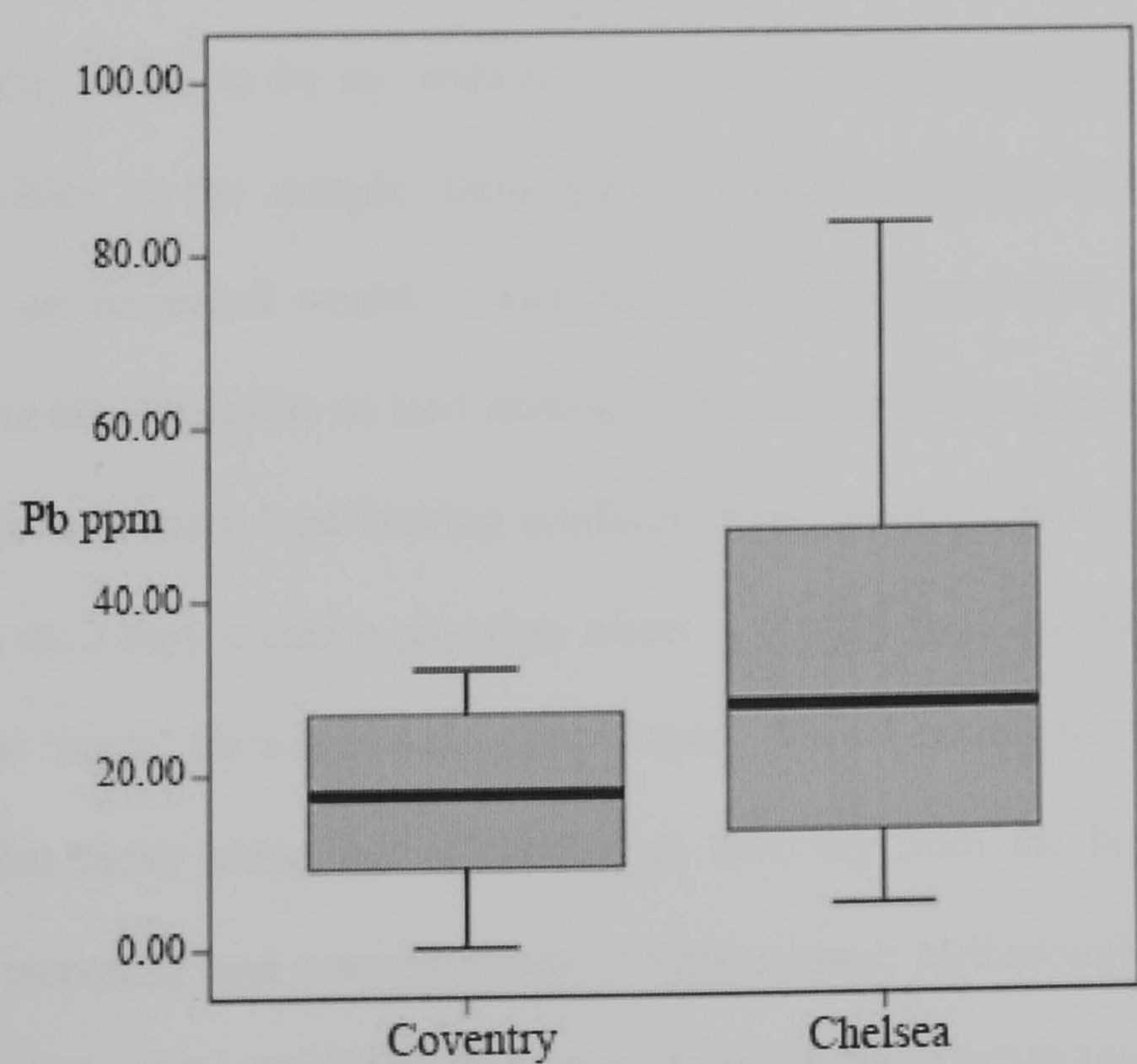


Figure 39: Box-plot of lead concentrations from Coventry and Chelsea.

The variation in lead isotope ranges in Chelsea and Coventry offers a potential analogy to the modern period, where alkyl-lead derived signatures are so dominant (Chiaradia *et al.* 1997; Dunlap *et al.* 1999; Chiaradia and Cupelin 2000; Alfonso *et al.* 2001; Brännvall *et al.* 2001, etc.). As can be seen from fig. 40, above, lead concentration (Pb ppm) are not only lesser than Chelsea, but also far more restricted in terms of range. Could this represent the shift from Wrigley's (1998) 'organic' to 'mineral' economy? The historical character of the two sites are different – from the domestic-industry dominant Coventry to Chelsea, a 'village of palaces' that didn't undergo significant industrialisation and construction until the mid-to-second half of the nineteenth century (L'Estrange 1880; VCH 1969, In Press).

As mentioned elsewhere, the 'character' of the Coventry and Chelsea samples are quantitatively and qualitatively different, not only in terms of separating into distinct populations (see above for carbon, nitrogen, strontium and oxygen), but also in the life experiences of the individuals themselves as revealed through palaeopathological analysis. While Coventry seems to be an 'industrial' population indicated by the predominance of osteoarthropathies in the sample, these pathologies are lacking in the Chelsea sample. Furthermore, an increased wealth – and therefore liquid resources – may offer another explanation for the variability in lead isotopes between the two populations. That is, a more limited ability to procure lead-bearing artefacts (lead- or tin-glazed ceramics, pewter, lead crystal glass, etc.) may create a situation where a limited lead isotope signature would be considered the 'norm' for a lower-class population. Visual examination of fig.39 does seem to indicate that those individuals identified as deriving from the higher socio-economic classes have increased lead concentrations in their enamel: Milborough Maxwell (CHE792; potential 'elite' from the Caribbean); Gideon Richard Hand (CHE35); John Long Esquire (CHE713); and Thomas Long (CHE654). However, the suggestions of status-linked diet represented through $\delta^{15}N$ (e.g. increased $\delta^{15}N$ through increased access to protein-rich meats, fishes and other 'elite' foods) seems not be represented in a consideration of the lead concentrations in the sample.

While the lead distribution is approximately consistent with that found in a consideration of $\delta^{13}C/\delta^{15}N$ in Chelsea, the same pattern is not viewed in Coventry. Of those individuals determined to be historically 'high status' – James Brown (COV978) and John Ballard (COV1119) – only James Brown was analysed for lead. Whilst James Brown does have a 'high' level of lead in his enamel compared to modern material (Budd *et al.* 2004*c*), 'low status' individuals have higher concentrations, namely: Hannah Denney (COV434), Harriet Parsons (COV866), William Wagstaffe (COV808), Eliza Sparkes (COV672) and COV50 ("...ein..." on the coffin plate). This is more clearly represented in fig.41.

6.7.2. Lead Exposure from 5500 BP to ca. 1850 ACE

With the recent publication of lead isotope analyses covering the period 5500 BP to approximately the late fifteenth or early sixteenth century, it is interesting to see how the post-medieval lead isotopes relate to that of the previous periods. Fig. 42 represents post-medieval lead exposure in terms of lead concentration against $^{206}Pb/^{207}Pb$.

As can be seen from fig.42 the lead isotope ratios of the post-medieval period present a similar picture to that previously discussed in Budd *et al.* (2004*b*). That is to say as above lower lead concentrations show a greater diversity in lead isotope ratios and as the concentration increases the variation from the mean value decreases (Budd *et al.* 2004*b*). The average value of lead concentration (Pb ppm) is higher for the post-medieval population than any of the previous periods. Furthermore, there is a defined shift of the post-medieval (median $^{206}Pb/^{207}Pb$ 1.179) period away from that the early medieval period (median $^{206}Pb/^{207}Pb$ 1.182) and within a range that is consistent with the later medieval and Romano-British periods, a shift that increases as lead exposure (e.g. Pb ppm) increases.

There are two commonly recognised sources of lead pollution within the post-medieval period and, indeed, before. These are, simply, release of lead into the atmosphere through the combustion of fuel sources (primarily coal but also including organic fuel sources) and exposure to lead through lead ores included in domestic products.

Farmer *et al.* reports mean $^{206}Pb/^{207}Pb$ values for UK coal of 1.184 ± 0.006, with the Derbyshire/Mendip and Durham coal field values (major sources of coal for Coventry and London, respectively) at 1.181 and 1.184, respectively (Farmer *et al.* 1999). Further, lead concentration in UK coal averages at 11 ppm (mg kg^{-1}), the dominant source of coal used in the UK in the late eighteenth and early nineteenth centuries, while Scottish coals have a much higher concentration of lead, 23.9 ppm (Farmer *et al.* 1999).

While the post-medieval data does plot near to the mean value for Derbyshire/Mendip coal values, it is also important to note that *all* the data plots around this mean value suggesting that the dominant source for coal during this period to Coventry and London was the Derbyshire/Mendips coal field, which would not be in agreement with the historical evidence (Rohl 1995).

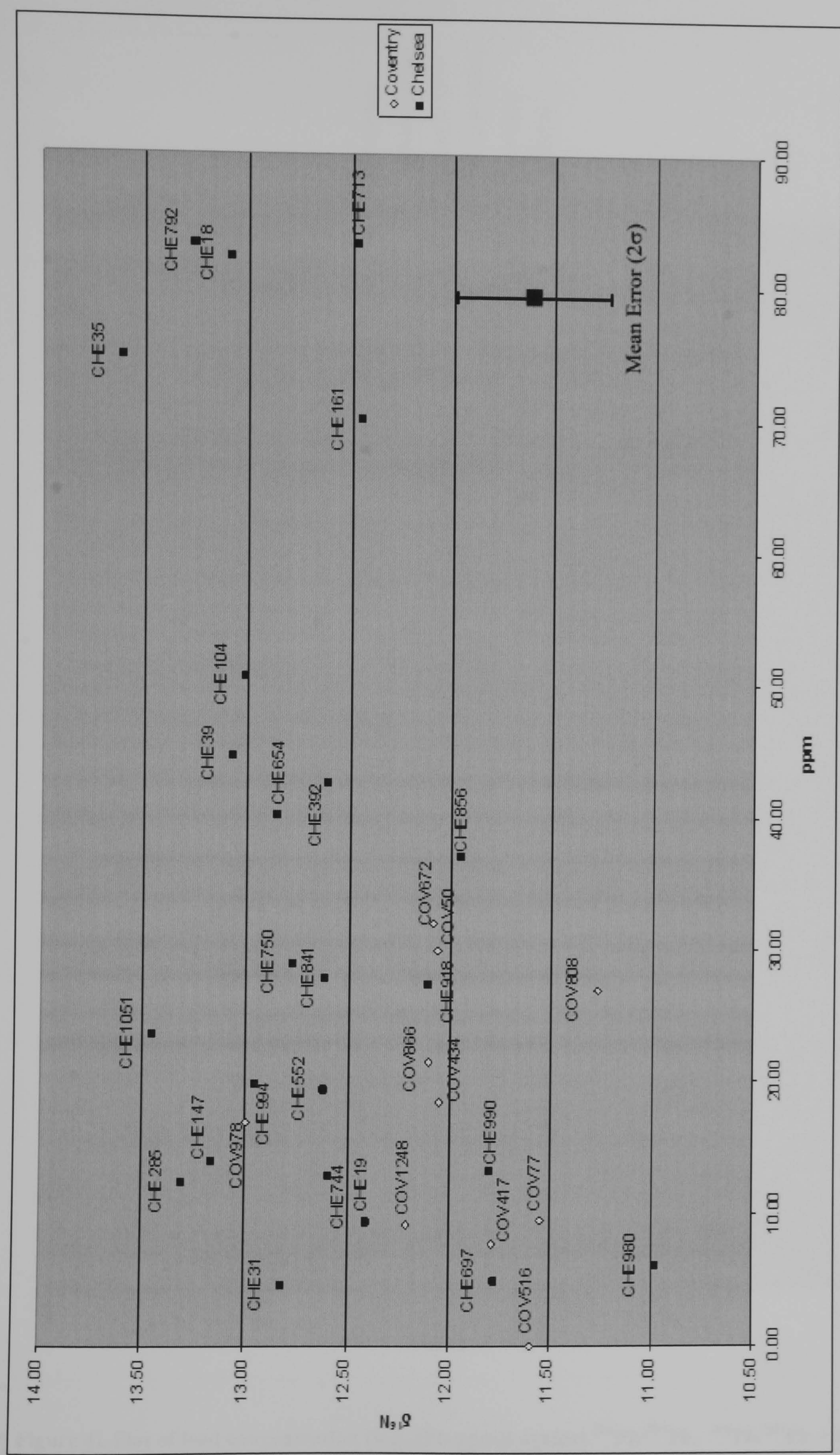


Figure 40: Plot of Pb concentration (ppm) against $\delta^{15}N$.

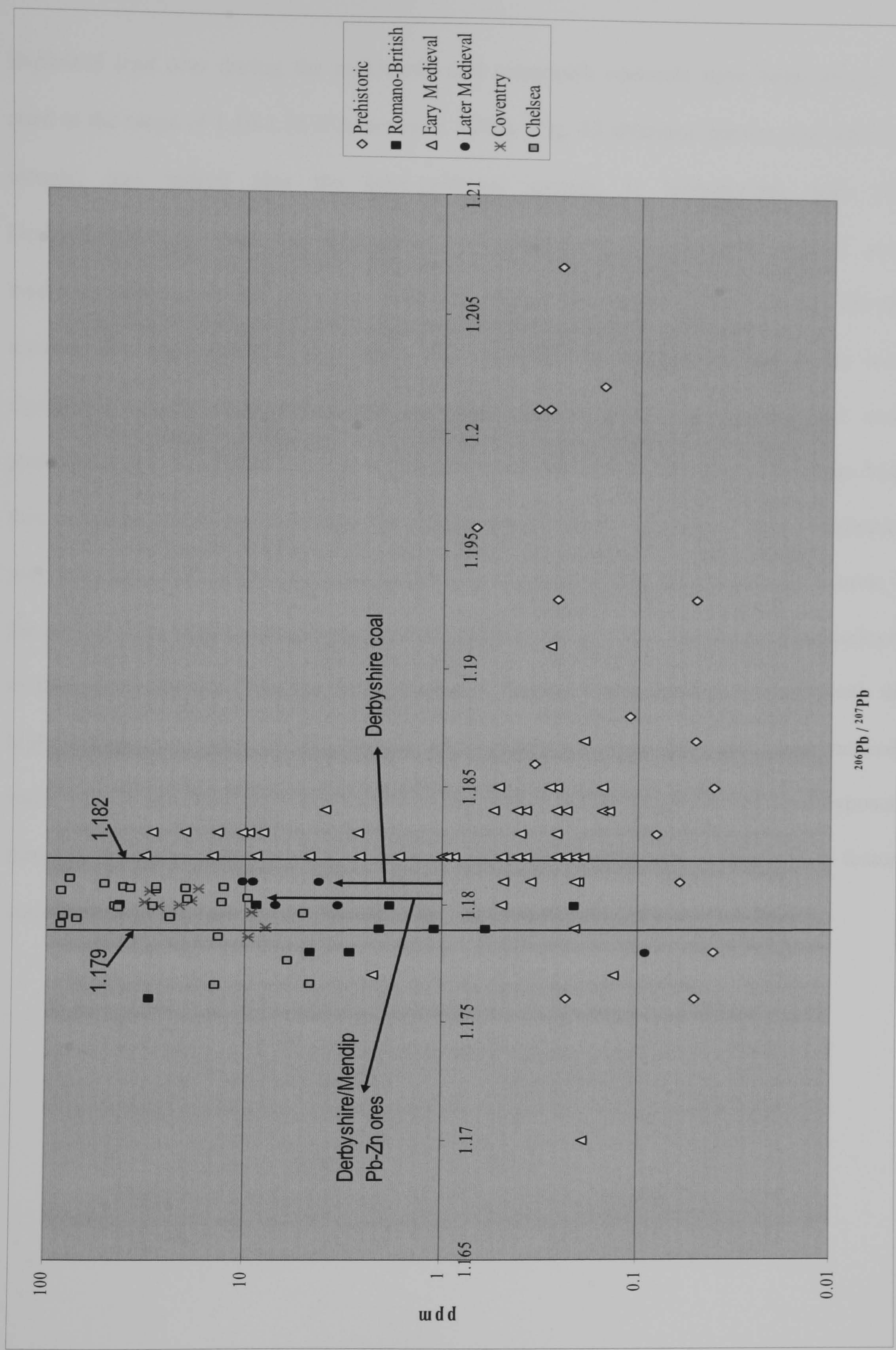


Figure 41 Plot of lead concentration ($\log_{10}$[Pb ppm]) against $^{206}Pb/^{207}Pb$. $^{206}Pb/^{207}Pb = 1.179$ is the mean value of the post-medieval sample, $^{206}Pb/^{207}Pb = 1.182$ median value for the early medieval sample. Arrows indicate direction of relative contribution from ores/coal (Budd *et al.* 2004*c*.) Errors smaller than symbols.

Exploited lead ores during the eighteenth and nineteenth centuries have been previously cited in the range of 1.16-1.18 (Farmer *et al.* 1999). Fig. 42 indicates that the post-medieval sample, and indeed also the later-medieval sample, is homogenous with both Derbyshire/Mendip coal and Bristol/Mendip/Cheshire ore field values. As the post-medieval samples are shifting away from UK average coal values ($^{206}Pb/^{207}Pb$ ~1.184) and towards that reported from ore values this suggests that ore-derived lead is the more significant contributor to human lead exposure. Indeed, given that digested lead, more particularly that in a liquid form, is the primary means by which lead enters the human body this would be consistent with domestic artefact contribution. While coal load contribution may have increased in time with the burgeoning adoption of this mineralised fuel source, in the period 1650-1850 the primary source of lead was the artefacts that the people employed in their everyday life (Weeden 1984; Richards 1999). While those individuals with the highest exposure were of the highest socio-economic class, the correlation between status/wealth and lead exposure was not clear and therefore suggestive of lead exposure through multiple pathways, e.g. domestic goods and 'industrial' exposure, a feature consistent with the homogenisation of $^{206}Pb/^{207}Pb$ isotope ratios (Budd *et al.* 2004*c*).

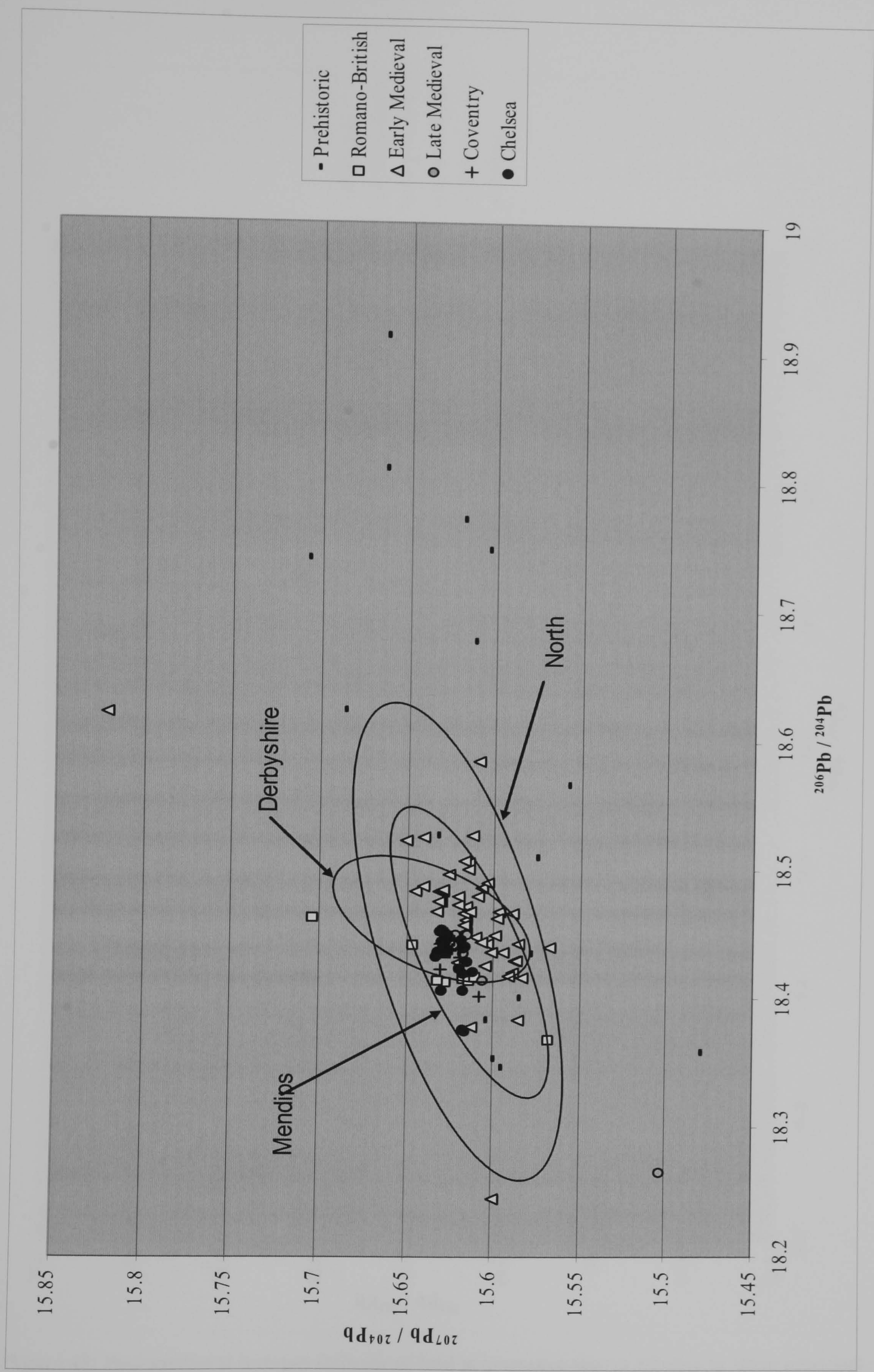


Figure 42: Post-medieval lead isotopes indicative of lead provenance shown relative to three principal UK Pb-Zn ore fields for comparison (Budd *et al.* 2004*c*). Errors smaller than symbols.

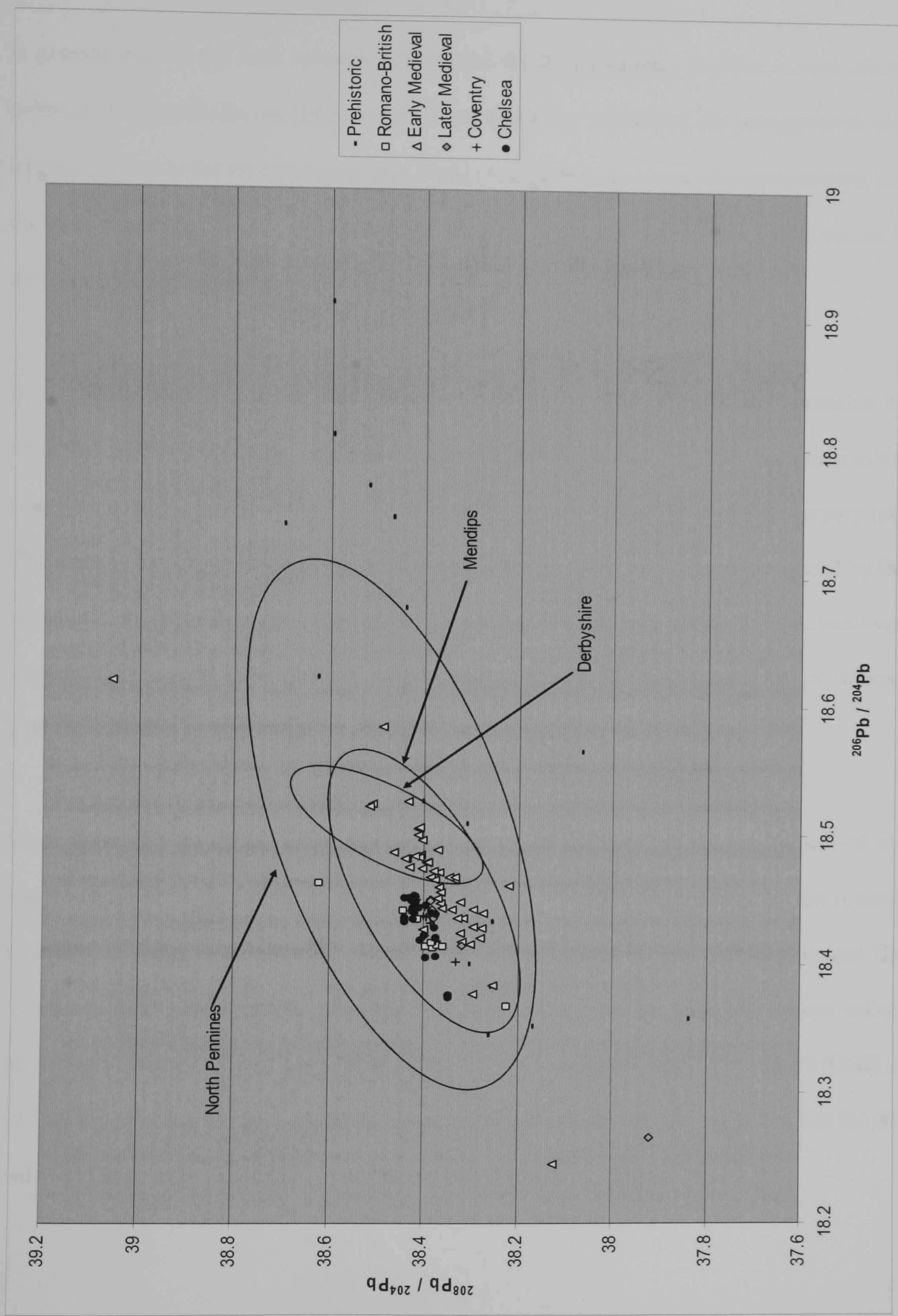


Figure 43: Post-medieval isotopes indicate of lead provenance shown relative to three principal UK Pb-Zn ore fields for comparison (Budd *et al.* 2004*c*). Errors smaller than symbols.

6.7.3. Variation in Lead Sources from 5500 BP to ca. 1850 AD

A general plot of the lead isotopes determined for lead sourcing is given in figs. 43-44, below, indicating Pb-Zn ore fields in the United Kingdom. Similarly, the post-medieval data has been added to the figure presented in Budd *et al.* (2004*c*) to extend the interpretation into the post-medieval period. All data other than the Coventry and Chelsea information is derived from this source.

In discussing lead sources it is necessary to consider the possibility of contamination by tetraethyl lead utilised as an "anti-knock" agent in petroleum fuels from the beginning of the twentieth century, though more significantly in the second half of the twentieth century (see Chapter 4). The range of tetraethyl lead is considerably different to that experienced by the post-medieval population, i.e., the source of tetraethyl lead derives from a defined, non-local source (Alfonso *et al.* 2001) thereby suggesting that modern contamination is less of an issue than the variation in lead exposure during the period (Budd *et al.* 2004*c*).

Once again, the restricted range of lead isotope values indicated in figures 43 and 44 are suggestive of homogenisation of lead sources though it is difficult to determine the relative contribution from these sources. Budd *et al.* utilises plots of lead isotopes against the inverse of lead concentrations to extrapolate mean values for the analysed isotope ratios, returning a result of $^{206}Pb/^{204}Pb = 18.46$, $^{207}Pb/^{204}Pb = 15.62$ and $^{208}Pb/^{204}Pb = 38.40$ (Budd *et al.* 2004*c*). Plotting the post-medieval information and calculating the regression line for the enhanced data set presents only minor divergence from these values.

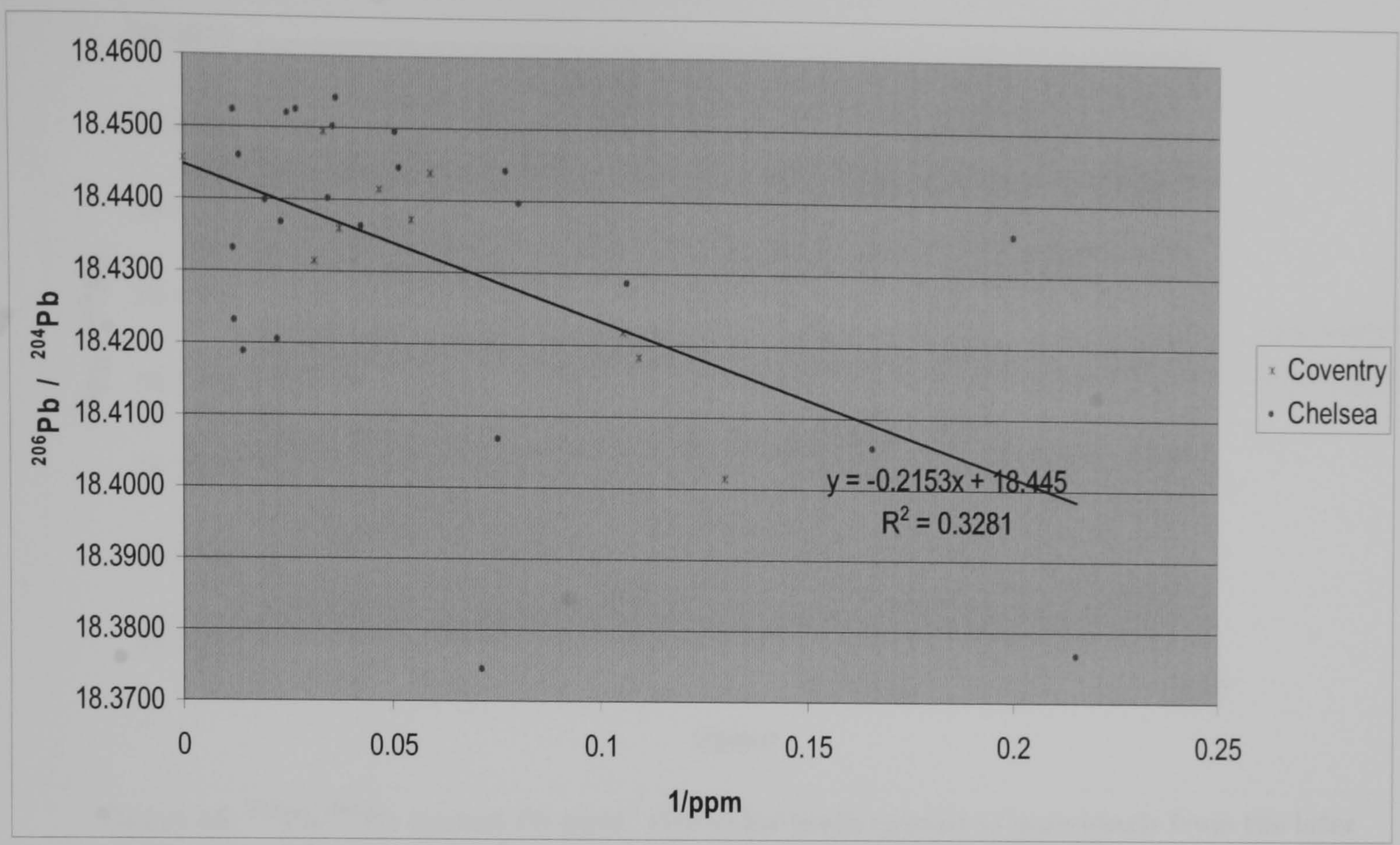


Figure 44: $^{206}Pb/^{204}Pb$ against Pb ppm^{-1} (1/Pb) for tooth enamel of individuals from Chelsea and Coventry. Errors smaller than symbols.

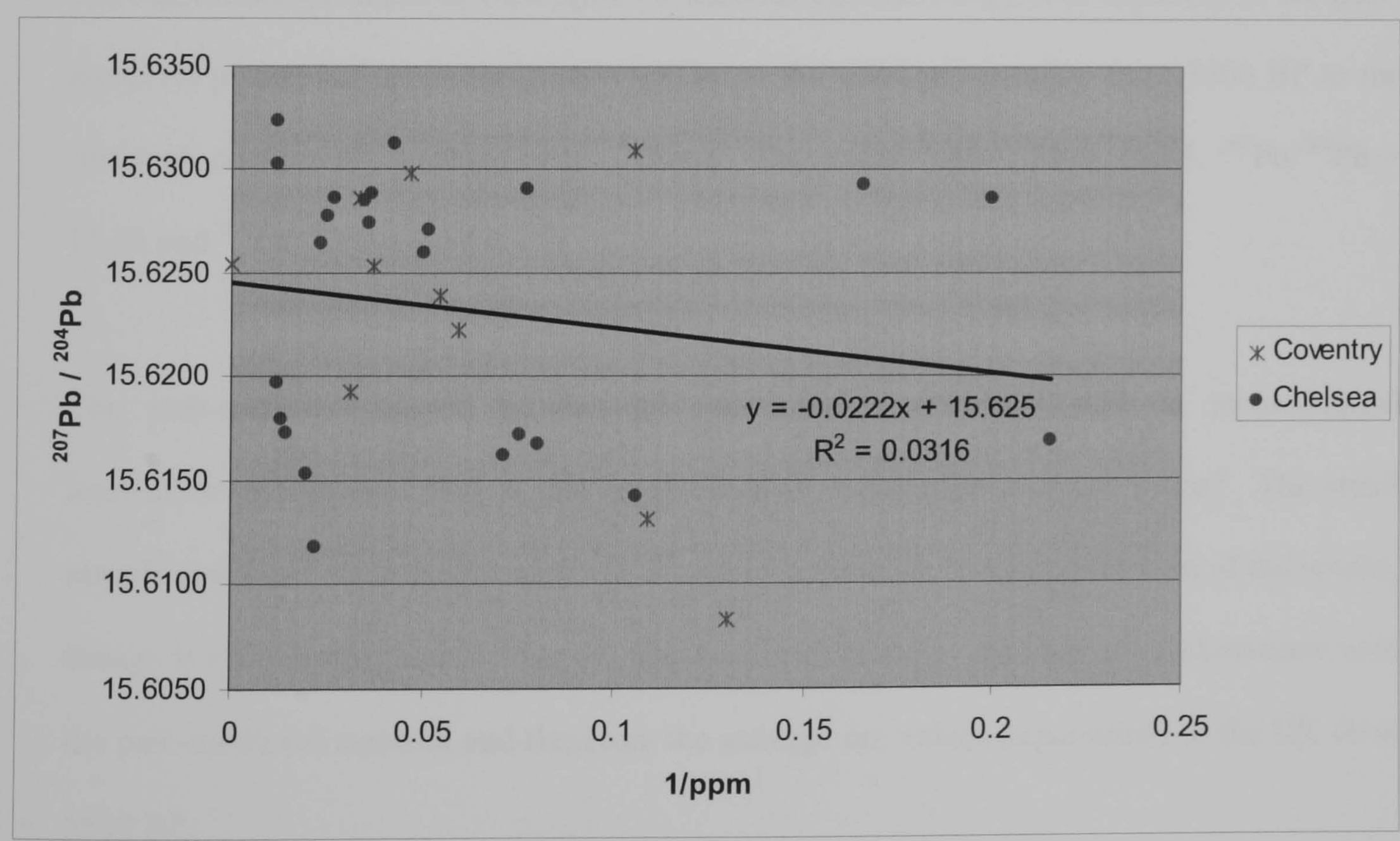


Figure 45: 207Pb/204Pb against Pb ppm-1 (1/Pb) for tooth enamel of individuals from the later medieval period (Lihou, Rivenhall and Blackfriars) (Budd et al. 2004*c*). Errors smaller than symbols.

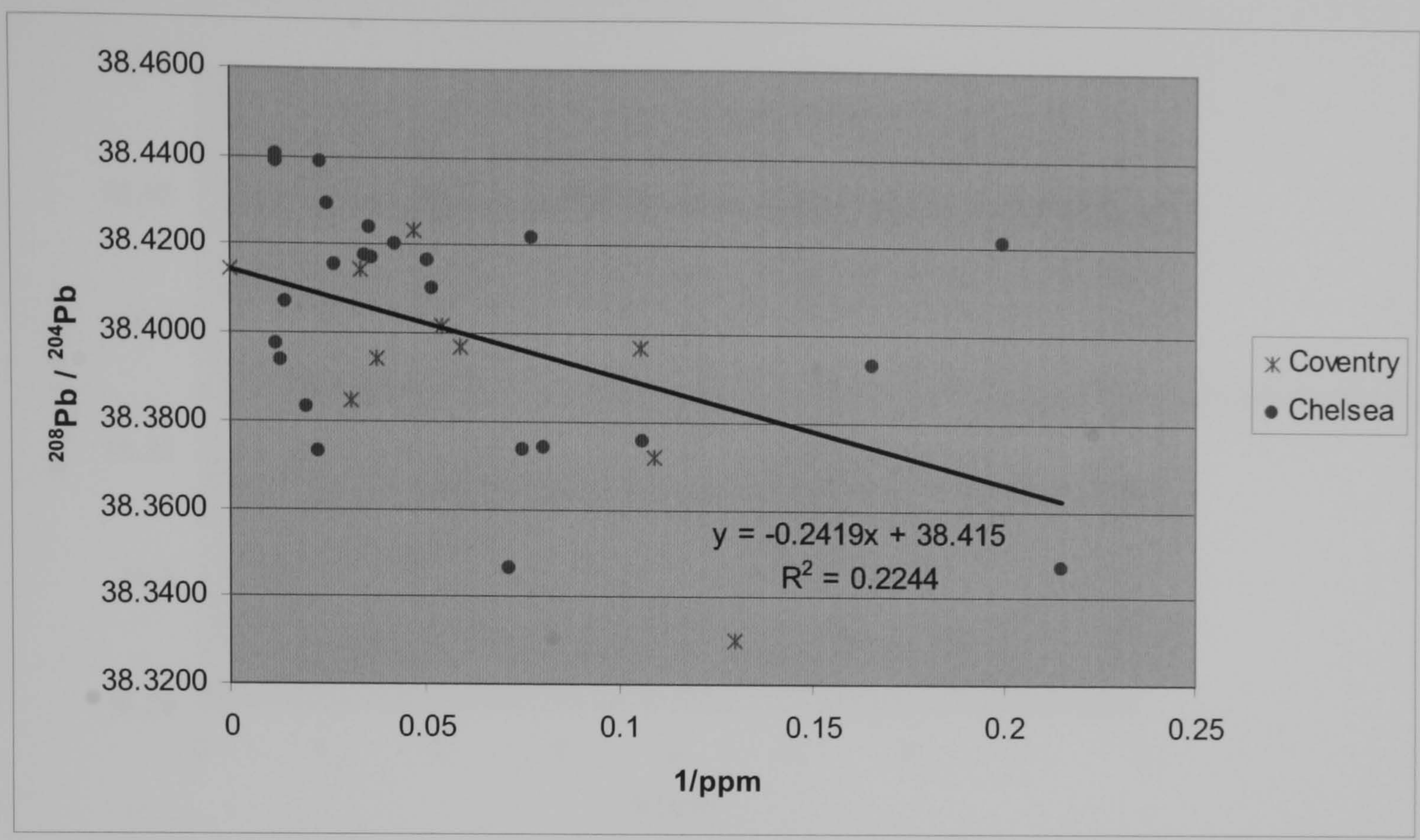


Figure 46: ^{208}Pb/^{204}Pb against Pb ppm^{-1} (1/Pb) for tooth enamel of individuals from the later medieval period (Lihou, Rivenhall and Blackfriars) (Budd *et al.* 2004*c*). Errors smaller than symbols.

The regression formulae to 1/Pb ppm = 0 indicate that the Pb-Zn ores exploited in the post-medieval period had an isotopic ratio similar to the average ore value from 5500 BP to the sixteenth century ACE (Budd *et al.* 2004*c*). These are: ^{206}Pb/^{204}Pb = 18.45, ^{207}Pb/^{204}Pb = 15.63 and ^{208}Pb/^{204}Pb = 38.42.

The post-medieval period purportedly represents a paradigm shift in technological innovation and thought, but is this represented in differential lead ore ratios? The small sample size must necessarily enforce a degree of scepticism into interpretation of the results, though it is interesting to note that the later medieval material shows good conformance with the post-medieval material and therefore the average ore values experienced in the UK from 5500 BP.

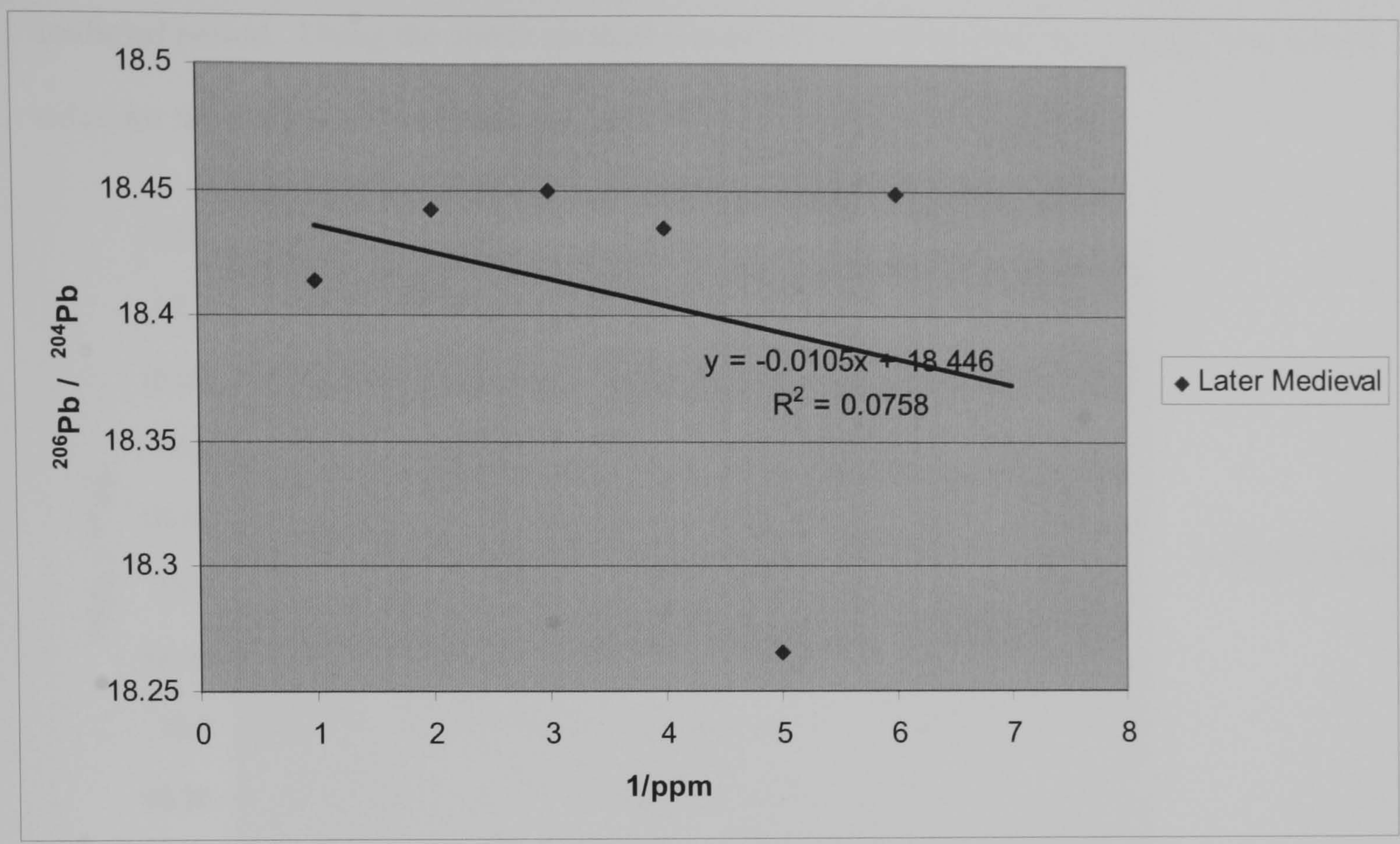


Figure 47: $^{206}Pb/^{204}Pb$ against Pb ppm^{-1} (1/Pb) for tooth enamel of individuals from the later medieval period: Lihou, Rivenhall and Blackfriars (Budd *et al.* 2004*c*). Errors smaller than symbols.

Considerations of other isotopes of lead in the later medieval period are limited by the small data set and, as such, are not included here.

The Pb isotope ratios of individuals from the later medieval period are approximately consistent with those seen in both the post-medieval period and also the average value from 5500BP: $^{206}Pb/^{204}Pb$ = 18.45, $^{207}Pb/^{204}Pb$ = 15.62 and $^{208}Pb/^{204}Pb$ = 38.38. Lead resource exploitation within the later medieval period is therefore contiguous with that of the post-medieval, showing continuity rather than the disparity that might be imagined if one has a sharp paradigm shift in resource exploitation and technology. While scale might have changed, the resources exploited had not.

However, as can be seen from fig. 42 the conformance of the later medieval material to the post-medieval and by inference that of the Romano-British is not surprising. There is a difference in the lead isotope ratios of the post-medieval period and that of the early

medieval period. Using the above method it is possible to determine the average lead source value for the early medieval material.

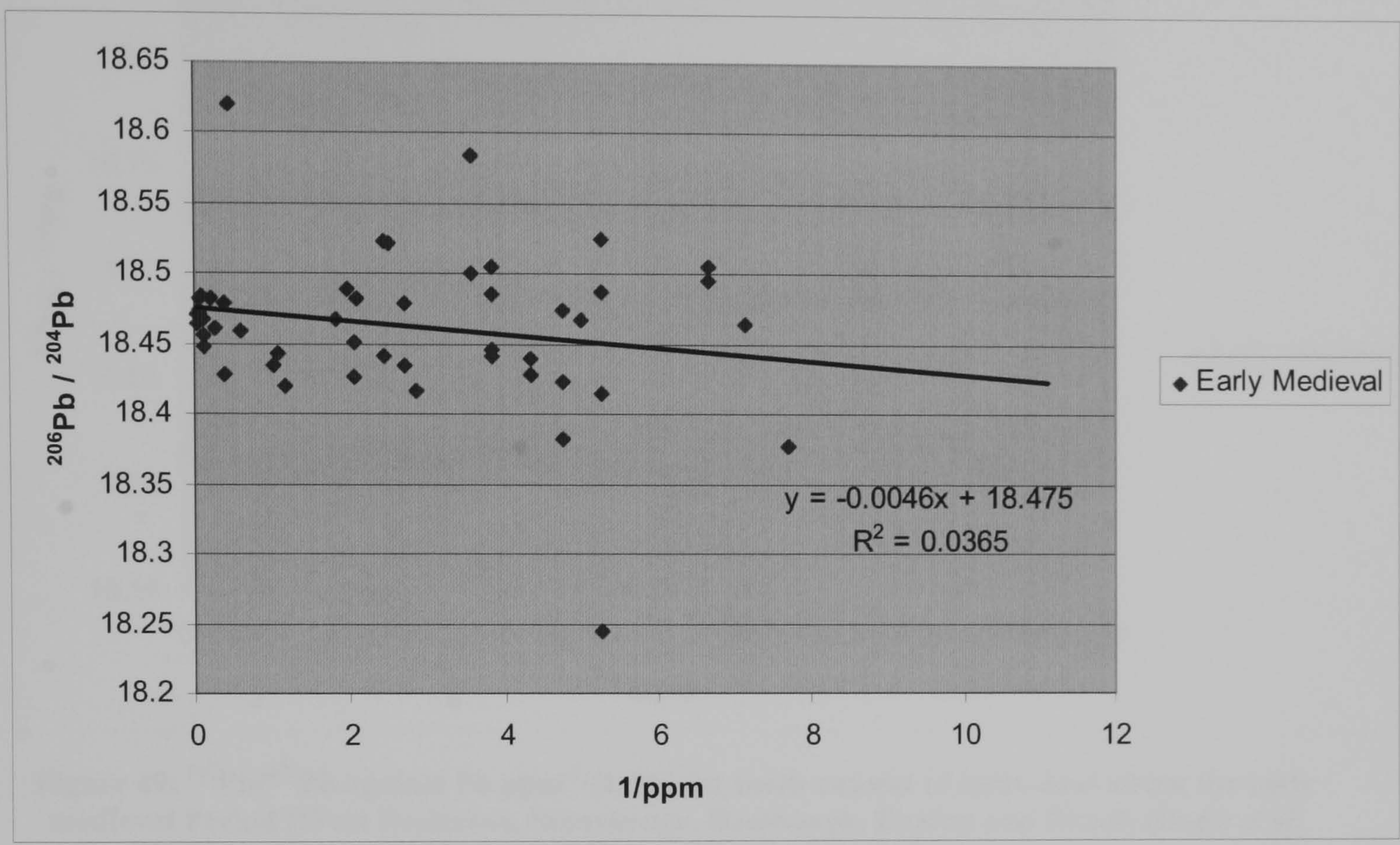


Figure 48: ^{206}Pb/^{204}Pb against Pb ppm^{-1} (1/Pb) for tooth enamel of individuals from the early medieval Period [West Heslerton, Stonehenge, Bamburgh, Repton and Ricall] (Budd *et al.* 2004*c*). Errors smaller than symbols.

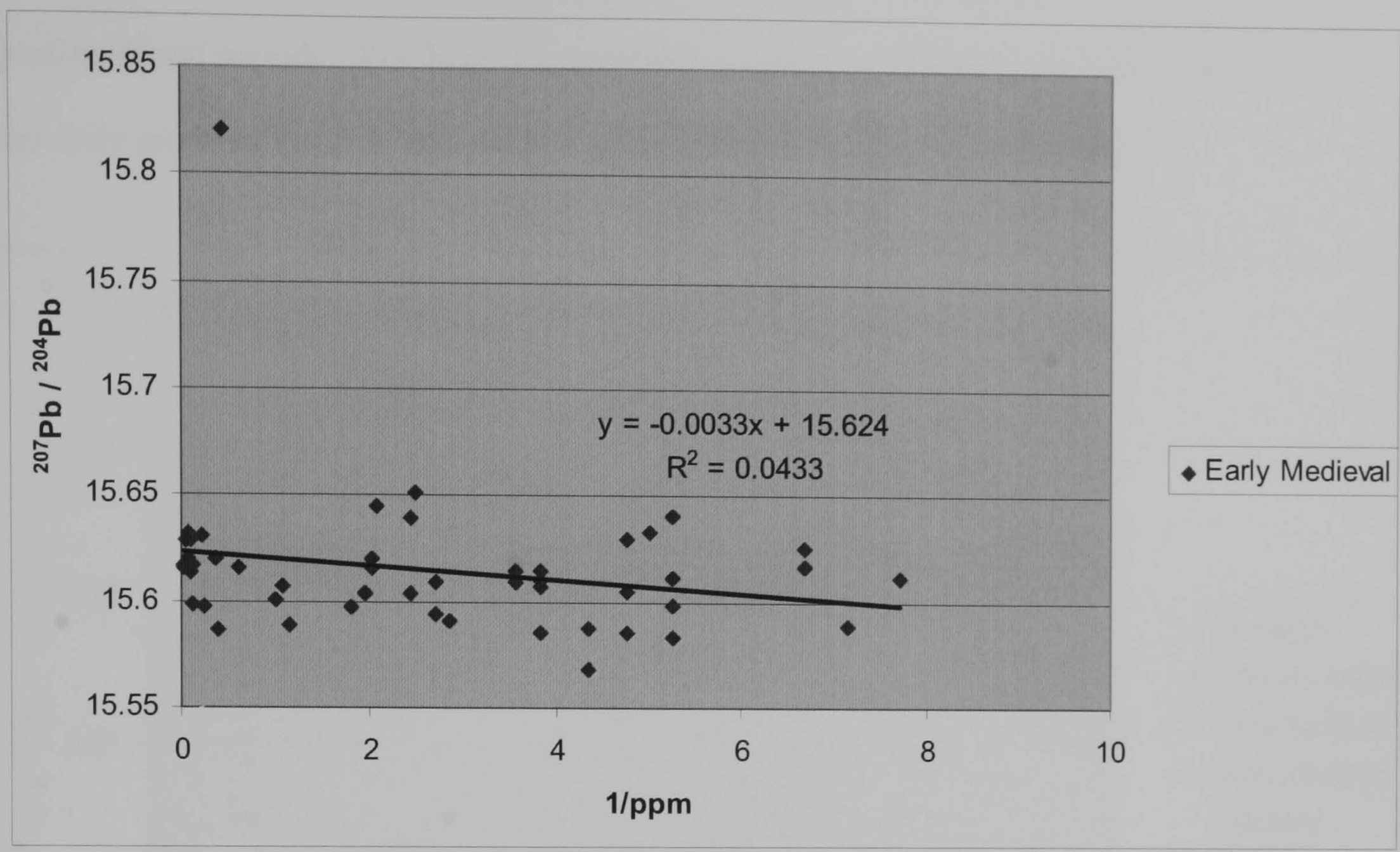


Figure 49: $^{207}Pb/^{204}Pb$ against Pb ppm^{-1} (1/Pb) for tooth enamel of individual sfrom the early medieval Period [West Heslerton, Stonehenge, Bamburgh, Repton and Ricall] (Budd *et al.* 2004*c*). Errors smaller than symbols.

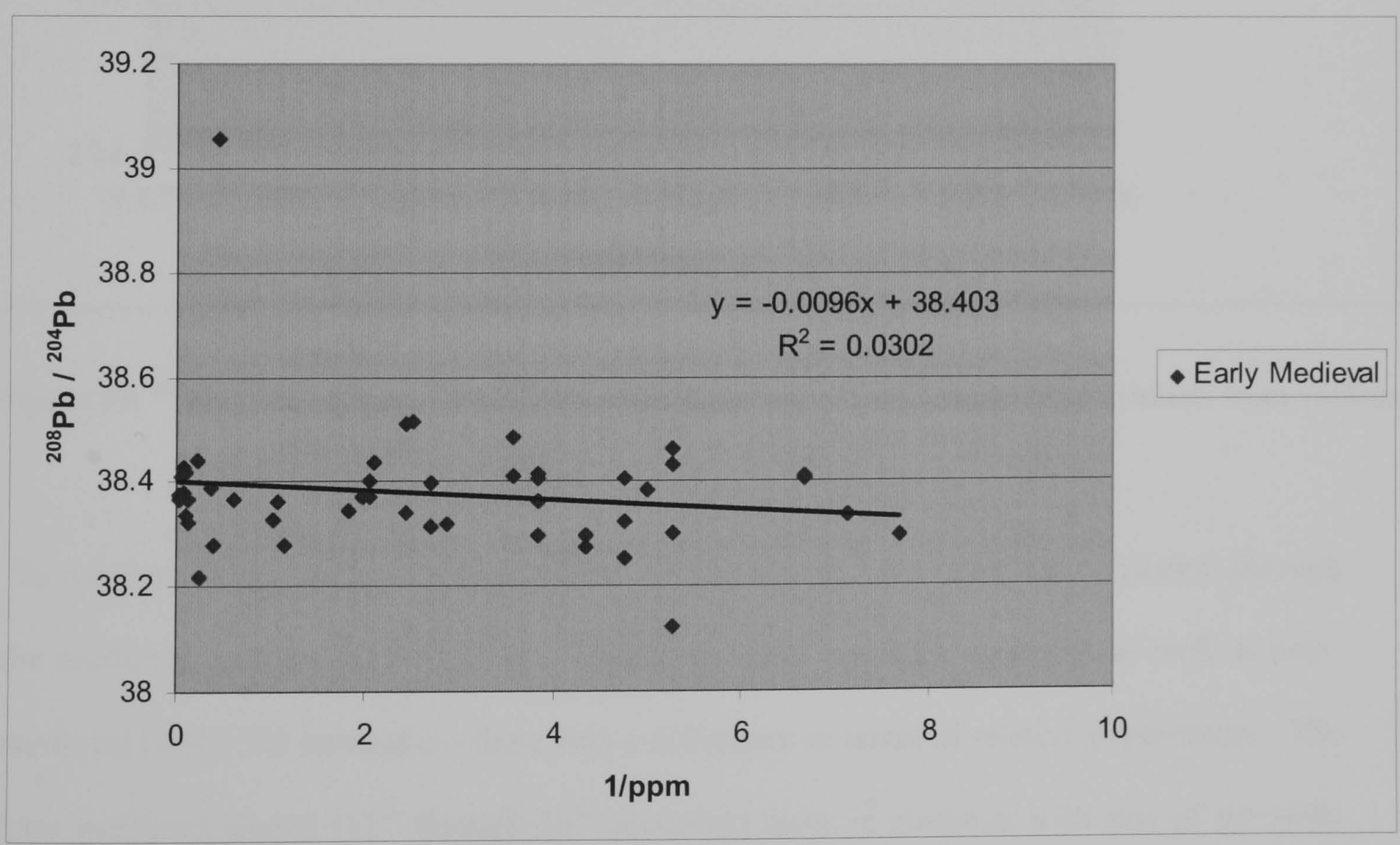


Figure 50: $^{207}Pb/^{204}Pb$ against Pb ppm^{-1} (1/Pb) for tooth enamel of individual sfrom the early medieval Period [West Heslerton, Stonehenge, Bamburgh, Repton and Ricall] (Budd *et al.* 2004*c*).

Overall, the source of lead isotopes seems to have remained broadly the same in the late and post-medieval periods. Yet there is a quantitative difference between the post-medieval and the early medieval periods, the nature of which may be explored in future studies.

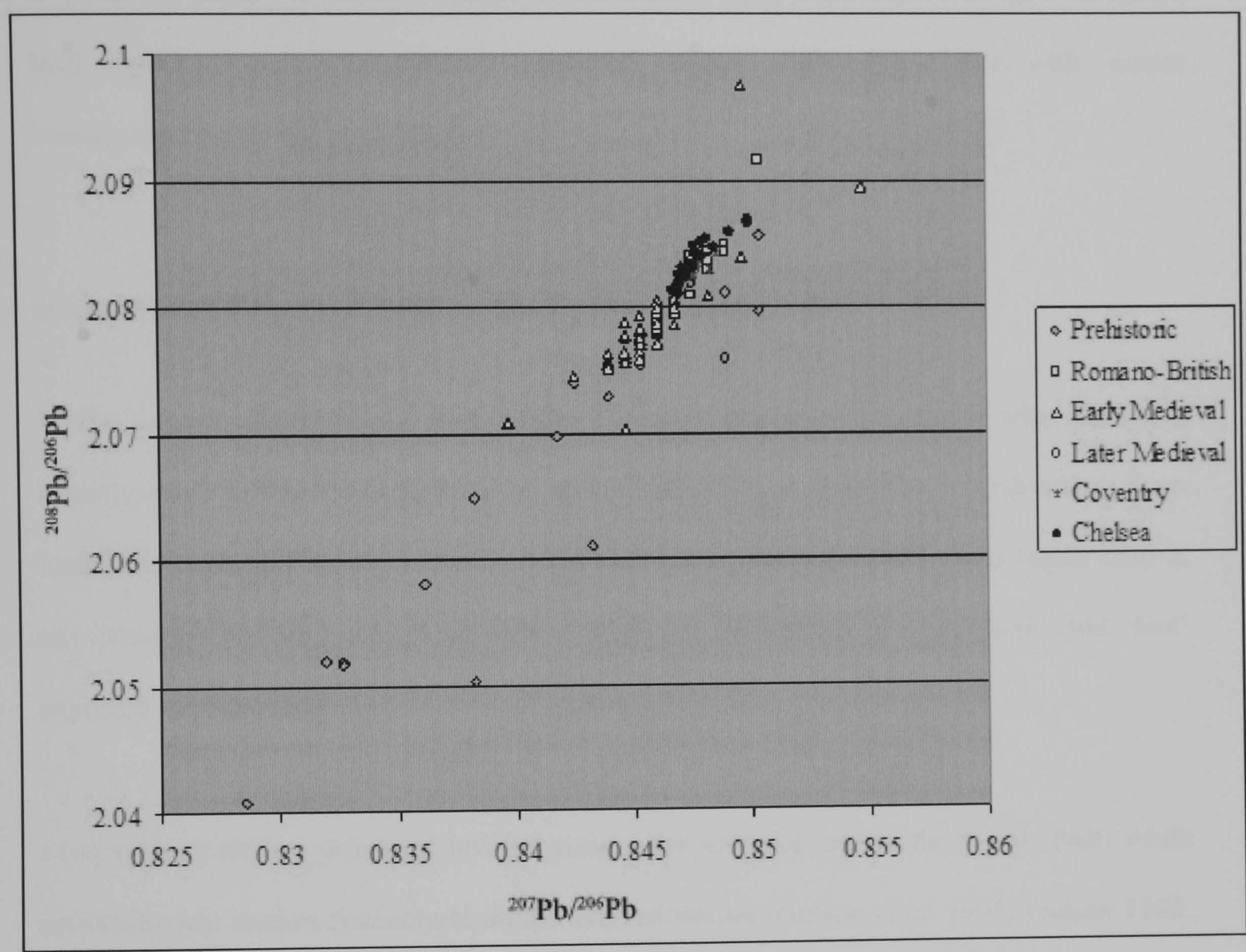


Figure 51: $^{208}Pb/^{206}Pb$ against $^{207}Pb/^{206}Pb$ for tooth enamel of archaeological individuals from various sites in the UK from 5500 BP to 1850 AD (Budd *et al.* 2004*c*).

To reiterate, while the source of exploited lead seems to have remained consistent through the medieval period (AD 410-1540) – including early and later medieval as well as post-medieval (AD 1532 onwards) – there was a difference in terms of relative exploitation. The later medieval shared (11th through 16th centuries) more in common with that of the post-medieval period, and both were quantitatively different from the early medieval period (4th through 11th centuries). There is a continuum of experience between the two periods in terms of resource exploitation, yet this differs significantly from the early medieval period.

That is not to say, however, that the early medieval period was in any way 'rustic' or primitive. As with the post-medieval period it is clear that there are two groups represented in the early medieval: (1) those who have minimal exposure to lead sources with a respectively larger variation in isotope ratios; and (2) those individuals who have increased lead exposure and concomitantly restricted isotope values consistent with source homogenisation (Budd *et al.* 2004*c*).

6.7.4. Health Effects of Lead in the Post-medieval Period

While sources and levels of lead pollution remain important questions, what does this actually *mean* to the life experience of an individual? It is clear that the individuals from both Coventry and Chelsea experienced an average lead exposure (Pb ppm) higher than in any previous period, although of course there are individuals of both 'high' and 'low' exposure in all periods.

Lead toxicity studies primarily revolve around the study of lead in the blood (PbB) while archaeological studies concentrate on the skeletal tissues (Gulson *et al.* 1995; Gulson 1996; Gulson and Gillings 1997). While bone acts as a 'lifetime reservoir' for lead, measuring the total exposure through life minus that of excreted lead through bone turnover, etc., enamel measures exposure over the period of mineralisation only. Quantification of enamel (PbE) to blood (PbB) lead is therefore necessary to be able to relate historical lead exposure to the clinical effects caused by such exposure.

Grobler *et al.* (2000) have suggested from a study of South African children that the following variation can be seen in human skeletal tissues and their relationship with blood (in mg kg^{-1} or "ppm"): blood (PbB) = 0.025; enamel (PbE) = 0.25; dentine = 2.04; and circumpulpal dentine = 6.71 (Grobler *et al.* 2000). Thus it is suggested that the relationship of PbB:PbE is on the order of 1:10 (Grobler *et al.* 2000). The literature, however, reveals a

highly variable relationship (*cf.* Rabinowitz 1988; Rabinowitz and Bellinger 1988; Gulson 1996, 1997, etc.).

In comparison to the highest recorded PbE for the Coventry and Chelsea samples – ~83.4 ppm for both John Long Esquire (CHE713) and Milborough Maxwell (CHE792) – or PbB of 834 ppm. Dental enamel of the samples, however, records the *averaged* exposure over the period of formation, or approximately three years. The daily exposure is therefore ~2.3 ppm assuming continual exposure, which is substantially below the threshold for acute or chronic health effects (40-80 ppm PbB) (ATSDR 1992, 1997). However, studies have shown that the human body excretes 90% of ingested lead and of the 10% is incorporated into the human body, primarily (9.5%) into the bones and teeth (Farrer 1993). Of this 9.5% approximately 2.9% enters the teeth which, for the purposes of this estimate, will be considered an indivisible whole rather than combining enamel and the pulp-dentine complex (Farrer 1993). This translates to a *chronic* exposure of approximately 77 ppm, which is within the boundary of defined health effects (DHSS 1980; ATSDR 1992, 1997; Farrer 1993).

It remains at this point impossible to determine the extent to which lead affected the health of the individuals analysed as a part of this project. While it remains clear that the individuals from both Coventry and Chelsea were exposed to high levels of lead, indeed with a median value that is higher than for previous periods, a more precise relationship between lead in blood and the various skeletal tissues must be provided before further inference can be made.

7. Conclusions

This thesis has provided a broad interpretative background and the results of a combined isotope biogeochemical analysis of the post-medieval skeletal remains from the sites of Holy Trinity and St. Luke's. In summarising this information, it is useful to return to the research questions in section 1.3.

7.1. Carbon and Nitrogen Isotopes

Is there a difference between the diet of Coventry and Chelsea, two locations that historically have a different socio-economic experience of the post medieval-period?

The isotopic results in terms of both $\delta^{13}C$ and $\delta^{15}N$ for the two sites showed clear distinctions in diet between the two locations, as can be seen in fig.28. The nature of this dietary separation seems most likely tied to a combination of factors, but most importantly differential access to protein (meat) resources. Fig.32 illustrates the highly enriched nature of the diet of both populations beyond that of primary terrestrial fauna consumers, suggesting that both Coventry and Chelsea had a greater reliance on freshwater resources and terrestrial omnivores, i.e., pig (Richards *et al.* 2001; Privat *et al.* 2002). Indeed, pig is historically attested as being a common addition to the diet of even the relatively poor agricultural labourers of the eighteenth and nineteenth centuries (*cf.* Chapter 2).

While this is a status-based explanation for the enriched nitrogen isotope signal of Chelsea over Coventry, one cannot ignore the different characters of the locations themselves. Although both locations are likely to have had easy access to aquatic resources, the location of Chelsea on a tidal river may suggest that the less negative carbon isotope signal

experienced by the Chelsea population might result more from availability than a consideration of status (figs. 28-32).

A secondary explanation for this shift is an increasing contribution of C_4 foods to the diet of Chelsea. However, while C_4 crops such as maize and millet were available during the period, neither were significantly utilised by the British. Maize or 'Turkie corne' was considered by some observers to be unsuitable for human consumption, and was never a successful crop in Britain (Spencer 2000). While sugar cane was present and consumed in Britain from the fourteenth century by the elites, and is a common ingredient in the recipe books of the period, it is unlikely to contribute significantly to the dietary signal (Raffald 1970; McKendry 1973; Black 1992; Spaulding and Spaulding 1999).

If diet does vary between the sites is it purely a function of socio-economic status or may other variables be responsible for this variation?

The biographic analysis of named individuals from both Coventry and Chelsea aided in the identification of broad socio-economic status – defined 'high' and 'low' status – for a number of individuals. From Coventry, 'low status' was determined for John Chattaway, the son of an agricultural labourer who needed charitable support for his apprenticeship. High status could be inferred from registration on the Voter's List for Coventry and thus identified Richard and John Ballard – brother and likely eponymous son of John Ballard – and James Brown as owners of property of significant value (£5-10). Similarly, the burial register allowed the identification of 'low status' individuals for Chelsea, i.e. Sarah and Charity Adams, first and second wives to the bricklayer Nicholas Adams. High status individuals included members of the Hand family (Gideon Richard and Richard Gideon) and the Long family (Thomas Long, John Long Esquire and John Long), as well as Thomas Langfield all mentioned as 'gentleman of Chelsea' in their wills and all of whom left sizeable sums of money and property in their wills.

With this socio-economic framework in mind, it is possible to identify a general pattern within the $\delta^{15}N$ values recovered from the Coventry and Chelsea material. Namely, in both sites individuals with high socio-economic status consistently had higher $\delta^{15}N$ values compared to those of identified low socio-economic status. In general, low $\delta^{15}N$ values are consistent with individuals whose primary diet is composed of terrestrial plants and grains, and meat from terrestrial herbivores, the dominant source for 'peasant' diets in the medieval and post-medieval period (Hammon 1993; Roberts and Cox 2003). Similarly high $\delta^{15}N$ is indicative of increased consumption of protein sources, i.e. increased trophism or elevated position within the food-web composed of plants, herbivores, omnivores and carnivores (Iacumin *et al.* 1996; Sealy 2001).

The separation of $\delta^{15}N$ by socio-economic class is most distinct with Coventry, where the separation of John Ballard, James Brown and Thomas Thomson from the average $\delta^{13}C/\delta^{15}N$ values was more significant than between high status individuals in Chelsea and the dietary centroid.

The pattern of increasing $\delta^{15}N$ with socio-economic status was not repeated in the $\delta^{13}C$ values returned for both Coventry and Chelsea. Those individuals with a high status did not consistently have enriched or depleted carbon isotopes in relation to the average diet of either site. This strongly suggests that locality, not socio-economic class, played a greater part in access to marine resources as was seen to be the case in Mays' study of coastal and inland medieval sites (Mays 1997).

A number of outliers were identified within the two sites in terms of their diets. Most obviously from Chelsea in terms of carbon isotopes are Milborough Maxwell and CHE19. Interpretation of the strontium and oxygen isotopes used for determining childhood

residence strongly indicated that Milborough Maxwell was not of local origin but instead most likely Caribbean based upon the very low strontium and oxygen isotope ratios. The historical record hints at something similar, with 'Milborough' being a common name in the Caribbean and, similarly, the surname 'Maxwell' being associated with a number of high-status individuals in the area. Status for Milborough Maxwell is, in this case, associated with the elevated $\delta^{15}N$ comparable to 'high status' individuals such as Thomas Langfield as well as Thomas Long and his wife, Catherine. Milborough Maxwell's isotopic signature may therefore represent a contribution from C_4 plants (tropical and sub-tropical grasses) or, similarly, a significantly increased contribution of marine resources in the diet. While no biographical information was available for CHE19, the strontium and oxygen isotopes place this individual outside of the normal ranges experienced by an individual from Chelsea. Once more this is approximately consistent with an individual from a tropical or sub-tropical environment such as the Caribbean, although one that did not derive from what is likely one of the volcanic islands scattered therein, rather from a mixed geology similar to that of Jamaica.

Within Coventry the main outlier was Thomas Thomson (fig.33), whose diet is more consistent with an individual from the Chelsea sample. However, only the carbon isotope ratio for Thomas Thomson was significantly different to the Coventry sample and not the nitrogen isotope ratio, though that too was elevated by 0.5 ‰ over the majority of the sample. As such, this individual could represent someone of high status with a diet similar to that of individuals from Chelsea. Alternatively, Thomas Thomson could have been a recent immigrant into Coventry, or enjoyed an occupation or status that gave preferential access to meat resources, including marine-based fauna. Without further biographical information the nature of Thomas Thomson's separation from Coventry sample remains a mystery.

Outliers in terms of $\delta^{15}N$ include John Ballard and James Brown from the Coventry sample and Charity Adams from the Chelsea sample. John and James enjoyed a diet that was relatively enriched in ^{15}N, indicating preferential access to meat resources, i.e. freshwater fish and/or terrestrial omnivores. While the biographical evidence would suggest that both individuals are relatively wealthy, e.g., their presence on the Voter's List for Coventry, John Ballard's association with the inn/tavern might also have offered the opportunity for a more diverse diet (Hammond 1993; Roberts and Cox 2003). Charity Adams, on the other hand, seems to either have less meat, or a lesser contribution of ^{15}N enriched food such as terrestrial fish, in her diet. Further, the pathologies found upon her remains are more closely in keeping with Coventry than they are with Chelsea.

The average diet of Chelsea and Coventry are remarkably similar, varying primarily in access to meat-resources (Richards *et al.* 2001; Privat *et al.* 2002). An average Coventian would therefore be eating less meat than an individual from Chelsea, where not only their increased wealth but also their geographical location would have contributed to an elevated nitrogen isotope ratio.

Does diet vary significantly between males and females in the two sites?

Only the Chelsea sample was of sufficient size to allow a comparison to be made between the diets of males and females. Mann-Whitney tests revealed that for both carbon and nitrogen there was no significant difference in the diet of men and women in the eighteenth and nineteenth centuries. However, as attested in the historical record, Coventry and Chelsea enjoyed significantly different experiences in terms of the post-medieval period. With a higher average socio-economic status, the lack of difference between the diets of males and females may be an artefact of this increased status (*cf.* Müldner and Richards 2005).

To address this issue fully, carbon and nitrogen isotopes must be recovered in sufficient quantities from sites with defined socio-economic differences, for example from the working- and middle-class. Ideally this would be paralleled with biographic reconstruction as this can offer insight into specific variations that are otherwise impossible to determine from the archaeological and biogeochemical record.

7.2. Strontium and Oxygen Isotopes

The application of strontium isotopes for provenance studies was hindered by the absence of faunal samples that would have aided in the characterisation of the local strontium isotope "signature". Despite this, strontium and oxygen isotopes did successfully identify migrants into the locations in question.

Are the populations of Coventry and Chelsea isotopically discrete? Can migrants or locals be securely identified in the isotopic record?

Despite lacking samples that would define the local isotopic signature (e.g. local, non-migratory faunal samples), at least with reference to strontium, the mean values and clustering of the strontium and oxygen ratios can be shown to be statistically distinct from one another (fig.38). While there is some overlap between the two populations, this may be the result of similarities in the underlying geology and/or common food sources, such as with the regionalism of agriculture. The extent to which this might have affected the measured strontium isotope ratios remains unclear and requires further study, e.g. monitoring the isotopic ratios over the lifetime of a city.

With regards to the identification of migrants, combined strontium and oxygen analysis was successful in identifying several candidates. Milborough Maxwell (CHE792) had drastically different strontium and oxygen isotope ratios from the Chelsea mean. While the strontium isotope composition of her tooth enamel offers a potential British origin – certain parts of northern England (Evans pers. comm.) – the oxygen isotope ratios point to a tropical environment. Given the historical connections between Britain and the Caribbean, it is possible that Milborough Maxwell spent her early childhood on one or more Caribbean islands.

James Brown (COV978) is one of two individuals in the combined Chelsea and Coventry sample where the historical sources indicate migration did occur between the cities of Coventry and Warwick, situated approximately 23 miles apart from each other (fig.22). The fact that Coventry and Warwick share broadly the same bedrock and superficial geology (fig.22) once again reinforces the requirement to utilise local archaeological fauna to characterise the local strontium isotope signature. Without this, the nature of the difference in James Brown's strontium isotope ratio and the median ratio for Coventry cannot be ascertained with any degree of certainty. The interpretation of the strontium isotope ratios of John Chattaway (COV1248), the second individual from Coventry known to have undergone migration, is likewise problematic. It is tempting to suggest that the similarity in John Chattaway's strontium isotope ratio is a result of the small distance of migration, i.e. two miles from the hamlet of Radford into Coventry city. However, this raises the question of the variability of strontium isotope ratios in a given locale and the definition of the aforementioned local isotope signature.

Oxygen isotope analysis also reveals a further two outliers with tooth isotope signals similar to Milborough Maxwell, though unlike Milborough Maxwell their strontium isotope ratios are similar to the Chelsea and Coventry mean isotopic ratios. These values would support a

non-local hypothesis, but without any biographical information it is not possible to determine where these individuals might have migrated from.

Do the calibration formulae utilised in oxygen isotope analysis return a value consistent with location?

With specific reference to oxygen, none of the calibration formulae utilised in the biogeochemical literature was capable of returning a value consistent with the archaeological and historical record. While the Levinson calibration recovered a value within error, it is unlikely, given a single individual, that the correct precipitation band would be determined. The other calibrations commonly used – Luz and Longinelli – were even less accurate in reporting back correct values, with Longinelli failing to report back a correct value even when one takes into account the error associated with.

While the calibration formulae do not return a value consistent with local groundwater, the complexities of oxygen fluxes into the human system as affecting the calibrated oxygen isotope ratio have recently come to light (*cf.* Millard 2004). A number of possibilities present themselves that might help to explain the discrepancy between the expected values and those recorded in the Coventry and Chelsea populations. These include contribution to the oxygen flux from foods from a non-local source, or the drinking of water from evaporation pools – rainwater butts – common to the eighteenth and nineteenth centuries. The extent to which this might have affected the measured oxygen isotope ratios is, however, unknown.

It is therefore necessary for the concept of biophosphate-precipitation calibration to be re-addressed, and the use of biographically identified individuals provides the means by which this might be achieved.

7.3. Lead Isotopes

Along with carbon and nitrogen, lead isotopes offers one of the particular success stories in the interpretation of the archaeological and historical record of Coventry and Chelsea. Returning to the research questions mentioned in the introductory chapter:

Is there significant difference in the 'pollution' exposure between Coventry and Chelsea, nominally low- and high-status sites respectively?

Statistical tests of difference between the lead isotopes of Coventry and Chelsea reveal no significant difference between the two sites. That is, while their specific experience of exposure to lead may differ – wood *versus* coal burning, pollutants adhering to plant surfaces or exposure through the use of domestic products – there is no statistical difference in the origins of the polluting lead. While the standard deviation for lead concentration in human dental enamel is large, in general lead exposure is greater in Chelsea than it is in Coventry. The majority of individuals with defined high socio-economic status also have greater exposure to lead, again likely a result of the leaching of lead into food and drinks from pots, glasses, pewter, etc. (Weeden 1984; Richards 1999).

The picture of increasing socio-economic status translating to increased exposure to lead while generally true of Chelsea is not true of Coventry. Those individuals from Coventry whose carbon and nitrogen isotopes would suggest are of lower socio-economic status have increased exposure to heavy metal pollution. While the historical record remains quiet on this subject, it is possible that this is a manifestation of poor housing conditions; proximity to significant out-flows of lead into the environment, etc.

Can the lead levels measured in human dental enamel be specifically associated with clinical effects of lead 'poisoning'?

Current relationships between human dental tissues and reported childhood lead exposures suggest extreme exposure to lead in several individuals from the Chelsea sample and, indeed, the post-medieval population in general. Even the lowest lead exposure recorded in the sample from Chelsea (CHE31, 4.65 ppm) when converted between tooth lead and blood lead leads to PbB of 46.5 $\mu g\ dl^{-1}$. This is sufficient to result in lowered fertility, damage to the peripheral nervous system, reduced haemoglobin synthesis and psychosensory and behavioural alterations (see Chapter 4). In individuals such as Milborough Maxwell and John Long Esquire the suggested PbB would be an astonishing PbB of 834 $\mu g\ dl^{-1}$ in their childhood. Not only did both individuals survive to the age of 68 despite these phenomenal lead exposures but also the will of John Long Esquire presents a picture of an astute businessman. While approximated calculations reveal that individuals with lead exposures in the 70-80 ppm levels would likely have suffered some form of lead poisoning, e.g. lead being consumed at a rate greater than 2.62 $mg\ kg^{-1}$ per day, it is difficult to then relate this to lead levels in the blood and from there to any clinical effects of plumbism.

It is now certain that individuals from Coventry and Chelsea and by inference those from the post-medieval period in general, had much greater exposure to lead and 'pollution' in their environment than experienced in previous periods. Pollution was an everyday part of their lives and, for some, would have had a great impact upon that life. Determining the specific, clinical effects remains problematic. The discrepancy between the suggested relationship between lead in the blood and in the dental tissues requires that this subject receives further attention in the biogeochemical literature. In this case the sampling of biographically identified individuals from, for example, the manufacturing towns of the north of England and individuals from a rural village, as well as modern individuals, may shed further light

and allow a more precise determination of plumbism and its effects in archaeological populations.

What is the dominant source of lead in the post-medieval period and how does this vary from the later-medieval and earlier periods?

Lead isotopes in pre-metallurgical societies can be used to determine childhood residence and, within lead-exposed technological societies, determine the source of that lead exposure. Following methods previously employed by Budd *et al.* (2004) it was possible to determine the isotopic composition of lead to which the post-medieval population of Coventry and Chelsea were exposed: $^{206}Pb/^{204}Pb$ = 18.45, $^{207}Pb/^{204}Pb$ = 15.63 and $^{208}Pb/^{204}Pb$ = 38.42. These values are consistent with British lead-zinc ore values reported in the literature (Rohl 1995). Separate linear regression of lead derived from human dental tissues in the later medieval period shows close conformance with those of the post-medieval period: $^{206}Pb/^{204}Pb$ = 18.45, $^{207}Pb/^{204}Pb$ = 15.62 and $^{208}Pb/^{204}Pb$ = 38.38. The picture presented is therefore one of continuity in terms of resource exploitation between the later medieval and post-medieval periods. Inclusion of the post-medieval data into consideration of an aggregate lead source for 5500 BP to 1850 AD does not vary the regressed isotopic composition. Indeed, the value is consistent with 'technological' lead exposure from the Iron Age and Romano-British period onwards.

What is also clear from a consideration of $^{206}Pb/^{207}Pb$ is that there is a difference in the use of lead sources between the later/post-medieval and that of the early medieval period. The early medieval period shows a differencing selection of lead sources ($^{206}Pb/^{204}Pb$ = 18.48, $^{207}Pb/^{204}Pb$ = 15.62 and $^{208}Pb/^{204}Pb$ = 38.40) than that of subsequent periods, resulting in a peak-shift in $^{206}Pb/^{207}Pb$ ($^{206}Pb/^{207}Pb$ 1.179 later medieval and post-medieval; $^{206}Pb/^{207}Pb$ 1.182 for the early medieval). While all periods considered clearly operate on a mixing line, it is the difference between the post-medieval period and the early medieval period, and

indeed the similarity of the post-medieval with the later medieval and Romano-British, that is most interesting. While the lead source is broadly invariable, the use to which lead-bearing products are being utilised in the two periods appears to vary.

How does lead exposure vary through time? Is the post-medieval period different from others in this regard? How is it similar?

The picture presented by the lead isotope analysis of the post-medieval populations of Coventry and Chelsea is consistent with lead exposure from 5500 BP to the sixteenth century (Budd *et al.* 2004*c*). Budd *et al.* previously suggested that low concentrations and a highly variable $^{206}Pb/^{207}Pb$ ratio was representative of 'natural' dietary lead exposure, while the increased lead concentration conformed to a restricted $^{206}Pb/^{207}Pb$ ratio range consistent with homogenised 'technological' lead (Budd *et al.* 2004*c*). Lead exposure in the eighteenth and nineteenth century seems consistent with preceeding periods. That is to say that while two groups are clearly present as has been identified in previous research (Budd *et al.* 2004*c*), one with a diverse range of isotopes and low lead concentrations and the other with a restricted range and much higher concentrations, the suggested threshold of 1ppm for 'natural' and 'technological' lead simply does not apply with the post-medieval sample. Lead exposures for individuals of all socio-economic classes were much higher during this period, and further work on post-medieval samples is required to fully elucidate the cause of this shift.

7.4. Osteological Intepretation

The osteological interpretations of the human remains from Coventry and Chelsea were necessarily restricted, not only as part of the original project outline but also from the preliminary nature of the available osteological reports. Despite this, the quality of the

analysis was high and presented parallel information in the reconstruction of the biographies of the named individuals. Further, the palaeopathological differences between the sites were consistent with the historical record proving the robust nature of osteoarchaeological analysis in determining the socio-economic class of a given population.

Is the osteological record of the two sites consistent with the historical record?

The type and distribution of pathologies between Coventry and Chelsea strongly suggests a different experience of life during the post-medieval period, with the exception of dental hygiene, which equally affects both populations. Trauma and degenerative joint disease predominate in the Coventry sample, affecting some 25% of the population in each case. The affected joints also tend to be in the shoulder and the arm, sites that are consistent with occupational stress. Indeed, degenerative joint disease of the spine is present not only in adults. It also affects sub-adults in the Coventry sample, indicating that occupational stress began with childhood labour. In comparison to other post-medieval collections, which are composed primarily of individuals of high socio-economic status, Coventry has a significantly elevated incidence of this pathology.

While Chelsea shares many of the same pathologies as Coventry, the extent to which they are present is significantly different. Trauma and degenerative joint disease are found only in a small fraction of the population, although the presence of occupational osteoarthritis (i.e. osteoarthritis in the shoulder and arm) indicates that the Chelsea sample was not solely comprised of high status individuals. Indeed, Sarah and Charity Adams are defined as low status and have pathologies more similar to that of the Coventry sample than other biographically identified individuals from Chelsea.

One significant obstacle in any interpretation of the osteoarchaeology of the post-medieval period, as reported by Roberts and Cox (2003), is not only the lack of consistency in

recording biometric and palaeopathological data but also in the publication and presentation of skeletal reports. Standardisation has long been a concern for osteologists and various professional bodies, such as the 'British Association for Biological Anthropologists and Osteoarchaeologists' (BABAO). Furthermore, in the light of political movements towards blanket reburial of skeletal collections and the experiences in the United States with regards to the Native American Graves Protection and Repetriation Act (NAGPRA), and subsequent publication of 'Standards for Data Collection', consistency and methods of recording must necessarily be addressed (Buikstra and Ubelaker 1994).

Although the reports utilised for this project cannot be considered representative of this phenomenon – both are entirely preliminary, awaiting either completion of analysis in the case of Coventry, or funding for detailed osteological analysis in the case of Chelsea – they are a part of an increasingly important issue. Discussion about the establishment of a central database for osteoarchaeological records in some way addresses the concept of standardisation of reporting, but to be fully accessible any such electronic 'forms' must be of *use* to not only the laboratory osteoarchaeologist but also the field osteoarchaeologist (Caffell 2004). Although challenging, the creation of a hierarchal recording form and database is entirely possible and would advance osteoarchaeology in the United Kingdom significantly.

7.5. Biographic Reconstruction

The use of biographically identifiable individuals enabled a unique perspective on the populations of Chelsea and Coventry. In the majority of archaeochemical investigations that use human remains, inferences are drawn in isolation from an understanding of the identity of an individual. Rather, material culture is used to imply, amongst other things, cultural affiliation. With the identity of human remains determined through the presence of a coffin

plate, etc., the individual's biography can then be traced through any records of burials, baptisms, apprenticeship enrolment registers, etc. With information on occupation, or extant wills, it is possible to determine socio-economic status. In some cases it is even possible to determine the 'how' of death, though this becomes easier after the period of this study, from 1856 onwards. It is also possible to assess migration, which for the most part occurred only on a small scale for the majority of individuals within the post-medieval period.

The use of these historical data, paralleled by the osteoarchaeological evidence, allows us to reconstruct and interpret the biogeochemical record to an extent not previously found to any degree in the archaeological literature. While dietary and socio-economic variation might have been inferred in the absence of the biographic reconstruction of the named individuals, it could not have been done *within* the populations. For example, although the historical literature would suggest a wealth-based access to meat resources, which is consistent with the biogeochemical results of this thesis, it also suggests a discrepancy between male and female diets that is not borne out in this study (Wohl 1983; Privat *et al.* 2002; Müldner and Richards 2005).

A similar situation is found with regard to questions of locality and migration. The current calibrations utilised in biogeochemical studies of human biophosphates to determine location through association with drinking/groundwater has increasingly been brought into doubt (Millard 2004). In the absence of historical records to determine birth location an interpretation of the oxygen isotopes would have created a picture where mid- to long-distance migration was the norm (fig.37), which certainly contradicts the historical literature on the subject (see Chapter 2).

The insight and limitations provided by the thesis point to several avenues of future research. While strontium isotopes are able to distinguish between population groups and individuals from significantly different geologies, their use to determine childhood residence of single

individuals is debateable when applied outside of a sample population. However, the variation in strontium in the local environment around a site may sometimes be ideally suited for the study of the short-distance migration that is common in the post-medieval period (Paul Budd pers. comm.). Similarly, while oxygen isotopes have been shown to distinguish between local and migratory individuals, the calibration curves used to derive groundwater isotope ratios from biophosophate need to be re-addressed. As applied to the Coventry and Chelsea samples, all of the calibration curves failed to determine childhood residence, implying that further research into the fluxes of oxygen within the human body and their interaction with the environment will greatly expand the use of this technique.

While carbon, nitrogen and lead isotopes conform to the expected model, questions regarding the variation of diet between sexes have not been fully addressed, nor has the potential of determining health effects from high enamel lead levels been adequately explored. Further research on sites not only with biographically identified individuals (Christchurch Spitalfields Crypt, St. Brides), but with un-named individuals from a more diverse range of post-medieval contexts could greatly advance our understanding of this complex period.

The use of biographically identified individuals has shown itself to be a significant tool for the interpretation of human remains. In a field of archaeology that is increasingly becoming aware of methodological issues and the increasing complexities of interpretation, biographic reconstruction offers an avenue through which the various chemical models can be tested, thereby advancing our understanding of past populations. Historical information can be used not only to reduce the number of variables that have plagued the consistent application of biogeochemical studies for many years but provide new insight into many of the methodological issues that have been recently raised (Budd *et al.* 2004*c*; Millard 2004). Although there are a number of extant collections utilised for forensic studies, such as the Todd collection, biographically identified archaeological populations also avoid many of the

limitations of modern populations on the geochemical samples including: homogenisation of food resources; increasing use of bottled mineral water; and labile soil strontium comprised primarily of modern fertilisers, etc.

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Appendix 1 – Osteoarchaeological Samples

This appendix contains descriptions of the osteoarchaeological materials utilised in this study, primarily concentrating on those individuals from either Coventry or Chelsea that contributed both dental and bone samples, and is ordered numerically and by site.

Note: It does not contain all material listed in the thesis, only that which was included in the isotopic analysis, e.g. CHE1023 is not listed here, nor is COV78 (fetal skeleton associated with COV77).

Chelsea Samples

Chelsea 18

The individual CHE-18 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: One rib sample taken and prepared for C/N analysis. Sample ~6.5cm in length. No pathologies evident.

- **Tooth**: Left Mandibular second premolar (35). The tooth shows very little wear, with post-mortem damage evident as two chips to the occlusal enamel (mesio-buccal margin and on the lingual cusp), and a hemi-elliptical scoring of the root at the centre of the buccal enamel dentine junction (mesio-distal ~5mm, inferiorly projects ~1.5-2mm). The root further shows a brown-green discolouration that circumnavigates the root beneath the enamel dentine junction and extends inferiorly for ~3-5mm, and is at its widest on the mesial and buccal sides. The mesial enamel shows evidence of what appears to be supragingival calculcus which extends horizontally for 4mm.

Chelsea 19

The individual CH-19 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: One rib sample taken and prepared for C/N analysis. Sample approximately 7cm in length. No pathologies evident.

- **Tooth**: Left mandibular second premolar.. No pathologies evident, although on possible (dubious) carious lesion on the mesio-buccal aspect. Possible post-mortem damage to the buccal enamel cap at the enamel dentine junction (at the site of a potential carious lesion or post-mortem chemical action?). The buccal cusp is extremely worn, angled at ~20 degrees from horizontal, sloping bucco-distally. Root is almost entirely composed of secondary, sclerotic dentine.

Chelsea 31

The individual CHE-31 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: Rib fragment approximately 11cm, curved. Sternal end present containing spicules of bone ossification in the superior aspect of the head.

- **Tooth**: Maxillary right first molar. Significant calculus deposits in the cuspal interstices. Large buccal carious lesion and, as such, the sample is taken from the other mesio-distal half. Secondary, sclerotic dentine is evident in the mesial root fragment, taking approximately half of the root.

Chelsea 35 (Gideon Richard Hand)

The individual CHE-35 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: Several rib fragments sampled over two visits two MoLAS. 4-5, 6 and 10cm in length respectively. No obvious pathologies present.

- **Tooth**: Right Mandibular second premolar. Root broken in extraction from Mandibular. No obvious pathologies, though there does appear to be a post-mortem break at the buccal enamel dentine junction. The mesio-buccal dimishment of the primary cusp does seem to show some minor wear.

Chelsea 39

The individual CHE-39 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: Two rib fragments, 3.5cm and 6cm. No pathologies evident.

- **Tooth**: Right Mandibular second premolar. Severe super gingival calculus evident, most notably on the lingual enamel surface and extending ~5mm beneath the enamel dentine junction. A superiorly concave calculus spar joins the lingual calculus to another major concretion on the buccal surface, more prominent in the mesial aspect. The distal surface also shows what might be a carious lesion at the enamel dentine junction, but it is difficult to distinguish with the degree of plaque mineralisation in the area. Approximately half of the tooth appears on external examination to be secondary, sclerotic dentine (i.e. transparent).

Chelsea 104

The individual CHE-104 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: Rib, approximately 8cm in length with no obvious pathologies.

- **Tooth**: Maxillary left second molar. Very little to no wear with flecks of supergigival calculus on the lingual enamel (5mm in length, ~1-2mm above the enamel dentine junction, distal surface at the enamel dentine junction and also on the disto-lingual surface. Appears to make a continguous arc consistent with interaction with soft tissue. The tooth also has a singe interstitial carious lesion at the centre of the occlusal surface (i.e. fissure caries).

Chelsea 147 (Thomas Langfield)

The individual CHE-147 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone:** Rib, approximately 5cm in length with no pathology evident.

- **Tooth:** Mandibular right first premolar. Wear facet on the disto-lingual enamel cap with carious lesion. Significant supragingival calculus deposits on the root, most evidently on the disto-lingual root. Extensive periodontitis evident. The major cusp shows wear such that in section the enamel is absent from the occlusal surface and primary dentine is exposed.

Chelsea 161

The individual CHE-161 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone:** Rib, approximately 7cm in length with no obvious pathologies.

- **Tooth**: Mandibular left second premolar. Little wear is evident on the occlusal surface of the tooth. One carious lesion is evident on the mesial enamel, with the dentine visible through the perforation. The affected tissue was drilled away in mechanical preparation of the sample.

Chelsea 218

The individual CHE-218 provided on a single sample of bone:

- **Bone:** Rib, approximately 5cm in length with no pathologies evident.

Chelsea 285

The individual CHE-285 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone:** Rib ~7cm. Sternal end present, with osteophytes circumnavigated the head.
- **Tooth**: Mandibular right second molar. No calculus evident. Minor carious lesion on the lingual surface which does not appear to penetrate the enamel. Sampled from the buccal surface.

Chelsea 392

The individual CHE-392 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: Rib, approximately 6cm with no obvious pathologies present.
- **Tooth**: Manidibular left second premolar. Excellent condition with no wear or obvious pathologies beyond supergingival calculus flecking on the mesio-lingual enamel surface.

Chelsea 432 (John M?)

The individual CHE-432 provided only a single sample of bone:

- **Bone:** Rib, approximately 2cm in length and with no pathologies present.

Chelsea 502

The individual CHE-502 provided only a single sample of bone:

- **Bone:** Rib, approximate 3.5cm in length with no pathologies.

Chelsea 552

The individual CHE-552 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: Rib, approximately 8cm. No obvious pathologies present.
- **Tooth**: Maxillary right second molar. Calculus on the distal enamel surface, and a single carious lesion on the lingual surface at the enamel dentine junction.

Chelsea 622 (Richard Gideon Hand)

The individual CHE-622 provided only a single sample of bone:

- **Bone:** Rib, approximate 4.5cm in length with no pathologies.

Chelsea 654 (Thomas Long)

The individual CHE-654 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: Rib, two fragments. Integrity/preservation is quite low. One fragment of first rib is very poorly preserved and is ~7cm at the head. Second fragment ~12cm. No obvious pathologies.
- **Tooth**: Maxillary right second molar. Occlusal carious lesion but otherwise no calculus or other pathologies evident.

Note: CHE-654 is historically documented as the spouse of CHE-722, Catherine Long (*q.v.*).

Chelsea 697

The individual CHE-697 provided two samples for analysis: one right intermediate phalange and a single tooth.

- **Bone**: Right intermediate phalange. Prominent enthsopathy on the medial proximal metaphysis. A possible lytic lesion on the lateral proximal metaphysis, expanding on to the lateral superior joint surface.

- **Tooth**: Maxillary right second premolar. Mineralised concretion evident in the occlusal fissures of the tooth, and some minor staining of the enamel but otherwise no significant pathology evident. Almost the entire root appears to be composed of secondary, sclerotic dentine.

Chelsea 713 (John Long Esquire)

The individual CHE-713 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: Rib, approximately 6.5cm. Ossification of the *intercostales* evident on both the superior and inferior borders of the rib.

- **Tooth**: Right maxillary third molar. The tooth shows some wear facets on the occlusal surface with some occlusal fissure carious lesions (possible). There is also a lingual lesion on the root that may be indicative of continued eruption of the tooth and subjection to the acidic oral environment. The root in section shows significant conversion to secondary, sclerotic dentine.

Chelsea 722 (Catherine Long)

The individual CHE-722 provided only a single sample of bone:

- **Bone:** Rib, approximately 5cm. No pathologies evident.

Note: CHE-722 is historically documented as being the spouse of CHE-654, Thomas Long (*q.v.*).

Chelsea 744 (John Long)

The individual CHE-744 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: Rib, approximately 7cm. No obvious pathologies present.
- **Tooth**: Maxillary right second premolar. Tooth root seems composed almost entire of secondary, sclerotic dentin except near the enamel casp. Wear of the occlusal surface is evident, most particularly on the mesial side of the central buccal cusp. The mesial fissure expresses a carious lesion consistent with this wear and exposure of the underlying dentine. The root shows significant post-mortem damage not related to sampling but which may be indicative of chemical alteration and subsequent destabilisation of the physical form.

Chelsea 750

The individual CHE-720 provided two samples for analysis: two fragments of rib and a single tooth.

- **Bone**: Rib, approximately ~6cm and 7cm. No obvious pathologies present.
- **Tooth**: Maxillary right second premolar. Buccal cusp is extremely worn and is approximately on the same level as the lingual cusp. Two carious lesions are evident. The largest on the distal surface extends from the occlusal surface to ~0.5mm from the enamel dentine junction (superior-inferior 5mm, transversely

~3mm). The second lesion is smaller and on the mesial surface. 3mm by 1.5mm (longest axis is superior-inferior) and the surrounding enamel is highly polished indicating continued use, possibly functional? The tooth shows significant staining on the tooth, even after burring of the surfaces.

Chelsea 792 (Milborough Maxwell)

The individual CHE-792 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: Rib, approximately 7cm. No obvious pathologies.
- **Tooth**: Maxillary left second premolar. Extemely worn with dentine evident on the occlusal surface of both buccal and mesial cusps.

Chelsea 841

The individual CHE-841 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: Rib, approximately 6.5cm. No obvious pathologies.
- **Tooth**: Mandibular right second molar. The tooth shows unusual abrasion to the occlusal surface. Some minor flecks of calculus are evident on the distal surface at the enamel dentine junction. The mesial and mesio-buccal root at the enamel dentine junction also shows a carious lesion. In section the abrasion n the surface seems to penetrate linearly through the dentine towards the pulp-dentine complex. The root also appears to have been converted to secondary, sclerotic dentine with the exception of the distal root where primary dentine remains.

Chelsea 856

The individual CHE-865 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: Rib, approximately 8cm. No obvious pathologies.
- **Tooth**: Maxillary right second premolar. Little wear on the tooth, but a single large carious lesion is present on the distal enamel surface and crossing the enamel dentine junction into the root itself. Approximately 3mm in 'height' and the same in 'width', though it flares out in the superior part of the lesion to the buccal side.

Chelsea 918

The individual CHE-918 provided two samples for analysis: two samples of rib and a single tooth.

- **Bone**: Two rib samples, approximately 7cm each. Only one sample employed in the study. No obvious pathologies.
- **Tooth**: Mandibular left second molar. Root is shorter than other teeth present in the sample. Calculus present in quantity on the tooth, particularly the disto-lingual surface and the occlusal surface of the tooth. On carious lesion is evident on the mesial enamel surface, approximately circular with a diameter of 1-1.5mm. *Note*: The tooth was extremely tough and difficult to saw through. In section a similar situation occurs as with 841, possibly indicating chemical alteration?

Chelsea 980 (Sarah Adams)

The individual CHE-980 provided only a single tooth for analysis:

- **Tooth**: Mandibular left second premolar. Supragingival calculus present, most particularly on the lingual side where it extends over the mesio-distally over lingual surface from the enamel dentine junction to 2mm superior. Calculus also extends on to the mesial and distal surfaces, though not as dense as that on the lingual surface. No calculus is evident on the buccal surface, though a lesion is evident from the enamel dentine junction extending down in an hemi-ellipse for ~5mm. On drilling of the enamel, the lesion flaked off leaving a 'post-mortem' scar: proto-carious lesion? Very little wear is evident on the tooth, though a minor wear facet can be seen on the mesial slope of the primary cusp.

Chelsea 990 (Charity Adams)

The individual CHE-980 provided only a single tooth for analysis:

- **Tooth**: Maxillary left second molar. A mid-dark brown band circumnavigates the root dentine at the enamel dentine junction, externding inferiorly a variable distance though no greater than 1.5mm: specific oral chemistry or perhaps indicative of supragingival calculus (note: all previous mentions of calculus lie above the gingival line; this example might lie below it). Two carious lesions are evident on the tooth. The first is on the distal side at the enamel dentine junction, seeming to encompass only the enamel (i.e. the noted mid-dark brown band remains evident in the dentine indicating that the carious lesion primarily effected the cervical dentine. The second carious lesion is intercuspal in the fissure between the two mesial cusps, approximately circular with a diameter of 3mm. Wear is evident on the tooth, focussed to the distal half of the tooth creating a slight hemispherical indentation (i.e. approximately equal wear on both the buccal and lingual cusps of the tooth). In section the fissure carious lesion has caused significant damage to the underlying crown dentine, with an approximately hemi-spherical cavity with a depth of ~1-

2mm. A similar effect can be seen with the second carious lesion. though the lesion is focussed to the lingual half of the tooth.

Chelsea 994

The individual CHE-994 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: Rib, approximately 8cm in length. Osteoblastic activity on the dorsal surface of the rib, generally limited to the superior and inferior borders. Possible indication of trauma?

- **Tooth**: Mandibular left second premolar. The tooth shows significant wear, most particularly on the mesial side of the primary cusp, and extends inferiorly to the cervical margin. A lesion which may be the initiation of a root carious lesion is evident on the disto-buccal margin, situated 1-2mm from the enamel dentine junction with a maximum inferior extension of 3mm, tapering to the enamel dentine junction as one moves in the lingual direction. The extent of the wear required the preparation of both halves of the tooth to allow for combined Sr, Pb and O analysis.

Chelsea 1021

The individual CHE-1021 provided only a single sample of bone:

- **Bone:** Rib, approximately 5.5cm in length. No obvious pathologies present.

Chelsea 1051 (?Collon)

The individual CHE-1051 provided two samples for analysis: a diaphyseal shaft fragment and a single tooth.

- **Bone**: Diaphyseal shaft fragment, no pathologies evident.

- **Tooth**: Maxillary right first molar. Additional cusp (Caribelli's cusp) evident. Minor flecks of calculus with no specific concentrations. The mesial fissure, between the Caribelli's cusp and the mesio-buccal cusp shows possible evidence of a fissure. There is little to no wear on the tooth. The roots have approximately only half formed, although corollary evidence on the skeleton shows that the individual was an adult.

Note: Given the non-metric trait, the maxillary left first molar was reselected. Again it shows little wear and no obvious pathologies. Adhering soil in the fissures maks the detection of any fissure carious lesion difficult at this stage. In section a fissure carious lesion, present in the fissure between the mesial cusps, became evident through discolouration of the underlying enamel. A second carious lesion, noted only as a minor disolouration on the external surface of the tooth, also shows significant alteration to the underlying enamel. Indeed, the damage to the internal enamel surface is far more extensive than the outer carious lesion would first suggest. The enamel adjacent to the carious lesion(s) was extremely 'weak', burring away far more easily than with other samples. Could this be representative of *ameleogenesis imperfecta*?

Coventry Samples

Coventry 13 (Thomas Thomson)

The individual COV-13 provided only a single sample of bone.

- **Bone:** One rib sample taken, approximately 4cm in length. No pathologies in evidence.

Coventry 16 (Ann Kimberly)

The individual COV-16 provided only a single sample of bone.

- **Bone:** One rib sample taken, approximately 4.3cm in length. No pathologies evident.

Coventry 50 ("...ein...")

The individual COV-50 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone:** Rib, no pathology evident
- **Tooth**: Maxillary right first premolar. Calculus fleck evident on the buccal side of the tooth, supergingival in nature. Fissure carious lesions (minor) also evident, although they do not appear to penetrate or otherwise affect the enamel except superficially. In section, however, the dentine immediately underneath the fissure carious lesion is discoloured and the enamel is slightly altered in colour and other optical properties.

Coventry 77 (Elizabeth Burton)

The individual COV-77 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone:** Rib, no pathology evident.
- **Tooth**: Maxillary left second premolar. Discolouration of the enamel is evident in a small patch on the inferior lingual surface. A single carious lesion is present on the buccal crown, with wear exposing the crown dentine. Supergingival calculus can be seen circumnavigating the tooth, but most particularly in the distal and buccal sides of the tooth. There is some evidence of root transparency and, in section the entire root seems to have been converted to secondary, sclerotic dentine.

A child – inter-uterine death – was also interred in the grave, but was not sampled.

Coventry 147

The individual COV-147 provided only a single sample of bone:

- **Bone:** Rib, approximately 3.5cm in length with no pathology evident.

Coventry 417 (Sarah Green)

The individual CHE-417 provided only a single tooth for analysis:

- **Tooth:** Right first premolar. Mesiodistal discolouration focus, though more pronounced on the distal surface. Buccal discolouration at the cervical margin. Calculus 'flecks' (linear) 2-3 mm in length present on the buccal surface below the cervical margin, and the mesiolingual surface (1.5mm below the cervical margin). Secondary sclerotic changes noted in the root.

Coventry 434 (Hannah Denney)

The individual COV-434 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone:** Rib, approximately 5cm in length with no obvious pathologies present.

- **Tooth:** Left mandibular second molar. Mesial and distal discolouration (brown-green) with similar coloured material in the fissures (removed). Slight buccal wear facet. Calculus present on the lingual surface.

Coventry 516 ("Cooper")

The individual COV-516 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone**: Rib, approximately 4cm with no pathologies present.
- **Tooth**: Mandibular second molar. Contains a fissure carious lesion (~1mm diameter) between the cusps on the buccal side of the tooth. On the mesio-buccal margin of the tooth there is a small, darkened indentation, likely a carious lesion but difficult to see without drilling the tooth. Upon drilling this was revealed to be a carious lesion, although it had only just penetrated the enamel and with no underlying staining of the dentine. Another small carious lesion is evident on the disto-buccal margin of the tooth and penetrates into the pulp-dentine complex, though was originally obscured by adhering dirt and discolouration to the enamel itself. Wear facets are evident on the tooth, particularly the lingual cusps. In section the enamel immediately inferior to the fissure carious lesion is discoloured. Upon removal of the dentine, a semi-spherical depression could be discerned, approximately 2-3mm in diameter. The intra-root dentine is also beginning to show secondary, sclerotic changes.

Coventry 672 (Eliza Sparkes)

The individual CHE-972 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone:** Rib, approximately 4cm with no pathologies present.
- **Tooth:** Right mandibular second molar. Minor discolouration to the enamel surface with calculus present on the mesial and distal surfaces, though primarily on the mesial. Flecks of calculus run into the approximal line at ~2-3 mm above the

cervical margin. Possible small fissure carious lesion on buccal cusp. In physical preparation of the tooth a 1-2mm cervical carious lesion was revealed that penetrated to the dentine but not through to the pulp cavity. Material around the carious lesion was burred away.

Coventry 808 (William Wagstaffe)

The individual COV-808 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone:** Rib. No pathologies evident.
- **Tooth:** Right first premolar. Cervical carious lesion at mesial border. Destruction of enamel, though it did not continue into the pulp cavity. Secondary sceloritic changes over entire root.

Coventry 866 (Harriet Parsons)

The individual COV-866 provided only a single tooth sample for analysis:

- **Tooth**: Mandibular right second molar. The mesial lingual root shows a lesion that extends approximately half way down (inferior) the root (~1cm) and is likely a carious lesion. The lesion has affected the cervical enamel to create a hemi-elliptical impression of 5mm mesial-distal length and unknown 'height'. A similar lesion can be seen on the distal mesial root, though only ~2mm in 'height' and with no apparent enamel involvement. A single line of enamel extends inferiorly between the two carious lesions and appears to disappear into the interstice between the two roots. The root shows some change to secondary, sclerotic dentine in section. Some minor fissure carious lesions evident, although no alteration to the enamel was observed.

Coventry 978 (James Brown)

The individual COV-978 provided two samples for analysis: one fragment of rib and a single tooth.

- **Bone:** Rib, no pathologies noted.
- **Tooth:** Right mandibular first premolar. Slight calculus flecks on mesial and distal enamel. Possible fissure carious lesion in the buccal-distal fissure.

Coventry 1119 (John Ballard)

The individual CHE-1119 provided only a single sample of bone:

- **Bone:** Rib, approximately 6cm in length. No obvious pathologies.

Coventry 1248 (John Chattaway)

The individual COV-1248 provided two samples for analysis: one fragment of bone and a single tooth.

- **Bone:** Rib, approximately 5cm. No pathologies noted.
- **Tooth:** Mandibular left second molar. Banded brown-green discolouration on the enamel surface that was burred away in preparation. Slight damage to the mesial enamel surface, probably resulting from post-mortem damage. Cervical enamel on the mesial side also damaged revealing primary dentine. Supregingival calculus present on the mesial border. Detritus in occlusal fissures, though no evidence of carious lesions.

Appendix 2 – Transcription of Wills

The following appendix contains the transcriptions of the wills and PCC records recovered for individuals present in the Coventry and Chelsea samples.

Will of Thomas Longfield (CHE-147)

Source: FRC, Prob 11/1486, 814-815 (PCC). 20th August 1808.

In the Name of God Amen. I Thomas Langfield of Danvers Street in the Parish of Saint Luke, Chelsea, in the County of Middlesex, Gentleman, being of sound mind, memory and understanding do make and publish this my last Will and Testament in manner and form following that is to say first and recommend my soul to almighty God who gave it and my body to be correctly and finally interred at the direction of my Executria and Executors hereinafter named. And as to all my freehold, leasehold and personal estate situated and being in the County of Middlesex and the County of Somerset or elsewhere in the Kingdom of Great Britain whatsoever and wheresoever wherewith it may please God to bless me. I give devise and bequeath the same after payment of my funeral expenses and the expenses of proving this my will and all my just debts in manner following that is to say I give and bequeath unto Ann Grant, Sister of Mrs Potts of Turnham Green in the County of Middlesex twenty pounds of lawful money of the United Kingdom of Great Britain and Ireland of English value and currency. I give and bequeath to Mary Grant, another sister of the said Mrs Potts, twenty pounds of like lawful money. I give and bequeath to Hannah Lattery, wife of Josiah Lattery of Rae Street near Clarkenwell Green, the sum of three hundred pounds of like lawful money to be pad to her as soon after my decease as conveniently may be into her own proven hand and not to be subject or liable to the rent debts contracted or engagements of her pursuant on any future husband but that her receipt alone notwithstanding covature

shall only be a sufficient discharge to my Executria and Executors for the same. I give and bequeath to Mary Lattery, daughter of the said Hannah Lattery, the sum of one hundred pounds of like lawful money. I also give and bequeath to Harriot Lattery, another daughter of the said Hannah Lattery, the sum of one hundred pounds of like lawful money. And it is my will and desire that the said two legacies shall be paid to the said Mary Lattery and Harriot Lattery on their severally attaining their age or respective ages of twenty one years. And the interest and dividends and proceeds thereof in the mean time to be paid and applied by my said Executrix, Executors and Trustees in and about their maintenance and education. And if either of them shall die before their age of twenty one the surviving to be entitled to both the said legacies. I give and bequeath to Miss Mary Newman now living with me the sum of one hundred pounds of like lawful money, together with all my furniture, plate, linen, china and books that may be in house at the time of my decease to and for her own use and benefit and as to all the rest, residue and remaining of my estate and effects whatsoever and wheresoever and of what nature or kind so ever the same maybe which I shall die possessed or by any ways or means by entitled to at the time of my decease, freehold or leasehold properties in the Counties of Middlesex or Somerset or wherever in the Kingdom of England and all rents, mortgages, [bonde] bills [illegible], sum or sums of money due or owing to me. I give and bequeath the same to the said Mary Newman, Richard Nowiter Burnard of Crookham in the County of Somerset, Surgeon, and my nephew Joseph Langfield of Hatfield Broad Oak in the County of Herts., my Executria and Executors and Trustees herein after named (subject as hereinafter mentioned) upon trust to receive the rents, profits, interest and dividends and divide the same in manner following (that is to say) to divide the same into three equal parts or shares. And one third part or share I give, devise and bequeath the interest and dividends of the same to Betty Langfield of Stokeunderhan in the same County of Somerset (my half sister) for and during the term of her natural life. One other third part or share thereof I give, devise and bequeath the interest and dividends of the same to my brother, John Langfield of Coalpool in the said parish of Stokeunderhan, gentleman, for and during the term of his natural life. And the remaining one third parts

thereof I give devices and bequeath the interest and dividends of the same subject to such dedications herein after mentioned to Ann Boult, wife of James Boult of Taunton in the said County of Somerset, gentleman, for the term of her natural life. But it is my express will and desire that the part or share coming to the said Ann Boult shall be for her own sole and separate use and be no ways subject or liable to the debts, power, control or engagements of her present husband that her receipt along notwithstanding covature shall only be a sufficient discharge of my said Executria and Executors for the same. And whereas there is due from the said Ann Boult to the said Mary Newman on an amount delivered to the sum of two hundred and ninety three pounds with interest for the same from the first day of April one thousand eight hundred and one making together the sum of three hundred and ninety five pounds four shillings due to the said Mary Newman on the first day of April last past it is my will and desire that the same sum of three hundred and ninety five pounds four shillings together with interest thereon after the rate of five pounds per [coutum] per annum from the first day of April now last past up to the time of my decease shall be retained by the said Mary Newman or paid to her Executors, Administrators or Assigns out of such part of my estate as shall be coming to the said Ann Boult. And is by further wish and desire that the said Ann Boult shall only receive the interest and dividends of the remainder after the said debt and interest is discharged but if the said Ann Boult shall happen to die in my lifetime or before she shall become entitled to receive any part or share of my estate as aforesaid though it is my will and desire that the said debt and interest then due shall be paid and retained by the said Mary Newman, her Executors, Administrators or Assigns out of my said estate in the same manner as thought it was a debt due from me notwithstanding any statute, law or custom or any thing herein contained to the contrary thereof and to confirm the same and make it a debt due to the said Mary Newman. I have this day signed a provisionary note for the said sum of three hundred and ninety five pounds four shilling payable to the said Mary Newman, her Executors, Administrators or Assigns within three months after my decease with interest for the same and from and immediately after the decease of the said Betty Langfield, John Langfield and Ann Boult or any or either of them though I devise and

bequeath the whole of such shares as the same may fall into the said Richard Nowiter Burnard and my said nephew Joseph Langfield, their heirs, Executors, Administrators and Assigns for ever to be equally divided between them share and share alike as tenants in common and not as joint tenants. And I do hereby make, ordain, nominate, constitute and appoint the said Mary Newman, Richard Nowiter Burnard and the said Joseph Langfield Executria and Exectors provided always. And my will further is that my said Executria and Executors and Trustees and the survivors and survivor of them and the Executors and Administrators of such survivors or survivor shall and may at all times in the first place reimburse, indemnify, deduct and retain to themselves, herself and himself respectively, out of the said trust monies and estate all such costs, charges, damages and expenses or for the necessary repairs of the said premises hereby devised and bequeathed as they or either of them shall or may at any time expand, lay out and be put into for or by reason or means or account of all any or either of the trusts hereby in them reposed and that neither of them shall be accountable for any loss which may happen to any of the said trust premises unless such loss happens through his or there wilful neglect or default nor shall one of them be answerable for the other or others of them nor for more money than shall actually come to each of their hands respectively but each of them for her his and their own deeds, receipts, neglects and defaults only. And so I hereby revoke, annul and make void all and every one and other will and wills by me at any time heretofore made do declare this [illegible] only to be and contain my last Will and Testament. In witness whereof I the said Thomas Langfield the Testator have to this my will contained in three sheets of paper set my hand at the bottom of the two proceeding sheets and my hand to this third and last sheet this twentieth day of August in the year of our Lord one thousand eight hundred and eight. Thomas *X* Langfield, his mark – Signed, sealed, published and declared by the said Thomas Langfield the Testator as and for his last Will and Testament in the presence of us who at his request in his presence and in the presence of each other have published our names as witnesses hereto: *Joseph Freeman, William Abbot, Richard Wilson, Kings Road Chelsea.*

This Will was proved at London on the seventeenth day of October in the year of our Lord one thousand eight hundred and eight before the worshipful George Ogilvie, Doctor of Law and Surrogate of the right honourable Sir William Wyme, Knight Doctors of Laws, Master Keeper or Commissary of the Prerogative Court of Canterbury, lawfully constituted by the oaths of Mary Newman, Spinster, Richard (in the will written Nowiter) Burnard and Joseph Langfield the nephew of the deceased the Exectors named in the said to whom administration was granted of all and singular the goods and credits of the said decease they having been first sworn duly to administer.

Will of Thomas Long (CHE-654)

Source: FRC Prob 11/1733 (PCC). 22nd August 1816.

I Thomas Long the Older of Beaufort Street in the Parish of Saint Lunk Chelsea in the County of Middlesex, Gentleman, hereby revoke all my former wills, codicils and other testimony, dispositions and declare this to my last will and testament. Whereas I have five sons named Thomas Long, John Long, Pierre Long, Charles Long and George Long, and five daughters, namely Maria the wife of Charles Lahee the Younger, Eliza Long, Esther Long, Emily Long and Catherine Mary Long. Now I devise my freehold, messuages or tenement in Duke Street in the Parish of Saint Luke, Chelsea, aforesaid now or late in the house or occupation of William Cranbrook the Younger with the appurtenances unto and to the use of my said son Thomas in fee. And I bequeath all my household goods and furniture, books, wines and other liquors, plate, linen and china which may be in and about my dwellinghouse at the time of my decease to my said daughters Eliza, Esther and Catherine Mary equally to be between and amongst them for their respective absolute benefit. And I bequeath all my wearing apparel unto my said son Charles for his absolute benefit. And I bequeath all my loanhold, messuages or tenement, lands and hereditaments not in ?ment and the appurtenances unto my said sons Thomas, Pierre and George and my

said daughter Emily their Executors, Administrators and Assigns for the respective estates which I shall have therein at the time of my decease upon trust to receive the yearly rents, issues and profits thereof and with and out of the same to pay, absolve, performed and keep the rents and Covenants for the time being due or to be performed in respect of the same messuages or tenements and hereditaments and upon further trust on or before the tenth day of March and the tenth day of September in every year to divide the residue of the same yearly rents, issues and profits which shall remain after answering the purposes aforesaid into forty equal parts and to pay four of the same forty equal parts to each of my said sons Thomas, John, Pierre, Charles and George, his Executors, Administrators and Assigns for his and their absolute benefit and five of the same forty equal parts to each of my said daughters Eliza, Esther Emily and Catherine Mary, her Executors, Advisors and Assigns for her and their absolute benefit. And I hereby direct that the Trustee or Trustees for the time being of this my Will shall at all times during the continuance of the aforesaid Trusts or any of them keep a proper book or books in which shall be entered fully and a time account of the rents, issues and profits of the said loanhold, messuages or tenements, lands and hereditaments and also of all disbursements which may said Trustors or Trustee for the time being shall make in respect of the same and that they, he or she shall twice at least in every year if thereunto lawfully required produce such book or books to each of my said sons and daughters in trust for whom the said loanhold, hiesmanges or tenements and hereditaments are hereinbefore bequeathed as aforesaid and his or her Executors, Administrators Assigns and shall allow him her or them full opportunity to examine and take copies of the whole or any part or parts of such book or books as aforesaid. I also bequeath unto my said sons Thomas, Pierre, and George and my said daughter Emily, their Executors, Administrators and Assigns the sum of three hundred pounds upon trust to invest the same in their his or her names or name in the Parliamentary Stocks or public funds of Great Britain and to pay the annual produce thereof to such person or persons only and for such purposes only as my said daughter Maria Lahee whether sole or married shall from time to time by any writing or writings signed by her with her own hand appoint but not to as deprive herself while under

Covature of the benefit thereof by way of anticipation and in default of and until such appointment into her own hands for her sole and separate use exclusively of that said Charles Lahee or any husband or husbands whom she may marry after his decease and without being in any wise subject to his or their debts, control, interference or engagements. And also that the receipts of her or of such person or persons as she shall from time to time appoint to receive the said Annual produce or any part thereof shall be effectual discharges for the money therein mentioned to be received. And after her decease the said sum of three hundred pounds and the stocks and funds thereof shall be in trust for all and every the child and children of my said daughter Maria Lahee who being a son or sons shall respectively attain the age of twenty one years and being a daughter or daughters shall respectively attain that age or marry under that age with the consent of her or their parent or parents, Guardian or Guardians, for the time being and to be equally divided between or among them (if more than one) for their respective absolute benefit. And if there shall be no such child than the same small sink into my residuary personal estate. And I empower the said Trustees or Trustee for the time being after the decease of my said daughter Maria Lahee and until the resting of the portion or respective portions so provided for her child or children as aforesaid to apply the annual produce of the said portion or respective portions to which such child or children shall be entitled in expectuary towards his her or their maintenance and education. And to direct the residue or whole (as the case may be) of the said Annual produce to be accumulated at Compound interest in the names or name of the said Trustees or Trustee for the time being in any of the aforesaid stocks or funds and the said accumulations and the annual produce thereof shall be held upon the trusts and with and under the powers, provinces and declarations in this my will declared and contained concerning the fund or funds from the annual produce of which the same shall have respectively proceeded or as near thereto as circumstances will permit. And as to all the residue of my seal and personal Estate and Effects of what nature or kind so ever and such seal and personal Estate and effects as by virtue of any power I am or shall be enabled to dispose of by this my will (except such seal and personal Estate and Effects as are or may be rested in me as a Trustee

or mortgages) I devise and bequeath the same until and to the use of my said sons Thomas, Pierre and George and may said daughter Emily, their heirs Executors. Administrators and Assigns respectively upon trust with all convenient speed after my decease and in such manner as the said Trustees or Trustee for the time being shall in their his or her discretion think most beneficial to poll dispose of call in and convert into money all the said residuary, seal and personal estate and effects (except such part thereof as shall consist of ready money) and to make and execute all such contracts and assurances as may be proper for effecting such sales and to apply all the moneys which shall come to their his or her hands by virtue of the aforesaid residuary, devise and bequest and of the trusts relative thereof as follows (namely). Upon trust with and out of the same to pay and discharge all my just debts, funerary and testamentary expenses and the pecuniary legacies given by this my will or to be given by an Codicil or Codicils hereto and also the legacy duty in respect of all the legacies as well operating as pecuniary hereby given or to be given by my Codicil or Codicils hereto and subject to the trusts aforesaid the said residuary trust monies shall remain and be in trust for all and every my said sons and daughters (except my said daughter Maria Lahee) in the same and proportions as I have hereinbefore provided as to my other property. And I appoint my said sons Thomas, Pierre and George and (so long as they continue unmarried) my said daughter Emily, Exectors and Executrix of this my will. And I declare that the receipts of my said Trustees or Trustee for the time being for any money payable to them, him or her under this my will shall effectually discharge the person or persons to whom the same shall be respectively given from being obliged to see to the application or from being answerable or accountable further application or nonapplication of the money therein respectively mentioned to be received. And as often as any of my first or future Trustees shall die or decease to be discharged from or refuse or decline or become incapable to act in the trusts hereby in them reported as aforesaid or shall become bankrupt or take the benefit of any act of Parliament for the relief of insolvent [illegible] or being a female or females shall intermarry with any person whomsoever before the said trusts shall be fully executed. I empower the then surviving or continuing Trustees or Trustee with the

consent of the majority of persons interested or the Executors or Administrators of the last surviving or continuing trustee by any deed or deeds by them him or her sealed and delivered in the presence of and attested by two credible witnesses to appoint any new Trustee or Trustees in the place of the Trustee or Trustees so dying or desiring to be discharged or refusing, declining or becoming incapable to act or so becoming bankrupt or insolvent or so marrying as aforesaid. And in case the person so dying or desiring to be discharged or refusing, declining or becoming incapable to act or so becoming bankrupt or insolvent or so marrying as aforesaid shall be my said daughters Emily the person to be approved in her stead shall be my said daughter Catherine Mary if she shall be then living and unmarried. And as often as any new Trustee shall be appointed as aforesaid all the trust, estates, monies, promises the Trustee or Trustees whereof shall so die or desire to be discharged or refuse, decline or become incapable to act or so become bankrupt or insolvent or so many as aforesaid and which shall now be subject to the trusts aforeshall shall be thereupon with all convenient speed legally and effectually vested in such now Trustee or Trustees either solely or jointly with surviving or continuing trustee or trustees as occasion shall require upon the trust hereinbefore declared concerning the same respectively and than capable of taking effect. And every such new trustee shall have all the powers of the trustee in whose soon he shall be substituted. And I lastly declare that my said several first and future trustees and every of them and the heirs, Executors and Administrators of them and every of them shall be chargeable respectively for such monies only as they respectively shall actually receive by virtue of the trusts hereby in them reposed notwithstanding their or any of their joining in giving any receipt or receipts for conformity's sake and any one or more of them shall not be answerable for this other or others of them or for involuntary losses. And that they may with and out of the monies which shall come to their respective hands by virtue of the trusts aforesaid retain to and reimburse themselves respectively and also allow to their respective Co-trustee or Co-trustees all damages and expenses which they or any of them may sustain disburse or be put unto in the execution of the aforesaid trust or in relation thereto. In witness whereof I the said Thomas Long have to this my last Will and

Testament contained in four sheets of paper to the first three sheets of my hand and to this fourth and last sheet hereof my hand and seal this twenty second day of June in the year of our Lord one thousand eight hundred and twenty seven. *Thos Long.* Signed, sealed published and declared by the said Thomas Long the Testator as and for his last will and testament in the presence of us who at his request in his presence and in the presence of each other have hereunto subscribed our names as witnesses: Thomas R Aswith, Richard Herve Gisaud, JH Cromwell, Russel J Funivals.

This is a Codicil to my last will and testament whereas I have bequeathed to my Executors and Executria in trust the sum of three hundred pounds to invest in their names for the benefit of my daughter Marie Lahee and her children. Now my Will is that interest thereon at five percent shall commence six months after my decease and provided the interest is regularly paid to my said daughter half yearly within three months after it becomes due my Executors or Exectria shall not be compellable to invest that said sum of three hundred pounds before the tenth day of October one thousand eight hundred and forth but should she die previous to that time the accumulating interest shall be added to the principal and invested as directed by the will or as before.

This is a Codicil to my last will and testament. I do hereby give and bequeath to my son Pierre a legacy or sum of one hundred pounds in addition to his share of my personal property under my said will. In all other reports I confirm my said will in witness whereof I have to this codicil set my hand and seal the 24th day of October 1827, Thos Long. Signed, sealed and published in the presence of Mary Bailey.

Appeared personally William Carpenter of Duke Street Chelsea in the County of Middlesex _____ before and Richard Hicks of N°9 Riley Street, Chelsea. Aforesaid carpenter and make oath that they knew and were well acquainted with Thomas Long the Older, late of Beaufort Street in the Parish of Saint Luke, Chelsea, in the County of Middlesex deceased

for many years before and down to the time of his death and with his manner and character of handwriting and subscription having often seen him write and also write and subscribe his name and having now with care and attention viewed and inspected the paper writings hereto annexed purporting to be and contain two Codices to the last will and testament of the said deceased the first of the said Codicils beginning thus "this is a Codicil to my last will and testament" ending thus "the accumulating interest shall be added to the principle and invested as directed by the will on or before October 10/1840" and thus subscribed "Thos Long July 6th 1827" and the second of the said Codicils beginning thus "This is a Codicil to my last will and testament" ending thus "In virtue whereof I have to this Codicil set my hand and seal the 24th day of October 1827" and thus subscribed "Thomas Long" they _____ appearing say they do verify and in their [constieures] believe the whole body _____ and contents of the said first Codicil beginning ending and subscribed as aforesaid and also the said name "Thos Long" so set and subscribed to the said second Codicil to be the own proper handwriting and subscription of the said Thomas Long the Older deceased and of no other person whatsoever. *Willm Carpenter – Richard Hicks* – On the 19th November 1827 the said William Carpenter and Richard Hicks were duly sworn to the truth of this affidavit before me. W.C. Curtis _____ _____ _____ _____.

Proved at London with two Codicils the 21st November 1827 before the worshipful John Trenchard Picland, Doctor of Law, and Surrogate by the Oaths of Thomas Long, Pierre (in the will written Pierre) Long and George Long the sons and Emily Long, Spinster, the daughters (so long as she shall continue single and unmarried), the Exectors to whom Administration was granted having been first sworn duly.

Will of John Long (CHE-744)

Following is a transcription of the will of Thomas Long of Chelsea (CHE654), originally held by the Prerogative Court of Canterbury. The formatting of the original document is maintained.

Source: FRC Prob 11/1664 (PCC). 22nd August 1816.

In the Name of God Amen.

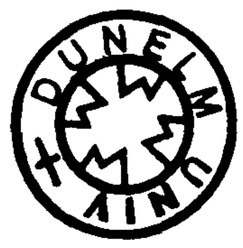
I John Long of 18 Beaufort Row in the Parish of Saint Luke Chelsea in the County of Middlesex, Gentleman, being of sound and disposing mind, memory and understanding so make, publish and declare this to be my last Will and Testament in manner following (that is to say) first I desire that all my just debits, funeral expenses and the expense of proving this my will be fully paid and discharged. And after payment and satisfaction thereof I give and bequeath to Sarah Butler, wife of James Butler of Hammersmith in the County the Count of Middlesex aforesaid barge builder the sum of one hundred pounds of lawful English Currency to be paid into her own proper hands for her own use and benefit. I also give and bequeath to the said Sarah Butler all the wearing apparel which I shall have at the time of my decease for the use of her family. I give and bequeath unto the churchwardens are overseers of poor for the time being of the Parish of Saint Luke Chelsea aforesaid for the time being shall from time to time on the fourteenth day of January in every year lay out the interests or dividends of the said sum of one hundred pounds in purchasing bread and shall on such day in every year distribute the same amongst such of the poor of the Parish of Saint Luke Chelsea aforesaid as are not wholly supported at the expense of said Parish. I given and bequeath to Sarah Poulter now residing with me one share or half part of all my household furniture, plate linen and china which I shall be possessed of at the time of my decease to be by her the said Sarah Poulter chosen and allowed for her own use and benefit. and the other moiety I give bequeath to my sister Esther Long for her own use and benefit.

And whereas there is now due to me from my brother Thomas Long the sum of seven hundred pounds as a security for which I have this bond or writing obligatory under his hand and seal bearing date the twenty eighth day of March one thousand eight hundred and four. Now I give and bequeath unto my said sister Esther Long all the interest to become due on the said seven hundred pounds for and during the term of her natural life together with all such interest as shall be due therein at the time of my decease. And after the decease of my said sister I give and bequeath the said sum of seven hundred pounds unto my said brother Thomas Long and desire that the said bond shall on such event be delivered up to him my said brother, his Executors or Administrators and be cancelled. I also give and bequeath to my said sister Esther Long the sum of one hundred pounds of lawful English currency to be paid to her within two months next after my decease for her own use and benefit. I give and bequeath unto my five oldest nephews and nieces (that is to say) Thomas Long the Younger, Maria Long, Eliza Long, John Long and Pierre Long all my leasehold messuage or tenement No. 56 in Upper Sloane Street Chelsea together with the Tenement at the back thereof in New Road both included in one lease together all other the premises and appurtenances included in the same lease. To hold the same unto my said five oldest nephews and nieces for the remainder of the term which shall be then to same therein as tenants in common and not as joint tenants the rents, issues and profits thereof or produce thereof by sale or otherwise to be equally divided between and amongst them share and share alike subject nevertheless to the payment of the ground rent reserved by the lease and to the Covenants therein contained. And in case of the decease of any or either of my said five oldest nephews and nieces without leaving issue or being unmarried before my decease then I give and bequeath his or her share of and in the said leasehold premises to be equally divided between the survivors of them my said five oldest nephews and nieces. I give and bequeath unto my said brother Thomas Long the Older all my leasehold, messuage or tenement numbered 18 in Beaufort Row Chelsea aforesaid in which I now reside to hold the same unto my brother Thomas Long the Older, his Executors, Administrators and Assigns for the remainder of the term which shall be then to come therein subject to the rent and Covenants

contained in the said lease upon trust nevertheless to permit and suffer the said Sarah Poulter to continue and reside in my said house for the term of six months next after my decease without paying any rent for the same and then on trust to receive the rents, issues and profits thereof or produce thereof by sale or otherwise as to my said brother shall seem most expedient and beneficial and to divide the same between and amongst my five youngest nephews and nieces (that is to say) Esther Long, Charles Long, George Long, Emily Long and Catherine Mary Long equally share and share alike on their respectively attaining the age of twenty one years and in case of the decease of any or either of my said youngest nephews and nieces during their minority without leaving issue or being unmarried I will and direct that the share of him or her so dying shall be equally divided between the survivors of them my said five youngest nephews and nieces in manner aforesaid. And I further direct, request my Executria and Executor hereafter named shall immediately after my decease collect in all such other monies as shall be due to me and transfer my stock in the consolidated three per cents and such part of my stock in the Bank long annuities as that the interest and dividends of the same shall amount to and produce the sum of fifty pounds per annum in the joint names of the said Sarah Poulter and John Long my Executria and Executors hereinafter named upon trust that the said Sarah Poulter shall receive the said annuity or clear yearly sum of fifty pounds to be paid to be retained or paid or payable to her the said Sarah Poulter from the time of my decease for and during the term of her natural life. And I direct that she shall receive and deduct the same out of the dividends of my said stock without the concurrence or authority of my other Executor or any other person whatsoever the same to be paid into her own proper hand at the Bank of England and not to be liable to the debts, control or engagements of any husband she may hereafter marry but that her receipt alone shall be a sufficient discharge for the said annuity of fifty pounds. And after her decease it is my will and bequest that the principal money and the interests or dividends then due on the said annuity shall sink into the residue of my said estate and be divided as hereinafter mentioned provided always. And is it my particular desire and request that my said Executria and Executors shall pay and deduct out of the residue of my estate all

such sum or sums of money that may be charged as the legacy duty on the several legacies I have hereinbefore and hereinafter bequeathed to the said Sarah Butler, Sarah Poulter, my said sister Esther Long and my nephew John Long. It being my request that the said legacies and annuities shall be paid to them in full clear of the present or any further duty on legacies or other charges or expenses whatsoever. Also I give and bequeath to my said Executria and Executors the further sum of twenty five pounds each for the trouble they may have in the execution of this my Will. And as to all rest, residue and remainder of my said estate, goods, chattels and effects whatsoever, wheresoever and of what nature or kind soever which I may die possessed of or be any wise entitled to at the time of my decease I give and bequeath the same to my said ten nephews and nieces to be equally divided between them and share and share alike as tenants in common and not as joint tenants on their severally attaining the age of or respective ages of twenty one years. And I will and direct that my Executria and Executor or the survivors of them their Executors or Administrators shall pay into the hands of my brother Thomas Long the Older all such share or shares of the residue of my said estate as may be coming to such of my ten nephews and nieces as may be under the age of twenty one years to be by him invested in the Bank in the name or names of such children till they shall attain the age or respective ages or twenty one years and then to transfer the same to him, her or them. And I do hereby nominate, constitute and appoint the said Sarah Poulter and my said nephew John Long, joint Executrix and Executor of this my last Will and Testament. And in case of the decease of the said John Long in the lifetime of the said Sarah Poulter then I nominate and appoint my nephew Thomas Long the Younger to succeed his brother in the execution of this my Will and to be joint executor with the said Sarah Poulter in the place of his said brother. And my will is and I declare that my said Executrix and Executor or either of their Executors or Administrators respective [3] by virtue of this my will their joining in any receipt or receipts for the sake of conformity notwithstanding nor for any loss or damage which may happen by

[3] shall not be charged or chargeable with or accountble for any sum or sums of money other than such as shall actually come to her his or their own hands respectively.

reason of the execution of this my Will without her his or their wilful neglect or default. And hereby invoking and annulling all former and other will and wills by me at any time heretofore made. I do publish and declare this to be my last Will and Testament whereof I the testator the said John Long leave to this my last Will and Testament contained in three sheets of paper and also to a duplicate thereof bearing even date herewith and executed at the same time at my hand and seal that is to say my hand to the two preceding sheets and to this third and last sheet my hand and seal this twenty second day of August in the year one thousand eight hundred and sixteen – *John Long*. Signed, sealed, published and declared in by the said John Long on and for his last Will and Testament in the presence of us who in his presence at his request and in the presence of each other have subscribed our names as witnesses thereto to the words "to me" in the twenty fifth line from the top of the first sheet having been previously interlined. *Richard Watson, Kings Road Chelsea, Thomas Watson Clerk to Nelson J Hutchinson same place.*

Proved at London 10th December 1822 before the worshipful John Lanberry, Doctor of Law and Surrogate by the oaths of Sarah Poulter, Spinster, and John Long the nephew, the Executors to whom administration was granted having been first sword duly to administer.