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A Preliminary Assessment of Ancient Diet and Mobility in Archaic Period Asia Minor: A view from Panormos, near Didyma

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Abstract:

The Archaic Period in the Aegean marks the establishment of colonies and settlements in the larger Mediterranean and Black Sea. But little is known of the character of any demic expansion and the character of daily life for non-elites. We report first results of stable carbon and oxygen isotope ratios in tooth enamel from thirteen individuals buried in an Archaic Period necropolis located in western Turkey. We also measured multiple teeth in three individuals, which allow us to consider life events during childhood. Results indicate greater dietary diversity than has been observed in other palaeodiet studies in the region. From a wide range of oxygen values, including individual inter-tooth variation, we suggest that some of the individuals buried at Panormos may have spent some time during childhood outside the Aegean climatic zone, including the Black Sea and the interior of Asia Minor.

Highlights:

- Enamel of skeletal remains from an Archaic period (later 1st millennium BCE) site in southwestern Anatolia were analyzed for stable isotopes of carbon and oxygen
- Results from teeth in different periods of formation indicate a primarily terrestrial diet, despite high marine values of carbon in the Aegean.
- Oxygen isotopes suggest some individuals migrated from areas with lower oxygen isotope values, like the Black Sea or interior Anatolia

1. Introduction

Isotopic analysis of various elements present in human skeletons has been widely used to address questions surrounding diet and lifetime mobility (e.g., Makarewicz and Sealy, 2015, Balasse, et al., 2002, Balasse, et al., 2006, Perry, et al., 2011, Dupras and Schwarcz, 2001). These approaches can provide new data with which to illuminate various aspects of social identity in the past (Knudson and Stojanowski, 2008, Buikstra and Lagia, 2009), including lifetime events such as weaning (Dupras and Tocheri, 2007) and childhood migration (White, et al., 2007). The Archaic Period in the Aegean (ca. 1st half of the 1st millennium BCE) is well-attested in certain aspects (Hall, 2014), but there are few bioarchaeological perspectives on daily life and the character of non-elite society in this period (but see, Panagiotopoulou, et al., 2016, Papathanasiou, et al., 2013, Bourbou and Tsilipakou, 2009). In the Aegean, the turbulent period following the collapse of Late Bronze Age polities has traditionally been seen as one of Greek migration and colonization, as settlements were established in the Black Sea and elsewhere in the Mediterranean world. Yet there is scant direct evidence for the nature and magnitude of population mobility, and ways that it did or did not differ from other recorded movements of people in the Mediterranean (Tsetskhladze, 2006, van Dommelen, 2012). This article presents the first results of stable isotope ratios of carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) in tooth enamel from the Archaic period necropolis of Panormos on the west coast of Turkey. This work is a continuing part of an on-going bioarchaeological study of the human skeletal remains from the site. A holistic investigation of patterns in diet, health, and mobility in the people buried there will augment our understanding of life in urban hinterlands, as the site is situated between the metropolis of Miletos to the north and the sanctuary at Didyma to the south. We offer an initial assessment of possible childhood mobility that hint at a relatively cosmopolitan population that used the necropolis.

2. Background

2.1. The necropolis of Panormos, Miletos & the Greek Archaic era

The necropolis of Panormos, near Didyma on the Milesian peninsula (now on the west coast of Turkey, Fig. 1), was discovered in 2011 when geologists working in the area examined a recently re-excavated modern ditch, used to insert a drainage pipe, just outside of modern Mavişehir on the road towards modern Didim in the province of Aydın. Visible ceramic and bone fragments, as well as burnt lenses seen in the profile and base of the ditch suggested the presence of Archaic-period burials, confirmed by the subsequent 3 seasons of excavations at the site (2012-2014) undertaken under the auspices of Project Panormos, a collaborative enterprise by members of the Istanbul branch of the German Archaeological Institute (DAI) and the regional archaeological museum at Balat/Milet (Slawisch 2014, Slawisch & Wilkinson 2016). In total approximately 80 probable burial events were identified in an excavated area of only 25m^2, with initial assessment of associated ceramic finds dating the use of the necropolis to between ca. 700/650 and 500 BCE. Burial events included a large range of different traditions, including cremations and inhumations, placed alone, inside or within vessels such as amphorae, hydriai or pithoi. A preliminary study of the finds and stratigraphy has identified 4 phases of mortuary usage: B (7th century BCE), C1 (late 7th to early 6th century BCE), C2 (early to mid 6th century BCE) and C3 (mid to late 6th century BCE). Analysis of human skeletal assemblage from the site is pending, and this paper represents a sample from 2012 and 2013 seasons, all of which date within the C2 or C3 phases. It is hoped that an expansion of the analysis can be undertaken, with further samples planned to be taken from finds of the 2014 season, which will include some of the oldest burials (phase B) excavated at the site.

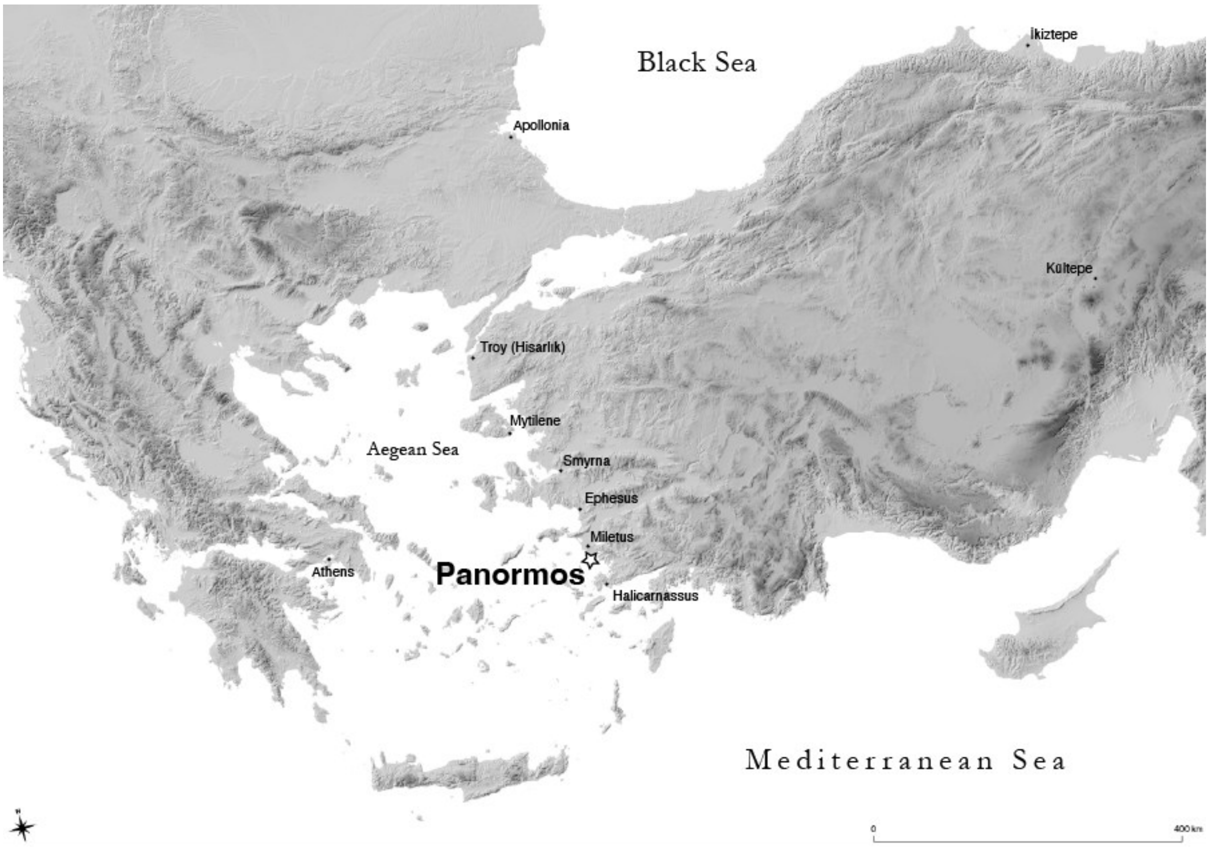

Figure 1: Map showing the location of Panormos and some selected period sites.

The site is exceptional not only for its status as one of the only Archaic cemeteries excavated in southern Ionia but also for the apparent stratigraphic potential. Many graves appear to have cut into older burials, suggesting very intensive use of this tract of land over a 150 to 200 year period (see plan in Fig. 2). The degree of overlap is useful from a stratigraphic point of view for sequencing objects. However, the apparent re-use of the same area, with probable secondary redeposition of remains (usually identified by disarticulated skeletal formation) has meant that in some instances, distinguishing different burial events is difficult. This is the case, for example, for samples presented in this analysis as being from different individuals Ph202 and Ph203: the teeth from each were found in very close proximity to each other, but given the distinct isotopic signatures and the disturbed nature of the context (by the modern drainage ditch), we have taken the view that these are different individuals whose remains have been mixed by redeposition. The necropolis lies along the most obvious route to the Sanctuary of Apollo at Didyma from the sea at Mavişehir/Kovala bay (the textually-attested ‘Panormos’), which although historical sources show was patronized by citizens from across the Greek world (e.g., Hdt. 1.157.3, 2.159.3), also lay on the territory of the metropolis of Miletos (Thuc. 8.24.1). Ancient texts have led classicists to view this city as a major economic, cultural and political hub during Archaic Greek era, founding trading colonies across the Mediterranean and, more especially the Black Sea and providing the socio-cultural environment which enabled the ‘Ionian enlightenment’, an intellectual movement which many have seen as Europe’s first scientific revolution (Graham, 2013). In addition, Miletus was connected by the Meander river into the Anatolian interior, including direct political interactions with Lydia, and thence to distant societies beyond including Assyria, Persia and the highlands of Urartu (Alkier and Witte 2003; Bryce 2019). Nonetheless, much remains unknown about the material, economic and demographic dynamics of the city and its hinterland during this critical period since, archaeologically, much of the evidence is obscured by later Hellenistic and Roman rebuilding.

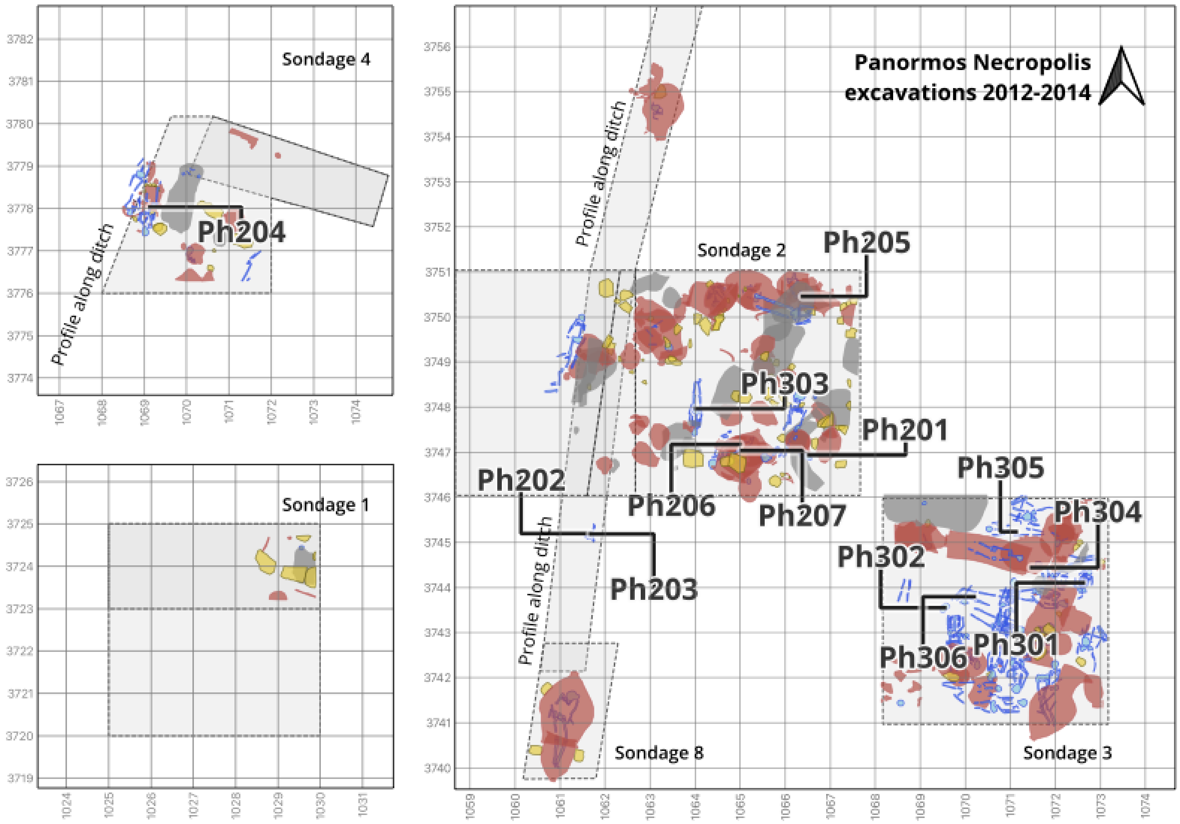

Figure 2: Plan of the excavations showing degree of burial event superposition, and showing context locations for tooth samples presented here (local Didyma coordinate system).

While the results presented here are preliminary in nature, the necropolis at Panormos provides a rare opportunity to address many bottom-up questions regarding the constitution, health and mobility of the population of the peninsula, as well as their relationship to material objects and burial traditions, at the time of Milesian economic dominance and the assumed demic mobility across the entire Mediterranean world during the Archaic colonizing period. Until now there have been no direct data regarding the lives of ordinary individual residents of the region. Much of the information about this place in the Archaic period involves only the relatively sparse historical or epigraphic references to elite persons. By applying stable isotope analysis to the corpus of human remains from Panormos, some directionality can be given to speculation about the extent to which those buried in the necropolis were ‘local’ residents or not, what kinds of diet was typical for this place and time period and ultimately to contribute to large-scale databases of equivalent data to identify spatial and diachronic patterns. Unfortunately while physical anthropology of the assemblage is in progress, we cannot report data for estimated sex or age for this study sample, at present. We felt it important nonetheless to report on the current results in order to encourage other similar studies of age-based analysis of stable isotopes from human remains in the region.

2.2. Carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes as paleodietary indicators

Carbon isotopes ratios are measured as $^{13}C/^{12}C$ relative to an agreed standard, which for carbon is PeeDee Belemnite (VPDB), calculated against NBS-19, using the standard delta notation (Hoefs, 2009), represented as $\delta^{13}C$. Stable carbon isotopes vary in the environment primarily according to anatomical and ecological factors affecting primary producers (Lajtha and Marshall, 1994, Farquhar, et al., 1989, Ehleringer, 2005, Smith, et al., 2002), with physiological effects through the food web (Passey, et al., 2005, Kohn and Cerling, 2002). In general, plants utilizing the C3 photosynthetic pathway display values significantly depleted in ^{13}C (negative) relative to C4 plants, which are more tolerant to drought and more abundant in regions with higher mean annual temperatures (Ehleringer, 2005). Plants utilizing the CAM pathway display $\delta^{13}C$ values that overlap with those of C3 and C4 plants. Values in mammalian tissues are enriched compared to their dietary input (Cerling and Harris, 1999). Of particular significance to archaeologists is the difference between values in skeletal collagen and mineral (bioapatite) values (Lee-Thorp, et al., 1989). Controlled feeding studies demonstrate that these two components reflect differing aspects of diet. There is correlation between collagen and apatite (or enamel) carbon isotopes, with the mineral portion reflecting the aggregate diet and collagen dietary protein sources (Ambrose and Norr, 1993). Although it has been suggested that $\delta^{13}C$ from any skeletal element can be useful to investigate paleodiet (Warinner and Tuross, 2009), there is a lack of empirical data demonstrating a relationship between enamel $\delta^{13}C$ and bone bioapatite $\delta^{13}C$, especially for humans (Loftus and Sealy, 2012). While the assumption is that these two tissues respond similarly, dietary and cultural factors may create significant differences between analyzed tissues (Warinner and Tuross, 2009). This complicates interpretation of enamel $\delta^{13}C$, both in terms of equivalent datasets and in 'translating' published collagen data into possible enamel $\delta^{13}C$ values. Additionally, local food web $\delta^{13}C$ values have been shown to vary in similar species in different regions, and interpreting dietary compositions can be confounded in situations with mixed energy and protein sources (Kellner and Schoeninger, 2007). In the absence of significant collagen isotope data from local fauna and humans, we will focus on human bioapatite as a proxy for whole diet in the Panormos specimens. Samples were taken for collagen analysis of $\delta^{13}C$ and isotope ratios of nitrogen ($\delta^{15}N$). Collagen was extracted according to standard procedures (Sealy, et al., 2014, Ambrose, 1991) from the tooth roots. Collagen isotope ratios represent the protein component of the diet (Ambrose and Norr, 1993). Diet spacing between collagen and bioapatite represents the difference between signatures of whole diet versus protein helping identify sources of diet in the ecosystem.

Oxygen isotopes ratios are measured as $^{18}O/^{16}O$ using standard delta notation ($\delta^{18}O$), but the normalized scale used varies in the literature stemming from studies that focus on carbonates (VPDB) or hydrology (VSMOW) (Hoefs, 2009). We analyzed the carbonate portion of enamel simultaneously with carbon isotopes. Since our focus is to interpret individual human relationships with their water sources, we report the latter using the established relationship to convert VPDB to VSMOW (Coplen, et al., 1983, Chenery, et al., 2012). Oxygen isotope ratios can vary significantly in precipitation based on conditions conducive to evaporation and condensation, including seasonal temperature, humidity, elevation, and orographic features (Dansgaard, 1964, Gat, 1996). In the biosphere, they vary based on similar principles, that is, on evapotranspiration, physiology, and the $\delta^{18}O$ values of source waters (e.g., Levin, et al., 2006, D'Angela and Longinelli, 1990, Delgado-Huertas, et al., 1995). Values displayed in skeletal tissues reflect those of body water, which depend on all sources of ingested water. There is a correlation between skeletal $\delta^{18}O$ and meteoric water (Longinelli, 1984). Because of the climatic and geographic nature of variation in $\delta^{18}O$, archaeologists have sought to use these as proxies for ancient mobility similar to strontium isotopes (e.g., Bentley and Knipper, 2005, White, et al., 2000, White, et al., 1998, Evans, et al., 2006). These efforts have not been unproblematic, however, due to the high degree of variability in human behaviors—including storage and cooking/brewing (e.g., Brettell, et al., 2012)—as well as inherent complexities in comparing $\delta^{18}O$ measured in skeletal tissues with estimates of values in annual mean precipitation (Pollard, et al., 2011, Knudson, 2009). It is nonetheless clear that $\delta^{18}O$ values display variation in human populations that, especially when used in multi-isotope approaches, can provide important insights into past diet, environment, and behavior.

2.3. Tooth formation

Tooth enamel is the most mineralized tissue in the mammalian body and is composed primarily of biological mineral apatite containing significant (ca. 4-6% by mass) inclusions of carbonate (CO_3^{2-}) in its crystal lattice (Kohn and Cerling, 2002). Enamel forms during a particular period in life, and unlike bone, is not thereafter biologically modified (Hillson, 2005). The high degree of mineralization renders enamel more resistant to post-depositional chemical alteration (i.e., diagenesis) than other more proteinaceous (e.g., bone collagen) and porous skeletal elements for long periods (Budd, et al., 2000, Kohn, et al., 1999, Schoeninger, et al., 2003, Lee-Thorp, 2008). Enamel begins forming from the apex of the tooth and proceeds downward toward the root in a complex multi-stage process (Smith, 1998) that ‘averages’ biological values of isotopes over this period. Timing of tooth development in humans has been established by a variety of methods, but significant detail has been achieved through counting incremental structures (Risnes, 1998, Reid and Dean, 2006, Reid, et al., 2008, Smith, 2006). The periods of formation for individual teeth in Fig. 3 are based on the results of these studies.

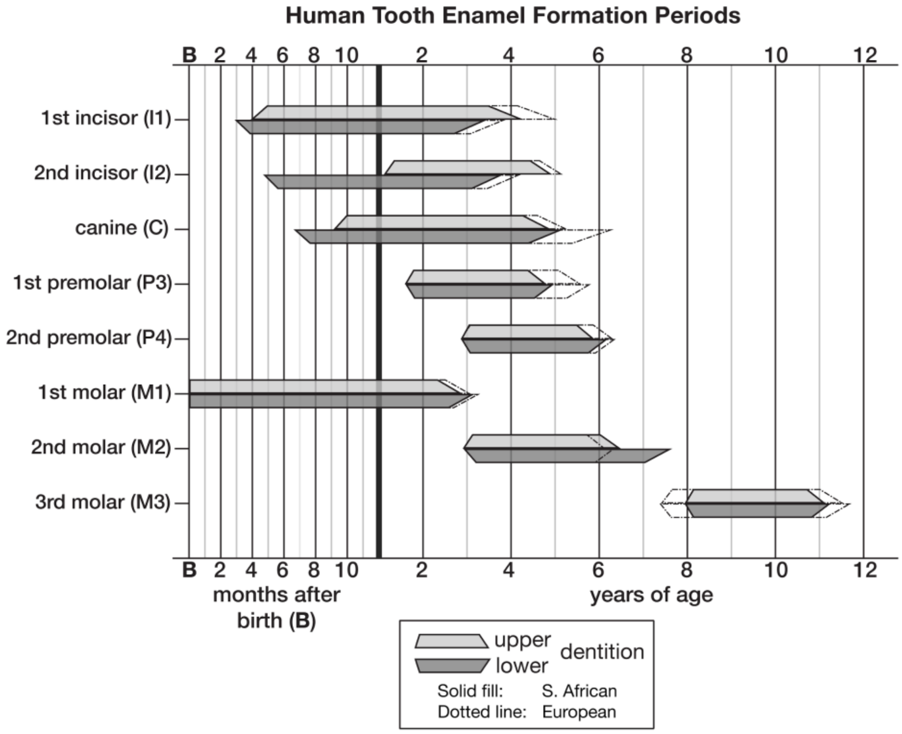

Figure 3: Human enamel formation times (Harris and Buck 2002; Reid and Dean 2006, 2008).

The human permanent dentition begins forming very early in life—the M1 begins forming in utero around the time of birth—and continues until roughly 12 years of age (Reid and Dean, 2006, Reid, et al., 2008, Moorrees, et al., 1963). While there are some differences between regional populations in the precise onset and duration of enamel formation, these variations are relatively small compared to the length of time enamel is forming on an individual tooth. It is important to note particularly that the enamel of the first molar (M1) reflects a maternal signature and subsequent values prior to weaning (cf. Gulson, et al., 2003). While culturally variable, weaning typically occurs around 2-2.5 years (White, et al., 2004, Richards, et al., 2002). To be consistent with archaeological recording (Hillson, 2005, White and Folkens, 2005), the first and second premolars will be referred to as P3 and P4 in this study. To contextualize isotope values with period in which enamel is forming, the onset of mineralization for teeth included in the study are presented in chronological order based on data summarized in Fig. 3. Specifically, the first incisor (I1) and first premolar (P3) begin enamel formation prior to the M2. While a full dental arcade has not yet been analyzed from Panormos, this presentation should further illuminate trends observed in the molar teeth.

3. Materials & Methods

Examination of material excavated in 2012 and 2013 from Panormos, curated at the Milet Museum in the Turkish province of Aydın on the Milesian peninsula, identified 13 individuals that were selected for sampling in this study (Tables 1 and 2). Although consistency was attempted in which teeth specifically were included in the study sample, preservation frequently precluded collecting the same teeth from each individual. However, all teeth come from individual skeletons and no loose teeth were sampled. Samples were examined in the Archaeology Laboratory at the Rochester Institute of Technology and selected for isotope analysis. Prior to isotope sampling, basic tooth metrics were recorded using digital calipers, including the buccal-lingual length, mesial-distal length, and tooth height (Bass, 2005). Teeth were then cleaned in an ultrasonic bath using ultra-pure deionized water until adhering detritus was removed. The surface of the enamel was then mechanically cleaned using a micro-motor dental drill equipped with tungsten carbide bits under a binocular microscope (10X). Particular attention was paid to remove any enamel deterioration or erosion present. Once a sufficient area of intact enamel was cleaned, a bulk sample was removed using a diamond disc saw from near as possible to the occlusal surface. Sampling preserved the majority of the enamel surface for further anthropological analysis. Samples were also taken for collagen analysis.

Analysis of carbon, oxygen, and nitrogen isotope ratios was conducted at the Stable Isotope Ratios in the Environment Laboratory (SIREAL) at the University of Rochester. Enamel samples were thoroughly crushed in a mortar and pestle, and approximately 2mg was weighed for analysis with no further treatment. Enamel was reacted with several drops of 103% phosphoric acid at 70°C for at least 0.5 hours to evolve CO_2 gas. Samples were analyzed using a GasBench unit attached to the ThermoFinnigan Delta Plus XP mass spectrometer run in continuous flow mode in the Department of Earth and Environmental Sciences at the University of Rochester. Approximately 1g of collagen was weighed into tin boats and run in an elemental analyzer also attached to the Delta XP. Isotopic results are reported using the standard delta notation in permil (‰), with carbon values calculated relative to VPDB (Vienna Pee-Dee Belemnite), oxygen values to VSMOW (Vienna Standard Mean Ocean Water) and nitrogen values to atmospheric air (AIR). Internal analytical precision based on measurement of internal laboratory standards was 0.1 ‰ for $\delta^{13}C$ was 0.2‰ for $\delta^{18}O$. Bioapatite data were normalized to internal laboratory and international (NBS-19) standards (Hoefs, 2009, Coplen, et al., 1983), and collagen data to internal and external protein standards.

4. Results

The full carbon and oxygen isotope results for individuals from Panormos are presented in Table 1. The range of enamel $\delta^{13}C$ values is -13.23 to -9.73‰ (n=19, s.d.=0.96; Fig. 4) and appears to be consistent with intra-site variability in a variety of periods from sites in Greece and Asia Minor (see below). The most enriched (i.e., more positive) samples are early-forming teeth (M1, I1) in individuals Ph202 and Ph305. These values are distinctly more enriched than from other individual early forming teeth.

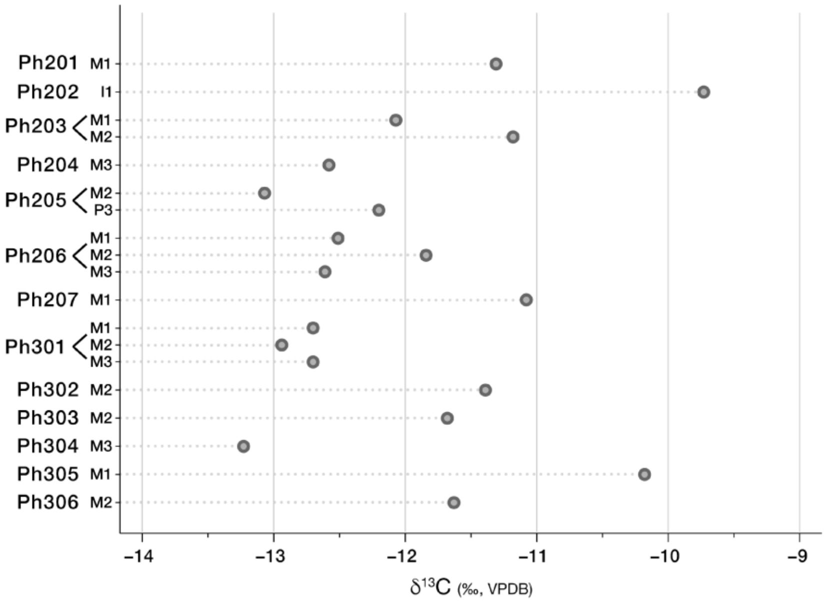

Figure 4: Enamel carbon isotope ($\delta^{13}C$) values from Panormos

Of particular interest are the three individuals for whom sequentially forming teeth were analyzed (Ph301, Ph203, and Ph206), and the implications for dietary change (carbon isotope values presented sequentially by individual in Fig. 5). The trend for individuals Ph203 and Ph206 is similar, $\delta^{13}C$ increases between the M1 and M2. In contrast, in Ph301 values are depleted (become more negative) from the M1 to M2. In both Ph301 and Ph206, M3 values in $\delta^{13}C$ return to nearly the same as M1. As mentioned above, the M1 should primarily display the maternal dietary signature, while the M2 will indicate diet of an individual post weaning, if started approximately 2-3 years of age. Breastfeeding has been observed to enrich the $\delta^{13}C$ value by ca. 1‰ and weaning can occur in the first two or three years of life (Dupras and Tocheri, 2007, Fuller, et al., 2006, Wright and Schwarcz, 1998). Thus the lowering values from M1 to M2 in Ph301 could imply earlier weaning. While the negative shift in Ph301 is consistent with this pattern, the shift is substantially less than 1‰ (-0.24‰) and the trend in $\delta^{18}O$ values additionally suggest that weaning can be excluded as a cause (Fig. 8 and 9). The patterns in Ph203 and Ph206 indicate these individual's diet became more enriched sometime in their 3rd year, but only slightly so, with shifts again less than 1‰ at +0.89‰ and +0.67‰, respectively, from M1 to M2. These latter trends do not allow an interpretation of weaning, but represent changes in overall diet.

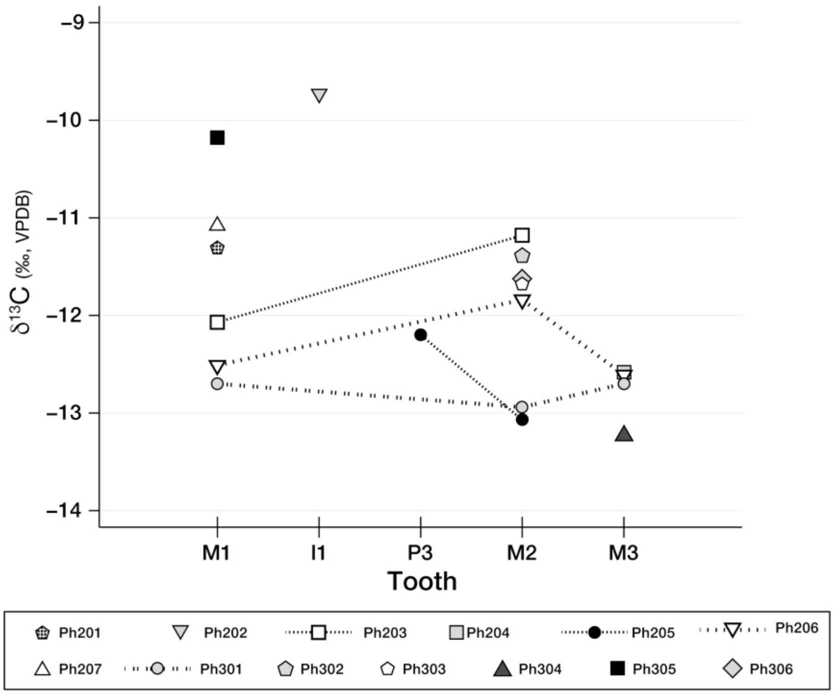

Figure 5: Carbon isotope (δ^{13}C) values from Panormos by individual, arranged along x-axis by enamel formation period (see text). Sequential teeth from same individuals (and thus trends) indicated by dotted lines.

Although several studies have analyzed prehistoric diet through δ^{13}C in the region (Vika, 2011, Petroutsa and Manolis, 2010, Papathanasiou, 2003, Yazıcıoğlu Santamaria, 2015, Triantaphyllou, et al., 2008, Bourbou and Richards, 2007), they have, with some exceptions, exclusively analyzed carbon in bone collagen rather than in enamel carbonate. This complicates comparisons between the Panormos results and pre-existing published corpus. Yazıcıoğlu Santamaria (2015) presents stable isotope data for both bioapatite and collagen from the Early Bronze Age site of Kültepe in central Anatolia. Values of δ^{13}C enamel are consistent with the Panormos sample, although somewhat narrower, varying between ca. -11 to -12.6‰. The Kültepe values were suggested by Yazıcıoğlu Santamaria as diets based on terrestrial products and herbivores.

In order to clarify these issues, we attempted analysis of collagen from tooth dentine to create a comparable dataset, but the preservation was only adequate for two samples, with C:N ratios between 2.9 and 3.6 (Ambrose, 1990). The carbon isotope ratios in Ph206 M3 and Ph301 were -21.00‰ and -21.03‰ and the nitrogen isotope ratios were 7.79‰ and 7.73‰, respectively. These collagen values are consistent with those from other sites in the region, falling within the range of individuals from Early Iron Age sites (see below). The diet spacing also implies to us that protein sources were predominately terrestrial (see e.g., Yazıcıoğlu Santamaria 2015). But without analysis of local fauna, it is difficult to further contextualize these data. Additionally, they do not address the possibility of fish consumption, as analysis of freshwater and marine fish show significant overlap (Vika and Theodoropoulou, 2012).

Despite the lack of directly comparable data, four regional sites were used for comparison that are generally contemporaneous with Panormos. These date to the Late Bronze Age (Petroutsa and Manolis, 2010) and two to the Early Iron Age (Panagiotopoulou, et al., 2016, Papathanasiou, et al., 2013). Three of the four Late Bronze Age (LBA) (ca. 1600-1200 BCE) sites were inland, except for Almyri on the coast of the Saronic Gulf south of Corinth, and both of the Early Iron Age (EIA) (ca. 1100-700 BCE) sites were near the coast. The standard deviation in enamel $\delta^{13}C$ in Panormos is s.d.=0.96 and a kernel density distribution created using the Stata 14 *kdensity* function (Fig. 6) indicates the sample is skewed slightly more negative than a normal distribution, with tailing values enriched. The enamel and protein values of the Panormos sample are more consistent with C_3-protein sources (Kellner & Schoeninger, 2007), as are the collagen data in groups from coastal Almyri and Halos. It is worth noting the dietary values at Almyri reflect a narrower isotopic composition than that at Panormos, at least statistically. The standard deviation of collagen $\delta^{13}C$ at Almyri was s.d.=0.25. While the large Panormos variation may be an artifact of a smaller sample set or of effective biological averaging of isotopic composition of skeletal collagen being formed over longer periods than enamel, there are also potential social explanations for variation in the data. For example, diachronic changes in the diversity of individual dietary composition around the Aegean may contribute to the difference. This last option finds some support in studies of $\delta^{13}C$ addressing various periods in the Eastern Mediterranean, which suggest isotopic data mirrors trends in other archaeological evidence. That is, the Archaic Period individuals from Panormos likely represent a population whose diet focused primarily on C_3 food sources, including protein. Loftus and Sealy (2012, 505) further note a poor correlation between enamel and bone apatite, creating significant uncertainty in direct comparison. While terrestrial C_3 plants almost certainly contributed to diet at Panormos—a category that includes the vast majority of agricultural staples (cereals, legumes) and wild plants in the region—it is the protein component that begs clarification to ascertain contributions from aquatic resources or C_4 plants. As mentioned, the Panormos collagen data do not resolve the issue as the values overlap with other EIA sites where fish consumption is also a question, but the two Panormos values suggest a primarily terrestrial dietary composition comprise the diet, with more enriched invidivduals possibly including low trophic value marine foods (Papathanasiou, et al., 2013).

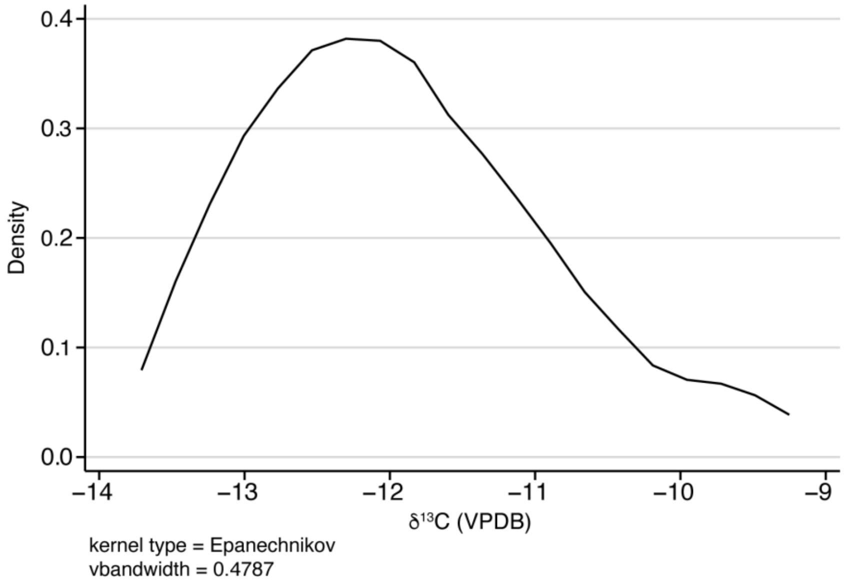

Figure 6: Kernel density estimate for carbon isotope ($\delta^{13}C$) values for all analyzed samples from Panormos

Oxygen isotope ratio values range from 22.07 to 27.23‰ in the Panormos study sample (Fig. 7), a slightly greater range than that observed at other sites in the region. Patterns in individuals with multiple analyzed teeth are again of particular interest for inferences about childhood events, including age at weaning (Fig. 8). It is expected that $\delta^{18}O$ values will decrease with weaning (Wright and Schwarcz, 1998, Britton, et al., 2015). The only individual where such a pattern is evident is Ph301, where $\delta^{18}O$ decreases -1.63‰ from M1 to M2, and -0.98‰ from M2 to M3. There is no other evidence for weaning in the data , as early forming teeth in the sample are not generally enriched relative to later forming teeth. It is intriguing that, for individual Ph206, $\delta^{18}O$ values consistently increase across all three molars. This may imply a change in residence, or a shift in diet composition or preparation techniques (e.g., Warinner and Tuross, 2009, Brettell, et al., 2012).

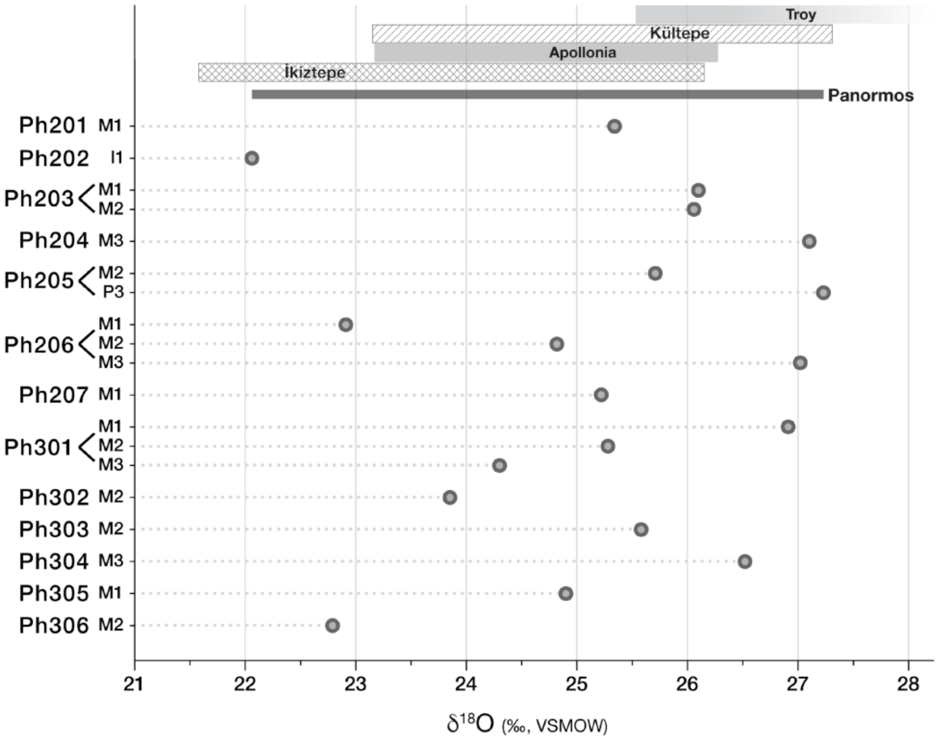

Figure 7: Enamel oxygen isotope (δ18O) values from Panormos. Bars at top indicate ranges from other regional sites for comparison.

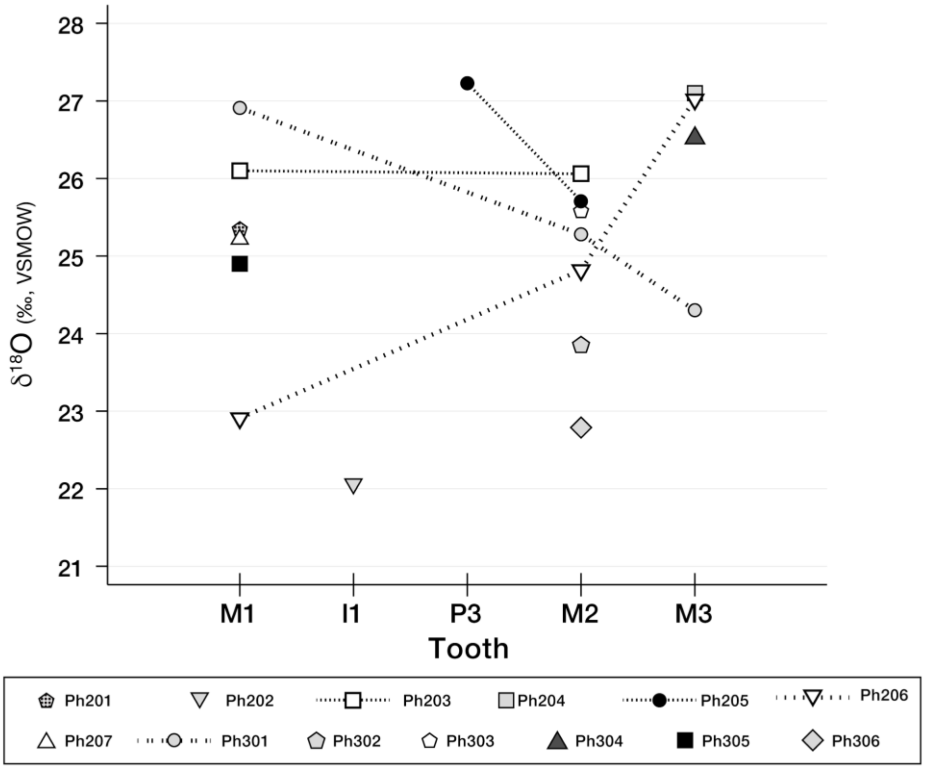

Figure 8: Oxygen isotope (δ18O) values from Panormos by individual, arranged along x-axis by enamel formation period. Sequential teeth from same individuals indicated by dotted lines; symbols same as Fig. 4.

Perhaps as a result of their proximity to the sea, Panormos $\delta^{18}O$ values are remarkably similar to other coastal sites in the wider region, like Apollonia Pontica (Keenleyside, et al., 2011) and EBA İkiztepe (Welton, 2010) on the Black Sea, or Troy (Meiggs et al., in prep.). This confounds identification of 'local' individuals without further lines of evidence, particularly strontium isotope ratios ($^{87}Sr/^{86}Sr$). Panormos oxygen values also show surprising overlap with interior sites like EBA Kültepe (Yazıcıoğlu Santamaria, 2015), suggesting more complex factors at work in regional baseline values. These comparative data represent a broad temporal range and thus effects of regional climate shifts cannot be discounted. Paleoclimate reconstructions suggest that the EBA should have been slightly wetter than the Archaic period (Roberts, et al., 2011), thus oxygen isotope ratios may be generally lower for EBA samples, particularly on the coast of the Black Sea (i.e., İkiztepe). Despite these constraints, some observations about mobility in the Panormos data are justified. First, a relatively large inter-tooth range of $\delta^{18}O$ for Panormos individuals Ph206 and Ph301 (4.11‰ and 2.61‰, respectively) may reflect individuals with mobility around the Aegean, Black Sea or beyond. Mobility to the interior plateau cannot be discounted because, as mentioned, Panormos $\delta^{18}O$ values also overlap with those from Kültepe, near Kayseri, over 700 km to the east in central Anatolia.

5. Discussion

Taken together, the carbon and oxygen isotope data suggest that some individuals at Panormos had distinctly different childhood diets, a greater diversity than that so far evidenced at many sites in the region (Fig. 7). However, to our knowledge, the only other study to analyze sequential teeth from the same individual is Yazıcıoğlu Santamaria (2015). This diversity at the site may partially be due to the different averaging of the isotopic traces of diet represented analysis of bone collagen (protein) versus mineral enamel apatite, since bone is remodeled throughout life and so documents diet during adulthood. Enamel bioapatite values measured here, but only two Neolithic sites in Greece (Alepotrypa, Tharrounia) reveal as great a range in $\delta^{13}C$ values (Papathanasiou, 2003). While there are certainly temporal differences, the diversity at Panormos may represent local dietary differences across the Milesian peninsula, or could represent individuals raised elsewhere who settled on the peninsula as merchants, tradesmen, enslaved peoples or other migrants. For example, the increasing oxygen values for individual Ph206 with minimal shift in carbon from M1 to M3 could indicate childhood mobility from an area with more depleted $\delta^{18}O$ ratios, like the Black Sea or interior Anatolian highlands. Also, individual Ph202 is remarkable for having the most enriched carbon and most depleted oxygen values, suggesting this person may have had greater marine component of their diet in a cooler locality during their first four years than the average $\delta^{18}O$ at Panormos ($\underline{x}$ = 25.25‰, s.d. = 1.52). This pattern contrasts with individuals, such Ph304 and Ph205, who both display a stronger terrestrial signal in carbon and enriched values of oxygen that are closer to individuals from Neolithic to Byzantine contexts from Troy (Fig. 7). The increase in carbon values associated with minimal change in oxygen for individual Ph203 is difficult to interpret and underscores potential complexity in stable isotope data in the region.

Though the context from which Ph202 was recovered was found in profile, disturbed by modern construction work (see Fig. 2) and hence there are no associated finds, its stratigraphic position makes this likely to be one of the oldest amongst the samples analyzed here, Phase B or C1 (7th or early 6th century BCE). In the context of historically-attested foundation of colonies by Miletos in the Black Sea during this era, this individual's greater marine diet in a cooler locality, could reflect mobility associated with such a process, though clearly the exact mechanisms or point of origins cannot be deduced from these results alone. Nonetheless, the connection demonstrates the potential for this type of analysis if applied more widely and consistently across larger samples.

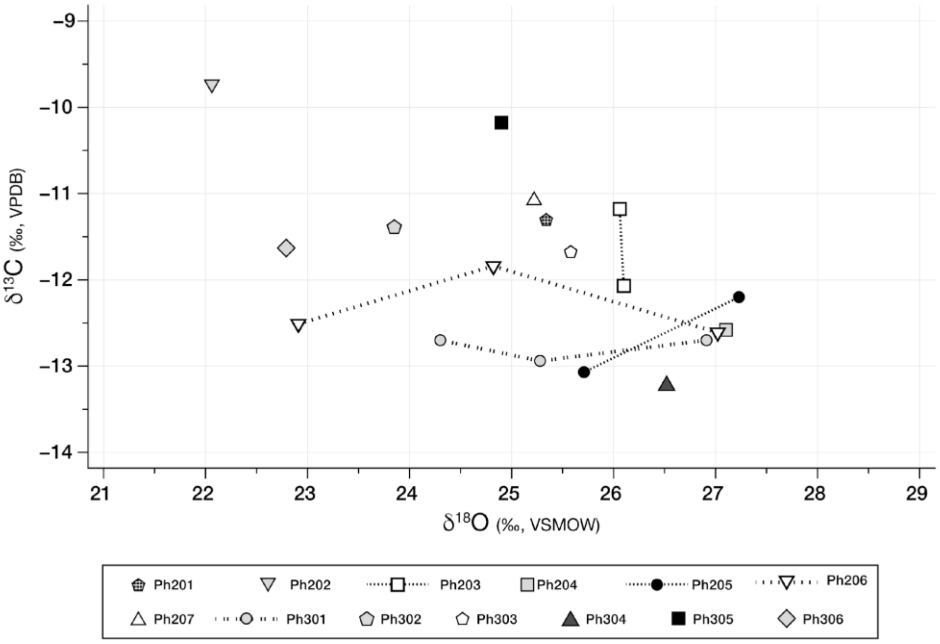

Figure 9: Oxygen versus carbon isotope ratio data in Panormos individuals.

6. Conclusion

This study has presented stable isotope evidence from the Archaic Period necropolis at Panormos. As part of the urban sphere of Miletos, both carbon and oxygen values we suggest dietary diversity is representative of a cosmopolitan population with diet derived from varying degrees on C3 terrestrial and marine resources. This diversity also hints at a potentially high degree of mobility or else distinct dietary patterns in childhood, such as divergent weaning practices. Both may have arisen either from the heterogeneity of mercantile, colonial or subsistence activities in a period when new social and political structures arose and a shift in the configuration of spatially-dispersed social networks, reaching far across the Mediterranean and the Black Sea, was profound (e.g., Wallace, 2003). Future work will apply strontium isotope ratios will help clarify mobility in this Panormos sample.

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Table 1: Study samples and isotope data for Panormos burials

Panormos Individual	Tooth	Symm.	Upper/Lower	d^{13}C (PDB)	d^{13}C s.d	d^{18}O (PDB)	d18O s.d.	d^{18}O (SMOW)
Ph201	M1	R	U	-11.31	0.06	-5.4	0.11	25.34
Ph202	I1	R	L	-9.73	0.06	-8.58	0.16	22.06
Ph203	M2	L	L	-11.18	0.06	-4.7	0.14	26.06
Ph203	M1	L	L	-12.07	0.06	-4.67	0.13	26.1
Ph204	M3	L	L	-12.58	0.06	-3.7	0.21	27.1
Ph205	M2	L	L	-13.07	0.03	-5.04	0.19	25.71
Ph205	P3	L	U	-12.2	0.04	-3.57	0.17	27.23
Ph206	M1	L	L	-12.51	0.06	-7.76	0.28	22.91
Ph206	M2	L	L	-11.84	0.04	-5.91	0.15	24.82
Ph206	M3	L	L	-12.61	0.06	-3.77	0.18	27.02
Ph207	M1	L	L	-11.08	0.06	-5.52	0.09	25.22
Ph301	M1	R	L	-12.7	0.07	-3.88	0.15	26.91
Ph301	M2	L	L	-12.94	0.07	-5.46	0.25	25.28
Ph301	M3	L	L	-12.7	0.03	-6.41	0.22	24.3
Ph302	M2	R	L	-11.39	0.03	-6.85	0.11	23.85
Ph303	M2	L	L	-11.68	0.06	-5.17	0.09	25.58
Ph304	M3	R	U	-13.23	0.06	-4.26	0.09	26.52
Ph305	M1	R	U	-10.18	0.06	-5.83	0.09	24.9
Ph306	M2	R	U	-11.63	0.06	-7.88	0.24	22.79

Table 2: Contextual information for sampled individuals from Panormos necropolis

Panormos Individual	Grave No	Phase	Context	Grave Context Notes
Ph201	G1	C3	S2/9	Imported basket handled amphora burial with cremated remains
Ph202	G6?	C1-2?	P/6	Fragments of inhumation damaged by drainage ditch (potentially part of same individual as Ph203, but more likely redeposited secondarily by later burial events)
Ph203	G6	C1-2?	P/12	Partially preserved inhumation, damaged by drainage ditch, with south Ionian amphora
Ph204	G5	C2	S4/5	Supine inhumation, partially preserved, with substantial amounts of burnt ceramic
Ph205	G19	C1-2?	S2/69	Partially preserved dislocated inhumation (articulated head and one half of torso), covered by stones
Ph206	G3 (b)	C2	S2/32	Inhumation, skeleton lying adjacent to and associated with large pithos (potentially buried at same time Ph207)
Ph207	G3 (a)	C2	S2/19	Inhumation, small skeleton lying inside large pithos (potentially buried at same time as Ph206)
Ph301	G32	C2	S3/20	Partial inhumation, apparently cut by later insertion of sarcophagus (G22)

Ph302	G71	C2?	S3/22	Inhumation, skull only in 2013 (thought part of G35), the rest uncovered 2014 as S3/71, revealed as discrete, almost complete burial
Ph303	G25	C2?	S2/85	Supine near complete inhumation, local aryballos at feet
Ph304	—	C2?	S3/19	Remains of inhumation (potentially redeposited as result of excavation for sarcophagi?)
Ph305	—	C2?	S3/30	Incomplete inhumation/skeletal remains to north of sarcophagus
Ph306	G35	C1-2?	S3/39	Potentially disturbed partial inhumation, with skull and large bones apparently redeposited (near to G71, but probably not part of same event

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