Do ‘dead men tell no tales’?

Geographic Origin of a Mid-19th to Early 20th Century Anglican Cemetery Population in Adelaide, South Australia Determined by Strontium and Oxygen Isotope Analyses of Tooth Enamel and Dentine

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Abstract

Tooth enamel and dentine samples from thirteen individuals who were buried in the unmarked section of St Mary’s Anglican Cemetery, St Marys, Adelaide, were analysed for oxygen and strontium isotopic composition, to help determine if they were from Adelaide or were immigrants. The life history of these individuals is not documented in the historic record and so the results from the isotope analysis provide novel information on mobility in colonial South Australia. The results suggest that 38% of individuals may have been born in Adelaide, 23% may be from the United Kingdom and 39% may be from other areas of the world. 92% have different dentine and enamel values, suggesting either mobility during amelogenesis (enamel formation) or post burial diagenesis. The diversity of origins shown by the isotope analysis, mirror the results of skeletal morphology and historical records, which suggest that individuals from a range of ethnicities were buried at St Mary's cemetery.

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Chapter 1: Introduction

Tooth enamel and dentine samples from the first or second molars of thirteen individuals who were buried in the unmarked section (no remaining gravestones or monuments) from circa 1847 to 1927 at St Mary's Anglican Cemetery, St Marys, Adelaide, were analysed for oxygen and strontium isotopic composition, to help determine if they were from Adelaide, or were immigrants. Oxygen and strontium isotopes are found in human biomaterials, including teeth, bones, hair and fingernails. Oxygen comes primarily from the atmospheric precipitation and groundwater consumed, and strontium from food, as it has travelled up through the food chain from the soil (Owen and Casey 2017:25).

The life history of the individuals analysed is not documented in the historic records and so the results from the isotope analysis provides novel information on mobility in colonial South Australia. Based on the known history of migration to Adelaide and Anson's PhD thesis, the hypothesis was that they were predominately of European ancestry, and either from Adelaide, Ireland or the United Kingdom. This was based on their skeletal morphologies, and on surnames in the church records (Anson 2004:199, 311). However, these records were incomplete. Migration of non-Indigenous people to Adelaide officially occurred from 1836 onwards, although there were likely some Europeans present before this, who came from other colonies. St Marys was settled early in the history of South Australia, with the second St Mary's Anglican Church being built in 1848, but the cemetery began to be used before the completion of the church in 1847 (City of Mitcham, St Mary's Walk brochure 2009).

Site Location

St Mary's Anglican Cemetery is in the suburb of St Marys in Adelaide, South Australia. The location of Adelaide is shown in inset on **Error! Reference source not found.**, which shows the location of St Marys. Originally, St Marys was a colonial country parish.

This image has been removed due to copyright restrictions. Available from Pate and Anson 2012 *Stable Isotopes and Dietary Composition in the Mid-Late 19th Century Anglican Population, Adelaide, South Australia.* Journal of the Anthropological Society of South Australia *35:1-17.*

Questions and aim

The primary question is: Were the people in unmarked burials in an Anglican Cemetery, immigrants or from Adelaide? The secondary question is: If the people were immigrants, from where did they likely originate?

The aim is:

- To identify likely origins of individuals and to test the hypothesis that they were from the United Kingdom.

Research significance

Although there are many international examples, there are very few Australian examples of historic cemetery isotopic studies, hence the importance of this thesis. As there is also a lack of historical documentation about these unmarked burials and the burial registers are incomplete, the identities of the individuals are unknown. Although this project cannot identify individuals, it could help to provide information about the group of people who were buried in the unmarked section, adding to previous research. According to Anson (2004), the people are believed to have been from the working class, therefore, they are less likely to be included in historical documents than the wealthy. Archaeology and biological anthropology are the only ways to learn about these people.

Thesis chapter contents

Chapter 1: The Introduction will introduce the study, location of the site, primary and secondary questions, aim, importance of the research and the thesis chapter contents.

Chapter 2: The Archaeology of Cemeteries and Isotope Studies chapter will address cemetery studies both nationally and internationally, provide an isotopic background and discuss factors which affect the isotopic composition of teeth. Cemetery isotopic studies and baseline studies will also be addressed.

Chapter 3: The Geology and Environment chapter will address strontium's relationship to geology, the geology of the Adelaide Plains, Adelaide Hills and more specifically, the St Marys area. In addition, oxygen isotopes of rainwater and strontium and oxygen isotopes for faunal remains in Adelaide will be discussed.

Chapter 4: The History, previous studies and individuals studied chapter will cover reasons for migration within Britain and to South Australia, information about South Australia, the history of St Marys, St Mary's Anglican Church and the current knowledge of the unmarked burials.

Chapter 5: The Methods will present a definition of mass spectrometry, provide reasons why the techniques were chosen, a basic overview and applications of Thermal Ionisation Mass Spectrometry (TIMS) and Gas Source Isotope Ratio Mass Spectrometry (IRMS), as well as potential limitations. Tooth background, reasons why teeth were chosen as the material for analysis and the detailed steps undertaken during this project will also be discussed.

Chapter 6: The Results will report the oxygen and strontium isotopic results using tables and graphs. This will involve comparing results to other studies and geology and what the isotopic data suggest about possible origins for the individuals studied.

Chapter 7: The Discussion will include an interpretation of the data, age, palaeopathology and the historical record versus geographic origin as determined by isotopic analyses, explain discrepancies between dentine and enamel results and potential limitations of this study.

Chapter 8: The Conclusion will summarise the results, discussion, reiterate the primary and secondary questions and aim, and suggest areas for further research.

Finally, Chapter 9: The Appendices will present the raw data and the teeth photographs.

Chapter 2: Archaeology of Cemeteries and Isotope Studies

Introduction

This chapter will examine traditional cemetery studies, as this shows how cemeteries are generally analysed. However, these methods generally exclude certain groups such as the poor, some children, early settlers and those whose graves have been reused or whose monuments have deteriorated. It is important to conduct isotopic analyses due to the limitations of traditional techniques for identifying geographical origins. For example, studying historical documents, analysis of skeletal morphology and artefacts only reveal ancestry or trade links, not necessarily geographical origins. A discussion of isotopic background will introduce some of the concepts, the isotopes studied and how they are incorporated into the bones and teeth. Factors which can affect the isotopic composition of teeth are also discussed.

The section on isotopic cemetery studies will indicate how this study will fit with the available literature. Isotopic baseline studies will be examined, as they are essential for interpreting the results from archaeological sites. It is important to be able to compare the isotopic values in the tooth samples with local values to determine whether an individual was local. However, a potential limitation of isotopic research is that imported food may have been ingested, adding to the isotopes in the teeth and thereby skewing results. Therefore, isotopic studies may not definitively reveal the origins of people.

Cemetery Studies

Traditionally, archaeology relies on grave goods and burial practices or the skeleton's morphology to identify a person's geographic origins. Pestle et al. (2014), for example, examined mortuary practices, skeletal similarities and differences between individuals, and grave goods to identify geographical origins. However, if there are no grave-goods, the cranial morphology only provides a general idea about an individual's ancestry — that is, whether their ancestors were European, African or Asian. Therefore, an individual's origins cannot be determined by these methods.

Most historical cemetery studies involve examining gravestones and monuments. There are many reasons for studying gravestones. They have dates and can provide information on kinship, sex, age, marital status, and sometimes ethnicity, religion and profession. Epitaphs and motifs such as angels, can provide information on social values and religious beliefs (Dethlefsen and Deetz 1966:502; Pate 2006:67).

However, this limits the study to those social classes who could afford a gravestone or monument. In addition, some early burials and those of children may be in unmarked graves, some of which may be outside of cemeteries (Pate 2006:66-67), while others have had the headstone removed, due to grave reuse or urban development (Pate 2006:63). Some researchers have tried to address this gap through studying unmarked graves (Lever 2009) or conducting isotopic analysis of human remains (Pate and Anson 2012; Owen and Casey 2017).

Dethlefsen and Deetz (1966) analysed gravestones in Massachusetts, dating from the seventeenth and eighteenth centuries. They found that there were three main motifs on gravestones and that their popularity changed through time (Dethlefsen and Deetz 1966:503). This was quantified through the creation of battleship curves. When a motif first appears, it occurs rarely, gradually reaches its maximum popularity and then declines in popularity (Dethlefsen and Deetz 1966:504). The changes in epitaphs and motifs can be linked to religious and social changes (Dethlefsen and Deetz 1966:506). This way of analysing cemeteries has been highly influential for archaeological studies, internationally.

Pate (2006) examined social status and wealth through gravestones and monuments. Cemetery choice, location of burial, family versus individual plots, size and cost of memorial, materials used, and inscriptions can all indicate social status (Pate 2006:58). Muller (2015) investigated the colonial period Catholic and general sections of West Terrace Cemetery, Adelaide, as a cultural landscape through a phenomenological approach. This involves using the senses to perceive how people in the past may have experienced a landscape. West Terrace Cemetery was originally a garden cemetery, based on the Kensal Green Cemetery in London (Muller 2015:16). Muller interpreted this type of cemetery as focusing on family reunion in Heaven, and European order being imposed, using roads, equal spacing between graves and distinct areas based on denomination (Muller 2015:17). Post 1854, larger, more elaborate grave monuments were placed in prominent positions, indicating high social status (Muller 2015:19-21). Similar to Dethlefsen and Deetz (1966), Muller noticed changes in epitaphs and motifs over time (Muller 2015:23-24).

Due to an absence of headstones, unmarked graves are less obvious and require excavations or geophysical surveys. Consequently, they are rarely included in cemetery studies. Therefore, segments of the population may not be represented including the poor, children and early settlers (Pate 2006). Through studying a previously forgotten cemetery in San Francisco, Buzon et al. (2004) were able to examine the health and living conditions of people without headstones (Buzon et al. 2004:2). Aspects studied, included the presence of disease, physical trauma and age at death.

Paupers are among those who tend to have unmarked burials. However, Hurren and King (2005) argue that the perception of pauper burials in the literature is oversimplified, as it only tends to focus on city paupers and does not directly engage with pauper’s views (Hurren and King 2005:323-

324). They found that the poor often wrote to the authorities or had someone write on their behalf, so it is possible to have an insight into their thoughts and actions (Hurren and King 2005:324). Late Victorian funerals were becoming more elaborate and there was great variations in pauper funerals (Hurren and King 2005:327). The hierarchy of pauper burials in England included cheap mass graves for vagrants and still-born children but most poor people had individual burials and headstones. Some had basic coffins and others had more expensive coffins (Hurren and King 2005:331). In Hulme, Lancashire, pre-1840, paupers' families were paid generous funeral payments to cover all aspects of the funeral including copper coffin fittings and entertainment for the mourners, and it was also common to pay the family, a pension, up to a year after the funeral. Families and communities often tried to pay for at least part of a publicly funded funeral (Hurren and King 2005:328-329). After cutting welfare payments in the 1870s, the authorities in Brixworth, Northamptonshire, tried to remove the provision of a pauper funeral in 1885, and if families could not afford to collect their relative, the dead could be sold to medical schools for dissection (Hurren and King 2005:333). Consequently, the poor campaigned for their right to a decent burial (Hurren and King 2005:339). Although this example is from England, it indicates that attitudes towards pauper funerals and the nature of the burials may have been more complex than our current perceptions of them.

Lever (2009) examined nineteenth century unmarked Jewish burials at Melbourne General Cemetery. In Victoria, similarly to England, 1854 legislation ensured that cemetery trustees provided free burials for paupers. Unfortunately, in Melbourne, people who had publicly funded pauper burials were not permitted a gravestone. Traditionally, the Jewish community would pay for the proper burial of the poor Jews, due to the belief that everyone should be treated the same in death (Lever 2009:466). It appears likely that Melbourne's wealthy Jews assimilated into Melbourne society much more easily than in England and placed greater emphasis on social status than traditional religious compassion towards the poor Jews (Lever 2009:472-473). Even charities had disdain for the poor, believing them to be "…intentional crafty parasites…" (Lever 2009:474). This indicates the common attitude towards the poor in Melbourne and probably other cities during the Victorian period. Lever (2009) found that pauper burials, which here involved multiple burials per grave, were most frequently for infants but there were also many adults buried (Lever 2009:469). Although this is a Melbourne Jewish example, understanding how the poor were viewed is important for understanding other unmarked burials, including those at St Mary's Anglican Cemetery.

Although cemetery layouts and monuments have been analysed in archaeology, this limits our knowledge to those who could afford a monument or those whose monuments have been preserved. It excludes those who never had a gravestone— the poor and some children, those whose graves have been reused or monuments which have deteriorated— such as those of some early settlers or areas used for redevelopment. These same individuals are likely to have been omitted from historical records, so if the unmarked graves are not studied, these people will remain unnoticed. Anson (2004) conducted research on unmarked grave records, but these will not generally reveal where an individual originated, and even if they do, it is difficult to link the records to a particular individual's skeleton. Skeletal morphology and grave goods may indicate ancestry or trade links but may not indicate individuals' geographical origins. Therefore, as traditional techniques cannot reveal their origins, it is important to conduct isotopic analyses, so that more is known about these people.

Isotopic background

Isotopes are versions of an element that have the same number of electrons and protons but a different number of neutrons. Strontium has two main isotopes which are relevant to this thesis: ^{86}Sr which is not radiogenic, and ^{87}Sr, which is formed by the radiogenic decay of one of the rubidium isotopes, ^{87}Rb (Faure and Powell 1972:1). The oxygen isotopes, ^{16}O and ^{18}O, are stable isotopes, which means that they do not decay (Michener 2007:1). Isotopic differences between materials are very small, so they are represented in delta parts per thousand, δ ‰ (Michener 2007:3). A positive δ value indicates that there is more of the heavier isotope, in this case, $_{18}$O, compared to the lighter isotope, ^{16}O. A negative δ value indicates more of the lighter isotope compared to the heavier isotope (Michener 2007:6).

Some isotopes vary with different locations and therefore can be used to help determine geographic origins. Commonly used isotopes for determining geographical origins are oxygen and strontium, although sulphur and lead isotopes have also been used in some studies. Similarly to strontium, lead and sulphur primarily come from the soil (Linderholm and Kjellström 2011:927; Price et al. 2017:5).

Strontium derives from underlying rocks which are weathered to form soils. Different rock types have different strontium isotopic values. The ratio of ^{87}Sr, which is formed by the radiogenic decay of rubidium, and ^{86}Sr which is not radiogenic, depend on the age of the rocks and the lithology or rock type (Bentley 2006:141). Therefore, it is possible to determine the rock type where an individual sourced their food and, hopefully, where they lived.

Strontium in human teeth derives from the soil and passes up the food chain (Owen and Casey 2017:26). Bio-purification occurs – this means that the amount of strontium present decreases by 20% through each step of the food chain, reducing the amount and possibly variation in strontium (Bentley 2006:154). Consequently, those individuals with a plant-based diet are likely to contain more strontium in their teeth than those with an animal-based diet (Pate 1994:166). The strontium ratios are preserved, allowing geographic origins to be determined. Strontium may enter or leave rocks due to weathering, fertilisers, the atmosphere and absorption by plants and animals (Bentley 2006:141). This means that not all the strontium in rocks will be bioavailable—that is, enter the food chain, and, therefore, geological values may not match the isotopic ratios in teeth and bones.

Strontium and oxygen are ingested through water and food, strontium originating in the soil and travelling up the food chain and oxygen primarily found in the atmosphere and water. Strontium has a similar chemical structure to calcium and therefore, it can substitute for calcium in bones and teeth (Owen and Casey 2017:26).

In addition to human remains, faunal remains should also be isotopically examined to assist in determining the locally bioavailable isotope ratios (Bentley 2006; Perry et al. 2017). Due to sea spray, seawater can affect the strontium values of terrestrial areas which are near the ocean (Bentley 2006:146). Seawater isotope values are the average of weathered soils from around the world and due to slow turnover of seawater will be the same for millennia. Regular consumption of marine foods may also give similar values (Waterman et al. 2014:122). However, Evans et al. (2010) believe that the consumption of marine animals would not have a significant effect on the strontium composition of skeletal tissues, but that plant strontium would dominate due to its larger quantities (Evans et al. 2010:2).

Oxygen isotopes

Oxygen isotopes are found in rocks, the atmosphere and water. However, the oxygen absorbed by animals and humans would be from water and the atmosphere. The variations that occur in nature are shown in **Error! Reference source not found.**, below.

This image has been removed due to copyright restrictions. Available from Hoefs (2015) *Stable isotope geochemistry (7th Edition):88*. Switzerland: Springer International Publishing.

Oxygen derives from the water ingested by an individual, and to a lesser extent, from the food consumed (Owen and Casey 2017:26). There is a quantitative relationship between latitude, altitude, distance from the sea, temperature and the isotopic composition of groundwater and rainwater (Budd et al. 2004:129). Therefore, it is possible to determine the geographical area from which the water, and the individuals who consumed it, originated.

Biological processes, such as respiration and cellular respiration, alter oxygen isotopes by changing the ratios of $_{18}O$ to $_{16}O$ (fractionation) but these processes are similar between mammals. Although oxygen isotopes vary, based on body mass, diet and metabolism, calibrations have been developed to cope with these variations (Budd et al. 2004:128). Budd et al. (2004:139) believe that oxygen isotopic analysis is more effective than strontium isotopic analysis, due to large areas having similar strontium isotopic values, in some cases. However, they suggest that the oxygen isotopic composition of rainwater may have changed, along with the climate, and therefore, different isotopic values to the present, may not necessarily indicate migration (Budd et al. 2004:128). For St. Mary's Anglican Cemetery, as the individuals studied have died within the last 200 years, climatic changes are considered to have been minimal but could have some small effect on data interpretation. However, there are other factors which can affect isotopic composition in teeth.

Factors which can affect the isotopic composition of teeth

Wright and Schwarz (1998) found that secondary dentition 2nd and 3rd molars were more depleted in ^{18}O than 1st molars and premolars and believe that this is due to a shift from consuming breast milk to drinking water (Wright and Schwarz 1998:1). Breast milk is formed from body water, which is more enriched in ^{18}O than drinking water, due to the ^{16}O component of drinking water being preferentially exhaled in water vapour (Wright and Schwarz 1998:3). Generally, it would be preferable to select 2nd or 3rd molars rather than 1st molars which are ^{18}O enriched due to breastfeeding, because the former are more likely to reflect the composition of the environmental water, and therefore, the area. However, there can be considerable differences in the ^{18}O composition of tooth enamel between individuals. Tooth enamel from teeth that developed later in childhood may still be more enriched in ^{18}O, where children were breastfed for longer periods (Wright and Schwarz 1998:15).

Greater consumption of fruit also alters the isotopic composition of body water. Plants, like humans, prefer ^{18}O and when humans consume the fruit, they increase the comparative levels of ^{18}O further. Beverage consumption including coffee and tea, can also affect oxygen isotopes, as boiling water also alters its isotopic composition, through preferential evaporation of ^{16}O (Wright and Schwarz 1998:14). Food preparation techniques can affect the oxygen isotopic composition of the food, and therefore, the teeth. For example, the techniques of stewing, boiling, fermentation and distillation can all have an effect (Pederzani and Britton 2019:94). Brettell et al. (2012) found that the oxygen isotopic composition of water used in ale can change significantly during the brewing process. The local spring water had a value of -7.5 ‰, which changed to -6.2‰ when the ale brewing process was complete. Fractionation occurred at every stage of the process: boiling, cooling, adding yeast and fermentation (Brettell et al. 2012: 779).

Consumption of cow's milk and alcohol can also affect the isotopic composition of teeth (Pederzani and Britton 2019:94). In addition, as wine is generally made from grapes, the grape vine prefers ^{18}O, so less ^{16}O is present in the grapes, and consequently in the wine (Lamb et al. 2014). Although it would be hoped that children did not consume alcohol, it is a possibility, particularly if water was considered unsafe to drink. For example, during the Medieval period, it was common for everyone, including children to consume alcohol, and for children, it was believed to help with their development (Brettell et al. 2012:781).

Isotopic applications in archaeology

Isotopic analyses can be applied to determine the origins of people, animals and artefacts, study diet or reconstruct past climates. A variety of isotopes may be used including lead, strontium, oxygen, sulphur, carbon and nitrogen. Carbon and nitrogen tend to be used to analyse past diets, while strontium and oxygen tend to be used to determine mobility. Sulphur can be used to reconstruct past diets and mobility and lead can be used to determine the provenance of artefacts.

Lead isotopes can be used to determine the provenance of metal, glass and lead pigments (Nord and Billström 2018). For example, Ling et al. (2013) analysed lead isotopes and trace elements in bronze objects found in Scandinavia, to determine whether the artefacts were imported, or if the ore was mined locally. Small amounts of lead were found in the copper and because these lead isotopes did not match local copper deposits, these could be traced to specific copper ore deposits. This led to the discovery that most of the artefacts were made from imported copper (Ling et al. 2013:301). Henderson et al. (2005) used oxygen, lead and strontium isotopes to trace the manufacturing locations of glass. They found that strontium was the most useful isotope for tracing glass.

Sulphur derives from the atmosphere and groundwater and is incorporated into the body's tissues. However, pollution can affect the bioavailable sulphur in the environment (Nehlich 2015:3). Applications are reviewed in Nehlich (2015) and include reconstructing past diets, ecology and animal and human mobility. Lösch et al. (2014) studied carbon, nitrogen and sulphur in bone collagen in gladiators and non-gladiators in Ephesus, Turkey.

Carbon reveals whether C_3 crops including wheat and barley or C_4 crops including millet and maize were consumed, and nitrogen increases further up the food chain, due to larger quantities of meat being consumed. Sulphur can indicate that seafoods were eaten or the proximity to the ocean, with sea spray increasing the sulphur in plants (Schoeninger and DeNiro 1984; Fry and Sherr 1989. Pate 1994). Lösch et al. (2014:14) found that most of the individuals had a similar diet of C_3 plants and low nitrogen values, possibly due to the consumption of pulses, such as legumes. However, two people appeared to have had different diets containing more C_4, and, therefore, may have been immigrants (Lösch et al. 2014:14).

There are also isotopic studies examining dental calculus to study diet. Scott and Poulson (2012) conducted carbon and nitrogen analyses on human remains, found under the Cathedral of Santa Maria, Vittoria, Spain. The individuals' dental calculus appears to correspond well with isotopes in European collagen. An advantage of studying dental calculus over dentine and enamel is that it does not destroy the actual teeth, allowing further analyses. However, they believe that there may be a need to use equations to convert between dental calculus and collagen, to make the results comparable, as there is with other biomaterials. The connection between dental calculus and diet is not well understood because it is unclear how much of the carbon and nitrogen isotopes originate from the human and how much from the bacteria forming the calculus (Scott and Poulson 2012:1391).

Oxygen isotopes can also be used to reconstruct palaeoclimates. Ice cores, mollusc shells and plant macro-remains are some materials which can be analysed. Ice cores provide climatic information over centuries to millennia and enable a higher resolution than do sediments. Thompson et al. (2000) reported on ice core studies in tropical South America. Leng and Lewis (2014) studied mollusc shells. As molluscs shells grow, they incorporate oxygen into their shells, providing information about the temperature and oxygen in the water at the time of formation. Molluscs provide daily to yearly climatic records (Leng and Lewis 2014:298). However, different mollusc species live in different environments, marine, freshwater, estuarine or terrestrial. Therefore, the different factors affecting the oxygen isotopes, for example, salinity and humidity differ (Leng and Lewis 2014:297). Stable carbon and oxygen isotopes in plant macro-remains can indicate the amount of water available for growing (Fiorentino et al. 2015).

Cemetery isotopic studies

Many isotopic studies of bones and teeth from people and animals' diet or mobility have been conducted in other regions, including Europe (Budd et al. 2004; ; Linderholm and Kjellstrōm 2011; Borić and Price 2013; Nowell et al 2013; Waterman et al. 2014; Price et al. 2017; Kaupová et al. 2018;), the Middle East (Perry et al. 2017) and the Americas (Wright and Schwarz 1998; Price et al. 2014b; Knudson et al. 2016; Delgado 2018). These techniques have also been used in Asia (Makarewicz et al. 2018), Africa (Tafuri et al. 2006) and the Pacific (Shaw et al. 2009).

One study was conducted by Perry et al. (2017), who studied a Roman and Byzantine site in Aila (Aqaba), Jordan, through strontium isotopic analysis of human and animal bone and dental enamel.

They raise an important limitation with isotopic analyses. Although the isotopic values may differ from local values, this may indicate that the food was imported and not that the people themselves were immigrants. Therefore, where possible, isotopes should be considered in conjunction with other archaeological and historical data (Perry et al. 2017:958).

Mbeki et al. (2017) studied a possible 18th and 19th century pauper, slave and hospital cemetery in South Africa, called the Victoria and Albert Marina Residence Burial Ground and compared this to the Coburn Street burials, which were 500 metres away and dated from the same period. There were differences in burial practice, with those at the Victoria and Albert Marina having unmarked graves, which were discovered during a development of the marina, and a lack of coffins. By contrast, those at Coburn Street were buried in coffins and had items buried with them. Mbeki et al. analysed carbon, nitrogen and strontium isotopes. The carbon isotopes suggest a predominately C_3 diet and nitrogen isotopes suggest that more seafood was consumed by those at the marina burial ground than at Coburn Street. Based on the strontium isotopes, there appeared to be more potential immigrants at the marina burial ground than at Coburn Street (Mbeki et al. 2017:486). It appears that a combination of social class and the individuals being recent immigrants and therefore, not being part of a local community who could pay for their burials, affected burial practices. This issue could be relevant to St Mary's Anglican Cemetery's unmarked burials.

Schroeder et al. (2009) studied oxygen, strontium, carbon and nitrogen isotopes in bones and teeth of individuals buried at the Newton Plantation, Barbados. Schroeder et al. (2009) aimed to distinguish between first and later generation slaves, and to study changes in diet, before and during slavery. They found that those who were not born in Barbados, likely originated from at least three different parts of Africa. This indicates that the slaves were shipped from various parts of Africa to the Caribbean and likely had a variety of different cultural backgrounds.

Although there are many international examples, there are very few Australian examples of historic cemetery isotopic studies, hence the importance of this thesis. Two examples of prior research are at St Mary's Anglican Cemetery (Taylor 2001; Anson 2004; Pate and Anson 2012) and Owen and Casey's (2017) study of the Old Sydney Burial Ground. A previous isotopic study of St Mary's Anglican Cemetery conducted by Taylor (2001), examined the diet of 54 individuals out of 70 excavated from the unmarked section. Diet was examined through carbon and nitrogen isotopic analyses of their bones, which were then compared to faunal remains from the area. The overall diet composition percentages for individuals from St Mary's unmarked graves are 39% marine, 15% meat, 41% C_3 (temperate) plants and 5% C_4 (tropical) plants (Taylor 2001:23). Twenty of these individuals were adults who ate 60% terrestrial meat, 32% seafood and 8% terrestrial vegetation.

Males consumed slightly more seafood, leading to higher nitrogen levels. In addition, infants had elevated nitrogen levels, due to consuming breast milk, as nitrogen levels increase further up the food chain and this is similar to a higher trophic level, as they are consuming this from the mother (Pate and Anson 2012:11-12). Interestingly, documents indicate that most of the 197 individuals, buried in this section, were from the working class, but two were gentlemen (Pate and Anson 2012:10). However, the identities of these individuals and their origins are unknown.

Owen and Casey (2017) is the first known Australian application of isotopic analysis to determine origins of individuals in a historical cemetery. They conducted strontium and oxygen isotopic analyses of dental enamel of ten individuals from the Old Sydney Burial Ground. This study highlights the importance of analysing more than one isotope, as the strontium values indicated that seven of the individuals studied could have been from Britain or Ireland or Sydney (Owen and Casey 2017:28). However, the oxygen values indicate that none were from Sydney and one was also not from Britain or Ireland (Owen and Casey 2017:29). When both sets of isotopic values were compared, they were able to determine possible regions, and, in two cases, possible towns of origin (Owen and Casey 2017:30). A similar approach will be undertaken for this thesis, which will be the first study in a South Australian historic cemetery, using strontium and oxygen isotopes to determine individuals' origins.

Baseline isotopic studies

Baseline isotopic studies are used to determine an area's local isotopic values and may use soil, water or faunal remains. These studies are important for archaeology because human remains can then be compared to the baseline values to determine if they are likely to be from the local area. Evans et al. (2010) conducted a baseline study to create a strontium isotope biosphere map for Britain. They used plant and water samples, which they compared to archaeological samples of known provenance, snail shells and diagenetically altered bone and dentine. They extrapolated the soil and water data collected, to areas with similar bedrock geology (Evans et al. 2010:1). They found that, although some rock types are isotopically uniform, others are not (Evans et al. 2010:2) and that snail shells do not reflect an average of biosphere isotope values from plants but are greatly affected by rainwater. However, they assumed that the diagenetically altered bone and dentine would be in equilibrium with ancient groundwater and compared these values to modern groundwater, to determine if there was any change over time (Evans et al. 2010:3). It is possible that diagenetically altered bone and dentine are affected by a mixture of ancient and modern groundwater and therefore cannot be used as reliable indicators of past groundwater composition. Despite its potential limitations, Evans et al (2010) provide a useful indicator of strontium isotopic composition of rocks in Britain.

Darling et al. (2003) created an oxygen isotopic map for Britain and Ireland, based on current groundwater composition, which is closely related to the average isotopic composition of rainfall (Darling et al. 2003:189 and Darling 2004:750). Owen and Casey (2017) combined this oxygen isotopic map with the strontium biosphere map by Evans et al. (2010), to create a map showing both isotopes across Britain and Ireland. This map will be used in this thesis (see **Error! Reference source not found.**), along with isotopic values, isotopic maps and geological atlases from other regions, as relevant.

Other relevant studies include Willmes et al. (2018), where strontium baseline maps were created for France, based on soil samples and plant remains, which were compared with local geology values. Willmes et al. (2014), resulted in the creation of the IRHUM (Isotopic Reconstruction of Human Migration) database which contains isotopic data from France, Israel, Corsica and New Caledonia. The data from France is most relevant for this thesis, as it is possible that individuals from St Mary's Anglican Cemetery came from France. Other isotopic values for countries and regions are shown in Table 1 and Table 2.

This image has been removed due to copyright restrictions. Available from Owen and Casey (2017) The Old Sydney Burial Ground: Using isotopic analysis to infer the origin of individual skeletons. *Australasian Historical Archaeology* 35:24-33.

This image has been removed due to copyright restrictions. Available from Lightfoot and O'Connell (2016) On the Use of Biomineral Oxygen Isotope Data to Identify Human Migrants in the Archaeological Record: Intra-Sample Variation, Statistical Methods and Geographical Considerations. *Plos One* 11(4).

Country or region	Source	Isotopic range	Article
Northern Scandinavia/ parts of the European Alps	Oxygen in rainfall	< -14	Lightfoot and O'Connell 2016:16
France/northern Spain	" "	-8 to -6	" "
China	" "	-0.02 to +0.49	Dayem et al. 2010
Austria	" "	-19 to +5	Kralik et al. 2017:926
Italy	" "	-11.38 to -4.91	Longinelli and Selmo 2003:78– 79
Sydney, Australia	Oxygen	No long-term oxygen data, Lucas Heights (Sydney) -4.5‰ ±0.21	Owen and Casey 2017:26.

Table 1 Oxygen Isotopic ranges by country or region

Country or region	Isotopic range	Article
France	0.7033 – 0.7213	Willmes et al. 2018:82
Netherlands	0.7074 – 0.7113	Kootker et al. 2016:8
Ireland	0.709 – 0.720	Price et al. 2014a:117
European Alps	<0.705 – 0.7100	Toncala et al. 2017:132 – 133
Denmark	0.7017 – 0.71185	Frei and Price 2012:107
Jordan	0.706178 – 0.728679	Perry et al. 2017: 947
China	0.70720 – 0.71600	Lv et al. 2018:334
Sydney, Australia	>0.707 to 0.7051	Owen and Casey 2017:26

Table 2 Strontium isotopic ranges per country/region

Conclusion

This chapter examined traditional cemetery studies, which focused on grave-goods and skeletal morphology, indicators of ancestry or trade links, or gravestones and monuments. However, such studies exclude the poor, some children and early settlers. This thesis helps to address this gap by studying individuals from the unmarked burial section of St Mary's Anglican Cemetery through isotopic analyses. Strontium and oxygen are absorbed through food and water into the teeth and other body tissues. Isotopic applications in archaeology include studying artefacts, human remains, ice cores and mollusc shells. Factors which can affect the isotopic composition of teeth include whether the teeth were formed before or after weaning and whether fruit or alcohol were consumed. Isotopic cemetery studies show the research that has been conducted internationally, while isotopic baseline studies are essential as they provide local bioavailable values for an area. Baseline data for different global regions was included for comparison with data collected from this study.

Chapter 3: Geology and environment

Introduction

This chapter addresses strontium's relationship with geology using data from France and the geology of the Adelaide Plains and Adelaide Hills to begin to understand the importance of geology to strontium isotopic analyses. This is to obtain an impression of local strontium values across various landscapes. Oxygen isotopic ratios in water for the Adelaide region and isotopes in faunal remains are also discussed.

The distribution and abundance of strontium across different geological zones will provide data regarding the strontium contained in rocks which may be available for plants and animals living in those areas. Expected values in limestone and dolomite are complicated by changes in past ocean strontium ratios and so the age of the rocks also needs to be considered. Not all components of rocks will be weathered to form soils, therefore, the strontium in soils may differ from that of the underlying rocks.

Different strontium baseline values in various regions of Adelaide are reflected in the teeth and bones of animals in those habitats. However, as not all the strontium in rocks will be bioavailable, in the absence of other isotopic data for human remains in Adelaide, the strontium from the human teeth in St. Mary's cemetery needs to be compared with that of faunal remains, rather than soil samples. The $^{87}Sr/^{86}Sr$ and $^{18}O/^{16}O$ ratios in faunal remains are included to indicate the bioavailable strontium and oxygen for the Adelaide Hills and Plains.

Strontium's relationship with geology

Strontium is found in the soil and soil is formed primarily from the underlying rocks. The ratio of $^{87}Sr/^{86}Sr$ varies, based on the underlying geology, see Table 3, below. The main factor that controls the strontium isotopic composition of the rocks is their age, as the rubidium decays to form ^{87}Sr. Consequently, older rocks will contain more ^{87}Sr.

Rock type	$^{87}Sr/^{86}Sr$
Dunite/peridotites: Peridotite: coarse grained, dark, ultramafic igneous rocks, low in silica, olivine primary mineral.	0.703 – 0.727

Dunite: Type of peridotite (King, H.M. n.d.)	
Oceanic basaltic rocks (mafic—magnesium/iron rich)	0.7012 – 0.7059 0.7037 (mean). Oceanic island basalts 0.702 – 0.706, seafloor basalts 0.702 – 0.707
Andesite/dacite: Andesite: Medium dark volcanic rock, contains iron and magnesium. Dacite: Light coloured volcanic rock, high in silica, also contains sodium and potassium (Oregon State University 2018).	0.703 – 0.707
Dolerites: Dark, medium grained igneous rock containing plagioclase, pyroxene (silicate minerals containing calcium, magnesium and iron) and olivine (Oxford Living Dictionaries 2018)	0.708 – 0.718
Granite	0.7000 – 0.7370
Carbonates	0.701- 0.718

Table 3 Strontium isotope composition of various rock types, after Rippon (2018) and Faure and Powell (1972):29,32,41,54,

The study of Willmes et. al (2018) in France, identified five isotope groups (**Error! Reference source not found.**). As similar rock types are likely to have similar values, this will provide a general idea of possible areas of geographic origin. However, it will also be necessary to analyse faunal remains to determine Adelaide's bioavailable strontium because analysis of the rocks will only show total strontium levels, not the bioavailable strontium.

This image has been removed due to copyright restrictions. Available from Willmes et al. 2018 Mapping of bioavailable $^{87}Sr/^{86}Sr$ isotope ratios in France for archaeology provenance studies, *Applied Geochemistry*, 90: 75-86.

A further complication is that strontium levels in the ocean have changed over time (**Error! Reference source not found.**). Therefore, the strontium ratios in rocks, such as limestone and dolomite, which are derived from marine organisms and sediments entering the ocean, will also vary based on their ages.

This image has been removed due to copyright restrictions. Available from Halverson et al. (2007) Evolution of the $^{87}Sr/^{86}Sr$ composition of Neoproterozoic seawater. *Palaeogeography, Palaeoclimatology, Palaeoecology* 256: 103–129.

Adelaide Geology

The oldest rocks in the Adelaide area are in the Adelaide Hills. These rocks are mainly metamorphosed sedimentary rocks. According to Preiss (1987), siltstone, sandstone, limestone, shale, slate, dolomite, granite, gneiss and quartzite are all found in the Adelaide Hills. This indicates that sedimentary and metamorphosed rocks dominate, except for the basement granite – an igneous rock. There was a marine environment, followed by orogenesis or mountain building which folded, faulted and metamorphosed rocks. This was the Delamerian Orogeny which occurred in the Neoproterozoic to Adelaidean, during the Proterozoic, which is within the Precambrian (**Error! Reference source not found.** and Figure 1 Geological map of Adelaide area). Australia separated from Antarctica 85– 30 Mya, which caused fault lines and the St Vincent Gulf to form. Rifting through fault lines 45 Mya caused Precambrian rock to subside more than 600 metres below the Adelaide Plains, and the Adelaide Hills to rise (Selby 1984:8; Australian Antarctic Division 2002). The geology under Adelaide's central business district is illustrated in **Error! Reference source not found.**.

This image has been removed due to copyright restrictions. Available from Gostin (2014) Peeling Back the Layers Under Adelaide. *Bibliophile* 13(4):3 – 8.

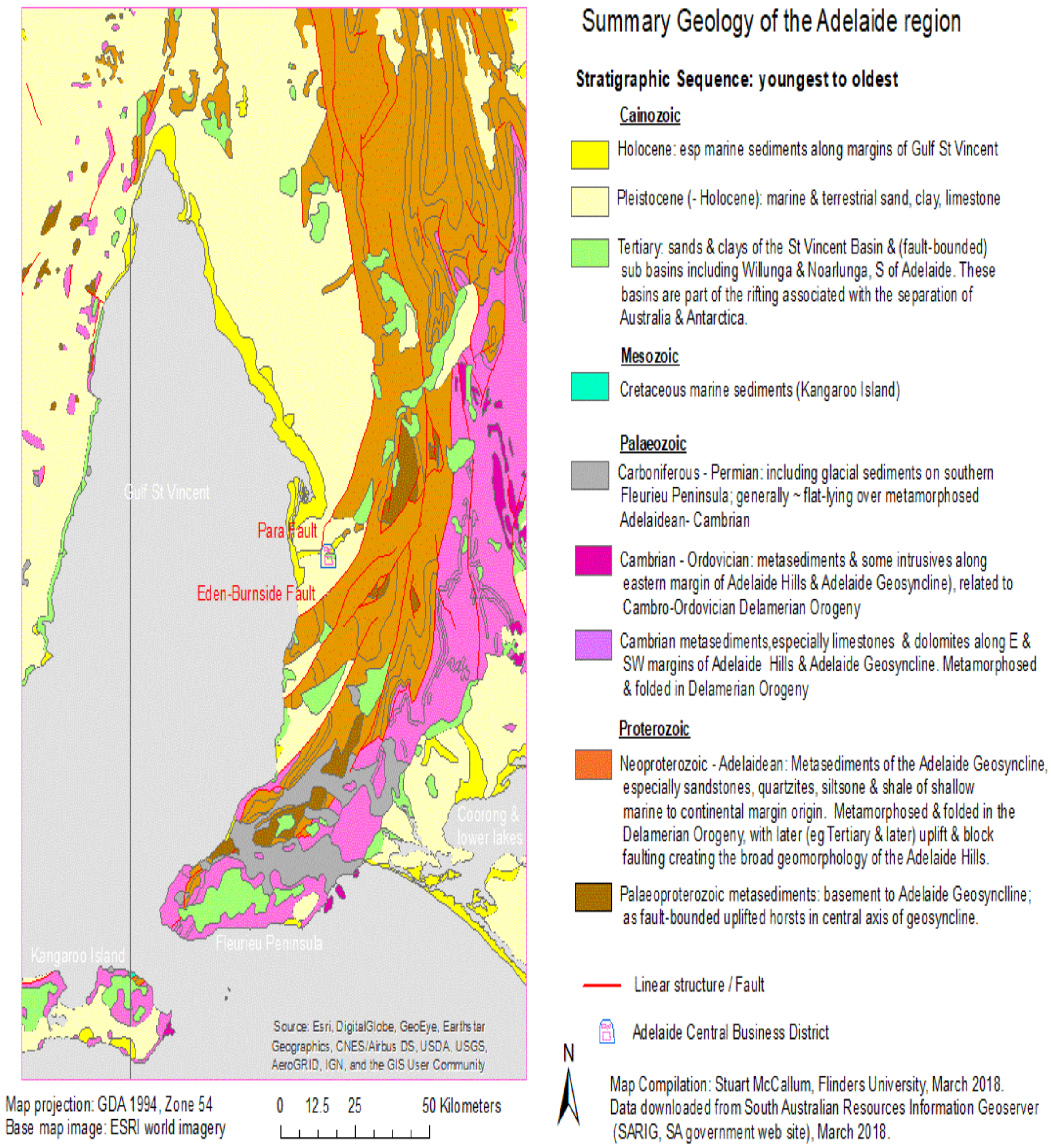

Figure 1 Geological map of Adelaide area, Stuart McCallum 2018, reproduced with permission

This image has been removed due to copyright restrictions. Available from Selby 1984 *Geology and the Adelaide Environment,* Department of Mines and Energy South Australia. Adelaide: Woolman Government Printer.

The oldest rocks exposed in the Mount Lofty Ranges, apart from those from the basement, are schist and gneiss (metamorphic rocks) from the Precambrian. The Burra Group dates to the Precambrian, specifically the Adelaidean.

The lithology consists of sandstones, dolomites, shales and quartzites (Daily et al. 1976:8). These rocks were laid down by shallow marine and lagoonal sediments which have formed clays (Parkin 1969:57; Drexel et al. 2012a:177). The Aldgate Sandstone, Glen Osmond Slates and Stonyfell Quartzite are in this group (Parkin 1969:60; Drexel et al. 2012a:181).

Parts of the older basement were uplifted, including the Barossa Complex, which consists of metamorphic rocks. Part of the Barossa Complex is the Myponga Inlier, where the lithology consists of gneiss and granites (Drexel et al. 2012a:104).

The Adelaidean sediments were overlain in late Precambrian and Cambrian times 1000 to 500 Mya by marine sediments to form the Mount Lofty Ranges and the bedrock beneath the Adelaide Plains (**Error! Reference source not found.**). Five hundred Mya, sedimentary rocks were folded, faulted and slightly metamorphosed, forming quartz veins, quartzite, dolomite and siltstone, also known as bluestone (Selby 1984:7). Most of the Precambrian and Cambrian rocks were weathered down tens of metres and were converted to clay.

The Kanmantoo group consists of rapidly deposited sediments, igneous, and sedimentary rocks, including limestone and siltstone, which were metamorphosed during orogenesis (Drexel et al. 2012b:16). Schists, gneisses, granites, dolomites, shale and marble are all found in this group (Parkin 1969:102 – 103). The St Kilda Formation refers to all Holocene coastal and shelf sediments (Drexel et al. 2012b:239).

Adelaide Hills soils vary from acidic to neutral and alkaline. Their parent materials tend to be quartz or feldspar rich. The soil colours vary from red and yellow to grey-brown.

For Adelaide Hills soils, see Table 4.

Unit	Landscape	Dominant soils	Soil description	Parent materials
Tc 1-3	Hills and valleys	Dy 3.41/ Dy 3.42, Dy 3.21, Dy 3.22, Dy 3.51?, Uc 6.11, Dr 2.22, Dy 3.43, Dy 5.43, Uc 2.2/Uc 2.3	Dy 3.41/ Dy 3.42: acidic and neutral sections, mottled yellow pedal (clusters of soil) clays,	Coarse grained, quartz-rich
			Dy 3.21: Acidic, yellow podzolic	“ “
			Dy 3.22: Grey-brown podzolic soils, neutral	“ “
			Dy 3.51?	
			Uc 6.11: acidic, lithosol (thin soil weathered rock fragments)	“ “

			Dr 2.22: non-calcic brown soils, red pedal clays, neutral	Finer grained feldspar-rich
			Dy 3.43: mottled yellow pedal clays, calcareous	Quartz-rich
			Dy 5.43: Sandy, mottled yellow clays, neutral, alkaline	Coarser grain quartz-rich
			Uc 2.2/Uc 2.3: Humus podzols (forested soils on sandy deposits), acidic	“ “
Ua 1/Ua 2	Hills and valleys	Dy 3.22, Uc 6.11, Dy 3.61, Dy 3.43, Dy 5.4	Dy 3.22: as above	
			Uc 6.11: as above	
			Dy 3.61: lateritic(iron/aluminium rich soil, tropical) podzolic/ yellow podzolic, mottled yellow clays, acidic	Deep weathering
			Dy 3.43: as above	
			Dy 5.4?	
Q1	Hill slopes	Dr 2.22	Dr 2.22: as above	
D1/D2	Steep hills	Uc 6.11, Dy 3.22, Dy 3.41, Dy 3.61	Uc 6.11: as above	
			Dy 3.22: as above	
			Dy 3.41: as above	
			Dy 3.61: as above	

Table 4 Soils of the Adelaide Hills (after Twidale et al. 63-65)

The rocks in the Adelaide Plains are sedimentary rocks, which are younger than those in the Adelaide Hills. The geological timeframes and associated events are shown in **Error! Reference source not found.**.

During the Tertiary period, there was a marine inundation, which formed fossiliferous sand, mud and lime rich deposits, which is an unnamed unit. The sea regressed 15 Mya but transgressed 5 Mya, depositing marine sand and clay, and freshwater aquifers were formed (Selby 1984:8). Several glaciations occurred. A more recent glaciation occurred 2.5 Mya, when sea levels fell, and rivers deposited sand, gravel and alluvial clay, which are undifferentiated sediments. Windblown silt was also deposited.

Limestone was deposited during the Tertiary and sandstone deposited during the Quaternary (Aitchinson et al. 1954:19–20). The limestone was deposited when the sea inundated the landscape. Weathering occurred, feldspars became clay, quartzites became gravel and sandstone became sand (Aitchinson et al. 1954:35). Near the Sturt River, there are slates, limestone, and tillites which contain materials transported by glaciers. The Adelaide Plains consists mainly of marine and alluvial clays and sand, undifferentiated sediments which date from the Pleistocene. Eleven thousand years ago, the Holocene began with rising sea levels, resulting from the melting of ice after the end of the last glacial maximum 18–21 Ka (Pickett et al. 2004:1382). Soft clay and shell beds were deposited between Glenelg and Port Gawler, creating the St Kilda formation. Most of this is now reclaimed land and the sea regressed several thousand years ago, causing reddish sand dunes to form, most of which have been covered or destroyed by urban development (Selby 1984:12). The Etina formation and Brighton Limestone are in the Umberatana group (Parkin 1969:63; Drexel et al. 2012a:173). The parent materials for Adelaide Plains soils vary from calcareous or calcium containing sands, siliceous or silica containing sands, clays and feldspars. The soils vary from alkaline to neutral and acidic. For Adelaide Plains soils, see Table 5.

Unit	Landscape	Dominant soils	Soil description	Parent materials
A2	Coastal dunes and plains	Uc 1.11, Uc 1.22 and various saline soils	Uc 1.11: Alkaline	Calcareous sands
			Uc 1.22: Neutral	Siliceous sands
01	Outwash plains	Dr 2.23, Dr 2.33 and Ug 5.1	Dr 2.23: Red brown earth, alkaline.	Fine grained feldspar
			Dr.2.33: “ “	“ “
			Ug 5.1: Black earths, black deep cracking clays, alkaline.	Clays
Lb3	Smooth undulating	Gc 1.12, Um 6.2	Gc 1.12: Solonised (high salt content caused by leaching), brown alkaline soils.	Calcareous
			Um 6.2: Terra Rossa soils, red, brown and black, pedal (contains soil clumps) shallow loams (sand, silt and clay), mix of	Calcareous

			acidic, neutral and alkaline sections.	
08	Slopes	Dr 2.23, Um 6.2, Um 6.4. Ug 5.1, Uf 6.11, Dy 5.4	Dr 2.23: see above	See above
			Um 6.2: see above	See above
			Um 6.4: same as 6.2?	See above
			Ug 5.1: see above	See above
			Uf 6.11: Rendzina (humus organic, rich, shallow soils), black pedal clays, alkaline	Calcareous
			Dy 5.4: coarse grained quartz-rich, sandy horizon with mottled yellow clays below, mix of neutral and alkaline	Siliceous sands
09	Undulating	As for 08 plus Dy 3.43 and Uc 2.2	Dy.3.43: coarse grained, quartz-rich, mottled yellow pedal clays, alkaline	Siliceous sands
			Uc 2.2: acidic soils	Siliceous sands

Table 5 Soils of the Adelaide Plains (after Twidale et al. 1976:63-65)

Geology in relation to St Mary's Anglican Cemetery

Table 6, below, shows the major geological units and their distance from St Mary's Anglican Cemetery. The cemetery has been chosen as a reference point for simplicity, as the suburb of St Marys is geologically complex with three rock groups within the suburb, namely the unconsolidated alluvial and fluvial sediments, the Umberatana group and Burra group. It is possible that people moved to the suburb of St Marys from another part of Adelaide, so other neighbouring rock groups are included.

Distance (km)	Group/subgroup	Lithology	Strontium isotope values	Comments
0	n/a	Undifferentiated alluvial and fluvial sediments	Pooraka formation 0.7131 ± 0.0025 to 0.7143 ± 0.0032 (Rippon 2018).	
0.90 south	Umberatana Group	Siltstone, dolomite, diamictite (sedimentary rock in sandstone or mudstone) orthoquartzite (made of quartz) glaciomarine, sandstone	Brighton limestone 0.7071– 0.7075, Younger Etina Formation (overlies Tapley Hill formation) 0.7076–0.7078 (McKirdy et al. 2001)	Rock samples
1.08 east	Burra Group	Siltstone, shale, sandstone, dolomite	Dolomites 0.709±0.00013 0.7116±0.00009 (Hill 1998) Stonyfell Quartzite 0.71222045-0.72022698 (Rippon 2018). Shale	Rock samples, likely metamorphosed
5.38 west	Saint Kilda formation	Undifferentiated coastal marine sediment	expected 7.090, actual values 0.71032073 (Rippon 2018:62).	Higher than may be assumed based on the sea curve, metamorphosed?
12.25 south-west	At Arckaringa and Troubridge basins Cape Jervis formation and Alpana formation	Undifferentiated glaciogenic rocks	Unknown	
14.27 north-east	Barossa complex, Myponga inlier	Gneiss, granite, pegmatite (granite), amphibole (metamorphic rich in amphibole mineral)	Unknown	
29.29 east	Kanmantoo Group, Keynes subgroup	Sandstone, siltstone, sand and marble	Kanmantoo Group 0.702642–0.720582 (Haines et al. 2009:1104)	Rock samples

Table 6 Major geological units of Adelaide, after ArcGIS data compiled by Stuart McCallum; Rippon 2018; Australian Government Geoscience Australia 2016; Hill 1998; Haines et al. 2009; McKirdy et al. 2001.

Strontium ratios of faunal remains

Rippon (2018) conducted a baseline study of Adelaide, using bones and teeth from rats and koalas. Samples from Mitcham relate to the Pooraka Formation, while the Adelaide CBD relates to the Keswick Clay, Port Adelaide to the St Kilda formation and Cleland is associated with the Burra Group (Rippon 2019). This data is essential for understanding the local values for the Adelaide Hills and Plains which can then be compared to the individuals from St Mary's Anglican Cemetery.

This image has been removed due to copyright restrictions. Available online from Rippon (2018) Where did they come from?' Baseline stable isotope mapping of the Adelaide Plains. Unpublished Master of Archaeology and Cultural Heritage Management thesis, Department of Archaeology, School of Humanities, Arts and Social Sciences, Flinders University, Adelaide.

Physiographic features of Adelaide

Adelaide has a Mediterranean climate, with summers often being hot and dry. There is a significant difference in elevation between the Adelaide Hills, with Cherryville, for example, at 493 metres, and the Plains, which are fairly flat, with Adelaide at just 43 metres above sea level.

	Mean maximum and minimum temperatures (Summer)	Mean maximum and minimum temperatures (Winter)	Rainfall (Summer)	Rainfall (Winter)
Kent Town (Adelaide Plains)	29.6°C (maximum), 17.3°C (minimum)	15.4°C (maximum) 7.6°C (minimum)	66.4mm	222.9mm
Mount Lofty (Adelaide Hills)	22.5°C(maximum) 13°C (minimum)	8.8°C (maximum) 5°C (minimum)	125.5mm	428.1mm

Figure 2 Temperatures and rainfall Adelaide Plains and Hills, Bureau of Meterology 2019

Oxygen isotopes in Adelaide

Liu et al. (2010) conducted a study measuring the oxygen isotopic composition of rainwater in relation to average temperature for Australia, including Adelaide, over a year (**Error! Reference source not found.**). The graph shows that there tends to be an inverse relationship between ^{18}O and temperature, oxygen isotopes ranging from -8 to -2 $_{VSMOW}$. That is, as temperature increases, ^{18}O decreases. It is expected that in teeth, the variations in oxygen isotopic composition over a year will cancel each other out, as tooth formation takes years. However, weather patterns may have differed slightly in Adelaide during the nineteenth and early twentieth centuries compared to the twenty-first century and this would affect the results.

This image has been removed due to copyright restrictions. Available online from Liu et al. 2010 Stable isotopic compositions in Australian precipitation. *Journal of Geophysical Research* 115:1–16.

Kayaalp (2001) and Liu (2010) give a combined range of 1.16 to -11.9 $\delta^{18}O_{VSMOW}$ for Adelaide rainwater.. Guan et al (2009) investigated the correlation between altitude and oxygen isotopes in water for the Adelaide region (**Error! Reference source not found.**). This table shows that areas at higher altitudes tend to have more ^{16}O isotopes relative to ^{18}O. However, there are exceptions, probably due to the distance from the ocean, as at Hallett Cove, for example, resulting in more ^{18}O than would otherwise be expected.

This image has been removed due to copyright restrictions. Available online from Guan et al. (2009) Orographic controls on rain water isotope distribution in the Mount Lofty Ranges of South Australia. *Journal of Hydrology* 374: 255 – 264.

Oxygen isotopes in faunal remains

Rippon (2018) also studied the oxygen isotopic composition of faunal remains using IRMS. She found that there were differences in oxygen isotopes between the Adelaide Hills and Plains. The Adelaide Hills generally had less ^{18}O and therefore more ^{16}O than the Plains. There were also differences between the bone and tooth samples, probably due to the bone being affected by diagenesis. The amount of rainfall varies significantly between the Adelaide Hills and Plains but there is some overlap between Port Adelaide and Adelaide. The rainfall ranges from 20 to 59mm for Port Adelaide, 20 to 70mm for Adelaide, 18 to 80mm for Mitcham and 30 to 130mm at Cleland. Regarding elevation, Mitcham is 92 metres above sea level and Cleland is 685 metres, while the Adelaide central business district is 29 metres and Port Adelaide, 10 metres above sea level. Mean annual temperatures range from 15 to 28°C in Adelaide and 8 to 23°C at Mount Lofty. For oxygen isotopes of faunal remains in Adelaide, see **Error! Reference source not found.**.

This image has been removed due to copyright restrictions. Available online from Rippon (2018) Where did they come from?' Baseline stable isotope mapping of the Adelaide Plains. Unpublished Master of Archaeology and Cultural Heritage Management thesis, Department of Archaeology, School of Humanities, Arts and Social Sciences, Flinders University, Adelaide.

Conclusion

In conclusion, Adelaide geology generally consists of sedimentary and metamorphic rocks. The key geological formations in Adelaide are the St Kilda Formation with bioavailable strontium values of 0.7131 ± 0.0025 to 0.7143 ± 0.0032, Keswick Clay with 0.71121293 $\pm$ 0.0024 to 0.71136933 $\pm$0.0068. The Pooraka Formation has bioavailable strontium values of 0.71318303 $\pm$ 0.0025 to 0.71430834 $\pm$ 0.0032 and the Burra Group with values of 0.71222045 $\pm$0.002 to 0.72022698 $\pm$0.002.

The oxygen isotopic composition of rainwater varies with temperature over the year, with an inverse relationship between O^{18} and temperature. In Adelaide, the annual rainfall isotopic range is from -8 to -2 $\delta^{18}O_{VSMOW}$, but it is expected that teeth will have an average of these values, as they take years to form. There is also a relationship between altitude and oxygen isotopic composition of water, with higher altitudes tending to have less O^{18}. Oxygen isotopic analyses have also been conducted on the faunal remains. The area around St Marys is geologically complex and it is expected that there would be considerable variation in strontium isotope values across Adelaide and surrounding areas. In addition, there is variation in oxygen isotopes between the Adelaide Plains and Hills from -4 $\delta^{18}O_{VSMOW}$ at Ashbourne to -5.98 $\delta^{18}O_{VSMOW}$ at Fox Creek, although Fox Creek was a one-time sample and therefore does not have a mean calculated. The bioavailable strontium isotopic values can be used with oxygen isotopes to help determine the geographical origins of individuals internationally versus different regions of South Australia.

Chapter 4: History, previous studies and individuals chosen for analysis

Introduction

The historical background of the migration of British and Irish working-class people within Britain and to South Australia is a focus of this chapter. Other historical background research includes the other nationalities who migrated to South Australia, St Marys and surrounding areas, and poverty in South Australia. The history of St Mary's Anglican Church and past research examining the unmarked burials in the cemetery are also discussed to provide context for this thesis.

Internal migration within Britain

Internal migration within Britain often preceded emigration. The birthplace of individuals may not have been the same as their port of departure or even their most recent place of residence before departure. This illustrates the importance of isotopic analyses, as records provide limited information on geographical origins.

There were many reasons for migration, and later, emigration. There was considerable poverty in Britain, due to the Napoleonic Wars and the Industrial Revolution, which led to wealth for industrialists but poverty for other people, particularly those in traditional trades or from the countryside. For example, in Glasgow and Paisley, there was a handloom employment crisis due to industrialisation as workers could not compete with mechanised looms (Richards 2004:139). Religious discrimination and surplus population led to unemployment, overcrowding and violence, which were all factors that encouraged people to emigrate (Whitelock 1977:20; Richards 2004:117). In addition, wages fell, farmers sold land to the wealthy and there was little education for the average person. Many could not even sign their name (Carter 1997:40 – 41).

The Great Famine of 1845 to 1849 occurred in Ireland due to the failure of potato crops, as the result of disease (Richards 2004:117). There were also the Scottish Highland Clearances of 1780 — 1855, where peasants were displaced, sometimes forcibly, from estates by their landlords which may also have contributed to the desire for emigration. Tenants were often offered inferior accommodation and land, as the landlords could earn more money through 'more efficient' farmers and sheep farming, than from cattle, and farmers' and labourers' rent (Richards 1985:3, 210).

This coincided with population increase, an employment shortage, high rent, propaganda enticing people to emigrate, and famines, as, similarly to the Irish— the Highlanders had become dependent on the potato (Richards 1985:216). Relief money was running out after several years of famine and relief and improvement schemes failed in the Highlands (Richards 1985:259). However, some landlords tried to assist their tenants financially (Richards 1985:258).

The British New Poor Law (1834), ensured that there was community responsibility for all paupers, rather than charity for a few. However, there was a legal responsibility for the family to support each other across three generations and only where this was impossible, were they eligible for public welfare. This welfare covered a larger area than the parish. The able-bodied unemployed were offered accommodation, food and work in the union. Only those who were sick, elderly or deserted and unable to protect themselves were classified as the 'deserving poor' (Dickey 1986:1).

Working class people and the unemployed could have been encouraged to emigrate from Britain to Australia under the New Poor Law, as Poor Law unions had the right to raise mortgages to help fund the emigration of dependent paupers, but parish subsidies were low. According to Poor Law correspondence (Haines 1991:34), many parish-subsidised emigrants were well informed and wanted to improve their lives via migration. People who were worried that they could lose their jobs wanted to emigrate, but various communities in Britain tried to reduce emigration to keep good workers in local economies (Gibbs 1990:29; Haines 1991:36;).

Emigration to Australia was unaffordable for many of the poorest people. Therefore, emigration did not always occur when people were at their poorest. For example, some people from the Scottish Highlands migrated to neighbouring areas, southern Scotland or England's industrial centres initially, rather than overseas. Others were seasonal migrants, living in the Highlands for part of the year (Richards 1985:205, 236). During the 1830s, it was cheaper to travel from Northern Ireland to Glasgow than from Skye to Glasgow, so there were also many Irish migrants to Scotland who were competing with the Scots for jobs and food (Richards 1985:237). Due to the Great Famine of 1845 – 1849, many Irish migrated to towns in England and Scotland (Richards 2004:117; see Figure 3). Migration to southern Scotland, Wales and England was very significant. In fact, from 1815 – 1845, migration into England exceeded emigration. However, a lack of records makes it impossible to determine the number of migrants. It is likely that the statistics underestimate the number of migrants within the United Kingdom and the number of emigrants, as some people left unofficially and were therefore not recorded (see Figure 3 and Table 7). Some individuals even built and sailed their own ships overseas (Richards 2004:123)! Another reason for emigration to Australia was because it had a better climate for individuals' health (Richards 2004:185).

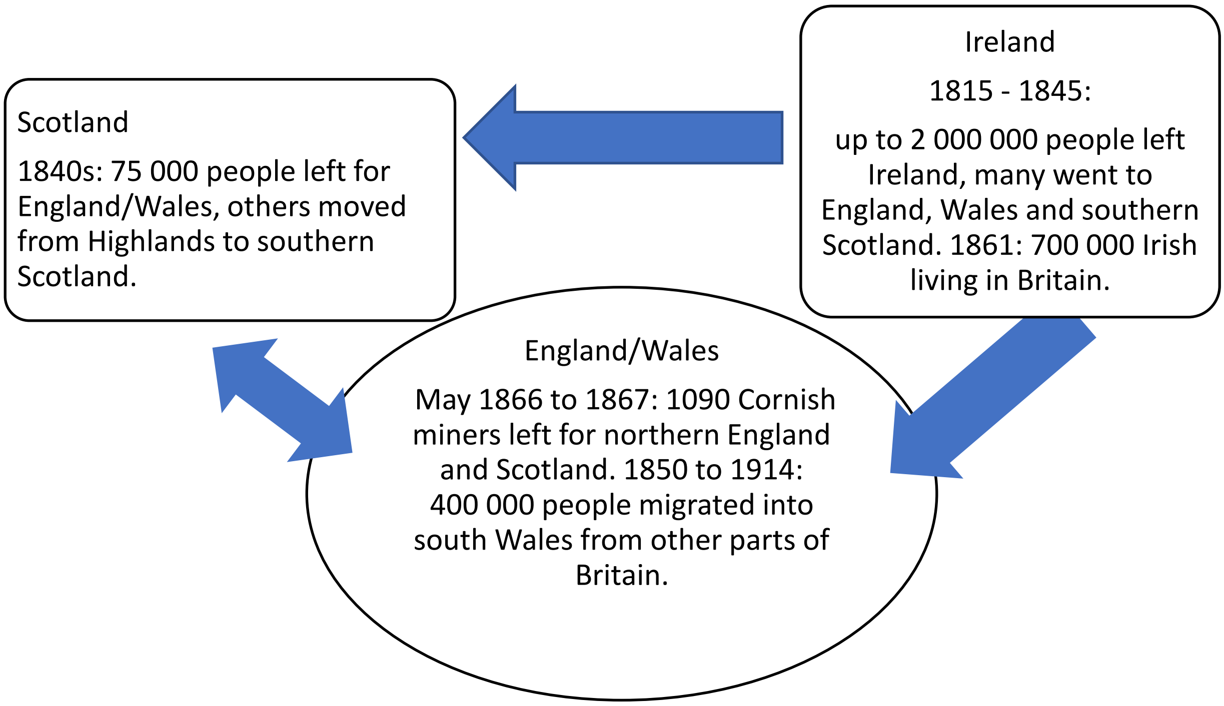

Figure 3 Migration within Britain in the early 19th century; after Richards (2004):118, 143, 163, 183.

Migration of British and Irish working-class people to South Australia

The National Colonisation Society was founded by Edward Gibbon Wakefield and Robert Gouger (Gibbs 1990:21). They planned for immigration to be controlled, as they wanted South Australia to have no convicts and for land to be sold at a fixed price. Immigration would solve the problem of hardworking, respectable English becoming unemployed and poor. Money from land sales was used to import labourers (Whitelock 1977:23; Gibbs 1990:22;). In 1834, the Foundation Act was proclaimed by the House of Commons to establish South Australia (Gibbs 1990:24). Europeans arrived in South Australia in 1836. The South Australian Company bought a large holding of land at a lower price, which they then sold (Gibbs 1990:26).

The establishment of South Australia as a British colony led to subsidised emigration for some, in the 1830s (Richards 1985:228). However, only 23 per cent of migrants to the British colonies received financial assistance from Britain or the colonies, which included the Australian colonies (Richards 2004:138). Unfortunately, some communities and families were separated, as not all could afford to migrate or qualified for subsidies. Some of the poor had their passage paid for by earlier migrants, especially relatives, which is called chain migration (Richards 1985:234).

The Highland and Island Emigration Society was formed in 1852, which encouraged family, rather than individual emigration (Richards 1985:260). During the late 1860s, the development of steam ships made emigration more accessible and feasible, as emigration costs were lowered. Railways, while providing employment, also made reaching the ports quicker and cheaper (Edwards 2004:153).

The Australian colonies funded unemployed agricultural labourers (Haines 1991:32-33), mechanics and domestic servants to emigrate (Haines 1991:43), particularly those from lower wage, rural areas (Haines 1991:39). Habitual paupers, for example, workhouse inmates, were generally ineligible for government assisted passage to Australia, which was relaxed for female labour during domestic employment crises. During the 1850s, the British government assisted women who were poor, unemployed, in workhouses or prisons, but after the 1850s, they did not need to be poor to receive financial assistance (Gothard 1991:98). From 1848 – 1849, there was the Irish orphans' scheme, 600 of whom were sent to Adelaide (Gothard 1991: 99-100). During the 1850s, British philanthropists helped women to emigrate as their wages were extremely low. In Britain, 50 000 women worked for less than a sixpence a day and 100 000 for less than a shilling (Gothard 1991:104). From 1852 – 1857, the Highland and Island Emigration Society provided free or assisted passage for families with many daughters (Gothard 1991:107). Unfortunately, once in Australia, it was found that many girls were not suited for domestic service and they were dismissed from employment (Gothard 1991:108). This would have resulted in poverty, once in Australia.

Generally, emigrants equipped themselves with necessary supplies or contributed towards emigration costs, so they were not the poorest people (Haines 1991:41). However, all of Oxfordshire's Poor Law Australian bound immigrants between 1837 and 1847 went to South

Australia. Unions borrowed money to assist those who were ineligible for government assistance, due to age, occupation or having too many children under the age of twelve (Haines 1991:43). Government assistance required immigrants to meet health, occupation, age and family size requirements and have a character reference. The gentry and Anglican clergy aided mobilisation of redundant labour (Haines 1991:45), as parish assistance to Australia virtually stopped between 1837 and 1870 (Haines 1991:55).

Before 1847, the majority of parish assisted emigrants from England, originated in Kent and Sussex. After 1848, the main counties with emigrants were Wiltshire, Cambridge and Suffolk, as wages had decreased significantly, or counties where wages had remained low, such as Cornwall, Devon, Dorset and Somerset (Haines 1997:115–116).

Cornish people were losing employment in agriculture and copper mining in England but had skills which were in demand in Australia (Richards 2004:132 – 133). Those in northern England had higher wages and were less likely to emigrate (Haines 1997:119–120). Table 7 may indicate possible regions of origin for people from St Marys but would be complicated by internal migrations, which occurred before emigration.

England	14 396
Ireland	10 553
Scotland	3 260
Wales	438

Table 7 1837 -1860 government assisted emigration from UK to South Australia; after Haines (1997):31

Other nationalities who emigrated to South Australia

South Australia was more multicultural before 1901 than may be commonly thought (Koivukangus and Martin 1986:97; South Australian Maritime Museum http://passengersinhistory.sa.gov.au/voyage-search). It is possible that a variety of people from different nationalities intermarried with the British, and therefore, the individuals interred in St Mary's Anglican Cemetery may be more multicultural than imagined by many. Besides the expected British, Irish and Germans, other nationalities emigrated to South Australia. For example, by 1881, there were over 1,000 Scandinavian settlers in South Australia. Many went to Port Adelaide. The majority were from Sweden or Denmark but there were also Norwegians (Koivukangus and Martin 1986:97).

The nationality of passengers departing Hamburg for Adelaide between 1877 to 1882 (shown in Table 13) shows the diversity of possible regions or origin.

Surname	*Possible nationality/region*	*Number of people*
Anderssen	*Scandinavian*	*4*
Duschka	*Eastern European*	*4*
Klemensky	*Russian*	*1*
Larssen	*Danish*	*4*
Szarkowski	*Polish*	*3*
Felicetti	*Italian*	*1*
Pacholsky	*Czech or Polish*	*1*
Christensen	*Scandinavian*	*29*
Jorginsen	*Scandinavian*	*1*
Lipschinski	*Polish*	*8*
Novak	*Slavic*	*6*
Wischmurski	*Polish*	*3*
Janeczek	*Polish*	*6*
Moreau	*French*	*4*
Redanski	*Polish*	*4*
Kanopka	*Eastern European*	*8*
Radistock	*Russian*	*3*
Sawoda	*Eastern European*	*5*
Taniszec	*Eastern European*	*1*

Table 8 1877–1882, International Migration to South Australia, after South Australian Maritime Museum Passengers in History; http://passengersinhistory.sa.gov.au/voyage-search

Poverty in South Australia

South Australia did not adopt the Poor Law as it was intended that the assisted migration for able-bodied farm workers would reduce the high poor rate in England and provide employment in South Australia. Therefore, there would be no paupers (Dickey 1986:2). After arrival in South Australia, immigrants were provided with one week's food ration. If they could not find employment by the end of the week, they were to be employed at reduced wages on government works and welfare was to be more selective in Australia than in England (Dickey 1986:3; Carter 1997:89). Migration did not guarantee employment or land ownership upon arrival. Many people became ill, which meant that they were unable to work upon arrival or died during the voyage, leaving children orphaned. Many of the jobs had already been taken, families were broken up on arrival and for the Scottish

Highlanders, an interpreter was required to find employment as they spoke Scottish Gaelic, not English (Richards 1985:266 – 267). An interpreter may also have been required for some of the Irish.

Soon after, thousands of pounds were spent to provide work and rations for the destitute people in South Australia, and a generation later, there was a poorhouse in Adelaide (Dickey 1986:4). Poverty increased with the financial crisis of 1841–1846 (Dickey 1986:8). The government introduced the *Maintenance Act 1843,* which required that parents support their children, poor children could become indentured servants, government support would only be granted if there were no relatives who could assist, and able-bodied workers would not be financially supported (Dickey 1986:12; Carter 1997:219). It is likely that the people in the unmarked section of St Mary's Anglican Cemetery were poor and it is possible that they may have spent time in the Destitute Asylum as many poor people were housed there. Piddock (2001) studied the building plans, documents and artefacts of the Destitute Asylum on Kintore Avenue, Adelaide. Similarly to St Mary's Anglican Cemetery, the artefacts found were generally simple and inexpensive. The artefacts found at the Destitute Asylum were ceramics, small personal items and those related to medical needs. The idea of the destitute asylum was based on the English workhouse but there were many elderly residents who were likely unable to work. Buildings were adapted for use as the Destitute Asylum and they lacked the space required for the large number of residents. Different types of residents were separated, for example, men from women, children from adults, and those who were giving birth for the first time from those who were having their second or third child.

Migration to St Marys and surrounding areas

This image has been removed due to copyright restrictions. Available from City of Mitcham, St Mary's Walk brochure 2009.

The suburb of St Marys was first settled by Europeans in the late 1830s. It became an agricultural area (**Error! Reference source not found.**). Initially, wheat and hay were grown. Later, other crops including almonds, grape vines and olives were grown (City of Mitcham 2009:1). The first settlers included the Daw and Ayliffe families (**Error! Reference source not found.**).

This image has been removed due to copyright restrictions. Available from City of Mitcham, St Mary's Walk brochure 2009.

There is limited information available on intrastate migration. 1841 is the earliest South Australian census and is the only one before Federation to have the census returns preserved, as the others were destroyed after the statistical reports were written. The 1841 census does not have the resolution required, because only the central business district is classified by streets. St Marys seems to fall in District B, as it includes the area near the Sturt River and the names Ayliffe and Daws occur. The only obvious non-British names are three which were from India— Pwynalda, Besasame and Abdullah (1841 South Australian Census). However, this was a large census district and therefore, they may not have lived in St Marys. Unfortunately, the census returns only list the names, sex and age of people, not generally where they originated.

The St Mary's Anglican church microfilm at the State Library of South Australia contained birth, deaths and marriage records. The baptisms, some of which were difficult to read, were mainly British, but Schmidt indicates German descent, and Paseo or Pasco possibly indicates French descent (State Library of South Australia, SRG 94/A94 reel no. 64, St Marys on the Sturt Baptisms 1846-1953, Marriages 1853-1953 and Burials 1847-1952). Most of the marriage records were burnt in a fire and were therefore illegible. Therefore, people of other nationalities may have married Anglicans, but their identities are unknown.

Anson (2004) studied the surnames of 129 individuals from the unmarked section burials by referring to burial records. Sixty-four had English names, thirty-three had English or Scottish names, twenty-four had Scottish names, four had German names, one Irish, one Welsh and two were of unknown nationality (Anson 2004:311). However, this only illustrates the ancestry of the men, not necessarily where they were born, and may obscure the nationalities of those who married British men. It was also difficult to find the relevant land returns, which would indicate ownership and rental of land, in the State Archives database.

Interstate Migration

It is also possible that people buried in St Mary's Anglican Cemetery migrated from interstate. Escaped and freed convicts did come to South Australia, despite attempts to keep them out and some may have even been in South Australia before 1836 (Sendziuk 2012:41). Some people in the late 1830s, including the explorers Charles Sturt and Edward John Eyre, drove their stock overland from New South Wales to settle in South Australia (Finkel 1975:45).

The people in the other colonies, apart from Indigenous people, were predominately British or Irish, but there were smaller numbers of other nationalities. In 1853 to 1854, 187 Eurasian workers emigrated to New South Wales, as there was a demand for workers. Eurasians spoke English and were Christian (Ohlsson 2013:154). Between 1837 and 1846, Indian 'coolies' were immigrants to New South Wales, and in 1847, 192 Pacific Islanders were recruited for employment. The Chinese indentured workers were labourers and shepherds, but many left their place of employment (Ohlsson 2013:153). Many of the first Scandinavians who emigrated to Australia settled firstly in New South Wales, some as free settlers, and others, having committed crimes in Britain, came out as convicts (Koivukangus and Martin 1986:25). Other Scandinavians emigrated to Queensland and Tasmania as assisted migrants, Victoria, especially once the Victorian gold rush began and Western Australia (Koivukangus and Martin 1986:33, 60, 79, 100).

Some Americans were sent to Tasmania as convicts because they had been trying to assist Canada to gain independence from Britain, and the French Canadians involved were sent to Sydney (Aitchison 1986:35). Other Americans arrived during the Victorian gold rush (Aitchison 1986:55). The Swiss emigrated to Victoria and New South Wales, especially during the gold rush (Wegmann 1989:53). In Sydney, in the 1820s, there were French, Spanish, Italian, Germans, Americans, Tahitians, Maoris, Pacific Islanders and Chinese people (Cigler 1983:5). Records state that Austrians settled in the Australian colonies but those recorded as Austrian could have originated from any part of the Austro-Hungarian Empire (Cigler 1983:6). The first known Czech immigrant to Australia was convicted for stealing in England and became a convict transported to Sydney (Cigler 1983:7).

St Mary's Anglican Church

There were two Anglican churches in South Australia before St Mary's, Holy Trinity on North Terrace, Adelaide and St Paul's Church, Port Adelaide (Edwards 1976:37). John Wickham Daw offered two acres of land upon which the church could be built, one for the first St. Mary's church in 1841, and another for its replacement in 1848 (**Error! Reference source not found.**). St Mary's Anglican Church was originally called St Mary's-on-the-Sturt (Edwards 1976:35). St Marys, the suburb, has no apostrophe but the cemetery and church are written as St Mary's.

Interestingly, it is noted that "Depression and unemployment faced all classes of colonists" at the time of the construction of the first church (Edwards 1976:36). This may have continued for some individuals, despite the discovery of copper from the 1840s to 1860s (Pioneers Association of South Australia 2018). The Ayliffe family provided free quarrying of stone from their property for construction of the second church (Edwards 1976:39), which was consecrated in 1849 (Edwards 1976:43). Prior to World War II, St Mary's was a country church.

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People who could afford a headstone were interred near the front of the church and it is possible that those who could not afford this were buried at the back of the church (Anson 2004:39). St Mary's Anglican Cemetery has 352 marked plots with a total of 398 grave markers, not including the memorial gardens, which have cremated remains. The earliest existing headstone dates to 1849 with the earliest burial in 1847. As the cemetery is still used for burials, they span 170 years (Walsh 2019).

Based on historic newspaper and newsletter reports, prior to 1900, there were probably 100-150 parishioners at St Mary's Church (Walsh 2019).

St Mary's Anglican Cemetery Unmarked Burials

This section is on the southern and south-eastern sides of the church and no gravestones were found. It is likely that there used to be wooden markers. The first burial for this section was in 1847 and the last was in 1927 (Matic 2003:2,37; Anson 2004:20; Pate and Anson 2012).

In August 1999, ground penetrating radar and soil resistivity tests were conducted, and in that September, a test excavation was conducted by Flinders University's Department of Archaeology. In 2000, two large excavations occurred in the rear of the churchyard and 71 individuals were recovered. An equally large area was left unexcavated and is likely to contain more burials. The skeletons were analysed for trauma, geographic origin based on skeletal morphology, pathologies, stature, sex and age at the University of Adelaide, and coffins and the artefacts found inside them, were studied at Flinders University (Matic 2003:4; Anson 2004).

Of the 70 skeletons excavated from the unmarked cemetery section, which were found at the rear of the church and studied by Anson (2004), 43% were from people aged less than one year old, 30% were aged between one and fifteen and 28.6% were older than 20. 70% of the adult skeletons were males (Anson 2004:141). Death certificates for members of the St Marys community indicated that 60% of those who had an occupation listed were farmers or labourers (Anson 2004:167). Other occupations listed were gardeners, bricklayers, brickmakers and builders, but, surprisingly, two were listed as gentlemen (Anson 2004:168). Up to 73% of those in the unmarked section of the cemetery, possibly died from infectious diseases (Anson 2004:171). Tooth loss and tooth decay appeared to be common (Anson 2004:205) and will therefore limit the sample size for this study. Almost all adults studied had enamel hypoplasia, due to nutritional deficiencies or infection in childhood (Anson 2004:211). Analysis of the skeletons indicated that almost all the individuals were of European ancestry, but one may be a mixture of European and African, and another individual was likely of Asian ancestry, with no evidence of Indigenous Australians being present (Anson 2004:199). However, this only provides a general idea of geographical origin.

The church burial register was consulted by Anson (2004) to try to identify individuals but is incomplete. Headstones, coffin plates and administrative records were not available (Anson 2004:92) and the descriptions of burial locations in the free ground (unmarked section) were vague. By 1847, more detail about individuals was available on death certificates (Anson 2004:94), but in 1953, a fire destroyed some of the church burial records (Anson 2004:95). Based on historical records, Anson (2004) believed that the individuals were most likely of British or Irish origins and based on his analyses, most of the skeletons appeared to be of European ancestry (Anson 2004:117 – 118).

Stable carbon and nitrogen isotopic analyses of bone collagen and cholesterol analysis were conducted by Taylor (2001) on 24 adults and 34 subadults to determine their diet (Anson 2004:290; Taylor 2001). The isotopic analyses revealed that they ate seafood, domesticated animals and plants, with their diet mainly consisting of meat. However, no-one has previously conducted isotopic studies to determine the origins of the inhabitants. The isotopes to be analysed in this research will be different to those analysed previously (and studies will be on teeth, instead of bone collagen). In 2018, an honours project investigated skeletal manifestations associated with Vitamin C and Vitamin D deficiency and iron deficiency anaemia in the skeletal sample from St Mary's Cemetery using macroscopic and micro-CT scan methods. However, the results have not yet been released (Angela Gurr 2018).

Regarding artefacts, the coffins came in two shapes, hexagonal and rectangular (Matic 2003: 58) and iron coffin handles were used rather than more expensive brass, most of which had deteriorated, so their designs were not visible (Matic 2003:65). The breast plates, which would have revealed biographical information, had deteriorated, as had the coffins' decorations and screws (Matic 2003:72, 83). Other artefacts found include shell, glass and copper buttons (Matic 2003:87), two types of shroud pin— dressmaker's pins and safety pins (Matic 2003:88), beads and a set of dentures, pocket watch and lead pencil (Matic 2003:90). All the materials used in the artefacts would have been low cost, suggesting either the low social status of the individuals or that they were of a higher social status, but comparatively little money was spent on the burial.

Individuals studied

Teeth from thirteen individuals were analysed and these individuals are listed by burial number as their identities are unknown. The suggestions for identity below are based on Anson (2004) thesis but as the records are incomplete, there could be other possibilities. These individuals were chosen to represent different age groups and sexes. Some had identities suggested and others had skeletal morphology which suggested non-European ancestry. It was also necessary to choose those with enough teeth to allow for future study and to cause minimal impact to the skeletons.

Adults

Burial 9 was thought to be that of a 38 to 40-year-old male with spina bifida occulta and a healed fracture of the 7th left rib. His teeth have linear hypoplasia, he has lost his upper right incisor and upper second and third molars antemortem, tooth-wear due to pipe smoking and calculus is present (Anson 2004:409).

Burial 23 was that of a male aged from 43 to 58. He had suffered trauma to his right eye which had healed and had a pleural infection. His teeth have abscesses and carious lesions (Anson 2004:419).

Burial 53c was of a female aged between 28 and 32, who had given birth and had a syphilis infection. There was also a healed fracture at the styloid process (just below her ear), with prominent muscle attachments and teeth which have a pipe smoker's notch. The individual may be Margaret Anderson, buried in 1858 (Anson 2004:240). There were a few Margaret Andersons who arrived around the same time. If she is Margaret Anderson, she likely embarked from Southampton, London, Liverpool or Plymouth, but it is possible that she came from interstate (South Australian Maritime Museum).

Burial 57 was of a 45 to 50-year-old male. His teeth show evidence of pipe smoking, calculus and linear hypoplasia. He also had spondylosis (osteo-arthritis of the back), asymmetrical nasal aperture and light sandy hair which was preserved (Anson 2004:444).

Burial 59 was of a male in his late 40s to 50s, with poor dentition, periodontal disease and a pipe smoker's notch. He may be Henry Thomas Russell who arrived in 1839 from London. Surprisingly, he was a reasonably wealthy man, but his relatives did not pay for a marked burial plot (Anson 2004:231).

Burial 66b was that of a female aged approximately 30 who had previously given birth. She had enamel hypoplasia, caries, wear and calculus on her teeth. It appears that she was often in a sitting position and Anson (2004) believes that she may have been a milkmaid (Anson 2004:454).

Burial 68 was that of a male aged 40 to 55, with rigid spine inflammation, upper limbs which were much more robust than the lower limbs and legs which were likely locked in a sitting position, therefore, he may have been wheelchair bound. It is likely that he was of non-European ancestry. Due to a protruding jaw and non-European shaped nasal sill, he was possibly of African ancestry. He had most teeth present, tooth hypoplasia due to nutritional deficiency or illness and a possible pipe smoker's notch (Anson 2004:456). Similarly to many of the other burials, he showed signs of arthritis.

Burial 72 was that of a male aged 45 to 55. His hands, wrists and arms showed evidence of large muscle attachments, indicating a hard-working physical lifestyle. His low, wide skull and broad palate indicate that he may be of non-European ancestry, possibly African. All teeth were present, his teeth had a pipe smoker's notch, small caries and calculus but he appeared to have been well nourished (Anson 2004:460).

Burial 83 was of a 45 to 50- year-old male with spina bifida occulta, signs of arthritis and heavily fractured skull. The individual could be John Pell who fell off a bullock dray and was run over (Anson 2004:221). His teeth had calculus and caries. If John Pell, he probably arrived from London in 1847 (South Australian Maritime Museum).

Adolescents

Burial 28 was of a 12 to 13-year-old male with dental hypoplasia and caries (Anson 2004:28).

Burial 79 was of a female aged 16 to 18 with spina bifida occulta. She was likely of non-European ancestry as her nasal bridge was rounded and raised. Her large teeth included shovel shaped incisors indicating an Asian ancestry. She had most teeth present. According to Anson (2004), she could have been one of three people, Eliza Francis Stewart, Rosetta Moody or Eliza Denman (Anson 2004:466). Eliza Frances Stewart probably embarked from London or Liverpool, Rosetta Moody from London and Eliza Denman from Plymouth (South Australian Maritime Museum).

Children

Burial 52b was that of a ten-year old male with no dental caries and possible hypoplasia (Anson 2004:437).

Burial 75 was thought to be that of a five to six-year-old male with possible hydrocephalus, enlarged head, and he may have had some trauma to his chin (Anson 2004:462). For a summary of information about these individuals see Table 9.

Burial number	Age	Sex	Pathologies	Other information
9	38 –40	male	Spina bifida occulta, healed fracture of the 7th left rib, teeth linear hypoplasia, lost his upper right incisor and upper second and third molars antemortem, tooth-wear due to pipe smoking and plaque is present.	
23	43 – 58	male	Trauma right eye, pleural infection, teeth abscesses and carious lesions.	
28	12 –13	male	Dental hypoplasia and caries	
52b	10	male	Possible dental hypoplasia	
53c	28 –32	female	Had given birth and had a syphilis infection with a healed fracture at the styloid process (just below her ear), with prominent muscle attachments and teeth which have a pipe smoker's notch.	Possibly Margaret Anderson?
57	45 –50	male	pipe smokers notch, calculus and linear hypoplasia. He also had spondylosis (osteo-arthritis of the back), asymmetrical nasal aperture and light	

			sandy hair which was preserved (Anson 2004:444).	
59	Late 40s to early 50s	male	Poor dentition, periodontal disease and a pipe smoker's notch.	He may be Henry Thomas Russell.
66b	~30	female	Previously given birth, enamel hypoplasia, caries, wear and calculus on her teeth. It appears that she was often in a sitting position.	
68	40 –55	male	Rigid spine inflammation, his upper limbs were much more robust than the lower limbs and legs which were likely locked in a sitting position. He had most teeth present, tooth hypoplasia and a possible pipe smoker's notch (Anson 2004:456), showed signs of arthritis.	It is likely that he was of non-European ancestry due to a protruding jaw and non-European shaped nasal sill, he was possibly of African ancestry.
72	45 – 55	male	Large muscle attachments indicated a hard-working physical lifestyle. All teeth were present, his teeth had a pipe smoker's notch, small caries and calculus.	His low, wide skull and broad palate indicated that he may be of non-European ancestry, possibly African.
75	5– 6	male	Possible hydrocephalus and trauma to the chin.	
79	16 –18	female	Spina bifida occulta.	Likely of non-European ancestry nasal bridge was rounded and raised, her large teeth include shovel shaped incisors (Asian ancestry). Eliza Francis Stewart, Rosetta Moody or Eliza Denman?
83	45 – 50	male	Spina bifida occulta, signs of arthritis and heavily fractured skull.	John Pell?

Table 9 Individuals' summary

Conclusion

As historical documents provide limited information regarding the geographic origins of individuals who lived in the St Marys community, isotopic applications should provide valuable information regarding the birth places of European migrants. It is possible that not all the people interred in St Mary's Anglican Cemetery were from Britain or Ireland, as people from other nationalities arrived in

South Australia and their surnames, especially those of women, may have been obscured in historical documents.

Due to social upheaval, there was also migration within Britain during the nineteenth century. Even if their identities were known, their port of departure and their most recent home before emigrating may not indicate where they spent their childhood.

Previous skeletal analyses involving the St Mary's cemetery population indicate potential causes of death, demography, dental health, nutritional deficiencies and diet for those individuals studied from the unmarked section, but there has been little work addressing geographic origins of these nineteenth and early twentieth century migrants.

Chapter 5: Methods

Introduction

This chapter reviews the analytical techniques used for this research, Thermal Ionisation Mass Spectrometry (TIMS) and Gas source Isotope Ratio Mass Spectrometry (IRMS) and briefly explains why these methods were used for the data collection, rather than other methods, such as ICPMS (Inductively Coupled Plasma Mass Spectrometry), Laser Ablation MC-ICPMS and solution MC-ICPMS (Multi-collector Inductively Coupled Plasma Spectrometry). In addition, detailed procedures conducted during this project will be discussed. The section about material for analysis explains why teeth were chosen rather than bones, while the section on tooth development explains the ages at which teeth form.

Mass Spectrometry

The mass spectrometer separates elements or isotopes depending on the difference in their mass and quantifies their relative abundance (Sparkman et al 2011:3). Mass spectrometers contain an ion source, mass analyser and detector operated under vacuum conditions, therefore, no air is present (Gross 2004:3 – 4). The ions are separated, based on their mass to charge ratio (Sparkman et al, 2011:89) and the resulting data is called mass spectra (Sparkman et al. 2011:90). A mass spectrum is a two-dimensional representation of signal intensity versus mass to charge ratio. The peak intensity indicates the abundance of an ion (Gross 2004:4). A mass chromatogram plots the mass spectral data plot by ion over time (Sparkman et al. 2011:92). Small amounts of the analyte, that is the sample to be analysed, are consumed by the mass spectrometer but this is minimally destructive (Gross 2004:3 – 4).

Analytical Approaches to Trace Element and Isotope Measurements

A comparison of the techniques used, TIMS and IRMS, and other techniques, ICP-MS and LA-MC-ICPMS, are presented in Table 10.

TIMS	LA-MC-ICPMS	ICP-MS	IRMS
Analyses solid samples but it is necessary to dissolve them	Analyses solid samples *in situ*	Can analyse a range of sample types	Converts the sample to a gas
More time consuming	Faster and easier	More time consuming	Faster and easier
Precise. Purified sample is less likely to be affected by interferences from ions of similar mass (Copeland et al. 2010: 1441; Willmes et al 2016:103).	Less destructive 250x750µm sample size needed, compared to 5 to 20mg (Copeland et al. 2008:3194) for TIMS, but vulnerable to interferences from ions of similar mass.	High sensitivity, low background signals. Can detect small amounts of an element.	Precise/accurate, can measure low concentrations but vulnerable to contamination.
Provides only an average per tooth	Shows variation in isotope measurements within a tooth	Provides only an average per tooth	Provides only an average per tooth
Can be used for heavy isotopes, (Willmes et al. 2016:112)	Can be used for heavy isotopes	Can be used for elements only (McCurdy et al. 2001:45)	Can be used for light isotopes

Table 10 Comparison of isotopic techniques

Equipment

Teeth from thirteen individuals buried at St Mary's Anglican Cemetery were studied. For TIMS, an Isotopix Phoenix was used for the strontium isotopic analysis and a EuroVector NuCarb prep system inline with a Nu Instruments Continuous Flow Isotope Ratio Mass Spectrometer (CF-IRMS) was used for the oxygen isotopic analysis. The facilities were at the Department for Earth Science, University of Adelaide.

Material for analysis

A variety of biomaterials including hair, dental calculus (hardened plaque), fingernails, bones and teeth, contain isotopes consumed through food and water.

However, unless a body has been preserved by extremely cold temperatures or dry conditions, hair and fingernails are less likely to be preserved in archaeological sites than bone or teeth. Hair has a rapid growth rate of 0.25cm per week, compared to 0.05cm per week for fingernails and there is a much quicker turnover period for nails and hair than bones or teeth (Pate 2008:178). Therefore, even when nails or hair are present, a smaller period is represented, so they do not indicate childhood origins.

Bone or dental material are suitable for the isotopic analysis of archaeological provenance. The chemical composition of bone is remodelled during an individual's lifetime. Bone is altered over three to twenty years, in relation to dietary intake, depending on the bone type (Taylor 2001:4). By contrast, tooth enamel retains the chemical composition established during childhood, and is, therefore, a better indicator of origins than bone.

Tooth enamel and dentine are particularly sensitive indicators of origin, because they contain isotopes derived from food that people ate while their teeth were forming, and do not change after tooth mineralisation (Hand and Frank 2014:48). Tooth enamel is also less porous than tooth dentine, bone and dental calculus, so there is less diagenetic contamination — that is chemical contamination after burial (Perry et al. 2017:949).

Tooth development

Tooth development occurs at roughly the same time within a species. However, there are small variations between people from Africa, Asia and Europe in the age that enamel mineralises (Reid and Dean 2006:344).

For human primary dentition, the teeth begin their development in the human embryo. At birth, calcification of the teeth is underway, with crown or corona development being completed around the age of one. Tooth eruption occurs during the first few years and root formation is completed by the age of three (Hand and Frank 2014:47).

For secondary tooth development, the first molar's crown development occurs by the age of three, eruption occurs around six years, and root development is completed by ten years. The second molar's crown development occurs by seven to eight years, but the root will not have developed until the age of sixteen, and in the 3rd molar (wisdom teeth) (if present), the crown develops between twelve and sixteen years. Third molars generally erupt during a person's late teens or early twenties (Hand and Frank 2014:47; Nelson 2015:31).

Tooth photography and preparation

Before analysis, the teeth were photographed. Photographs were taken of the bag numbers, two sides of the teeth and the crown and the roots.

As the crown morphology needed to be studied subsequently, the teeth were sectioned horizontally below the crown rather than vertically. Chips of enamel and dentine were removed and divided into smaller samples for the oxygen and strontium analyses.

TIMS

TIMS is a commonly used method for analysing solid samples and can be used for detecting a variety of elements, including heavier elements (Pollard and Heron 1996:62). Isotopes of elements that can be studied using TIMS include osmium, strontium, lead, neodymium, uranium and selenium (Woodhead 2005).

In geology, TIMS has been used for dating minerals based on their relative percentages of isotopes, analysing weathering patterns, lead isotopes in ice cores to determine anthropogenic and natural inputs, for example, from volcanic eruptions, composition of ancient seawater and to reconstruct past ocean circulation patterns (Woodhead 2005:27 – 28).

Frei et al. (2011) used TIMS to analyse chromium isotopes in carbonates to reveal past ocean and atmosphere chemical composition. TIMS, when used to date cave formations, called speleothems, can provide dates for an archaeological or palaeontological site. For example, Roberts et al. (2009) dated cave deposits and river terraces to estimate the age of Homo floresiensis, using, amongst other techniques, TIMS for uranium-thorium dating (Roberts et al. 2009: 487).

In archaeology, TIMS can be applied to determining the provenance of people, animals or artefacts, such as pottery or metalwork, to analyse past trading patterns and individuals' movements (Li et al. 2006). Li et al. (2006) studied the source of the clay which was used for pottery. Renzi et al. (2009) studied metals from the Phoenician site of La Fonteta, near Alicante, Spain, using TIMS for lead isotopic analysis to trace the metals to the different regions of Spain where they were mined. Artworks made of alabaster can be traced to their quarries using TIMS and IRMS. For example, Kloppmann et al. (2013) used sulphur, oxygen and strontium isotopic analyses to determine past alabaster trade routes and whether artefacts were fakes.

TIMS, contains detectors called Faraday cups, which can be arranged in different positions to 'catch' ions from different isotopes (Rehkämper 2001:24). The analyser must be a vacuum to increase sensitivity and minimise interference, making the peaks on the screen easier to interpret. In addition, column chemistry is used to separate the strontium from the rest of the solution. Hydrogen fluoride (HF) or hydrochloric acid (HCl) can be used to dry and dissolve the sample solution, changing its chemical form (Makishima 2016:58). Strontium and rubidium can occur together, so must be separated, so that only the strontium is being analysed. Strontium and rubidium are absorbed on a resin, the strontium then recovered with HCl and dried (Makishima 2016:229). For TIMS, the dried strontium is dissolved, then 1µL of strontium is loaded on the filament, heated in the mass spectrometer, evaporated and ionised (Makishima 2016:60, 233). The strontium ions are separated, based on their masses, by deflection devices (Pollard and Heron 1996:62).

TIMS sample preparation

The Teflon ware was cleaned with hydrochloric acid and distilled water before analysis to prevent contamination from samples from previous studies. The teeth were placed in hydrochloric acid, and the acid evaporated on the hot plate. Strontium resin was pipetted into columns, rinsed three times with 8 molar nitric acid, rinsed three times with deionised water, rinsed a further three times with nitric acid, rinsed another three times with deionised water and again, three times with nitric acid. One millilitre of nitric acid was added to samples, placed on a hot plate and washed five times with 8 molar nitric acid. The strontium was collected by washing six times with 0.05 molar nitric acid, one drop of 1 molar phosphoric acid then added to each vial and dried on a hot plate at 140° C with one drop of nitric acid.

The used filaments were removed, covered with 30 % or 10 Molar hydrogen peroxide and heated at 80 °C for one hour, rinsed in acetone and placed in the oven to dry overnight. The filaments were then spot-welded and placed in a degassing chamber overnight.

1uL of 1 molar phosphoric acid was loaded using a pipette and evaporated using an electrical current of 0.5 amps, then 0.5-1uL Bircks solution was pipetted onto the filament and evaporated and 500ng Sr was loaded into the ~1uL Bircks solution and dried at 0.5 amps. To achieve this, 2mL of Birckes reagent was combined with the sample, 1 mL of this mixture was then pipetted onto the filament and evaporated to dryness using the electrical current. The amplitude was gradually increased to ~1 amp. Over about 1 minute, it was increased to 1.8 amps and left for 1 minute and was heated until just red for several seconds. The filaments were then removed and placed in the magazine for loading into the TIMS machine.

Run procedure

The $^{87/86}$Sr isotopic abundance ratio measurements were carried out on an ISOTOPX Phoenix thermal ionisation mass spectrometer (TIMS). At least 100 ratios (5 blocks of 20 ratios) of multidynamic Sr measurements were taken. The ratios were normalized to $^{86/88}$Sr=.1194 using exponential mass fractionation correction. The standard deviations after subtracted from the standard, range from 0.019 to 0.028. The standard error is ~0.000003.

Potential limitations and mitigation

As the tooth morphology needed to be studied later by researchers at the University of Adelaide, the teeth could not be sectioned vertically through the crown, but instead were sectioned horizontally below the crown. This is not the conventional technique; therefore, it may be more difficult to compare with results from other studies. Other limitations were that the techniques have not always given similar results with archaeological teeth as post-burial diagenesis may have occurred. Also, solution mass spectrometry, where the whole tooth is dissolved, results in an average isotopic measurement for the tooth and is a more destructive technique than LA MC-ICPMS (Copeland et al. 2008:3192). Laboratory standards including clam shell, and equations were used to minimise the effect of interference from other ions (Willmes et al. 2016:104 – 106).

Reference materials were analysed to check if there were machine errors and the margin of error can be determined for each sample (Paton et al. 2011:2512). For carbonate materials, analysis of strontium isotope variations can be affected by isobaric influences including trace amounts of krypton in the argon gas. However, this effect can be minimised by running the machine with blanks, no sample inside (Woodhead 2005:23). We exported the data to Microsoft Excel for statistical analyses.

Gas Source IRMS (oxygen)

Another technique used in this study is IRMS, the oldest type of mass spectrometry. More recently, it has been coupled to a gas chromatograph via a combustion interface (De Groot 2004:154), where it is then called GC/C-IRMS. Elements that can be measured are the light stable isotopes, for example, those of oxygen, nitrogen, hydrogen, carbon, chlorine, selenium and sulphur (Benson 2012:342, 344). This technique is used for ions with a smaller mass and involves converting the sample to a gas (De Groot 2004:168).

The sample or analyte gas is measured relative to the standard gas. This is achieved by the combustion interface, a glass or ceramic tube filled with copper oxide (CuO) and platinum, or CuO and nickel oxide and platinum. Water formed during combustion is removed by a water trap (De Groot 2004:168).

Applications are varied, including pharmaceutical and food identification, quality control, geolocation of wildlife and humans, and forensics (Benson 2012:352 – 353). For food identification and quality control, the geographical origin of the food and any adulteration or ingredient substitution can be detected; for example, addition of water or sugar to fruit juice (Kelly et al. 2018:376, 389).

In forensics, IRMS can be used to trace the origins of drugs and explosives and determine manufacturing techniques. Nail and hair samples can be analysed to determine an individual's diet and recent locations. IRMS can also identify types of paint and varnish, paper products and cellulose, timber and wood products, petroleum products, environmental pollutants, biological warfare agents, plant origins and detect performance enhancing drugs during sporting events (Benson 2012: 354 – 362).

Pederzani and Britton (2019) summarise applications in archaeology, which include studies of palaeoclimate, individual mobility and origins, animal husbandry and management including diet and birth seasonality, breastfeeding and weaning patterns (Pederzani and Britton 2019:83). As breast milk has higher ^{18}O values than water, teeth formed at different stages in an individual, such as first and second molars can be compared to determine when weaning likely occurred (Pederzani and Britton 2019:92).

IRMS sample preparation

The tooth fragments were weighed and ground with a mortar and pestle, then digested in hydrochloric acid.

Run procedure

Tooth enamel and dentine were reacted with 104% phosphoric acid in a helium atmosphere at 70º C overnight. This means that a H_3PO_4 solution was oversaturated with excess P_2O_5. Resultant CO_2 was analysed at the University of Adelaide on a EuroVector NuCarb prep system in line with a Nu Instruments Continuous Flow Isotope Ratio Mass Spectrometer (CF-IRMS). In-house isotope standards used for two-point isotope corrections (Ke et al, 2014) were ANU P3 (d13C = +2.24‰ d18O = -0.32‰), and UAC (d13C = -15.0‰ d18O = -18.4‰). The uncertainty for oxygen isotope measurements range from +/- 0.023 to 0.735984.

Potential limitations

An issue is that isotopes may fractionate or alter their isotopic composition, in the machine. However, this is less likely to occur with gases (De Groot 2004:159).

Equations used

The sample materials contain carbon and oxygen which are converted to carbon dioxide in the machine. Consequently, they were measured on the Vienna Pee Dee Belemnite scale, which is based on a rock formation. However, this can be converted to the Vienna Standard Mean Ocean Water scale for comparison with rainwater using the equation:

$\delta^{18}O_{VSMOW}$= 1.03091 $^{18}O\ VPDB$ + 30.91 (Lightfoot and O'Connell 2016).

As oxygen fractionates within the body and is species dependent, the equation used for humans is:

d18Ow= 1.786 x $_{VSMOW}$- 54.005 (modified Daux et al. 1998 equation 4 in Chenery et al. 2012).

Conclusion

In conclusion, although TIMS and Gas Source IRMS have their limitations, they are useful techniques for analysing isotopes which compare favourably with alternative techniques. These techniques are used for a variety of applications including in forensics, food quality control and authentication, geology and archaeology. In archaeology, these techniques can be used to trace the origins of people, animals and artefacts.

Chapter 6: Results

A total of 52 samples were tested, four samples each from 13 individuals, two dentine and two enamel samples, for oxygen and strontium analyses. The data are presented in Table 11, Table 12, Table 13 and Figure 6 and Figure 7. The teeth which were sampled for each individual were generally first or second molars and are mentioned in Table 11.

The condition of the teeth varied between individuals. For example, the tooth from burial 23 was in poorer condition than the tooth from burial 52b.

Figure 4 Burial 23

Figure 5 Burial 52b

Strontium results

Error! Reference source not found. shows the strontium isotopic values for the Adelaide region.

This image has been removed due to copyright restrictions. Available from Rippon (2018) Where did they come from?' Baseline stable isotope mapping of the Adelaide Plains. Unpublished Master of Archaeology and Cultural Heritage Management thesis, Department of Archaeology, School of Humanities, Arts and Social Sciences, Flinders University, Adelaide.

All of the samples fall within Adelaide strontium values, but similar strontium values are found in many parts of the world (Rippon 2018: 103). Therefore, on its own, strontium does not definitively provide a region of origin for an individual. However, possible regions of origin for some individuals are shown below. Based on the strontium values alone, the Adelaide Hills and Plains cannot be excluded as possible areas of origin.

For burials 23, 28, 52b, 57, 66b and 79: the strontium values indicate a mixture of sand, clay and limestone and overlap with the Keswick Clay of Gilles St and St Kilda Formation of Port Adelaide (Rippon 2018:103).

For burials 9, 53c, 59, 72, 75d, 83: the strontium values indicate limestone sediments and are close to the range for the St Kilda Formation of Port Adelaide (Rippon 2018:103).

For burial 68, the strontium value suggests a clay lithology, close to the values of the Keswick Clay of Gilles St values, north-central Scotland, central England and Wales (Owen and Casey 2017:27; Rippon 2018:103;).

St Marys skeleton sample no. Dentine	Dentine mean $\delta^{87}/^{86}Sr$	±2σ error dentine	St Marys skeleton sample no. Enamel	Enamel mean $\delta^{87}/^{86}Sr$	±2σ error Enamel	Tooth sampled
EN1 15 (standard)	0.709179	0.000003				
987 (blank)	0.710227	0.000003				
9D Sr	0.710882	0.000003	9E Sr	0.709179	0.000003	1st molar
23D Sr	0.711322	0.000003	23E Sr	0.711364	0.000003	1st molar
28D Sr rerun	0.711293	0.000004	28E Sr	0.711038	0.000003	1st molar
52bD Sr rerun	0.711788	0.000003	52bE Sr rerun	0.712016	0.000004	2nd molar
53cD Sr	0.710762	0.000003	53cE Sr	0.709862	0.000003	1st molar
57D Sr	0.711085	0.000003	57E Sr	0.710376	0.000003	2nd molar
59D Sr	0.711162	0.000003	59E	0.711173	0.000002	1st molar
66bD Sr	0.711085	0.000003	66bE Sr	0.711318	0.000003	2nd molar
68D Sr	0.711295	0.000003	68E Sr	0.711075	0.000003	2nd molar
72D Sr	0.710112	0.000003	72E Sr	0.710980	0.000004	1st molar
75DD Sr	0.709852	0.000003	75DE Sr	0.711378	0.000003	1st molar (deciduous)
79D Sr	0.711918	0.000003	79E Sr	0.711467	0.000003	2nd molar
83D Sr	0.710664	0.000003	83E Sr	0.711472	0.000003	2nd or 3rd molar

Table 11 Strontium $^{87/86}$ results

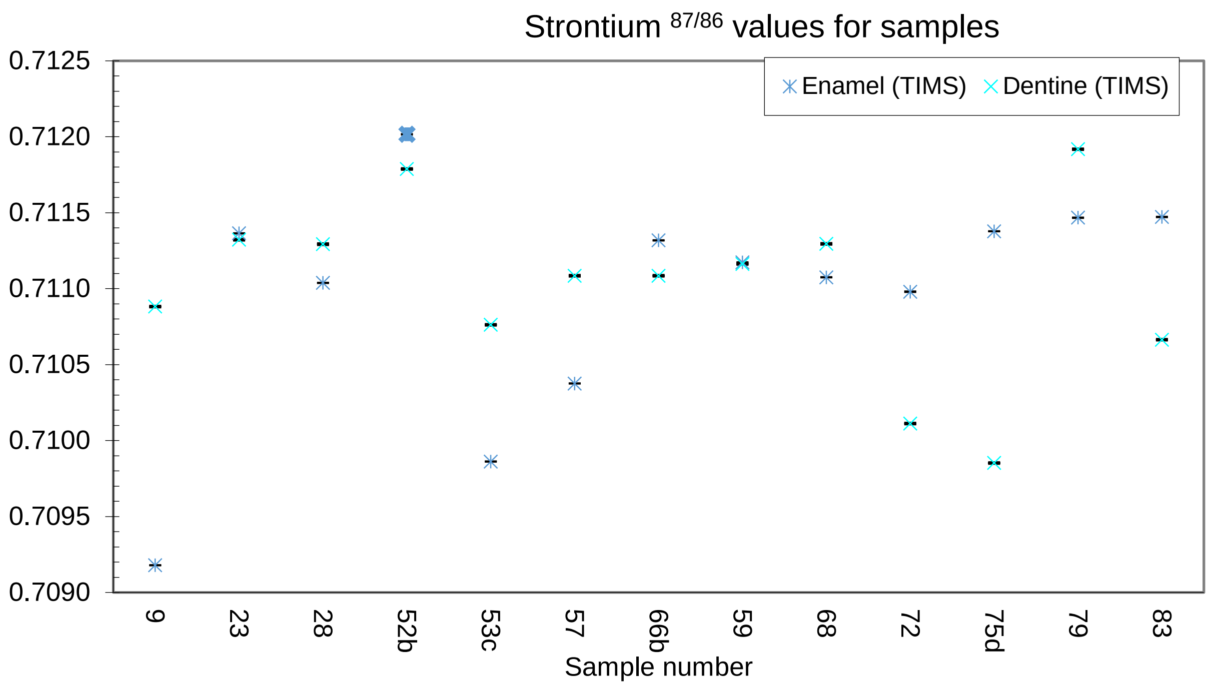


Figure 6 Strontium results

Oxygen results

The results of the oxygen analyses on the VPDB scale are shown below and in Figure 7.

Values for $O_{W\ VSMOW}$ in the Adelaide region range from 1.16 to -11.9 $\delta^{18}O_{VSMOW}$ (Kayaalp 2001; Liu 2010). Possible regions of origin for the teeth at St Mary's Anglican Cemetery based on the oxygen values are discussed below. Many of the sample values fall within the northern Scandinavian or European Alps values, which are below -14. Burials 9, 23, 28, 53c, 66b, 68 and 83, fall within northern Scandinavian and Alps oxygen values, as they are below -14 (Lightfoot and O'Connell 2016:16). Burial 52b fits within Adelaide and Chinese values, as the Chinese values range from -0.02 to +0.49 $\delta^{18}O_{VSMOW}$ (Dayem et al. 2010:223). Burial 57 falls within the values for parts of Ireland, Adelaide, south-western England and western Scotland, of -5 to -6 $\delta^{18}O_{VSMOW}$ (Owen and Casey 2017:27). Burial 59 falls within values for Mitcham and Cleland in the Adelaide region and parts of Ireland, which have values of -6 to -7 $\delta^{18}O_{VSMOW}$ (Owen and Casey 2017:27). Burial 72 values fall within parts of western Scotland and parts of Northern Ireland and Ireland with the values of -6 (Owen and Casey 2017:27). Burial 75 falls within Port Adelaide which has values of approximately -5 to -7 $\delta^{18}O_{VSMOW}$ (Rippon 2018). Burial 79 values fall within Adelaide values and are also close to the values for China, when corrected for temperature and amount of precipitation, particularly Guiyang in southern China, with a value of -0.4 $\delta^{18}O_{VSMOW}$, Hong Kong with a value of -0.47 $\delta^{18}O_{VSMOW}$ and Shijiazhuang in northern China, with a value of +0.49 $\delta^{18}O_{VSMOW}$ (Dayem et al. 2010:223).

St Marys skeleton sample no.	Dentine $\delta^{18}O/^{16}O$ PDB	Enamel $\delta^{18}O/^{16}O$ PDB	Dentine $\pm 2\sigma$ error	Enamel $\pm 2\sigma$ error
9	-4.517304529	-3.853251539	0.02313736	0.23511256
23	-2.05495178	-0.839671615	0.097599656	0.135041465
28	No result	-2.93869939	No result	0.139036152
52b	-4.030830907	-2.620297304	0.110495406	0.099246223
53c	-4.357848106	-2.242449169	0.2992541	0.142415746
57	-3.993836659	-4.104623673	0.104608929	0.112866813
59	-3.717334647	-3.603539067	0.131393119	0.058831619
66b	-4.954445409	-5.89109955	0.049370551	0.112798148
68	-4.592916654	-4.209346583	0.343542494	0.113694188
72	-3.973967696	No result	0.082630059	No result
75	-4.651237757	-1.637014284	0.085295465	0.16504079
79	-1.800442543	-0.391411392	0.093023132	0.12959286
83	-3.401320496	No result	0.040552382	No result

Table 12 Oxygen results on VPDB Scale

The oxygen results converted to water values on the $_{VSMOW}$ scale, are shown below.

Burial no	Dentine $\delta^{18}O_{VSMOW}$	Enamel $\delta^{18}O_{VSMOW}$
9	-20.88	-20.20
23	-18.87	-20.61
28	No result	-21.22
52b	-6.22	-3.62
53c	-6.82	-18.15
57	-6.15	-6.36
59	-5.64	-5.43
66b	-19.96, -20.60 (two measurements taken)	-23.88
68	-23.27	-22.68
72	-6.12	No result
75	-7.36	-1.81
79	-2.11	0.48
83	-18.92	No result

Table 13 Oxygen values VSMOW water values

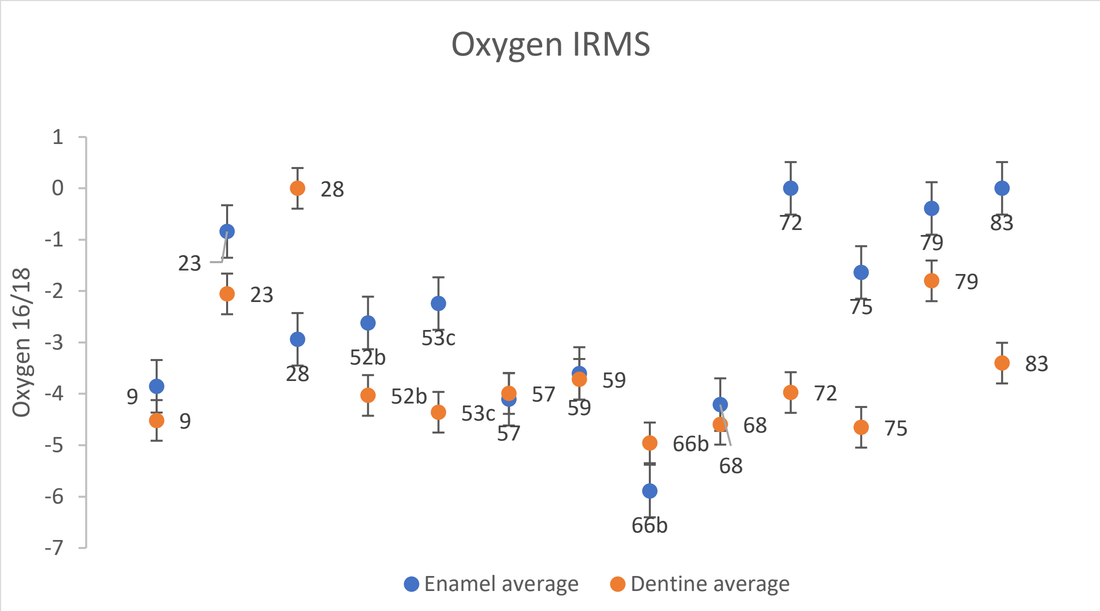


Figure 7 Oxygen values for samples on the VPDB scale

Oxygen and strontium results

The combined results for the oxygen and strontium analyses are shown in Figure 8.

Oxygen and strontium

The oxygen and strontium results of this study support each other and can be used to help refine the regions of origin. For burials 9, 53c and 83: the combined strontium and oxygen values fall within the range for the European Alps or northern Scandinavia regions with limestone geology (Lightfoot and O'Connell 2016:16; Toncala et al. 2017). Burials 23, 28, 66b, 68: the combined strontium and oxygen values are within the range for the European Alps and northern Scandinavia, in an area with a mixture of sand, clay and limestone (Lightfoot and O'Connell 2016:16; Toncala et al. 2017). For burial 52b, the values fall within those for Adelaide or China, in an area with a mixture of sand, clay and limestone (Dayem et al. 2010:223). For Burial 57, the strontium values fall within those for south-western England, northern Wales and Adelaide (Owen and Casey 2017:27; Rippon 2018). The oxygen isotope values fall with the range of Ireland, south-western England or Scotland. By comparing the strontium and oxygen values, this indicates south-western England as the likely region of origin for this individual.

Burial 59 falls within the range for Adelaide, based on the strontium and oxygen values.

Burial 72: The oxygen falls within the range for Western Scotland, Ireland or Northern Ireland and the strontium falls within Adelaide values. Burial 75 falls within Port Adelaide values, based on the oxygen and strontium isotopes. Burial 79 falls within Adelaide and Chinese values, based on the oxygen and strontium isotopes. This also fits with the skeletal morphology, which suggests Asian ancestry (Dayem et al. 2010:223).

9E

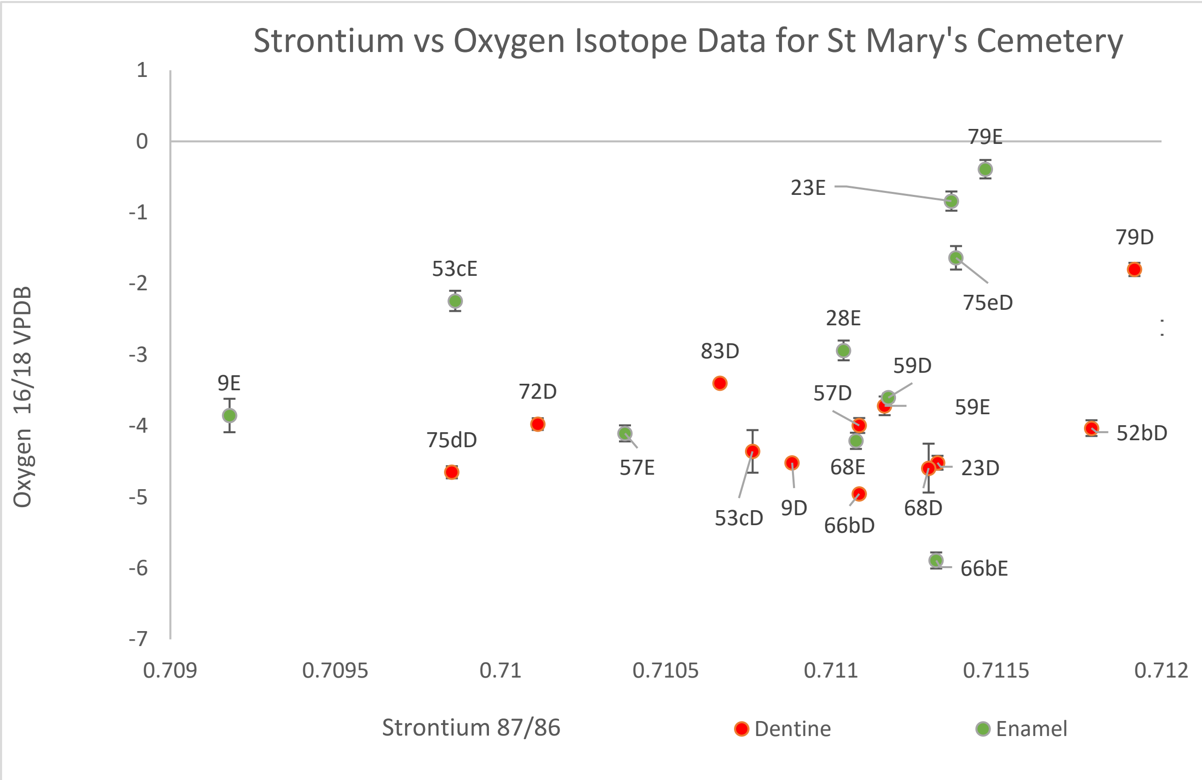


Figure 8 Strontium and oxygen VPDB

Chapter 7: Discussion

During this chapter, age, palaeopathologies and historical records are compared to the geographic origin based on isotopic analysis. In addition, the differences between the enamel and dentine values will be discussed.

Age versus geographic origin based on isotopic analysis

Burials 9, 23, 53c, 66b, 68 and 83, or 54% of all adult burials studied, have isotopic values which overlap with those of the European Alps and northern Scandinavia.

The other adult burials overlap with both Adelaide and overseas values, so it is unclear whether they are immigrants or not. For example, burial 57 has isotopic values which overlap with south-western England, Wales and Adelaide. Burial 59 and burial 72 fall within Adelaide values.

The adolescent burials are burials 28 and 79. Both are possible immigrants. Burial 28 falls within European Alp or northern Scandinavian values and burial 79 falls within Adelaide or Chinese values.

The children's burials are 52b and 75. Burial 52b falls within Chinese or Adelaide values and burial 75 falls within Port Adelaide values. As only two children's burials were sampled, it is unclear whether there would be a generally local or immigrant trend if more were studied.

As Mbeki et al (2017) commented on their study in South Africa, the high percentage of potential immigrants could have affected the decision to bury the individuals in the unmarked section, particularly if they were away from family and not part of a community who could pay for their burials.

Palaeopathology versus geographic origin based on isotopic analysis

Regarding palaeopathology, 46% of individuals studied had enamel hypoplasia, indicating nutritional deficiencies or illness, 38% had a pipe smoker's notch in their teeth, 33% had signs of arthritis or spinal inflammation, 30% had fractures, 26% had signs of tooth decay and 23% had Spina bifida occulta (Anson 2004). One individual may have had hydrocephaly. Based on isotopic analysis, two individuals with Spina bifida occulta may have originated in the European Alps or northern Scandinavia and one from Adelaide or China. Enamel hypoplasia does not seem to be restricted to one geographical area and was probably common during their lifetimes. It is unclear if there is any correlation between having arthritis and the region of origin. Isotopic analysis of all six pipe smokers suggests that they may have originated in the European Alps or northern Scandinavia, suggesting that the practice of pipe smoking may either have a cultural basis or may indicate that they are related.

Historical record versus geographic origin based on isotopic analysis

It was suggested that burial 53c may have been Margaret Anderson, who departed from England. The isotopic analyses suggest that this individual originated in the European Alps or northern Scandinavia.

It was suggested that burial 59 was Henry Thomas Russell who arrived from, and lived in London, and died in 1854. It is possible that this individual lived in London, but the isotopic analyses suggest that he originated in Adelaide.

Burial 83 was thought to be John Pell, who was mentioned as coming from London. It is possible that he later lived in London, but the isotopic analyses suggest that he may have originated in the European Alps or northern Scandinavia. Burial 79 was thought to be Eliza Francis Stewart, Rosetta Moody or Eliza Denman (Anson 2004:466), all of whom departed from England. However, the isotopic analyses suggest that she may have originated in China or Adelaide.

The isotopic analyses do not discount the possibility that the individuals are those that Anson suggested. Further studies, possibly of teeth that developed later, for example, third molars, would be required to determine the likelihood that they lived in the United Kingdom or Ireland and therefore whether there is a possibility that they are the individuals suggested.

As there is a lack of isotopic data for Australia, it is possible that the individuals originated from other Australian colonies. The only previous known isotopic studies in Australia are northern Queensland and Sydney (Owen and Casey 2017; Adams et al. 2019;). The isotopic analyses suggest that 38% of individuals may have been born in Adelaide, 23% may be from the United Kingdom and 39% may be from other areas of the world.

Dentine versus enamel

As the dentine and enamel samples across all teeth studied do not all have the same values as would be expected if they reflected the cemetery isotopic values, this suggests that instead of diagenesis occurring, the individuals likely moved during amelogenesis or enamel formation (Moffat 2013:1). This indicates a more complex history than if the individuals spent their childhoods in the same place.

Most of the dentine isotopic values differ from the enamel for the individuals studied. However, the individuals from burials number 23 and 59 have similar strontium values for dentine and enamel. For the oxygen values, the individuals from burials 57 and 59 have similar values for their dentine and enamel. It appears likely that the individual from burial number 59 did not move far from either Adelaide or Ireland during childhood, based on the oxygen and strontium values, but that burial number 23, who may have originated near the European Alps or northern Scandinavia, moved to an area with similar strontium but different oxygen isotopes, possibly at a lower elevation. Burial number 57 moved to an area with different strontium but the same oxygen isotopes, possibly within south-western England, Wales or Adelaide.

Conclusion

The strontium and oxygen results, when used together, help to refine possible regions of origin for the individuals studied. Both sets of isotopic values appear to support each other. However, there are many potential limitations to this study, and it is unclear if these trends were indicative of the general population of the unmarked section of St Mary's Anglican Cemetery, or just of these particular individuals.

Chapter 8: Conclusion and recommendations

This chapter summarises the results, discussion, questions and aim. In addition, limitations of the study are considered, as are further suggestions for research.

Questions and aim

The primary question is: Were the people in unmarked burials in an Anglican Cemetery, immigrants, or from Adelaide? The secondary question is: If they were immigrants, from where did they likely originate?

The aim is:

- To identify likely origins of individuals and to test the hypothesis that they were of British or Irish origins.

Two enamel and two dentine samples were analysed for each of the 13 individuals studied. The strontium isotopes have a comparatively narrow range from 0.709179 to 0.712016. However, the oxygen isotopes vary widely. On the $_{VSMOW}$ scale, range from -23.27 to +0.48.

Based on the strontium isotopes alone, all of the individuals could have originated in the Adelaide Plains and Hills. However, when oxygen isotopes are considered, many fall within the Adelaide and British values but six individuals have values which fall within the European Alps or northern Scandinavia ranges and two have values which fall within the range for China and Adelaide. For one of the individuals with values which fall within the range for China and Adelaide, the possibility of Chinese origins is supported by her skeletal morphology.

Limitations

There are many limitations to this study. Many regions of the world have not been isotopically mapped; therefore, the results may represent an area yet to be mapped and the regions mentioned in this thesis are only possibilities. The sample size of thirteen individuals is very small, therefore, a larger sample size would be required to determine trends in the dataset.

With every oxygen conversion equation, there is greater potential for error because if you make an early error with data entry or calculations, this error is compounded with every subsequent calculation.

There are different equations for converting between rainwater and biomaterials and between phosphate and carbonates. Therefore, the choice of a different equation may give different results.

The oxygen isotopic composition of rainfall varies, depending on a variety of factors, including temperature and altitude, so within the same location, oxygen values can vary. Therefore, there are a range of values for every site and the teeth will provide an average of these values.

Further research

Further research should be conducted to analyse historical documents to see if the individuals' potential origins can be refined, particularly with those where a specific identity is suspected. However, as the records are incomplete, there may be other possible identities for the individuals. Different individuals could be studied or different teeth, for example, third molars, could be studied from the same individuals, to see if they moved during tooth formation. Other isotopes could be studied, for example, lead or sulphur, to help further establish the areas of origin. It would also be interesting to compare the dietary information known from bones from these individuals with the possible regions of origin to provide more information about social class. Comparisons of results from this study with Angela Gurr's (2018) analyses of nutritional deficiencies in bones and teeth could also reveal whether an individual's social class changed over their lifetime. Isotopic analyses of dental calculus could provide further information on diet for individuals and differences based on demographics revealing which age groups consumed different foods. This would be less destructive because the calculus is not part of the teeth, so does not require cutting or dissolving parts of the teeth to collect the samples. However, it is unclear which life stage, the dental calculus would represent. Some DNA analyses appear to have been conducted but I could not access the data, further analyses may be required.

References

Adams, S., R. Grün, D. McGahan, J. Zhao, Y. Feng, A. Nguyen, M. Willmes, M. Quaresimin, B. Lobsey, M. Collard, M.C. Westaway 2019 A strontium isoscape of north-east Australia for human provenance and repatriation. *Geoarchaeology* 34(3): 231 – 251.

Aitchison, R. 1986 *The Americans in Australia.* Melbourne: AE Press.

Aitchinson, M.E, R.C. Sprigg and G.W. Cochrane 1954 *Soils and Geology of Adelaide and Suburbs*, Department of Mines Geological Survey of South Australia bulletin no 32. Adelaide: K.M Stevenson government printer.

Anson, T.J. 2004 The Bioarchaeology of the St Mary's Free Ground Burials: Reconstruction of Colonial South Australian Lifeways. Unpublished PhD thesis, Department of Anatomical Sciences, University of Adelaide.

Australian Government Department of the Environment and Energy Australian Antarctic Division 2002 Antarctic geology. Retrieved 30 May 2018 from <www.antarctica.gov.au/about-antarctica/environment/geology>.

Australian Government Geoscience Australia 2016 Australian Stratigraphic Units Database. Retrieved 25 May 2018 from <http://dbforms.ga.gov.au/pls/www/geodx.strat_units.sch_full?wher=stratno=3106>.

Bataille, C.P and G.J Bowen 2012 Mapping ^{87}Sr/^{86}Sr variations in bedrock and water for large scale provenance studies. *Chemical Geology* 304/305: 39 – 52.

Benson, S.J. 2012 Forensic applications of isotope ratio mass spectrometry. In M.S Lee (ed.), *Mass Spectrometry Handbook*, pp. 341 – 372. Hoboken, New Jersey: J. Wiley and Sons.

Bentley, A.R. 2006 Strontium isotopes from the earth to the archaeological skeleton: a review. *Journal of Archaeological Method and Theory* 13(3):135-187.

Borić, D. and T.D. Price 2013 Strontium isotopes document greater human mobility at the start of the Balkan Neolithic. *Proceedings of the National Academy of Sciences of the United States of America* 110(9):3298–3303.

Brettell, R., J. Montgomery and J. Evans 2012 Brewing and stewing: the effect of culturally mediated behaviour on the oxygen isotope composition of ingested fluids and the implications for human provenance studies. *Journal of Analytical Atomic Spectrometry* 27: 778 – 785.

Budd, P., A. Millard, C. Chenery, S. Lucy and C. Roberts 2004 Investigating population movement by stable isotope analysis: A report from Britain. *Antiquity* 78(299):127-141.

Bureau of Meteorology 2019 Climate summaries archive, accessed 21st October 2019 from http://www.bom.gov.au/climate/current/season/sa/archive/201908.adelaide.shtml

Buzon, M., P. Walker, F. Verhagen and S. Kerr 2005 Health and disease in nineteenth century San Francisco: skeletal evidence from a forgotten cemetery. *Historical Archaeology* 39(2):1-15.

Carter, M. 1997 *No Convicts There: Thomas Harding's Colonial South Australia.* Adelaide: Trevaunance Pty Ltd.

Chenery, C.A, V. Pashley, A.L Lamb, H.J. Sloane and J.A. Evans 2012 The oxygen isotope relationship between the phosphate and structural carbonate fractions of human bioapatite. *Rapid Communications in Mass Spectrometry, https://doi-org.ezproxy.flinders.edu.au/10.1002/rcm.5331*.

Cigler, M. 1983 *The Czechs in Australia*. Melbourne: AE Press.

City of Mitcham 2009 *St Marys Walk brochure.* Torrens Park, Adelaide: City of Mitcham.

Copeland, S. R., M. Sponheimer, P. J. Le Roux, V. Grimes; J. Lee-Thorp, D.J. Le Ruiter and M.P. Richards 2008 Strontium isotope values (87Sr/86 Sr) of tooth enamel: a comparison of solution and laser multicollector inductively coupled plasma mass spectrometry methods. *Rapid Communications in Mass Spectrometry 22(20): 3187-3194.*

Copeland, S.R., M. Sponheimer, J.A. Lee-Thorp, P.J. Le Roux, D.J. Le Ruiter and M.P. Richards 2010 Strontium isotope values in fossil teeth from South Africa: assessing laser ablation MC-ICP-MS analysis and the extent of diagenesis. *Journal of Archaeological Science* 37: 1437-1446.

Daily, B., J.B. Firman, B.G. Forbes and J.M. Lindsay 1976 Geology. In C.R. Twidale, M.J. Tyler and B.P Webb (eds) *Natural History of the Adelaide Region*, pp. 5 – 42. Unknown place of publication: Royal Society of South Australia.

Darling, W.G. 2004 Hydrological factors in the interpretation of stable isotopic proxy data present and past: A European perspective. *Quaternary Science Reviews* 23 (2004): 743–770.

Darling, W.G., A.H. Bath and J.C. Talbot 2003 The O and H stable isotope composition of fresh waters in the British Isles. 2. Surface waters and groundwater. *Hydrology and Earth System Sciences* 7(2):183-195.

Dayem, K.E., P. Monair, D.S. Battisti and G.H. Roe 2010 Lessons learned from oxygen isotopes in modern precipitation applied to interpretation of speleothem records of paleoclimate from eastern Asia. *Earth and Planetary Science Letters 295 (1-2): 219 – 230.*

De Groot, P.A. 2004 *Handbook of Stable Isotope Analytical Techniques.* Amsterdam, Boston: Elsevier.

Delgado, M. 2018 Stable isotope evidence for dietary and cultural change over the Holocene at the Sabana de Bogotá region, northern South America. *Archaeological and Anthropological Sciences* 10(4):817– 832.

Dethlefsen, E. and J. Deetz 1966 Death's heads, cherubs and willow trees: experimental archaeology in colonial cemeteries. *American Antiquity* 31(4):502-510.

Dickey, B. 1986 *Rations, Residence, Resources: A history of social welfare in South Australia since 1836.* Netley, South Australia: Wakefield Press.

Drexel, J.F., W.V. Preiss and A.J. Parker (eds) 2012a *Bulletin 54 The Geology of South Australia Volume 1 Precambrian.* Adelaide: Mines and Energy South Australia Geological Survey of South Australia.

Drexel, J.F. and W.V. Preiss (eds) 2012b *Bulletin 54 The Geology of South Australia Volume 2 the Phanerozoic.* Adelaide: Government of South Australia Primary Industries and Resources South Australia, Geological Survey of South Australia.

Edwards, R. 1976 *St Mary's South Road,* reprinted from Proceedings of the Royal Geographical Society South Australian Branch session 1954–1955. St Mary's Church, St Mary's South Australia.

Evans, J.A., J. Montgomery, G. Wildman and N. Boulton 2010 Spatial variations in biosphere $^{87}Sr/^{86}Sr$ in Britain. *Journal of the Geological Society, London* 167:1-4.

Evans, J.A, C.A. Chenery and J. Montgomery 2012 A summary of strontium and oxygen isotopic variation in archaeological human tooth enamel excavated from Britain. *Journal of Analytical Atomic Spectrometry* 27(5): 754 –764.

Faure, G. and J.L. Powell 1972 *Strontium Isotope Geology.* Berlin, Heidelberg: Springer Berlin Heidelberg.

Fiorentino, G., J.P. Ferrio, A. Boggard, J. Araus and S. Riehl 2015 Stable isotopes in archaeobotanical research. *Vegetation History and Archaeobotany* 24(1): 215 –227.

Finkel, G. 1975 *South Australia 1836 – 1900.* Adelaide: Thomas Nelson (Australia) Limited.

Frei, K.M and T.D Price 2012 Strontium isotopes and human mobility in prehistoric Denmark. Archaeological and Anthropological Sciences 4(2): 103 –114.

Frei, R., C. Gaucher, L.N. Døssing and A.N Sial 2011 Chromium isotopes in carbonates — a tracer for climate change and for reconstructing the redox state of ancient seawater. *Earth and Planetary Science Letters* 312(1):114 –125.

Fry, B. and E.B. Sherr 1989 d13C measurements as indicators of carbon flow in marine and freshwater ecosystems. In P.W. Rundel, J.R. Ehleringer, and K.A.Nagy (eds) Stable Isotopes in Ecological Research, pp. 196-229. New York: Springer-Verlag.

Gibbs, R.M. 1990 *A History of South Australia from Colonial Days to the Present.* Blackwood: Southern Heritage.

Gostin, V.A. 2014 Peeling Back the Layers Under Adelaide. *Bibliophile* 13(4):3 – 8.

Gotthard, J. 1991 'Pity the poor immigrant': Assisted single female migration to colonial Australia. In E. Richards (ed.) *Poor Australian Immigrants in the Nineteenth Century Visible Immigrants: two.* Canberra: Division of Historical Studies and Centre for Immigration and Multicultural Studies, Research School of Social Science, Australian National University, pp. 97 –116.

Gross, J.H. 2004 Mass Spectrometry: A Textbook. Berlin, Heidelberg: Springer Berlin Heidelberg.

Guan, H., C.T. Simmons and A.J. Love 2009 Orographic controls on rain water isotope distribution in the Mount Lofty Ranges of South Australia. *Journal of Hydrology* 374: 255 – 264.

Gurr, A. 2018 personal communication

Haines, P.W., S.P Turner, J.D. Foden and J.B. Jago 2009 Isotopic and Geochemical Characterisation of the Cambrian Kanmantoo Group, South Australia: implications for stratigraphy and provenance. *Australian Journal of Earth Sciences 56 (8): 1095–110.*

Haines, R. 1991 'Shovelling out paupers?': Parish assisted emigration from England to Australia 1834–1897. In E. Richards (ed.) *Poor Australian Immigrants in the Nineteenth Century Visible Immigrants: two.* Canberra: Division of Historical Studies and Centre for Immigration and Multicultural Studies, Research School of Social Science, Australian National University, pp. 33-68.

Haines, R.F 1997 *Emigration and the Labouring Poor: Australian recruitment in Britain and Ireland 1831–1860.* Houndmills, Basingstoke, Hampshire and London: MacMillan Press Ltd.

Halverson, G.P, F.O. Dudás, A.C Maloof and S.A. Bowring 2007 Evolution of the $^{87}Sr/^{86}Sr$ composition of Neoproterozoic seawater. *Palaeogeography, Palaeoclimatology, Palaeoecology* 256: 103–129.

Hand A.R. and M.E. Frank 2014 *Fundamentals of Oral Histology and Physiology*. Hoboken: Wiley.

Henderson, J., J.A. Evans, H.J. Sloane, M.J. Leng and C. Doherty 2005 The use of oxygen, strontium and lead isotopes to provenance ancient glasses in the Middle East. *Journal of Archaeological Science 32(5): 665 – 673.*

Hill, A.C. 1998 Mid-Neoproterozoic isotope stratigraphy of Australia. Unpublished PhD thesis, Macquarie University, New South Wales.

Hoefs, J. 2015 *Stable isotope geochemistry (7th Edition)*. Switzerland: Springer International Publishing.

Hurren, E. and S. King 2005 'Begging for a burial': form, function and conflict in nineteenth-century pauper burial. *Social History* 30(3):321-341.

Kaupová, S., P. Velminský, E. Herrscher, V. Sládek, J. Macháček, L. Poláček and J. Brůžek 2018 Diet in transitory society: isotopic analysis of medieval population of central Europe (ninth—eleventh century AD, Czech Republic. *Archaeological and Anthropological Sciences* 10 (4):923– 942.

Kayaalp, A.S. 2001 Application of rainfall chemistry and isotope data to hydro-meteorological modelling. Unpublished PhD thesis, School of Chemistry, Physics and Earth Sciences, Flinders University, Adelaide.

Koivukangus, O. and J.S. Martin 1986 *The Scandinavians in Australia.* Melbourne: AE Press.

Kelly, S., C. Brodie and A. Hilkert 2018 Isotopic-Spectroscopic technique: Stable isotope Ratio Mass Spectrometry (IRMS). In D. Sun (ed.) *Modern Techniques for Food Authentication,* pp. 349 –413. Academic Press, DOI: https://doi.org/10.1016/C2017-0-01345-9.

King, H.M n. d Geology.com dictionary. Retrieved 18 September 2018 from <https://geology.com/rocks/peridotite.shtml>.

Kloppmann,W., L. Leroux, P. Bromblet, C. Guerrot, E. Proust, A.H. Cooper, N. Worley, S.A. Smeds and H. Bengtsson 2013 Tracing medieval and renaissance alabaster works of art back to quarries: A multi-isotope (Sr, S, O) approach. *Archaeometry* 56(2): 203 – 219.

Knudson, K.J, C. Stanish, M.C Lozada Cerna, K.F Faull and H. Tantaleán 2016 Intra-individual variability and strontium isotope measurements: a methodological study using 87Sr/86Sr data from Pampa de los Gentiles, Chinca Valley, Peru. *Journal of Archaeological Science* 5:590–597.

Kootker, L.M., R.J. van Lanen, H. Kars, G.R. Davies 2016 Strontium isoscapes in the Netherlands. Spatial variations in 87Sr/86Sr as a proxy for palaeomobility. *Journal of Archaeological Science Reports* 6:1–13.

Kralik, M, R. Benischke, S.Wyhlidal and R. Phillippitsch 2017 First Water-Isotope-Map (δ18O, δ2H, 3H) of Austria: Applications, Extremes and Trends. *Procedia Earth and Planetary Science 17: 924 –927.*

Lamb, A.L., J.E. Evans, R. Buckley and J. Appleby 2014 Multi-isotope analysis demonstrates significant lifestyle changes in King Richard III. *Journal of Archaeological Science* 50:559 –565.

Leng, M.J. and J.P. Lewis 2014 Oxygen isotopes in molluscan shell: Applications in environmental archaeology. *Environmental Archaeology: the Journal of human palaeoecology* 21(3): 295 – 306.

Lever, M. 2009 When absence is the artifact: unmarked graves in the Jewish section, Melbourne General Cemetery. *International Journal of Historical Archaeology*, 13(4), pp.464–487.

Li, B.P., J.X. Zhao, A. Greig, K.D. Collerson, Y.X. Feng, X.M. Sun, M.S. Guo and Z.X. Zhuo 2006 Characterisation of Chinese Tang sancai from Gongxian and Yaozhou kilns using ICP-MS trace element and TIMS Sr-Nd isotopic analysis. *Journal of Archaeological Science 33(1): 56 – 62.*

Lightfoot, E. and T.C. O'Connell 2016 On the Use of Biomineral Oxygen Isotope Data to Identify Human Migrants in the Archaeological Record: Intra-Sample Variation, Statistical Methods and Geographical Considerations. *Plos One* 11(4).

Linderholm, A. and A. Kjelström 2011 Stable isotope analysis of a medieval skeletal sample indicative of systemic disease from Sigtuna Sweden. *Journal of Archaeological Science* 38(4):925-933.

Ling, J., E. Hjärthner, L. Grandin, K. Billström and P. Persson 2013 Moving metals or indigenous mining? Provenancing Scandinavian Bronze Age artefacts by lead isotopes and trace elements. *Journal of Archaeological Science* 40(1):291– 304.

Liu, J., G. Fu, X. Song, S.P. Charles, Y. Zhang, D. Han and S. Wang 2010 Stable isotopic compositions in Australian precipitation. *Journal of Geophysical Research* 115:1–16.

Lösch, S., N. Moghaddam, K. Grossschmidt, D.U. Risser and F. Kanz 2014 Stable Isotope and Trace Element Studies on Gladiators and Contemporary Romans from Ephesus (Turkey, 2nd and 3rd Ct. AD) - Implications for Differences in Diet. *PLOS One 9(10), DOI: 10.1371/journal.pone.0110489.*

Longinelli, A., E. Selmo 2003 Isotopic composition of precipitation in Italy: a first overall map. *Journal of Hydrology* 270(1-2): 75– 88.

Lv, Y., S. Liu, H. Wu, S.V. Hohl, S. Chen and S. Li 2018 Zn-Sr isotope records of the Ediacaran Doushantuo Formation in South China: diagenesis assessment and implications. *Geochimica et Cosmochimica Acta* 239: 330 – 345.

Makarewicz, C.A., C. Winter-Schuh, H. Byerley and J.L. Houle 2018 Isotopic evidence for ceremonial provisioning of late Bronze Age khirigsuurs with horses from diverse geographic locales. *Quaternary International*, in press: 1– 12.

Matic, A.M. 2003 "Here Lie I Because I am Poor" the History and Archaeology of the St Mary's Anglican Churchyard Pauper Cemetery. Unpublished Master of Arts thesis, Department of Archaeology, School of Humanities, Flinders University of South Australia.

Makishima, A. 2016 *Thermal Ionization Mass Spectrometry (TIMS): silicate digestion, separation and measurement.* Weinheim: Wiley-VCH.

Mbeki, L., L.M. Kootker, H. Kars and G.R. Davies 2017 Sickly slaves, soldiers and sailors. Contextualising the Cape's 18th –19th century Green Point burials through isotope investigation. *Journal of Archaeological Science*: *Reports* 11:480 – 490.

McCurdy, E., S. Wilbur, G.D. Woods and D. Potter 2001 Moving to the next level: sample introduction and plasma interface design for improved performance in ICP-MS. In S.D. Tanner and J.G Holland (eds), *Plasma Source Mass Spectrometry: the new millennium,* pp. 45 – 60. Cambridge: Royal Society of Chemistry.

McKirdy, D.M., J.M Burgess, N.M. Lemon, X.Yu, A.M. Cooper, V. Gostin, R.J.F Jenkins and R.A Both 2001 A chemostratigraphic overview of the late Crogenian interglacial sequence in the Adelaide fold-thrust belt, South Australia. *Precambrian Research* 106 (1):149–186.

Michener, R. 2007 *Stable Isotopes in Ecology and Environmental Science*. Malden, Massachusetts: Blackwell Publications.

Moffat, I.A. 2013 Spatially resolved strontium isotope micro-analysis of lower and middle-Palaeolithic fauna from archaeological sites in Israel and Southern France. Unpublished PhD thesis, College of Physical and Mathematical Science, Australian National University, Canberra.

Muller, S. 2015 Colonial experiences of death, burial and memorialisation in West Terrace Cemetery, Adelaide: applying a phenomenological approach to cultural landscapes in historical archaeology. *Australasian Historical Archaeology 33:15-26.*

Nelson, S.J. 2015 *Wheeler's Dental Anatomy, Physiology and Occlusion.* St Louis: Elsevier.

Nehlich, O. 2015 The application of sulphur isotope analyses in archaeological research: A review. *Earth-Science Reviews* 142: 1 – 17.

Twidale, C.R., M.J. Tyler and B.P. Webb (eds) *Natural History of the Adelaide Region.* Adelaide*:* Royal Society of South Australia.

Nowell, G., C. Macpherson, G. Young, S. Groves, C. Roberts, S. Lucy, G. Pearson and D. Gröcke 2013 Mobility histories of 7th-9th century AD people buried at early Medieval Bamburgh, Northumberland, England. *American Journal of Physical Anthropology* 151(3):462-476.

Ohlsson, T. 2013 "Better than nothing'' Eurasian labour in New South Wales, 1853 – 1854 *Labour History* 105: 153 – 169.

Oregon State University 2018 Volcano World Glossary. Retrieved 18 September 2018 from < http://volcano.oregonstate.edu/glossary>.

Oxford Living Dictionaries 2018 Dolerite. Retrieved 18 September 2018 from < https://en.oxforddictionaries.com/definition/dolerite>.

Owen, T. and M. Casey 2017 The Old Sydney Burial Ground: Using isotopic analysis to infer the origin of individual skeletons. *Australasian Historical Archaeology* 35:24-33.

Parkin, L.W. (Ed.) 1969 *Handbook of South Australian Geology*. Adelaide: A.B. James Government Printer.

Pate, F.D. 1994 Bone chemistry and paleodiet. *Journal of Archaeological Method and Theory* 1: 161-209.

Pate, F.D. 2006 Population expansion in early colonial Adelaide as reflected in gravestones and cemetery monuments, 1836-1865. In P. Smith, F.D Pate and R. Martin (eds), *Valleys of Stone: The Archaeology and History of Adelaide's Hill Face,* pp.56-68. Belair: Kōpi Books.

Pate, F.D. 2008 Geographic origin and mobility recorded in the chemical composition of human tissues. In M. Oxenham (ed.) *Forensic Approaches to Death, Disaster and Abuse,* pp. 177 – 188. Brisbane: Australian Academic Press.

Pate, F.D. and T.J. Anson 2012 Stable Isotopes and Dietary Composition in the Mid-Late 19th Century Anglican Population, Adelaide, South Australia. *Journal of the Anthropological Society of South Australia* 35:1-17.

Pederzani, S. and K. Britton 2019 Oxygen isotopes in bioarchaeology: Principles and applications, challenges and opportunities. *Earth-Science Reviews* 188: 77– 107.

Perry, M.A., C. Jennings and D.S. Coleman 2017 Strontium isotope evidence for long distance immigration into the Byzantine port city of Aila, modern Aqaba, Jordan. *Archaeological and Anthropological Sciences* 9 (5):945-964.

Pestle, W.J., C. Torres-Rouff and B. Daverman 2014 Strange people and exotic things constructing Akkadian identity at Kish, Iraq. In A.T. Boutin and B.W. Porter (eds), Remembering the Dead in the Ancient Near East: Recent Contributions from Bioarchaeology and Mortuary Archaeology, pp 61-96. Place publication not identified: University Press of Colorado.

Pickett, E.J, S.P Harrison, G. Hope, K. Harle ; J.R. Dodson, A.P Kershaw, I.C Prentice, J. Backhouse, E.A Colhoun, D. D' Costa, J. Flenley, J. Grindrod, S. Haberle, C. Hassell, C. Kenyon, M. Macphail, H. Martin, A.H Martin, M. Mckenzie, J.C Newsome, D. Penny, J. Powell, J.I. Raine, J; W. Southern J. Stevenson, ; J.P Sutra, I. Thomas, S. Kaars and J. Ward, 2004 Pollen-based reconstructions of biome distributions for Australia, Southeast Asia and the Pacific (SEAPAC region) at 0, 6000 and 18,000 14 C yr BP *Journal of Biogeography* 31(9):1381– 1444.

Piddock, S. 2001 "An irregular and inconvenient pile of buildings": The Destitute Asylum of Adelaide, South Australia and the English workhouse. International Journal of Historical Archaeology 5(1):73-95.

Pioneers Association of South Australia, 2018 Early SA History. Retrieved 17 June 2018 from < https://www.pioneerssa.org.au/early_sa_history.html>.

Pollard, A. M. and C. Heron 1996 *Archaeological Chemistry.* Cambridge: Royal Society of Chemistry.

Preiss, W.V. 1987 *Bulletin 53 The Adelaide Geosyncline: Late Proterozoic stratigraphy, sedimentation, palaeontology and tectonics.* Department of Mines and Energy Geological Survey of South Australia. South Australia: D.J Woolman government printer.

Price, T.D, K.M Frei and E. Naumann 2014 Isotopic Baselines in the North Atlantic Region. *Journal of the North Atlantic: 103 – 136.*

Price, T.D, S. Nakamura, S. Suzuki, J.H Burton and V. Tiesler 2014 New isotope data on Maya mobility and enclaves at Classic Copan, Honduras*. Journal of Anthropological Archaeology* 36: 32 – 47.

Price, T.D., R. Frei, Y. Bückström, K.M. Frei and A. Ingvarsson-Sundstrom 2017 Origins of inhabitants from the sixteenth century Sala (Sweden) silver mine cemetery—A lead isotope perspective. *Journal of Archaeological Science* 80:1-13.

Rehkämper, M., M. Schönbächler and C.H. Stirling 2001 Back to basics review Multiple Collector ICP-MS: Introduction to instrumentation, measurement, techniques and analytical capabilities. *Geostandards Newsletter the Journal of Geostandards and Geoanalysis* 25(1): 23-40.

Reid, D.J. and M.C. Dean 2006 Variation in modern human enamel formation times. *Journal of Human Evolution* 50(3):329 – 346.

Renzi, M., I. Montero-Ruiz and M. Bode 2009 Non-ferrous metallurgy from the Phoenician site of La Fonteta (Alicante, Spain): A study of provenance. *Journal of Archaeological Science 36(11): 2584 –2596.*

Richards, E. 1985 *A History of the Highland Clearances Volume 2: Emigration, Protest, Reasons.* London: Croom Helm.

Richards, E. 2004 *Britannia's Children.* London and New York: Hambledon and London.

Rippon, L. 2018 'Where did they come from?' Baseline stable isotope mapping of the Adelaide Plains. Unpublished Master of Archaeology and Cultural Heritage Management thesis, Department of Archaeology, School of Humanities, Arts and Social Sciences, Flinders University, Adelaide.

Rippon, L., M. Rollog, D. Bruce, J. Farkas, D. Pate, T. Owen, T. Lucas, S. McCallum and I. Moffat 2019 Baseline bioavailable strontium and oxygen isotope mapping of the Adelaide region. *Journal of Archaeological Science Reviews,* in press.

Roberts, R.G., K.E. Westaway, J.X Zhao, C.S.M. Turney, M.I. Bird, W.J. Rink and L.K. Fifield 2009 Geochronology of cave deposits at Liang Bua and of adjacent river terraces in the Wae Rachang valley, western Flores, Indonesia: a synthesis of age estimates for the type locality of Homo Floresiensis. *Journal of Human Evolution* 57(5): 484 – 502.

Schoeninger, M.J. and M.J. DeNiro 1984 Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. Geochimica et Cosmochimica Acta 48:625-639.

Schroeder, H, T.C. O'Connell, J.A. Evans, K.A. Schuler and R.E.M Hedges 2009 Trans-Atlantic slavery: Isotopic evidence for forced migration to Barbados. *American Journal of Physical Anthropology* 139: 547 –557.

Scott, G.R. and S.R. Poulson 2012 Stable carbon and nitrogen isotopes of human dental calculus: A potentially new non-destructive proxy for palaeodietary analysis. *Journal of Archaeological Science* 39(5):1388 – 1393.

Selby, J. 1984 *Geology and the Adelaide Environment,* Department of Mines and Energy South Australia. Adelaide: Woolman Government Printer.

Sendiziuk, P. 2012 No convicts here: Reconsidering South Australia's Foundation Myth. In R. Foster and P. Sendiziuk (eds) *Turning Points: Chapters in South Australian History.* Kent Town, South Australia: Wakefield Press.

Shaw, B.J., G.J. Summerhayes, H.R. Buckley and J.A Baker 2009 The use of strontium isotopes as an indicator of migration in human and pig Lapita populations in the Bismarck Archipelago, Papua New Guinea. *Journal of Archaeological Science* 36(4):1079 – 1091.

Sparkman, O.D., Z. Penton and F.G. Kitson 2011 *Gas Chromatography and Mass Spectrometry a practical guide.* Boston: Elsevier.

South Australian Maritime Museum, n.d. Passengers in History 1836. Retrieved 21 March 2018 from <http://passengersinhistory.sa.gov.au/voyage-search>.

State Library of South Australia, SRG 94/A94 reel no. 64, St Marys on the Sturt Baptisms 1846-1953, Marriages 1853-1953 and Burials 1847-1952.

State Library of South Australia, 929.39423 S726, South Australian Census 1841 returns.

Tafuri, M.A., R.A Bentley, G. Manzi and S. Di Lernia 2006 Mobility and kinship in the prehistoric Sahara: Strontium isotope analysis of Holocene human skeletons from the Acacus Mts. (southwestern Libya). *Journal of Anthropological Archaeology* 25(3): 390 – 402.

Taylor, D. 2001 Stable Isotope Ratio Analysis of the Human Bone Retrieved from St Mary's Churchyard and Chemical Analysis of the Surrounding Soil. Unpublished BSc. Honours Thesis. Department of Forensic and Analytical Chemistry, Flinders University, Adelaide, South Australia.

Thompson, L.G, E. Mosley-Thompson and K.A. Henderson 2000 Ice-core palaeoclimate records in tropical South America since the last glacial maximum. *Journal of Quaternary Science* 15(4): 377 – 394.

Toncala, A., F. Söllner, C. Mayr, S. Hölzl, K. Heck, D. Wycisk and D. Grupe 2017 Isotopic map of the Inn-Eisack-Adige-Brenner Passage and its application to prehistoric human cremations. In Grupe G., Grigat A., McGlynn G. (eds) *Across the Alps in Prehistory*. Springer, Cham.

Walsh, J. 2019 personal communication

Walsh, J. 2019 There's Something About St. Mary's: the relevance of burial archaeology in a colonial South Australian community. Unpublished honours thesis, College of Humanities, Arts and Social Sciences, Flinders University.

Waterman, A.J., D.W. Peate, A.M. Silva and J.T. Thomas 2014 In search of homelands: using strontium isotopes to identify biological markers of mobility in late prehistoric Portugal. *Journal of Archaeological Science* 42:119-127.

Wegmann, S. 1989 *The Swiss in Australia.* Grüsch: Verlag Rüegger.

Whitelock, D. 1977 *Adelaide 1836– 1976 A history of difference.* St Lucia, Queensland: University of Queensland.

Willmes, M., L. McMorrow, L. Kinsley, R. Armstrong, M. Aubert, S. Eggins, C. Falguères, B. Maureille, I. Moffat and R. Grün, 2014, The IRHUM (Isotopic Reconstruction of Human Migration) database - bioavailable strontium isotopes of France for geochemical fingerprinting, *Earth System Science Data*, 6: 761-777.

Willmes, M., L. Kinsley, M.H. Moncel, R.A. Armstrong, M. Aubert, S. Eggins and R. Grün 2016 Improvement of laser ablation in situ micro-analysis to identify diagenetic alteration and measure strontium isotope ratios in fossil human teeth. *Journal of Archaeological Science 70:* 102 – 116.

Willmes, M., C.P Bataille, H. James, I. Moffat, L. McMorrow, L. Kinsley, R.A. Armstrong, S. Eggins and R. Grün, 2018, Mapping of bioavailable $^{87}Sr/^{86}Sr$ isotope ratios in France for archaeology provenance studies, *Applied Geochemistry*, 90: 75-86.

Woodhead, J.D. 2005 Isotope ratio determination in the earth and environmental sciences: Developments and applications in 2003. *Geostandards and Geoanalytical Research*: 29(1): 26 – 36.

Wright, L.E. and H. Schwarcz 1998 Stable carbon and oxygen isotopes in human tooth enamel: identifying breastfeeding and weaning in prehistory. *American Journal of Physical Anthropology 106(1):*1-18.

Chapter 9 Appendices

Appendix 1

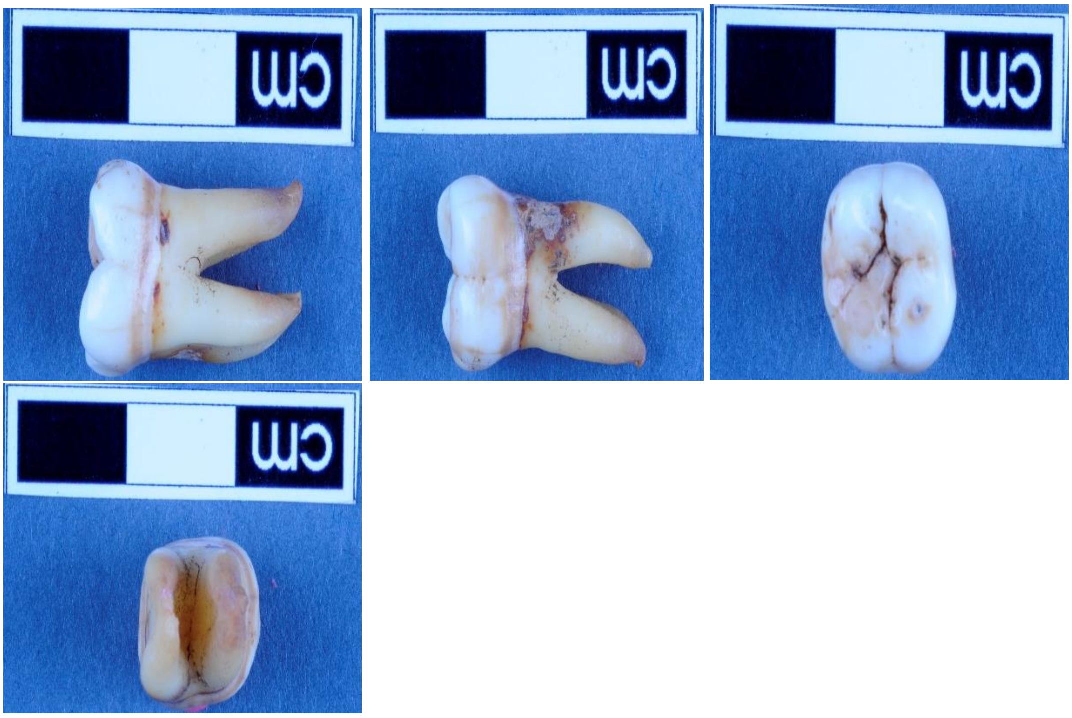
Burial 9



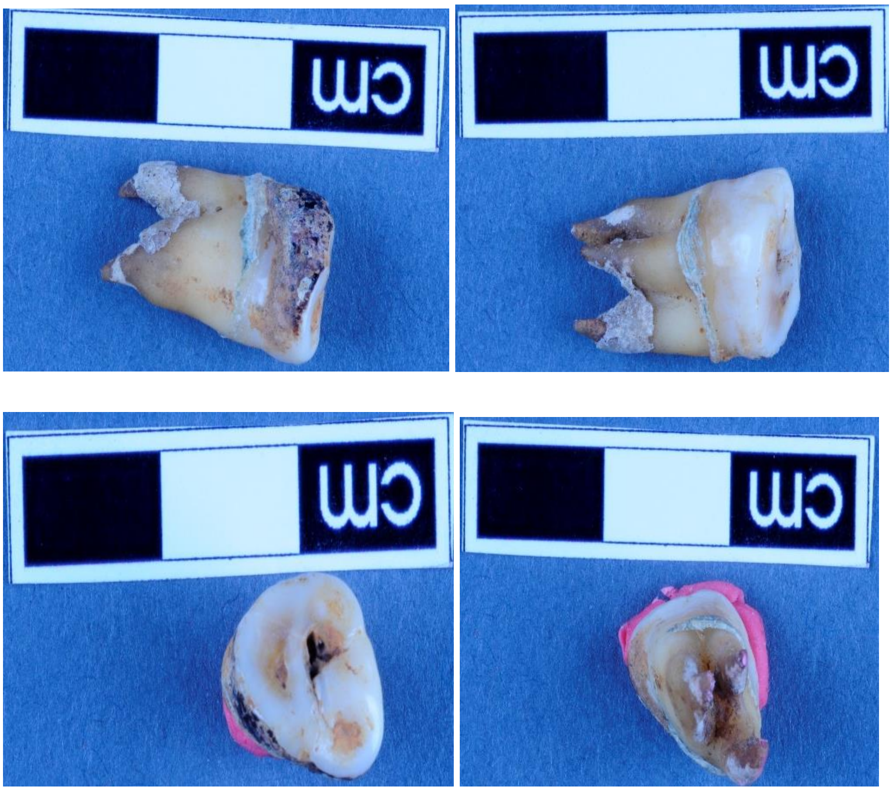

Burial 23




Burial 28

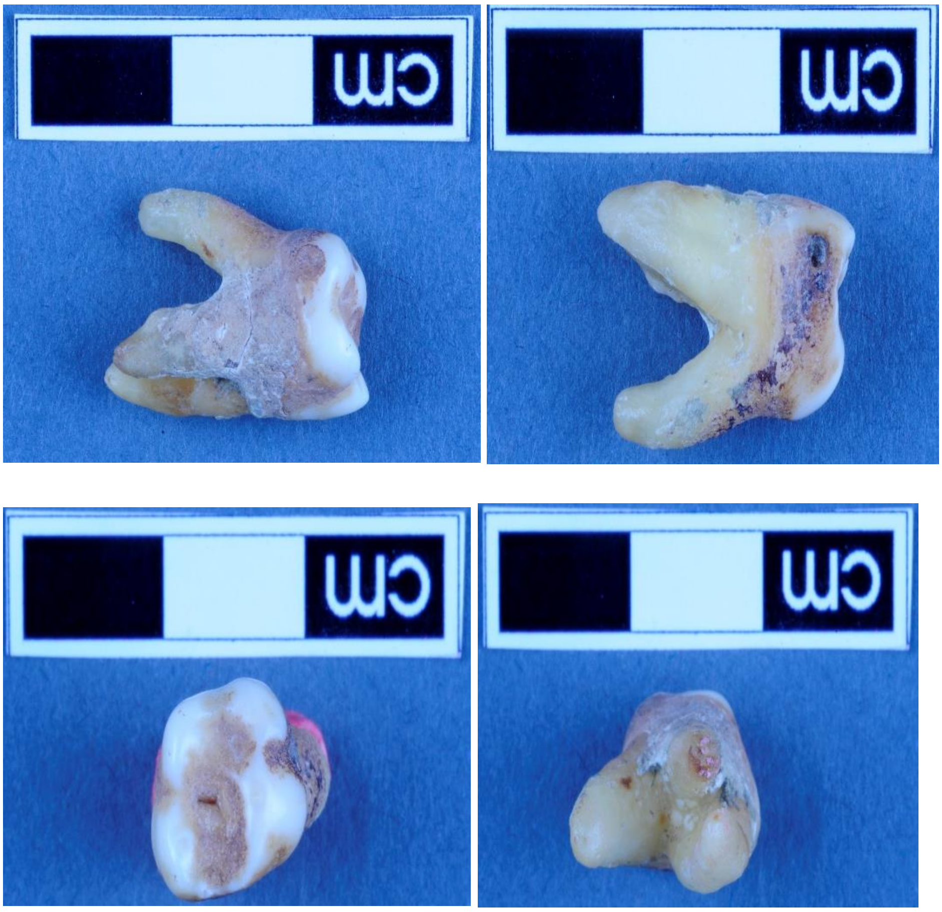


Burial 38

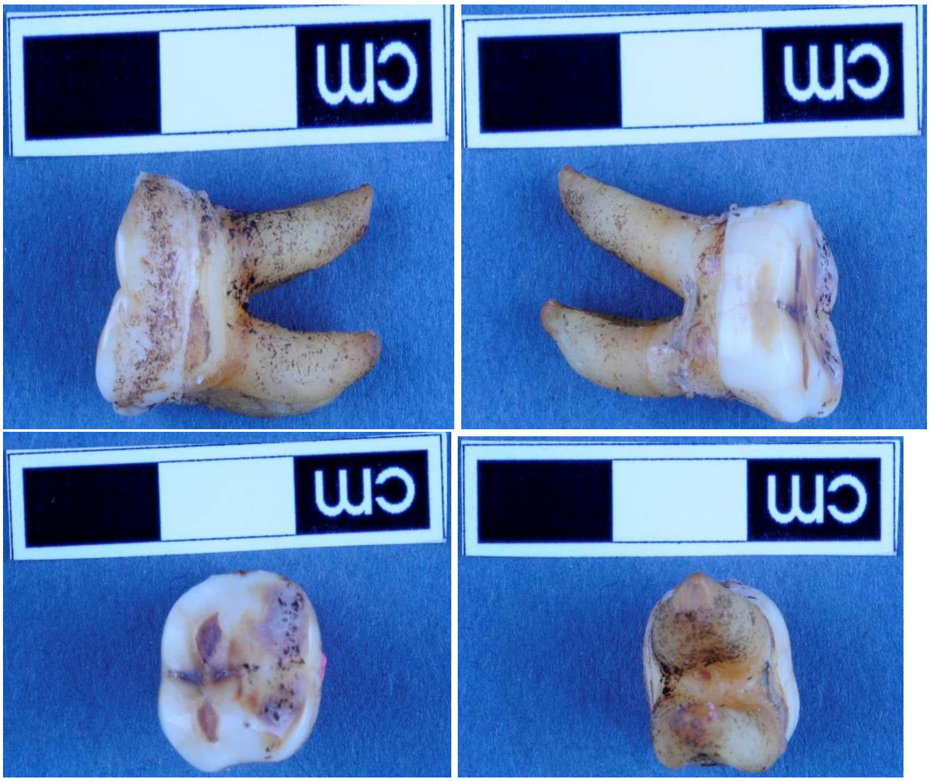


Burial 52b

Burial 53c



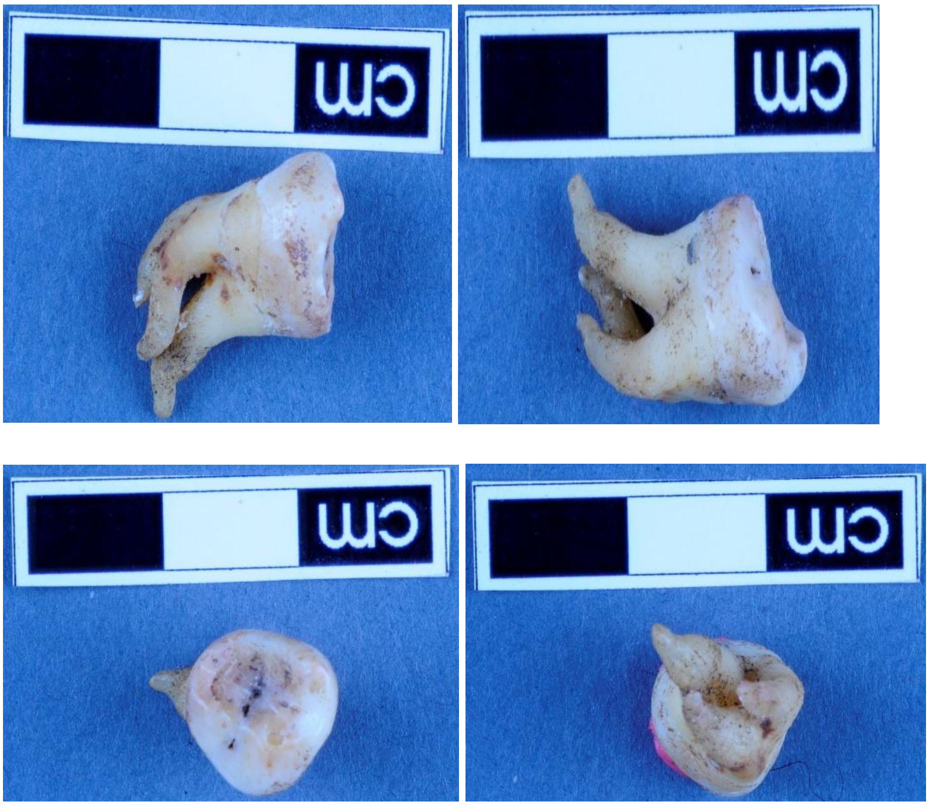
Burial 57



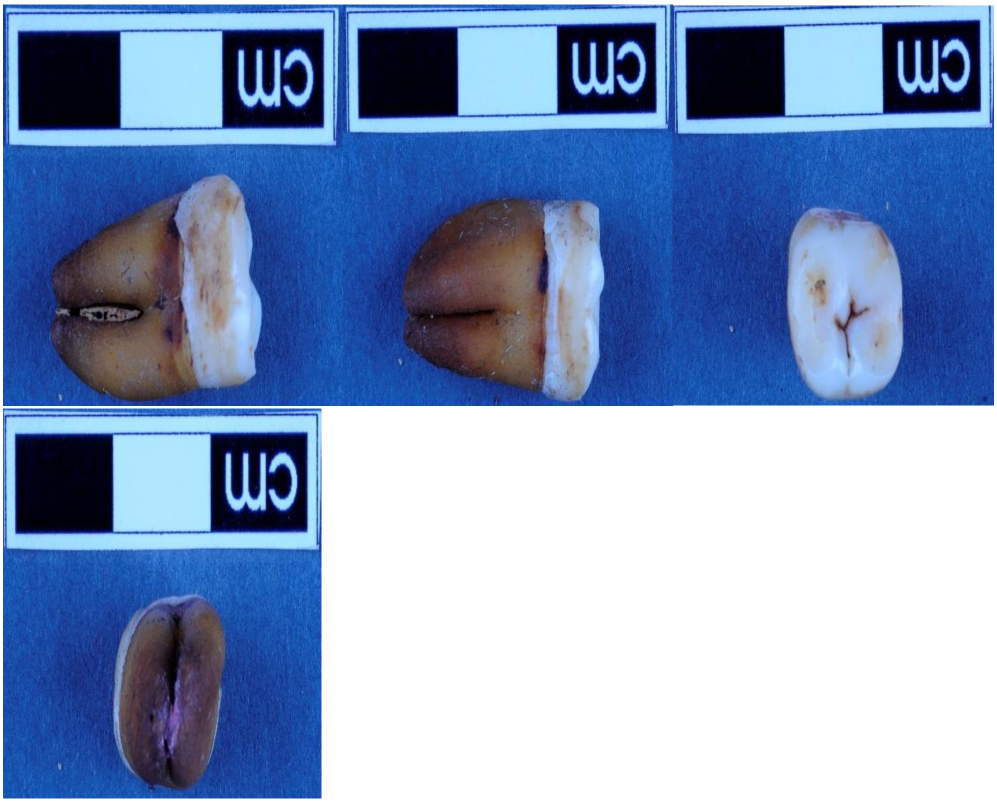
Burial 59

Burial 66b

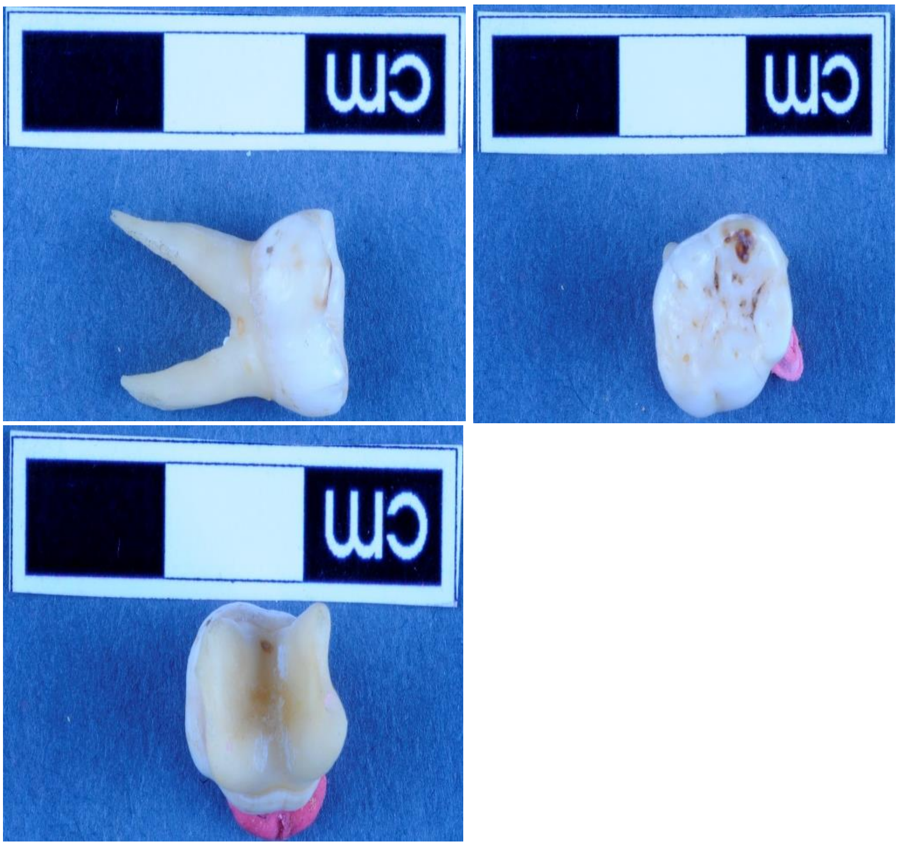
Burial 68



Burial 72



Burial 79



Burial 83

Appendix 2: Raw data from St Mary's Anglican Cemetery

Burial number/enamel or dentine	Peak	^{13}C mean	^{13}C ±2σ error	^{18}O mean $\delta^{18}O$ VPDB	^{18}O ± 2σ error $\delta^{18}O$ VPDB	$^{87/86}Sr$ mean	$^{87/86}Sr$ 2σ error
75DD	3	-9.41004	0.041449	-4.65124	0.085295	0.709852	0.000003
75DE	3	-11.5591	0.066569	-1.63701	0.165041	0.711378	0.000003
57E	3	-13.6873	0.04739	-4.10462	0.112867	0.710376	0.000003
57D	3	-11.3192	0.044617	-3.99384	0.104609	0.711085	0.000003
79D	3	-10.8649	0.019758	-1.80044	0.93023	0.711918	0.000003
79E	3	-11.7727	0.047376	-0.39141	0.129593	0.711467	0.000003
59D	3	-10.5952	0.046849	-3.71733	0.131393	0.711162	0.000003
59E	3	-12.116	0.024329	-3.60354	0.058832	0.711173	0.000002
72D	3	-12.2358	0.047542	-3.97397	0.08263	0.710112	0.000003
72E	NA	NA	NA	NA	NA	0.710980	0.000004
66BE	3	-13.6229	0.013906	-5.8911	0.112798	0.711318	0.000003
66BD	3	-11.49	0.213696	-4.83596	1.147125	0.711085	0.000003
66BD	3	-11.8417	0.04712	-4.95445	0.049371	NA	NA
83D	3	-10.9256	0.038142	-3.40132	0.040552	0.710644	0.000003
83E	NA	NA	NA	NA	NA	0.711472	0.000003

53CE	3	-10.5087	0.032868	-2.24245	0.142416	0.709862	0.000003
53CD	3	-13.7317	0.055704	-4.35785	0.299254	0.710762	0.000003
23D	3	-10.9013	0.030349	-2.05495	0.0976	0.711322	0.000003
23E	3	-11.8448	0.057064	-0.83967	0.135041	0.711364	0.000003
68E	3	-12.9693	0.031157	-4.20935	0.113694		
68E	3	-12.9078	0.048706	-4.04469	0.075518	0.711075	0.000003
68D	3	-13.2905	0.110218	-4.59292	0.343542	0.711295	0.000003
28E	3	-12.178	0.038817	-2.9387	0.139036	0.711038	0.000003
28D	NA	NA	NA	NA	NA	0.711293	0.000004
9E	3	-11.6206	0.054672	-3.85325	0.235113	0.709567	0.000003
9D	3	-11.9935	0.000255	-4.5173	0.023137	0.710882	0.000003
52BD	3	-11.232	0.048447	-4.03083	0.110495	0.711788	0.000003
52BE	3	-11.1159	0.028655	-2.6203	0.099246	0.712016	0.000004

Table 14 Raw data St Mary's Anglican Cemetery