Chapter Four: Materials and Methods

4.1 Materials

Tooth samples used in this study were from human permanent dentition (molars and premolars) from 29 individuals from the Tarbat Old Church (St. Colman's Church) site in Portmahomack and 2 individuals from Balnabruach, near Portmahomack. The 2 individuals from Balnabruach were discovered in 1992 during ground preparation for a pump house near Balnabruach. Daphne Home Lorimer conducted the skeletal report on the human remains in 1995 (Lormier, 1995). Field Archaeology Specialists Ltd. (FAS) discovered the remaining 29 individuals during the excavation of the Tarbat Old Church between the 1994 and 2002 field seasons (Carver, 2003). Field Archaeology Specialists Ltd. (FAS), University of York, sent all 31 samples for strontium and oxygen isotope analysis to determine possible local origins of individuals buried in and near the church. The samples represented varying phases, burial types, sexes and ages of human remains discovered during excavation as well as interesting burials (Appendix 1). Sarah E. King (2000) performed the skeletal analysis of these human remains. Phases represented within the sample included Phase 0 (Mid-Later Iron Age), Phase 1 (8^{th} Century AD), Phase 2 (later 8^{th}-11^{th} Century AD), Phase 3 and Phase 4 (12^{th}-16^{th} Century AD) (King, 2000). There were two distinct periods between Phases 2 and 3. Phase 2 represented a monastic settlement at Portmahomack, which was determined from the population demographic of the burials (Carver, 2008). A large number of male burials aged between 17 and 46+ years at death were excavated while few females and non-adults were present (King, 2000; Carver, 2008). The human skeletal assemblage found within Phase 3 burials led excavators to determine they were part of a medieval settlement. There was a mixture of males, females, and non-adults ranging in age at death (Carver, 1997; King, 2000; Carver, 2008). Burial types varied and included long cists, shrouds, coffins, head supports, wood/wicker, and unknown/unreported burials (Carver, 2008). Unique burials included burials 017, 030, 036, and 117. These will be analysed in detail in the discussion.

The analysis of the 31 enamel samples (one from each individual) had been completed on two separate occasions. The first analysis was a pilot study of 12 samples which was conducted by Dr Janet Montgomery. The author of the present study, under the supervision of Dr Janet Montgomery (removal of enamel and sample preparation) and under the instruction of Dr Jane Evans (NERC- Isotope Geosciences Laboratory), conducted the analysis of the remaining 19 samples. Both sets of samples were analysed at a class 100, HEPA-filtered laboratory facility at the NERC Isotope Geosciences Laboratory (NIGL) in Keyworth, UK for consistency. For the second analysis, macroscopic condition of each sample tooth were noted and photographs taken prior to sample preparation. Each tooth was photographed from the buccal, lingual, mesial, distal, occlusal and root angles and compiled into one photograph which can be seen in Appendix 2.

4.2 Methods of Analysis

Enamel was chosen for strontium and oxygen isotope analysis because several studies have shown that it is less susceptible to diagenetic change than bone (Budd *et al.*, 2000; Montgomery, 2002; Hoppe *et al.*, 2003). Each tooth demonstrates a period of time in an individual's life and demonstrates the strontium and oxygen isotopes from their surroundings during that period (Evans *et al*., 2006a). Most crowns complete formation between the ages 2.5 and 15 years (Table 1) so this analysis would demonstrate the local geology and climate at the time of childhood. The enamel preparation for strontium and oxygen isotopes was performed at the Department of Archaeology at Durham University and analysis of the isotopes were conducted at the NERC Isotope Geosciences Laboratory (NIGL) at the British Geological Survey in Keyworth, UK. The 12 pilot study samples were processed prior to the 19 samples in the secondary analysis. For oxygen isotope analysis, the 12 samples for the pilot study used phosphate (PO_4^{3-}) to extract oxygen, while the 19 samples for the secondary analysis used carbonate (CO_3^{2-}).

Tooth	Initial Crown Mineralisation	Crown Complete	Eruption	Root Complete
First Molar	Peri-natal-Birth	2.5-4.25 Years	5-8 Years	9-11.5 Years
Second Molar	2.5-3 Years	7-8 Years	10-14 Years	14-16 Years
Third Molar	8-11 Years	11.5-15 Years	___	17-19 Years
First Premolar	1.5-2 Years	4.5-7 Years	8-1 Years	12-14.25 Years
Second Premolar	2-2.5 Years	6-8 Years	9-14 Years	12-15.5 Years

Table 1: Permanent Dentition Crown Mineralisation and Root Completion. Source: Gustafson and Koch (1974), Third Molar Data from Anderson et al (1976).

The following methods section describes the process for the 19 samples in the secondary analysis undertaken by the author under the supervision of Dr Janet Montgomery and Dr Jane Evans. Tooth sample preparation followed guidelines outlined by Montgomery (2002) with slight modifications due to available laboratory materials. Studies using this method included Montgomery (2002), Montgomery *et al.* (2003), Montgomery *et al.* (2005), Montgomery *et al.*, (2006) and Montgomery *et al.* (2007). Dental tools used to remove enamel from sample teeth include tungsten carbide dental burs and a stainless steel saw with a diamond cutting edge. Each tooth was analysed macroscopically prior to sample preparation. Dental instruments were cleaned prior to use to prevent any contamination of samples. They tools were ultrasonicated in deionised water for 5 minutes to remove any remaining particulates. Dental tools were cleaned again after each sample was collected. The crown surface of enamel chosen for sampling was removed to a depth of >100μm by tungsten carbide dental burs. This removed areas of discolouration, carious lesions, or calculus on the enamel to prevent contamination. Removed enamel material was discarded. The flexible dental saw was used to cut away a thin portion of enamel, removing as little of the tooth and dentine as possible. The angle and section of the tooth was chosen to minimise loss of the sample and destruction of the tooth. Any dentine or discolouration still present on the enamel sample were removed with the tungsten dental carbide burs along with any saw surface to prevent dental saw contamination. These samples were then transported in sealed, clean test tubes to NIGL where they were separated in to oxygen and strontium samples and further prepared in a clean laboratory.

The remainder of the analysis was performed at a class 100, HEPA-filtered laboratory facility at the NERC Isotope Geosciences Laboratory (NIGL) in Keyworth, UK under the instruction and supervision of Dr Jane Evans. Strontium isotope samples were prepared as outlined in Evans *et al.* (2006a,b). Each sample was cleaned by adding acetone to remove oil and grease from the enamel surface. Samples were rinsed in deionised water two times before being placed on a heated plate for 45 minutes. After 45 minutes, samples were rinsed twice and then cleaned ultrasonically for 5 minutes to remove any small particulates from the enamel surface. Samples were rinsed once again and left empty of liquid on a heated plate overnight to dry. The next day the weight of each sample was recorded and a known amount of strontium tracer solution was added. Dowex resin columns were already prepared for the strontium samples. A small amount of 2.5M HCl was placed into resin beakers to soak into the resin. Afterwards, 2 mL of enamel solution were loaded into each beaker. A new pipette was used each time to prevent sample contamination. They soaked into the resin and the leftover enamel solution was placed in small test tubes and set aside. Once the sample had fully soaked into the resin, 46-47 mL of 2.5M HCl solution was added to the beakers to help push the enamel solution through the resin (~3 hours). This amount of 2.5M HCl pushes lighter elements through the resin more quickly than strontium. These elements, not including strontium, were collected in a beaker under the resin tubes and set aside. An additional 10 mL of 2.5 M HCl was added to the resin beakers to force the remaining strontium elements through the resin to be collected in plastic containers. Once collected the samples were placed on a heated plate and remained there for further testing. The concentrations of $^{87}Sr/^{86}Sr$ ratios were determined by Thermal Ionisation Mass spectrometry (TIMS) using Finnegan MAT262 thermal ionisation multicollector mass spectrometer. The repeated $^{87}Sr/^{86}Sr$ value for the strontium machine had given a value of 0.710251±0.00001 (2s, N=18).

Enamel designated for oxygen isotope analysis was crushed to a powder consistency in a mortar and pestle. The enamel powder was given to Dr Hilary Sloane of the NERC Isotope Geosciences Laboratory (NIGL) to prepare and analyse for carbonate oxygen. The following procedure is outlined from the laboratory at NIGL. Three milligrams of the crushed enamel were placed into glass vials and set on a large hot plate at 90°C. The vials were emptied and four drops of anhydrous phosphoric acid were added. The chemical reaction produced CO_2 that was collected cryogenically over 14 minutes. It was then transferred to a GV IsoPrime dual inlet mass spectrometer. The oxygen isotope values are reported in parts per mil (±‰, $^{18}O/^{16}O$). These were normalized to the v-PDB scale using an in-house reference material calibrated against NBS19 certified reference material. The oxygen carbonate material was converted to SMOW using the equation from Coplan (1988) (SMOW=1.03091 x $\delta^{18}O$ PDB +30.91). The pilot study was collected as $\delta^{18}O_p$, so $\delta^{18}O_c$ values had to be recalculated using Chenery *et al*. (2012) regression formula ($\delta^{18}O_p = 1.0322(\pm 0.008) * \delta^{18}O_c - 9.6849(\pm 0.187)$) with a maximum error of ± 0.013‰ , 1σ.

Chapter Five: Results

5.1 Results

Strontium ($^{87}Sr/^{86}Sr$), carbonate oxygen ($\delta^{18}O_c$) and phosphate oxygen ($\delta^{18}O_p$) results of all 31 samples from individuals buried at Portmahomack are located in Appendix 3. The 19 samples prepared and analysed by the author using $^{87}Sr/^{86}Sr$ and $\delta^{18}O_c$, are in Figure 8. The $^{87}Sr/^{86}Sr$ sample from burial 152 failed and could not be remeasured during the timescale of this project. Only 18 samples from the secondary analysis will be reported.

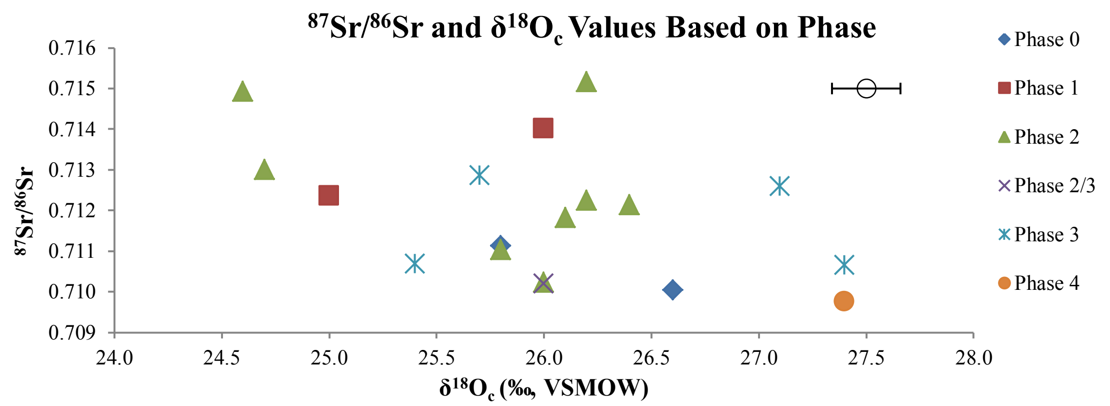

Fig 8: These are the $^{87}Sr/^{86}Sr$ ratios and $\delta^{18}O_c$ values for the 18 samples the author produced for the secondary analysis grouped by phase. These results are grouped by phase to show temporal trends. The analytical error value associated with the $\delta^{18}O_c$ values is ±0.16‰ (1σ) and can be found in the upper right corner of the graph. The 2σ errors for strontium are within the symbol.

The remaining 18 $\delta^{18}O_c$ were converted to phosphate values using the equation of Chenery *et al.* (2012) with an associated error of ±0.013, 1σ, in order to compare the 12 pilot samples with the current 19 samples. The local range of strontium isotope ratios was determined by comparing differences in $^{87}Sr/^{86}Sr$ between the enamel and dentine of the same individuals (Montgomery *et al.*, 2007) (Fig 9) and isotope maps (Appendix 4).

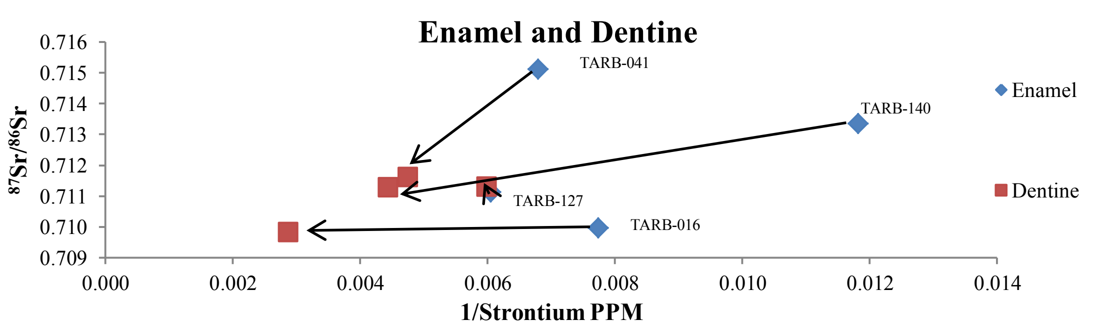

Fig 9: Enamel and dentine from the same tooth were analysed to detect changes from childhood to current burial soil to determine the local strontium isotope ratio range at Portmahomack. Based on this the local range for strontium isotopes lies between 0.7098 and 0.7112.

Approximately 16 individuals from this sample were within the local range. Drinking water maps adapted from Darling and Talbot (2003) aided in determining the local oxygen isotope value (Appendix 4). Evans *et al.* (2012) stated the range for $^{87}Sr/^{86}Sr$ is between 0.7078 and 0.7142 for England and Wales and up to 0.7165 in Scotland, while Chenery *et al.* (2010) found the 2σ range for $\delta^{18}O_p$ to be 16.8-18.6‰ (mean of 17.7‰ ±0.9 from 57 individuals from 9 sites). Anything outside of these ranges is likely to indicate someone originating outside of Great Britain (Eckardt *et al.*, 2009). The $^{87}Sr/^{86}Sr$ for the 30 individuals range between 0.7097 and 0.7152, with a median value of 0.7112. Medians are reported instead of means for strontium isotopes because the values are not normally distributed and usually cluster closer to rainwater values (0.7092) in Great Britain (Montgomery, 2010). The higher values in this study skew the mean toward higher strontium composition and concentrations and do not represent what is occurring within the data (Janet Montgomery, personal communication, 2012) See Appendix 5 for the descriptive statistics and graphs for $^{87}Sr/^{86}Sr$, $\delta^{18}O_c$ and $\delta^{18}O_p$. The $^{87}Sr/^{86}Sr$ concentrations are between 57 ppm and 200 ppm with a median value of 124 ppm. These values are higher than other studies of human enamel from archaeological sites within Britain (mean 98 ppm ±130 ppm, 2σ, *n*=197) (Montgomery *et al.*, 2000; Montgomery *et al.,* 2003; Evans *et al.*2006a,b; Montgomery *et al.*, 2007; Eckardt *et al.*, 2009; Leach *et al.*, 2009; Chenery *et al.*, 2010).

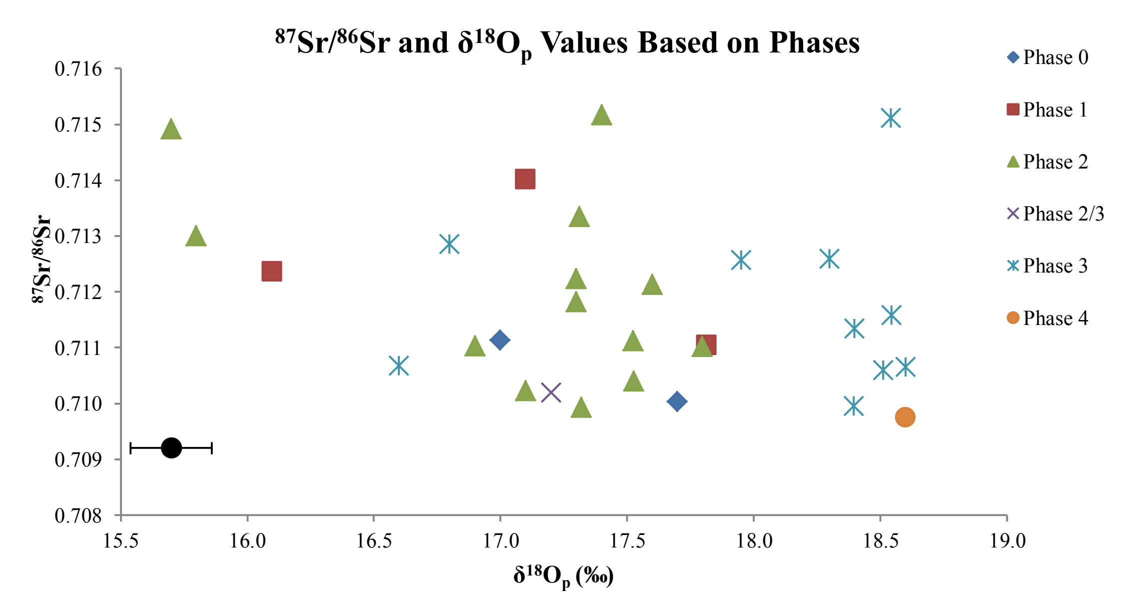

Fig 10: Graph of $^{87}Sr/^{86}Sr$ and $\delta^{18}O_p$ values for the 30 samples from Portmahomack. The phosphate values were converted from Chenery et al.*(2012) equation with a standard error of ±0.013. Since this error is much small than the one associated with analytical value (±0.16‰) the error bar on the graph in the lower left corner remains the same as previous graphs.*

The $\delta^{18}O_c$ values for the 18 samples prepared and analysed by the author range between 24.6‰ and 27.4‰ (±0.16, 1σ, based on Chenery *et al.* 2012), with a mean value of 25.9‰ ±1.6‰, 2σ. There are three $\delta^{18}O_c$ values that are higher than 27.0‰ belonging to Phases 3 and 4, while three $\delta^{18}O_c$ values are lower than 25.1‰ belonging to Phases 1 and 2. All 18 samples were converted to $\delta^{18}O_p$ using the equation from Chenery *et al.* (2012) and added to the original 12 samples from the pilot study (Fig 10). The $\delta^{18}O_p$ values for the 30 samples range between 15.7‰ and 18.6‰ with a mean of 17.5‰ ±1.6, 2σ. Like the $\delta^{18}O_c$ values, three samples from Phase 1 and 2 have lower values, while Phase 3 has higher values overall, with the exception of two outliers that were below 17.0‰.

Since isotope ratios can be affected by dietary influences (Ericson, 1985; Cox and Sealy, 1997) like breastfeeding or a heavy marine diet, enamel carbon isotope ratios were plotted to determine if diet had any influence over the ratios (Fig 11). Samples from Phase 1 and 2 have lower $\delta^{13}C_c$ values, while samples from Phase 3 and 4 demonstrate higher $\delta^{13}C_c$ values. Because there is a difference between Phase 2 and Phase 3 (the monastic and medieval phases), their $^{18}O_p$ values were converted to $^{18}O_{dw}$ with Daux *et al.*(2008) equation (4):

$$\delta^{18}O_{dw} = 1.73(\pm 0.21)*\delta^{18}O_p - 37.25(\pm 3.55)$$

Based on Darling and Talbot (2003) rainwater map (Appendix 4), Evans *et al.* (2012) discovered that areas with large amounts of rainfall in Great Britain (the west coast) had

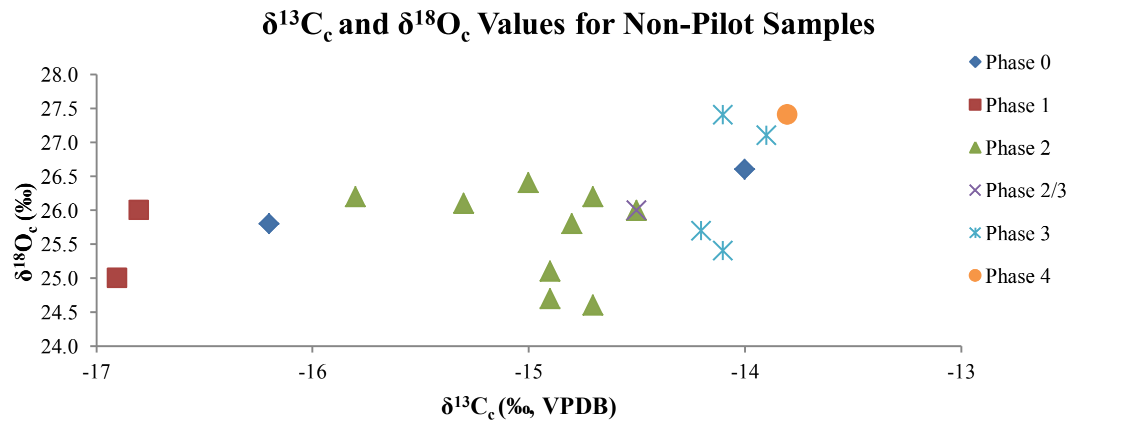

Fig 11: Carbon and oxygen isotope values were graphed to detect any temporal trends in terms of dietary intake of terrestrial or marine products. There are clear temporal trends with the consumption of marine products increasing through time.

higher $\delta^{18}O_{dw}$ values, while areas with lower amounts of rainfall had lower $\delta^{18}O_{dw}$ values. Areas in Britain with higher annual rainfall averages had an average drinking water value of -5.8±1.8‰[3] and lower rainfall areas had an average drinking water value of -7.5±1.8‰ (Evans *et al.*, 2012).

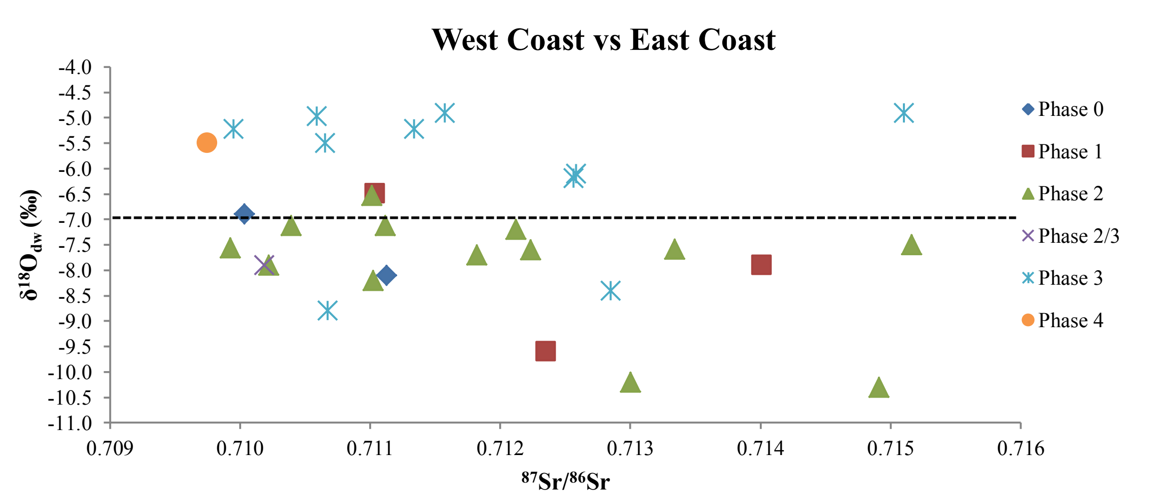

Fig 12: $\delta^{18}O_p$ values were converted to $\delta^{18}O_{dw}$ values with Daux et al.*, (2008) equation to detect geographical trends. Values higher than -7.0 are generally found on the western part of Great Britain, while values lower than -7.0 are generally found on the eastern part of Great Britain. Those from phase 2 generally originated from the eastern part of Great Britain and those from phase 3 and 4 originated from the western part of Great Britain. The black dotted line represents the dividing line between the west and the east. These values can vary, hence the dotted line and not solid line.*

Based on this information and the British Geological Survey Map (2004) (Appendix 4) individuals with $\delta^{18}O_{dw}$ above -7.0‰ are likely to be from the west coast and individuals with values below from the east coast. The majority of Phase 2 samples come from the east coast, while the majority of Phase 3 samples come from the west coast of Great Britain (Fig 12). There is a statistically significant difference between these two phases (t-Test; $p < 0.001141$, n=24).

Chapter Six: Discussion of Results

6.1 Discussion

The sample population from Portmahomack demonstrates a wide range of both strontium and oxygen isotope values. The strontium isotope range for Portmahomack was determined by analysing both the dentine and enamel from four burials to detect whether there was a change in strontium isotope ratios. Dentine is more susceptible to post-mortem changes and therefore more likely to reflect the values of the burial environment (Montgomery *et al.*, 2003). The dentine and enamel values of each burial sample were graphed (Fig 9, Chapter 5, pg. 25). Based on this graph the lower local boundary is 0.7098 and upper local boundary is 0.7112 for Portmahomack. The wide range in values for both strontium and oxygen isotopes indicate a variety of possible origins for this population, both within and outside of Great Britain. When the samples are categorised by phases (determined stratigraphically), patterns emerge, showing temporal trends of movement and diet.

6.2 General Population Comparisons from Around Great Britain

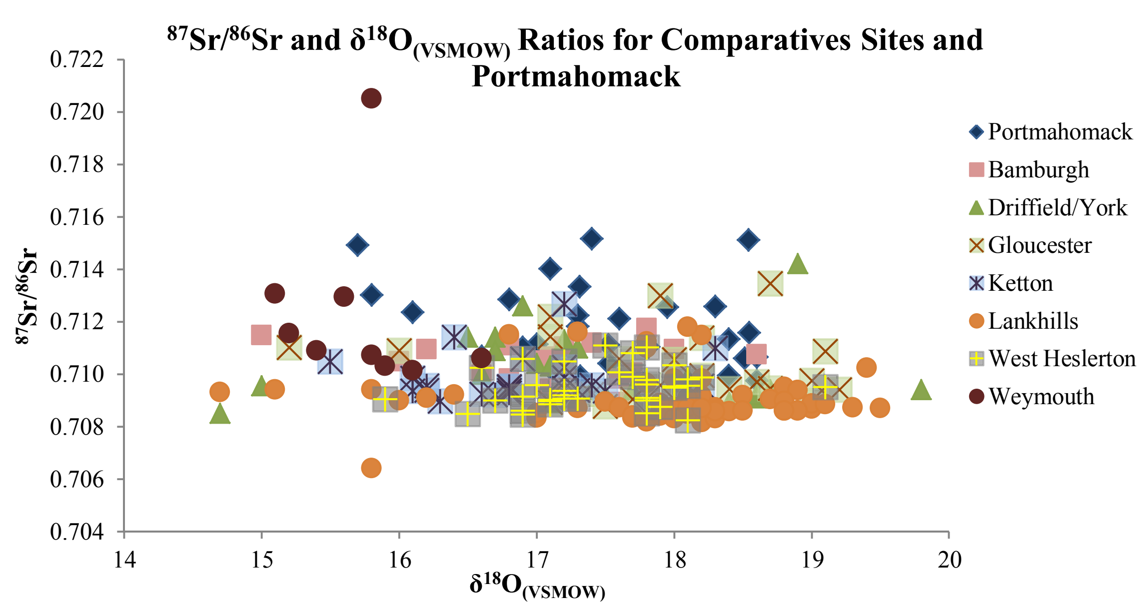

Fig 13: Scatter Plot of strontium isotope ratios and oxygen isotope values from Bamburgh, Driffield/York, Gloucester, Ketton, Lankhills, West Heslerton, Weymouth and Portmahomack. The strontium and oxygen isotope ratios used in this graph came from Appendix 1 from Evans et al.*, 2012.*

The wide range of isotopic values from Portmahomack limits the number of sites in Great Britain that can be compared. In Evans *et al.* (2012), a summary of strontium and oxygen isotope values were collected for analysis from 74 archaeological sites throughout Great Britain. Of these sites, only seven have comparably wide ranges to Portmahomack:

- Bamburgh, dates to Medieval period
- Driffield/York, dates to Roman period
- Gloucester, dates to Roman period
- Ketton (Rutland), dates to Anglo-Saxon period
- Lankhills (Winchester), dates to Roman period
- West Heslerton, dates to Anglo-Saxon period
- Weymouth (Ridgeway Hills), dates to Medieval period

All strontium and oxygen isotope values gathered for this paper are graphed in Figure 13 and gathered from Appendix 1 of Evans *et al.* (2012).

Portmahomack's human strontium isotope range is from ~0.7097 to ~0.7152. Non-parametric tests were performed and indicated a peak in values between 0.7104 and

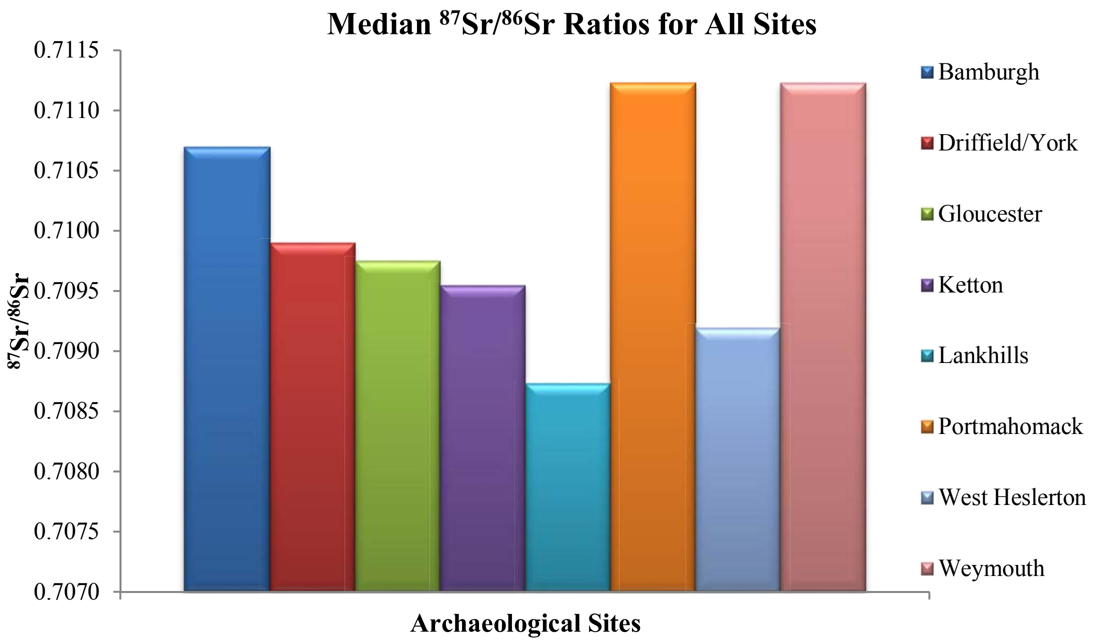

Fig 14: Graph of median strontium isotope ratios from all seven comparable archaeological sites and from Portmahomack. Portmahomack and Weymouth have medians of 0.71123 and 0.711225, respectively. Bamburgh is the only other site that had a median value above 0.7100 (0.710698). Ratios used to calculate median ratios of comparable archaeological sites from Appendix 1 in Evans et al.*, 2012.*

0.7128 (Appendix 5). The archaeological sites with a few human strontium isotope ratios that are higher than 0.7142 (the upper boundary of England and Wales (Evans *et al.*, 2012)), include Portmahomack and Weymouth. Approximately 10% of both

Porthmahomack's and Weymouth's sample population had strontium isotope ratios that were higher than 0.7142. Such values indicate origins in an area with older underlying

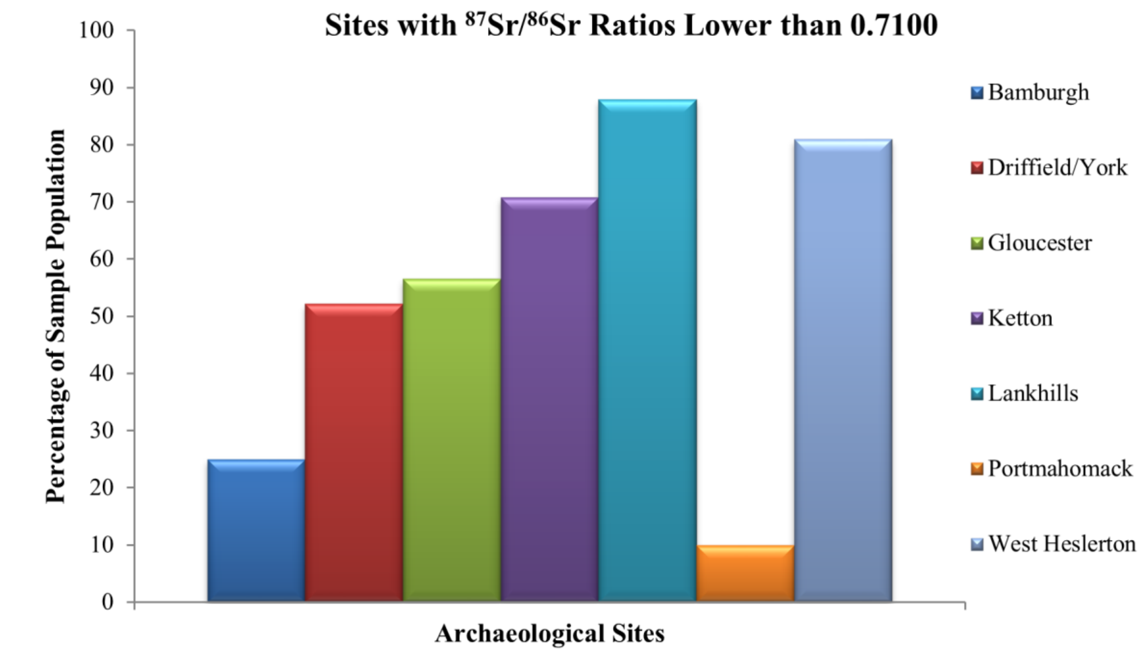

Fig 15: Percentage of the sample population from each comparable archaeological site with strontium isotope ratios lower than 0.7100. Bamburgh, Portmahomack and Weymouth (not graphed) have few ratios at or below 0.7100. Bamburgh has 25% of its sample population at or below 0.7100, while Portmahomack and Weymouth have 10% and 0%, respectively. Source for strontium isotope ratios for comparable archaeological sites are from Appendix 1 in Evans et al.*, 2012.*

bedrocks (Evans *et al.*, 2012). The median strontium isotope ratios from all comparable sites were calculated to determine which site medians were closest to Portmahomack (Fig 14). The sites with the closest values are Bamburgh and Weymouth. These three sites have ratios that are similar due to the fact that they are all located on the coasts of Great Britain, while the other five sites are located more inland. These five sites with lower strontium isotope ratios (Driffield/York, Gloucester, Ketton, Lankhills and West Heslerton) have a higher percentage of their sample population with ratios below 0.7100 (Fig 15). Portmahomack and Bamburgh have few in their sample population below 0.7100 (10% and 25%, respectively). These sites may have few lower strontium isotope ratios considering their sites' location are in the north-eastern part of England and Scotland, respectively. There are older underlying bedrocks in these areas which could give higher strontium isotope ratios.

The phosphate oxygen isotope values for Portmahomack are not as high as some archaeological sites and range between ~15.5‰ and ~18.5‰.

$\delta^{18}O_p$ Values	Percentage of Portmahomack
15-15.9‰	6%
16.0-16.9‰	16%
17.0-17.9‰	52%
18.0-18.9‰	26%

Table 2: Percentage of $\delta^{18}O_p$ values from the sample population at Portmahomack. Categorized into 10‰.

The majority of Portmahomack's phosphate oxygen isotope values are between 17.0-17.9‰ (Table 2). Comparative archaeological sites that demonstrate a higher percentage (>40%) of sample population with oxygen isotope values greater than 18.0‰ include Gloucester and Lankhills (Fig 16). Both Gloucester and Lankhills are located in areas with higher percents of rainfall, while the other sites are located more toward the eastern

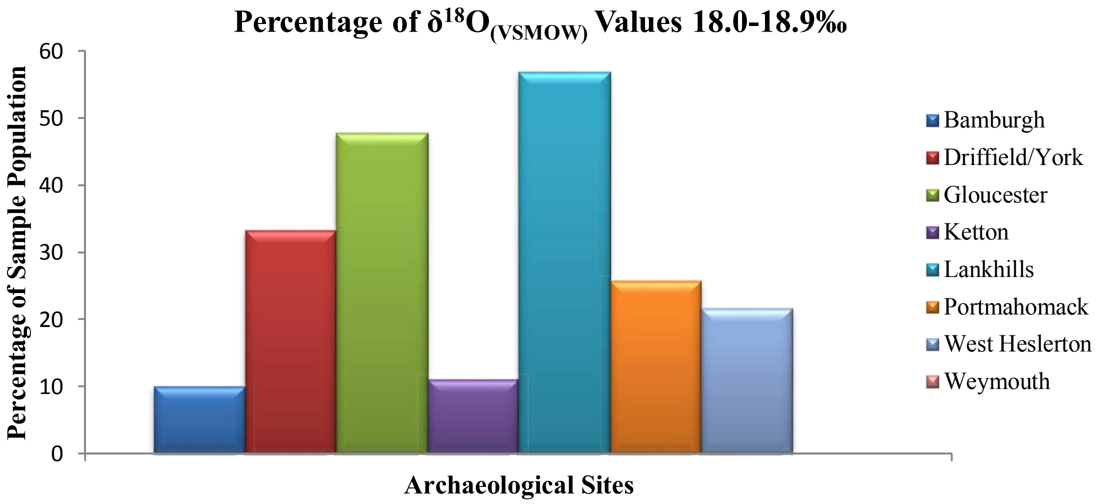

Fig 16: Percentage of sample population with $\delta^{18}O_{(VSMOW)}$ values between 18.0‰ and 18.9‰ from each comparable archaeological site. Gloucester and Lankhills have a larger percentage of their sample with higher $\delta^{18}O_{(VSMOW)}$ values, while the rest of the archaeological sites have fewer than 35% with these values. Source of $\delta^{18}O_{(VSMOW)}$ values of comparable archaeological sites from Appendix 1 in Evans et al.*, 2012.*

part of Great Britain. Only in Great Britain do higher values in oxygen isotopes indicate areas of higher rainfall (Evans *et al.*, 2012). The Gulf Stream in the Atlantic Ocean affects the weather patterns (especially winds) in the British Isles making the climate wetter on the western coasts and dryer on the eastern coasts of Great Britain (Janet Montgomery, personal communication, 2012) (Appendix 4). The median oxygen isotope values of all sites are in Figure 17. Bamburgh, Driffield/York and West Heslerton have similar oxygen isotope values to Portmahomack with median values between 17.2‰ and 17.5‰. These sites are located in the eastern part of England and Scotland. Ketton is located near the eastern part of England; however, its values are lower than these four sites. Weymouth is located on the southern coast and has values under 17‰. Two of Weymouth's samples date to the Viking period and came from individuals identified as being decapitated as part of an execution from a long-ship (Evans *et al.*, 2012). This large percentage of oxygen isotope values around 15‰ would suggest non- local people coming to Great Britain from other areas, perhaps Scandinavia. Portmahomack has two

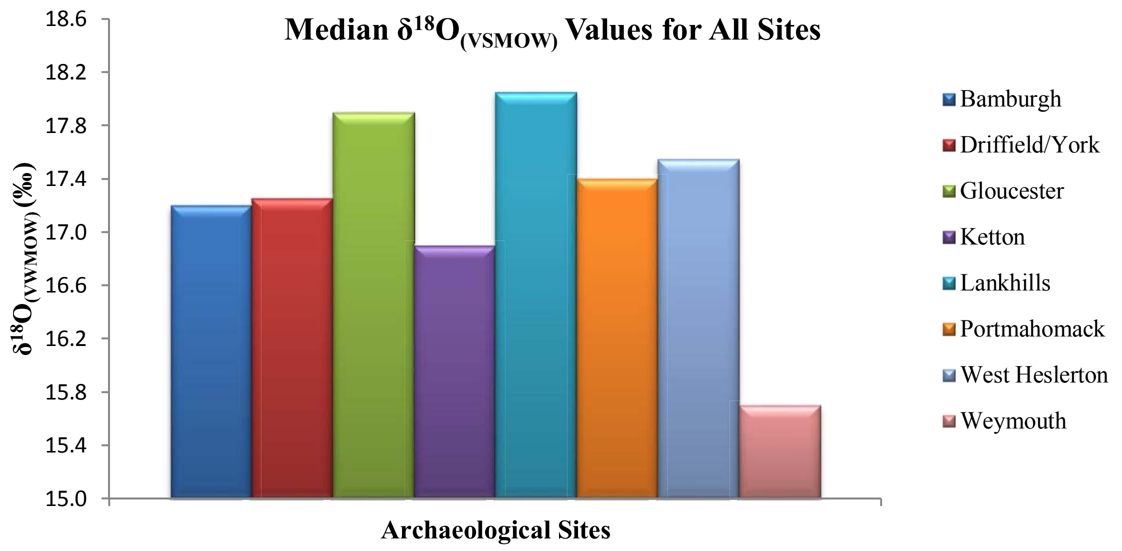

Fig 17: Graph of median $\delta^{18}O_{(VSMOW)}$ values from all comparable archaeological sites and Portmahomack. Gloucester and Lankhills have higher median $\delta^{18}O_{(VSMOW)}$ values than the majority of the sites. Sites that are close in range to Portmahomack's median value (17.4%o) include Bamburgh (17.2‰), Driffield/York (17.3‰) and West Heslerton (17.6‰). Weymouth has a lower median $\delta^{18}O_{(VSMOW)}$ value since some of its sample population was thought to be from Scandinavia (based on burial practice and trauma), which has lower $\delta^{18}O_{(VSMOW)}$ values. Source for $\delta^{18}O_{(VSMOW)}$ values for comparable archaeological sites from Appendix 1 in Evans et al.*, 2012.*

burials that fall into the 15‰ category for phosphate oxygen isotope values and will be discussed in a later section. There may not be many archaeological sites with strontium and oxygen isotope values that are similar to Portmahomack due to the fact that not many isotopic studies have been done in the north-eastern part of Scotland. This makes it difficult to compare and detect similar migration movements of the same time period and location, but it can help in identifying non-locals to Great Britain by identifying what is non-local at other sites throughout Great Britain.

6.3 Population Comparisons between Phases at Portmahomack

The sample population from Portmahomack is divided into phases to detect any temporal trends since, as discussed in Chapter 2, the history of the Picts fluctuates during the time periods represented in these samples. The samples processed by the author also had carbon values associated with the carbonate oxygen, so the individuals' carbon intake during childhood development (birth to 15 years of age- Table 1, Chapter 4, pg. 22) was analysed to detect temporal changes in diet. Figure 10 (Chapter 5, pg. 26) presents strontium isotope ratios and oxygen isotope values, while Figure 11 (Chapter 5, pg. 27) shows the carbonate oxygen and carbon values. Figure 18 is a map of Scotland and northern England demonstrating the location of comparable sites used in this discussion.

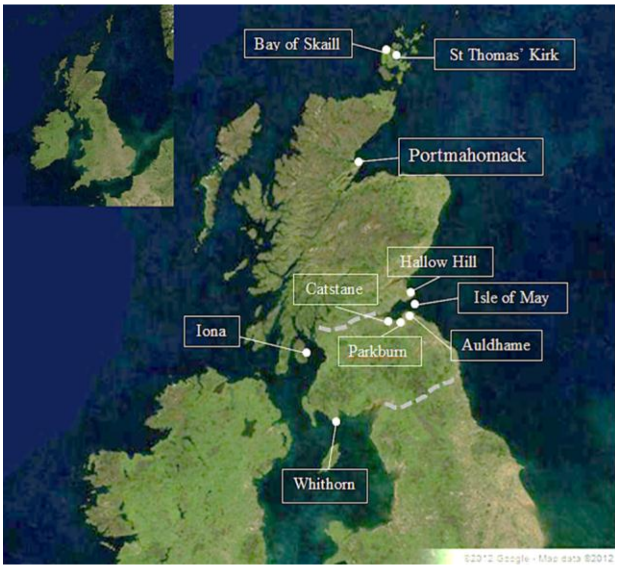

Fig 18: Map of archaeological sites within Scotland and its islands that are used to compare with Portmahomack. Source: Google Maps, 2012, additional elements added by author.

6.3.1 Phase 0 and Phase 1

There are only five samples that are from these two phases. This limits the amount of information that can be gathered about the population at Portmahomack during the Iron Age (Phase 0) and the 8th Century AD (Phase 1). The two Phase 0 burials are within the local range for strontium isotope ratios and are within 0.7‰ of one another in regards to their oxygen isotope values. The carbon values from carbonate oxygen demonstrate differences in the type of carbon (terrestrial or marine based) consumed during their childhood (Fig 11, Chapter 5, pg. 27). Balnabruach A has a higher carbon isotope value, indicating more marine intake in the diet, while Balnabruach C has a more terrestrial carbon isotope value. This is interesting because proteins from marine sources are not seen isotopically until the high medieval period (Müldner and Richards, 2007). These burials are thought to date to the mid to later Iron Age based on burial type, however a more defined date has not been established. This difference in the type of carbon consumed during childhood development could indicate two separate time periods, especially given the more marine value in carbon for Balnabruach A. A study by Jay *et al.* (forthcoming 2012), discovered a similar anomaly in the Beaker People Project. Two of their values indicated higher levels of marine food consumed, which was not expected during the time period these burials dated to (Late Neolithic to Early Bronze Age). Radiocarbon dates revealed they dated to the medieval time period and were included based on type of burial (short-cist with no grave goods) (Jay *et al.*, forthcoming 2012). This type of dating error could be occurring within the Balnabruach samples.

The three Phase 1 burials demonstrate no real patterns in regard to their strontium and oxygen isotope values. Only one burial (172) falls within the local strontium isotope ratio range for Portmahomack. The other two burials (186 and 187) have higher strontium isotope ratios, indicating they are probably not of local origin and came from places with older underlying bedrocks. Both have carbon isotope values, which demonstrate a terrestrial based diet (Fig 11, Chapter 5, pg. 27). All three have different oxygen isotope values indicating varying places of origin. Based on this data, it looks as though these three migrated to the Tarbat peninsula after the mineralisation of enamel had been completed (between 2.5 to 15 years of age- Table 1 Chapter 2, pg. 22). The type of burial they were discovered in was a long cist. Carver (2009) believes that long cist burials date back to prehistory, are not exclusively part of Christian burial practices and can be associated with Bronze or Iron Ages, which pre-date Christianity. Phase 1 burials date to the 8th Century AD, a time when many cemeteries have long cist burials, including the following cemeteries:

- Parkburn, Lothian, 6th-8th Centuries AD (Henshall, 1955/56)
- Catstane, Lothian, 5th-8th Centuries AD (James and Yeoman, 2008)
- Hallow Hill, St Andrews, 6th-9th Centuries AD (Proudfoot, 1996)

Parts of Catstane's and Parkburn's cemeteries are Christian in nature. The Catstane burials are organised into rows, while Parkburn burials are organised into well-spaced burials within organised rows (James and Yeoman, 2008). It is believed that Hallow Hill is an Early Christian cemetery belonging to a Pictish community considering its time period, location and organisation of burials (Proudfoot, 1996; James and Yeoman, 2008). These cemeteries are similar to Portmahomack, though the number of burials located and excavated are more numerous than Portmahomack. With cemeteries similar to Portmahomack during this time period, located further south, it is not hard to imagine that migration during this period occurred and perhaps why the three burials from phase 1 do not appear to have originated from Portmahomack.

6.3.2 Phase 2: The Monastic Period

The majority of the burials dating to Phase 2 consist of younger to older adult males with few females and non-adults. Most monastic populations contain only males, leading archaeologists to believe that Portmahomack was a monastery during the 6th-9th

Centuries AD (Carver, 2008), however, not all monasteries stayed exclusively male; a nunnery was added to Iona's monastery in the 13th Century AD (Ritchie, 1997). Other evidence of a monastic site at Portmahomack include different types of workshops like metal working, crafts, wool spinning, and production of manuscripts. These types of workshops are found at other monasteries like Whithorn, Iona, Isle of May and Inchmarnock (Fisher, 1997; James and Yeoman, 2008; Crowe, 2008; Crowe, 1987; Carver, 2008).

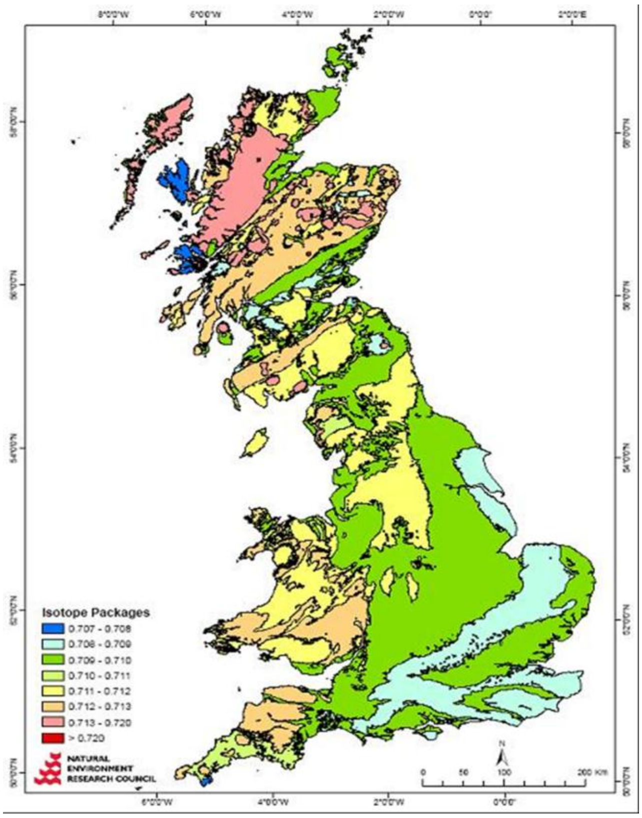

Fig 19: Biosphere strontium isotope ratio map for Great Britain. Source: Evans et al.*, 2010, pg 2*

Burials within Phase 2 range between 0.7099 and 0.7152 for strontium isotope ratios. This range of ratios can be found in a number of areas within Scottish and English territories (Fig 19) and can be interpreted as local to Great Britain. More specifically, these values can be found within Scotland. Of the 13 burials sampled from Phase 2, 6 fall within the local range of Portmahomack in terms of strontium isotope ratios, while the other 7 values are not local. It is not unusual to find people from varying places of origin in a monastic cemetery. Monasteries would accept monks and bishops from an assorted number of places, as well as lay individuals, to work for the monastery (Müldner *et al.*, 2009). One of the burials (158) has skeletal evidence of well-healed traumatic injuries (King, 2000) and demonstrates the highest strontium isotope ratio from Phase 2. This ratio indicates that the individual is not of local origin and therefore migrated from an area with older underlying bedrock. Since these wounds were well healed, it is likely these wounds were from an act of violence when the individual in burial 158 was younger. This could indicate possible conflict either from this individual's place of origin or while they were migrating. Very few of the burials from Phase 2 have violent injuries making it unlikely that these injuries were caused while at the monastery (King, 2000).

At the monastic site at Whithorn, Müldner *et al.* (2009) discovered that a population dating after the monastic phase at Portmahomack, the 11th-12th Century AD, demonstrated a hierarchical diet, with bishops eating more marine products, while the lower class or lay individuals ate more terrestrial based products. Carbon isotope values can be used to discriminate between marine or terrestrial based diets (Lamb *et al.*, 2012). The carbon isotope values from Portmahomack demonstrate that those in Phase 2 had more of a terrestrial based diet (Fig 11, Chapter 5, pg. 27). Prior to the 11th Century AD, those who could afford meat would consume more terrestrial based protein. During the 11th and 12th Centuries AD, a transition from consuming terrestrial based protein to marine based protein occurred(Müldner and Richards, 2007). Portmahomack's carbon isotope results during the monastic period demonstrate that those at the site were able to consume a rich diet of terrestrial based protein. After the "fish event horizon" (Barrett *et al.*, 2004) clerics at monasteries and churches ate more of a marine based diet due to fasting restrictions based on new religious guidelines, as evidenced at Whithorn's monastery (Müldner *et al.*, 2009). The diet consumed by those within Phase 2 seem to keep them in good health. King's (2000) analysis of the human remains at Portmahomack of Phase 2 individuals demonstrates good health and a stature range that is comparable with contemporaneous sites within Scotland. Portmahomack's demographic and overall health during Phase 2 most resembles that from the monastery on the Isle of May (King, 2000).

When looking at only strontium isotope ratios for Phase 2, one might assume that all individuals are native to Great Britain and can come from almost anywhere on the island. However, when oxygen isotopes are analysed in conjunction with the strontium isotope ratios, the possible areas of origin narrow. Of the 13 burials sampled from Phase 2, 11 burials group together with oxygen isotope values between 16.9‰ and 17.8‰, falling within the normal range for Great Britain (Chenery *et al.*, 2010). The other two burials, 129 and 153, are outliers of this group with oxygen isotope values of 15.7‰ and 15.8‰, respectively. According to non-parametric tests (Appendix 5), these values are much lower than the majority of the group (outliers). All oxygen isotope values were converted into drinking water values using Daux *et al.* (2008) equation 4 so that drinking water maps could be used to narrow possible origins of all samples, with the aid of strontium isotope ratios. According to drinking water values compiled by Darling *et al.* (2003) (Appendix 4), 10 of the 13 samples originate from the eastern part of Great Britain (except for the two outliers, whose values are not consistent with values in Great Britain) (Fig 20). The 13th burial, 147, has a drinking water value higher than what is expected on the east coast and might have migrated from the western part of Great Britain (though the error associated with converting phosphate values to drinking water values could eliminate this possibility). The varying strontium isotope ratios indicate that many of these individuals were not local to Portmahomack and travelled from various regions in eastern Great Britain. For example, burials 111 and 140 have higher strontium isotope ratios than what would be expected from the Portmahomack region. Based on age at death and the tooth analysed (Appendix 1), these individuals migrated to Portmahomack between the minimum age ranges of 15-26 and 8-17 years of age, respectively. The combination of local and non-local individuals may be due to the population demographic (few females to procreate) and pilgrimage (Carver, 2008). It would make sense that many of these individuals travelled because St Columba (possible founder of the monastery at Portmahomack) travelled to many places, including the Isle of Skye, Ireland and Pictland, to spread the word of Christianity (Ritchie, 1997). His pilgrimages may have influenced many to make pilgrimages to monasteries from far reaching places.

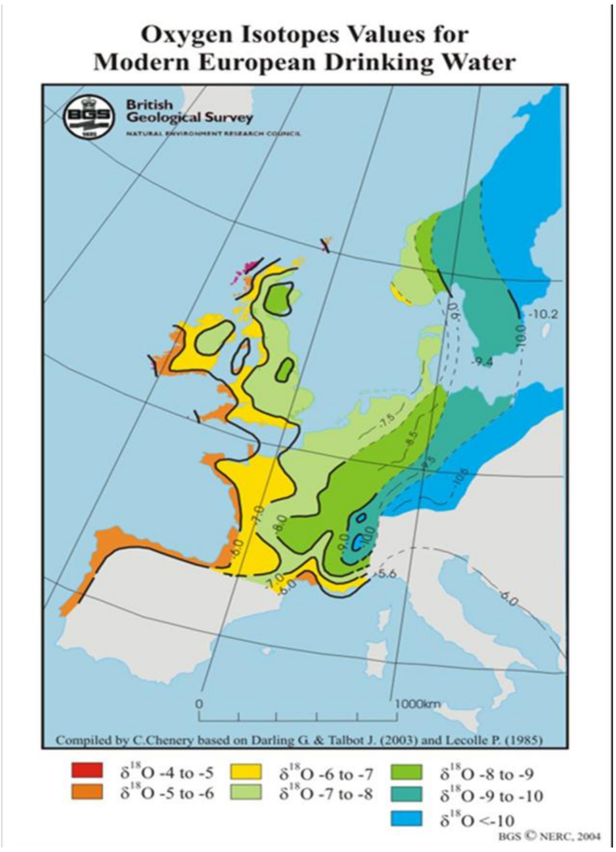

Fig 20: Oxygen Isotope values for modern European drinking water values. Great Britain has values ranging from ~-4.0 to~-9.0. The two outliers from phase 2 have drinking waters of -9.6 and -9.8, placing them originating outside of Great Britain. Source: British Geological Survey Website.

The two outlier values from Phase 2 lie outside the range of oxygen isotope values from Great Britain (Fig 20). Their drinking water values could place them in a number of different locations around Europe and possibly Scotland. Along with their strontium isotope ratios, burials 129 and 153's possible origins narrow. The following areas are possible locations of origins:

- Inland Scandinavia
- Central Europe
- Highland Scotland

Frei *et al.*, (2009) undertook a strontium isotope study on animal wool and discovered that some areas within inland Sweden could produce strontium isotope ratios as high as 0.7160; combined with lower oxygen isotope values, inland Sweden could be a possible origin. Another possibility is central Europe which has a range of strontium isotope ratios and their oxygen isotope values are lower than Great Britain (Evans *et al.*, 2006b). A study undertaken by Lamb *et al.* (2012) postulated that outliers from Auldhame, Scotland could be from central Europe or Scandinavia as well. A third possible location could be the Scottish Highlands. The Highlands are high in altitude and when there is a rise in elevation there is a progressive loss of ^{18}O, changing the oxygen isotope values (Darling and Talbot, 2003; Bentley and Knipper, 2005; Müldner *et al.*, 2009; Turner *et al.*, 2009). Darling and Talbot's (2003) study discovered that in the southern Highlands of Scotland there is an altitude effect in drinking water values between -0.25‰ and -0.3‰ per 100m increase in altitude. With these lower oxygen isotope values and the older underlying rocks located in the Scottish Highlands, this could also be a place of origin for the two outliers. However, little work has been done in the Highlands to discover if human habitation occurred during this time. Since these two skeletons were buried at a monastery believed to have been attacked by Vikings, it is more likely that they were from the Scandinavian area. Many monasteries have evidence of Viking raids on their lands, with burned structures and abandonment from the site. The monastery at Iona was raided several times in the 9th Century and was abandoned for Kells (Laing and Laing, 1993; Ritchie, 1997). Portmahomack was thought to have been abandoned by the monks, though there is evidence of occupation after the raid in the form of hearths (Carver, 2008). The age at death and type of tooth used for analysis for the two outliers were used to estimate an age range when they left their home. The type of tooth analysed and age at death for both 129 and 153 are in Appendix 1. Based on the mineralisation of the crown (Table 1, Chapter 4, pg. 22) and the age at death of burials 129 and 153, they travelled from their place of origin between the minimum age range of 15 to 17 years of age and 15 to 26 years of age, respectively. This wider age range for burial 153 does not reveal as much as burial 129; burial 129 indicates a recent western migration from their place of origin.

The burial practices (Fig 21) during Phase 2 are quite varied and include:

- 3 head supports (large flat slabs that support the head)
- 4 shrouded
- 1 wood and wicker matrix
- 5 unknown type (unrecorded)

This amount of variation is unusual, but may demonstrate the various time periods and cultural practices of those migrating to the monastery from a multitude of areas throughout Great Britain. Three burials (111, 130 and 156) are of the same age and sex, as well as type of burial. Their strontium and oxygen isotope values place them in a

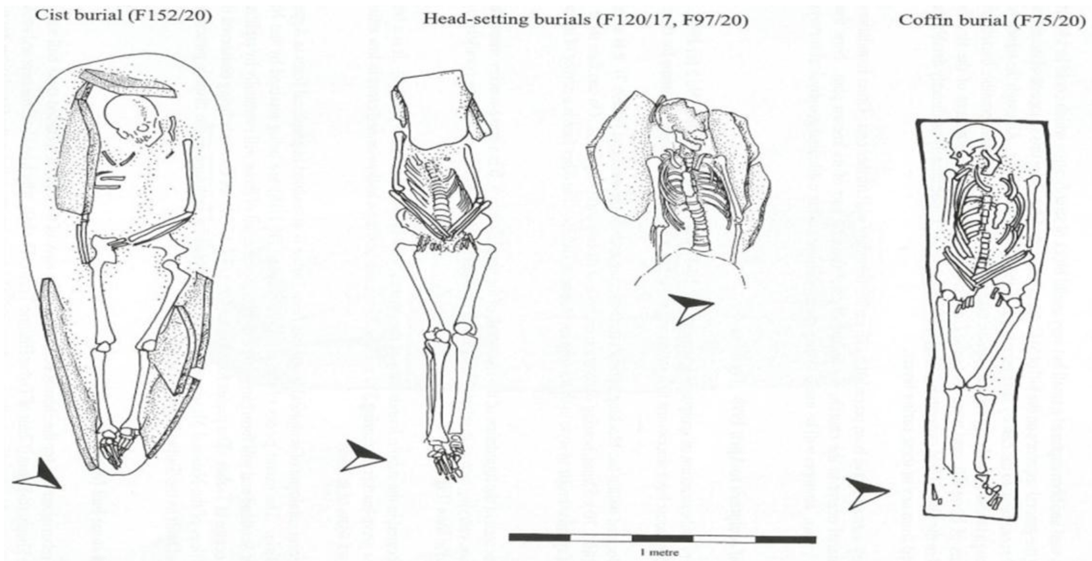

Fig 21: Illustrated renditions of three of the four known burial types at Portmahomack. Source: Carver, 1997, pg 15.

similar geographic region in the eastern part of Scotland with the geology of older underlying bedrocks. Based on their similar values, this could be a group of individuals who migrated to the monastery from the same area, and perhaps same time period (though burials in Phase 2 span 300 years, so this might not be likely). Four of the burials are shrouded, two of those belonging to individuals possibly from Scandinavia. The other two demonstrate the highest strontium values within Phase 2, with eastern Scotland values in oxygen isotopes, indicating possible migration. A unique burial discovered within this phase is one made from a wood and wicker matrix. This burial (147) has a strontium isotope ratio within the local range, but the oxygen isotope value is higher, suggesting an origin from the western part of Scotland. This burial's values for both strontium and oxygen isotopes are very similar to burial 172 from Phase 1. Since Phase 1 burials date to the 8th Century AD and Phase 2 burials date to the later 8th-11th Centuries AD, it could be possible that these two individuals are from a similar area and migrated to Portmahomack around the same time. The final five burials from Phase 2 have unknown or unreported burial types. It is interesting that all these burials fall within the local range for both strontium and oxygen isotope values. Another burial (117) demonstrates wounds caused by a violent attack from behind with a sharp weapon (King, 2000) and is in a shrouded burial dating between Phases 2 and 3. It has strontium and oxygen isotope values that are associated more closely with those dating to Phase 2 rather than Phase 3 and has evidence of violent injury. All shrouded burials date to Phase 2, making it more likely that this individual is from Phase 2 rather than Phase 3. All burial information was provided by Cecily Spall (Cecily Spall, email communication, 2012)

6.3.3 Phase 3: Medieval Period

The burial assemblage belonging to Phase 3 is very different from that of Phase 2. The demographic of burials during Phase 3 includes males, female, and non-adults ranging in ages as young as 6.6-10.5 years up to 46+ years. Other medieval cemeteries from Scotland dating around the time of this Phase (12th-16th Century for Portmahomack) include the Bay of Skaill in Orkney (11th-14th Century) (James, 1999), St Thomas' Kirk in Orkney (13th-14th Century) (Toolis, 2008), Whithorn in Galloway (13th-14th Century) (Müldner *et al.*, 2009) and Auldhame in East Lothian (7th-17th Century) (Lamb *et al.*, 2012).

Like Phase 2, there is a wide range of strontium isotope ratios for Phase 3 ranging between 0.7099 and 0.7151. Of the 10 burials designated to this phase, 5 are within the local strontium isotope ratio range of Portmahomack (Appendix 5), while the other 5 have higher strontium isotope ratios that are not local. The burial with the highest strontium isotope ratio is burial 041. The skeleton within this burial died between the ages of 17-25 years. The tooth used for analysis establishes possible migration of burial 041 during the ages 4.25-17 years. Three burials (036, 062 and 086) have the values of 0.7125. Burials 036 and 062 are of older adults (46+ years). Burial 086 is a non-adult aged between 6.6

years to 10.5 years old. Based on their age at death and the dentition used for analysis, they migrated to Portmahomack in the last 2-8 years of their life. The final burial (035) has a strontium isotope ratio of 0.7115. The strontium isotope ratios of a comparable site south of Portmahomack, Auldhame, are between 0.7086 and 0.7135 (Lamb *et al.*, 2012). The majority of their values are on the lower end of this range with only one value (0.7135) as an outlier. With this range, Lamb *et al.* (2012) determined that very little migration to this site occurred and that all burials were local, with the exception of the higher strontium isotope ratios indicating migration from the north. This is in contrast to Portmahomack, where half of the values indicate migration from areas with older underlying bedrock geology. By this time, the Scots and the Picts had formed as a unified community named Alba, so migration from all around Scotland might have occurred (Laing and Laing, 1993). Evidence of migration is seen with Christians from the western part of Scotland visiting the northern islands (Shetland and Orkney) as early as the 6th Century (James, 1999). Migrations south from these islands, as well as east, are not out of the question.

There is a shift in diet between Phase 2 and Phase 3 at Portmahomack. As stated previously, those in Phase 2 consumed more of a terrestrial based diet. Based on carbon isotope results, those in Phase 3 consumed a diet that included a measurable amount of marine protein (Fig 11, Chapter 5, pg. 27). The concentration (ppm) of strontium in the enamel has a wide range; between 74 ppm and 200 ppm. The majority (8 of 10) have a higher range between 100-200 ppm (Appendix 5). Those inhabiting Scotland have been known to use kelp or seaweed as both food and fertilizer (Fisher, 1997). Kelp has higher levels of strontium isotopes with a more marine signature which works its way up the food chain, making it appear that people are originating from areas of older underlying bedrock and are consuming higher amounts of marine products than they actually are eating (Evans *et al.*, 2012). Other sites, like Whithorn and Auldhame, have people consuming more marine products (Müldner *et al.*, 2009; Lamb *et al.*, 2012), so a diet composed of mostly marine products is more probable in contributing to higher carbon isotope values than just changes made to the soil through fertilization. This seemingly sudden change in diet might be due to a change in religious practice by fasting and not consuming meat on certain days (Lamb *et al.*, 2012). At the archaeological site St Thomas' Kirk on Orkney, one individual who demonstrated strontium and oxygen isotope values consistent with the western isles or northern Shetland and also had a childhood diet of marine products, while the natives to Orkney had a more terrestrial based diet (Toolis, 2008). Those who migrated to Whithorn (mostly bishops and clerics) consumed more marine protein, while the locals demonstrated lower isotope values indicating more terrestrial food intake (Müldner *et al.*, 2009). It is interesting that those who are migrating during this time period have childhood diets with measurable amounts of marine products.

The oxygen isotope values for those within Phase 3 range between ~16.6‰ and ~18.5‰ (average ~18.1‰ ±1.4). One value falls just outside the oxygen isotope range for Great Britain, however, if errors are considered, it falls within the range (Chenery *et al.*, 2010). Of the 10 burials from Phase 3, 8 burials form a cluster with higher oxygen isotope values; while two burials are much lower (Appendix 5). Like Phase 2, these oxygen isotopes were converted into drinking water values using Daux *et al.* (2008) equation 4 to aid in locating general areas where these types of values are found. The lower oxygen isotope value burials (030 and 062) are probably from the eastern part of Great Britain. These two burials have very different strontium isotope ratios, indicating they came from different areas within the eastern part of Scotland. The other eight burials are between ~17.9‰ and ~18.5‰ and have drinking water values that place them in the western part of Scotland. Within Great Britain, oxygen isotope values that are this high usually come from areas with higher precipitation, which can be found along Scotland's western coast (Appendix 4). This contrasts with burials from Auldhame, which has a similar overall range (16.5-18.3‰) as Phase 3, but has a lower average (17.4‰ ±1.4) than Portmahomack (Lamb *et al.*, 2012). There is a contrast between these two sites when the average of the eight burials (~18.4‰ ±0.4) is compared with Auldhame. Lamb *et al.* (2012) determined that the majority of their samples from the south-eastern part of Scotland were of local origins, while those dating to a similar period at Portmahomack show migration from the west. Of these eight burials, three (041, 036 and 086) are not closely related to the other five (016, 035, 088, 110 and 119). The three burials with higher strontium isotope ratios came from different areas of the western part of Great Britain. The age at which burials 041 and 086 migrated was discussed previously, while burial 036 migrated after the age of 15 years. The remaining five burials represent a unique demographic of one male, one female, and three non-adults. Burial 016 is an individual who most recently migrated from the west coast. Age at death was 6.6-10.5 years and the first molar was used for analysis, indicating a migration from the west coast between a minimum of 4 to 6 years of age. Burials 110 and 119 are individuals who also migrated during their childhood, based on age at death and tooth analysed. The final two burials, 035 and 088 belong to a young adult male (17-25 years) and older female (46+ years), respectively. Both migrated during different periods of childhood development; burial 035 after at least 2.5-4.25 years of age and burial 088 after at least 4-7 years of age. All came from the western part of Great Britain and their strontium values range between 0.7099 and 0.7115. This range of strontium isotope ratios is common in many areas throughout Great Britain, however, it is believed that these burials came from similar places of origin due to the fact that their isotope ratio are close in both strontium and oxygen isotope values (Fig 10, Chapter 5, pg. 26).

The types of burials associated with Phase 3 are shrouded or coffined burials. Five of the burials are shrouded and the other five are coffined. Two unique burials in this assemblage are burials 030 and 036. According to Field Archaeology Specialists, burial 036 was buried in a wood coffin that was furnished with four skulls and died from injuries caused by a sword (Cecily Spall, email communication, unpublished 2012). Based on this unusual burial, it was hypothesised that this burial belonged to a possible local leader or chief (Cecily Spall, email communication, unpublished, 2012). The possible local leader or chief's oxygen isotope value suggest an origin from the western part of Scotland. Burial 030 was buried in a similar fashion, with a wooden coffin, but buried over burial 036. Archaeologists believed that this individual could possibly be another local chief or leader that was related to burial 036. However, burial 030's strontium and oxygen isotope values places this individual on the opposite side of Scotland, in the east, from 036. It would be difficult to say that these two were related to one another. This demonstrates how strontium and oxygen isotopes can illuminate new details that are difficult to determine through artefacts and skeletal analysis.

In King's (2000) analysis of the human remains from Portmahomack, it was discovered that the general health of the burial assemblage from Phase 3 was not as healthy as contemporaneous sites within the region. They are slightly shorter in stature, especially among females. There is evidence of environmental stress on the population, including linear enamel hypoplasia and cribra orbitalia (porosity seen in the orbits of the eye in some non-adults). The combination of these skeletal indicators illustrates a population under environmental stress and possible malnutrition (King, 2000). Perhaps those who migrated from the west of Scotland had local environmental factors that prevented proper nutrition to support them, so they migrated east to new lands. There is evidence of people originating in the west visiting islands in Scotland as early as the 6th century (James, 1999), so it would be plausible that this behaviour continued through time. The reason for this migration could be based on the health of this population alone, or part of a migration to a former monastery and church to help heal the sick.

6.3.4 Phase 4

Only one sample was analysed dating to Phase 4. Burial 017 has the lowest strontium isotope composition value in the entire sample of Portmahomack of 0.7098. This is within the local strontium isotope ratio of Portmahomack, however, when the oxygen value is assessed (18.6‰), it indicates an origin from the western part of Scotland. Its values are close with the five values from phase 3. Burial 017 was buried in a coffin and archaeologists identified the individual as William Mackenzie (Cecily Spall, email communication, 2012). Based on age at death and the type of tooth used for analysis, William Mackenzie travelled to Portmahomack from the western part of Scotland between the minimum age ranges of 7-26 years of age. According to Carver (2008), William Mackenzie was a parish minister of Tarbat from AD 1638 until his death in AD 1642.

Chapter Seven: Conclusion

The goal of this study was to detect temporal trends of migration to the Tarbat Old Church in Portmahomack, Scotland. Using strontium and oxygen isotopes from human dental enamel, it was discovered that there were two distinct phases at Portmahomack between the Phase 2 (monastery -8th-11th Centuries AD) and the Phase 3 (medieval -12th-16th Centuries AD). Both phases saw migration to Portmahomack from various regions within and outside of Great Britain. During Phase 2, half of those sampled were discovered to be non-local in origin based on strontium and oxygen isotopes. The majority of non-locals within Phase 2 migrated from the eastern part of Great Britain. Two burials within this phase with lower oxygen isotope values were believed to have migrated from Scandinavia. Other regions were suggested, however, based on the time period in which they were discovered and the history of Portmahomack, Scandinavia was the region where they were most likely to have originated. Phase 2 burials had carbon isotope values that indicated a diet that relied on terrestrial based protein.

There is a clear difference between those in Phase 2 and those in Phase 3 in regards to their oxygen isotope and carbon isotope values. Like Phase 2, half of those sampled belonging to Phase 3 had strontium and oxygen isotope values that were not local to Portmahomack. The majority of the non-local burials migrated from the western part of Great Britain. The type of diet consumed by those within Phase 3 (based on carbon isotopes) had measurable amounts of marine protein. During this time there was a shift from terrestrial based protein to marine based protein called the "fish event horizon" where clerics switched their consumption of terrestrial based protein to comply with new religious fasting guidelines (Barrett *et al.*, 2004). Those from Portmahomack within Phase 3 were not as healthy as comparative sites, suggesting migration from the west due to environmental stress and/or malnutrition. The lack of comparative sites in the north-eastern part of Scotland made it difficult to compare Portmahomack to contemporaneous sites, so continued isotopic studies of sites within Scotland are recommended to discover and interpret Scotland's history more clearly.

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