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A new lease on life: using advanced analytical techniques in bioarchaeology to maximise the understanding of past populations of Sardinia

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For the co-joint degree of Doctor of Philosophy (PhD)

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A new lease on life: using advanced analytical techniques in bioarchaeology to maximise a new understanding of past populations of Sardinia

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Declaration

The project presents my original studies on skeletal remains collected by Prof. Carlo Lugliè and Archaeologist Giovanni Maria Costa. Financial support from the Research Training Program was jointly provided by the University of Cagliari and James Cook University. Some parts of the research were also supported by funds from Regione Autonoma della Sardegna, under the Garanzia Giovani project (5B in transnational mobility); from the University of Cagliari and Fondazione di Sardegna (Know the Sea to Live the Sea project); from the Comune di Pau (Monte Arci project).

I declare that this thesis is my own original work unless otherwise referenced or acknowledged. The thesis output includes manuscripts that have been submitted and/or published in the frame of my PhD project, and unsubmitted ones. The different chapters are outlined in the introduction, linked in the discussions, and summarised in the conclusion.

Rossella Paba

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Abstract

Sardinia has been a centre of cultural and economic exchange for centuries within the Mediterranean. This study provides the first comprehensive evaluation of two groups of people living during two key periods in Sardinia. First, life in the Middle Neolithic was investigated via the skeletal remains of Su Forru de is Sinzurreddus in Pau. Secondly, the Monte Luna Necropolis in Senorbì provided information on the Punic era.

The application of advanced analytical techniques to analyse the chemical composition of skeletal remains helped to assess the funerary rite in Pau. The site, which was a major hub of obsidian production and likely part of a complex trade network, contained a variety of artefacts, including obsidian, pottery, and beads. The multi-technique approach assessed the first archaeological evidence of cremation burials at the Monte Arci site in Sardinia dating to the 5th millennium BCE in the Middle Neolithic period. The funerary rite was crucial in understanding the type of exchange during these interactions showing that it was not only economic, but also cultural. This suggests that cremation was practiced in the region at least as early as the Middle Neolithic. The current evidence suggests that the Neolithic Demographic Transition had an impact in the region: the population increased, and people started to live in more densely populated areas which may have led to a decline in overall health, with an increase in disease and mortality rates. The island of Sardinia has a long history of isolation and low levels of genetic admixture, though there were significant interactions with seafaring peoples in the Middle Neolithic. While the island was more populated during the Punic/Roman Era, there are still many genetic similarities between modern Sardinians and people of the Middle Neolithic.

The regional differences due to the later arrival of farming communities, climate and environmental differences could have contributed to the evolution of the health profiles in Sardinia. Pau and Monte Luna follow the same trend: caries was age progressive, as were periapical lesions and antemortem tooth loss at Monte Luna. Pau showed a higher caries rate, probably due to a number of factors related to diet, fertility, and behavioural factors. The dental health profile of females at Monte Luna is suggestive of changes in diet and lower fertility compared to Pau. Indicators of stress in childhood showed rates of subadult mortality for both localities suggesting a proportion of frail children in both the Middle Neolithic and Punic Era. The stature and enamel hypoplasia (EH) recorded in Monte Luna suggested males were healthier than females. This was probably due to females, in childhood, not having the same access to quality food, not being looked after when ill, or having a genetic predisposition to disease such as beta-thalassaemia.

The osteobiography of Tomb 27 in the Monte Luna Necropolis details a young woman (T27.2) buried in an atypical prone deposition, having disturbed an earlier burial (T27.1), a subadult around 15 years of age. T27.2 suffered two distinctive types of perimortem trauma, a possible diastatic blunt force trauma to the occipital bone and a small quadrangular-shaped sharp force trauma lesion. The grave goods allow a very specific dating of this burial to the period of transition between Punic and Roman cultures. These, and the characteristics of the young woman's skeleton, are of significance in understanding funerary and cultural behaviour at the time of this transition.

An understanding of both site's geography was obtained through aerial mapping, GIS, and 3D modelling. The analyses helped to identify other potential influences on the behaviour of the ancient people and cultures, such as the environment and the social and political systems at the time. This can help to explain why certain behavioural patterns were observed and why certain changes in behaviour may have occurred over time. Finally, the analyses were also useful in understanding the dynamics of the ancient societies, their rituals, and their beliefs, which can help to better interpret their actions and behaviour. In addition, the 3D models and maps are useful as a record for teaching, and to involve the community in the preservation of the past.

The significant complexity of Sardinia in its position, geography, and climate resulted in an independent development of the island, but with a high level of connectivity with mainland Europe during the Middle Neolithic and the Punic Era. This study adds significant new information on demography, health, and environmental stress in the Pau and Monte Luna people. The profiling of the respective populations shows the differences and similarities of two communities separated by several millennia and characterised by different cultural and historical contexts. This thesis also provides valuable information to aid future research in Sardinia and the Mediterranean region.

Focus Map

Archaeological discoveries in Sardinia revealed an island conquered by a new population bringing in new customs, rites, behaviours, and policies. Studies on Sardinian genomics show signs of long isolation (10000 - 4000 BC), however, the population became more diverse and interconnected with the arrival of the Phoenicians (900 - 600 BC). Sardinia's geography and its long history of pastoralism, presents an interesting case study in cultural and genetic adaptations, suggesting connections between cultural adaptations and genetic diseases.

Most of the archaeological and genomic data published have not integrated analyses of the human remains to gain a wider context.

How did the interaction with different peoples influence the population of Sardinia? Were the interactions mostly violent or peaceful in nature? Were they either political or social, or both? Were they co-existing? Did the new populations mix with the local ones?

The analysis of human remains enhances our knowledge of the past in terms of social structure, customs, rites, and behaviour.

Using advanced analytical techniques to study human remains provides information on demography (sex and age), health and burial rites (inhumation or cremation). The data are presented in a digital output suitable for multiple platforms to support data circulation and facilitate future research.

The Middle Neolithic (MN) (~4300-4000 BC) collective burial site of Su Forru de is Sinzurreddus brought to light approximately 50,000 skeletal fragments which display signs of thermal alterations with different degrees of combustion.

Very few examples of cremation appear in older and coeval sites. The crucial shift of ritual behavior from primary inhumation to cremation in the interregional MN required research to understand this specific symbolic behavior. Additional evidence of cremation in Sardinia dates to the Phoenician-Punic Era (900-300 BC).

This peculiar archaeological context raised an unexpected issue: are we looking at a secondary burial rite due to the systematic and repeated cremation of several individuals over time? If this was the case, it would be the oldest and only example in the Neolithic of Sardinia.

The necropolis of Monte Luna was investigated archaeologically during the late 1970s to the early 1980s. Only a portion of the necropolis was excavated with at least 120 tombs partially documented, although there is a significant lack of recorded contextual information.

The human remains were collected by tomb and not by statigraphic position leading to analysis based on mostly commingled burials.

Were the remains positioned on the hill following specifics beliefs? Were there any rites linked to sex, age, disease, or societal position?

The study of commingled burials highly fragmented remains represents a challenge in bioarchaeology.

Standards in anthropology are based on complete skeletons.

Could the use of advanced analytical techniques benefit the study of human remains adding new information to better understand commingled burials?

The analyses of human remains create a bio-profile of each individual following standard methods: age-at-death, sex, ancestry, dental wear and development, dental health, skeletal development and evidence of stress are investigated through enamel hypoplasia, metrics, and stature.

Analyses are either non-destructive such as spectrophotometry to assess colour changes, and XRF for elementary chemical analysis, or partially destructive such as FTIR-ATR in molecular chemistry analysis.

The geo-terrestrial space analysis and 3D modelling are performed for a better geographical understanding of the settlements.

The application of standards in anthropology together with new advanced analytical techniques provide new information on this complex context.

The health status is then integrated with culture, environment, and history to assess social perspective, evolution of medical practices and knowledge in terms of healing processes and biological data such as pathology, genetic traits, and trauma.

The analysis of the crystallinity index (CI) of bone provides insights into bone mineral formation. The interpretation of changes in the CI sheds light on burial practices, the possible use of fire, approximate age-at-death and controls for the chemical behaviour of the crystal in specific disease shown on the skeletons.

The overview of the sites shows the location of the tombs and the remains. The maps allow a study of the distribution of the remains in terms of MNI, age ranges, health, and trauma cross - referenced with archaeological data (stratigraphy, grave goods etc). The biospatial analysis helps to contextualise the results in the wider cultural setting.

The results are compared to gain a better understanding of the evolution of the Sardinian population.

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Acronyms

AD: after Christ's birth

AMTL: ante mortem tooth loss

BC: before Christ's birth

CEJ: cemento-enamel junction

EH: enamel hypoplasia

MN: Middle Neolithic

PL: periapical lesions

1 INTRODUCTION

The prehistory of Sardinia (Figure 1) is complex and dynamic extending from the still debated first occupation in the Palaeolithic (400,000-120,000 yo) (Vona, 1997; Calò, et al., 2008) until early and classical antiquity (900 BC-456 AC). Essential to understanding both the complexity and dynamics of the Sardinian cultural and biological landscape are the people themselves. The people of Sardinia created the archaeological records, cultural materials, and buildings, demonstrating their use of, and ability to, adapt to their natural and cultural environment.

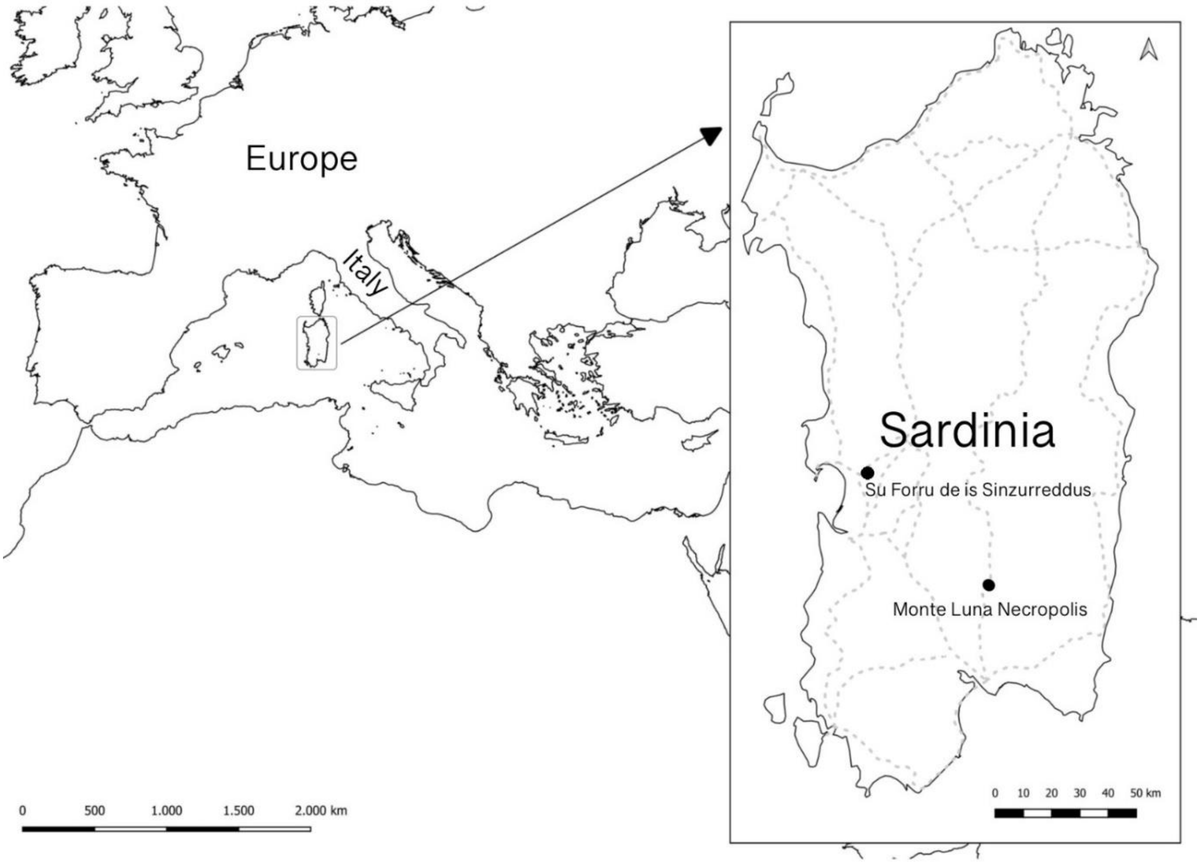

Figure 1 Sardinia.

Anthropological studies in Sardinia began in the late 19th century and initially focused on observations, descriptions and classifications of Sardinian human remains. A large amount of past research focussed on anthropometry, stature, craniometrics, and their interpretation with respect to migration (Ardu Onnis, 1895; Niceforo, 1896; Frasetto, 1907; Maxia, 1953; Maxia and Floris, 1961; Maxia and Fenu, 1963; Germanà, 1975, 1987, 1989, 1995, 2004; Floris, 1998; Sanna, 2015). Over the past few decades, molecular anthropology has greatly expanded our knowledge on the region's migration and genetic peculiarities (Piazza et al., 1988; Francalacci et al., 2003; Vona and Calò, 2006; Sanna, 2006; Francalacci et al, 2013; Capocasa et al., 2014; Modi et al., 2017; Chiang et al., 2018; Marcus et al., 2020).

In recent years, the study of Sardinian human remains has expanded (Piga et al., 2010), however, the exploration of behavioural and health-related aspects represents a new area of research. The aim of this project is to contribute to anthropological studies on the island of Sardinia through thorough analyses of health, funerary behaviour, and culture taking into account the natural and cultural environment in which people lived. Due to the wide variety of Sardinian history and the complexity gaining access to the human remains, the thesis investigates the lifeways of two sites, one from the advanced Middle Neolithic (~4300-4000 BC) and one from the Punic Era (900-300 BC). These periods were chosen as witnesses of significant socio-cultural changes: the Middle Neolithic shifted from hunter-gatherer to farming subsistence and village economy, while the Punic Era saw the introduction of monoculture.

1.1 UNDERSTANDING THE PAST

The study of the past has been used to discover the processes that have led to our contemporary societies, to better understand human evolution in terms of behaviour, both social and ritual, to understand past lifestyles and health, technology (buildings and tools), and demography through time. While the methods for studying the past have changed and developed, they have always been based on what was left behind by people: from written records to the material culture to human remains. Archaeology plays an important role in the study of the past, adding information through different approaches: from the study of material deposits (Clarke, 1973; Binford, 1981), artefacts and objects (Watson, 1971; Renfrew, 1972), buildings and burial forms (Childe, 1956) and human remains (Buikstra, 2006). All of the approaches could be applied to study both terrestrial and marine environments to inform about the life of people in the past (Gowland and Knüsel, 2006), past geomorphology and climate change (Pittau, 2012; Mannino, 2015; Pascucci, 2018), technical evolution (Fanti, 2018), and behaviour and economics (Matranga, Pascali, 2021).

The study of human remains needs to be separated chronologically. Prehistory, also known as pre-literary history, is the period from the first stone tools (3.3 million years ago) to the beginning of records and first writing systems. History is based on the appearance of written records first found in Egypt and dating to 3200BC (Tignor et al., 2011). Written records can provide much more detailed information than material remains, however, records written in extinct languages may be difficult to interpret, and there is the inherent danger of one-sided bias of authorship. Furthermore, information written down after many years of oral transmission may not accurately reflect the actual event be it by accident or on purpose (Tignor et al., 2011).

Archaeological data together with written sources have been used to develop multiple paradigms and theoretical perspectives with the intent to find an interdisciplinary approach (Feinman, 1997). When combined the study of written records and the analysis of material culture improves the understanding of technological evolution in architecture, the manufacture of artefacts, subsistence mode, and social and ritual behaviour.

The focus of archaeology is on people and, consequently, it is important to study their biological remains. This can be done using a humanistic (interpretative archaeology) and scientific (osteoarchaeology) approach (Soafer, 2006). This was outlined in the first acknowledged definition of culture by Edward Burnett Taylor: “Culture or civilization, taken in its wide ethnographic sense, is that complex whole which includes knowledge, belief, art, morals, law, custom, and any other capabilities and habits acquired by man as a member of society" (1871: 122), opening the concept of culture to a set of knowledge acquired from humans as members of a group. The originality stands in applying an evolutionary perspective to the analysis of culture, treating it as equivalent to all biological species.

Franz Boas expanded this idea of totality, considering culture as a number of interrelated elements:

> "Ethnological phenomena are the result of the physical and psychological character of men, and of its development under the influence of the surroundings... 'Surroundings' are the physical conditions of the country, and the sociological phenomena, i.e., the relation of man to man. Furthermore, the study of the present surroundings is insufficient: the history of the people, the influence of the regions through which it has passed on its migrations, and the people with whom it came into contact, must be considered" (1907: 928).

The people are the centre of interest, they interact with the world, people are affected by and affect the environment, material products, and networks of their local and global communities. The individual interconnects behaviour, products, relationships, and technological processes in a specific context. In addition to their physical environment, people are part of a complex network of relationships and exchanges. They are connected to each other through social and economic structures, political systems, and culture. People produce and use products while, at the same time, the products influence and transform people through their interactions with the environment. Archaeological remains are pieces of a larger puzzle which, when completed, outlines a population profile and its evolution.

Human bodies are the product of the environment (Boas, 1911) and the relationship between behaviour and evolutionary perspectives can be studied through osteological data to inform on health, disease, and environmental stress (Spencer, 1981; Haraway, 1988; Johnson and Mann, 1997). Understanding the connection between biology and human actions (Powell, 1991; Grauer, 1995; Larsen, 1997a/b) depends on the way objects, the focus of archaeology, and humans, the focus of osteology, are interpreted. Historically, this approach was pioneered by researchers who used material remains to understand human behaviour in an effort to correlate archaeology and anthropology (Binford, 1964, 1972). This started debates in social anthropology (Hinde, 1991; Goldschmidt, 1993; Toren, 1993; Robertson, 1996; Ingold, 1998) and archaeology (Johnson, 1989; Tringham, 1991; Meskell, 1998) on the connection between people and the archaeological record. In the UK, the divide remained through institutional distinction between physiology, focusing on the human body, and sociality, focusing on human behaviour. However, researchers with a medical background helped lead to the conceptualisation of the body as evidence of processes that occurred during life (Mays, 1997; Ingold, 1998; Gell, 1998; Tarlow, 1999). Therefore, the interpretation of human remains can combine both scientific and sociocultural analyses to investigate the material remains of a person's life (Sofaer, 2006).

In Italy, the divide between archaeology and anthropology waxed and waned. However, in the 1960s the crisis of colonialism and new social and political movements started the process of interdisciplinary collaboration (Cossu, 2016), although the disciplines remain clearly separated, especially at universities. A number of specialist subdisciplines have developed, but when applied in isolation there is always the risk of missing the bigger picture that the combination of the humanities and science can provide (Morin, 2000).

In the last decade the anthropo-poietic perspective (Remotti, 1993; Fabietti, 2015) was developed as a tool to overcome the divide between the humanities and science. The theory sees humans as free, undetermined subjects who form objects and themselves: they have the power to develop, create, and modify both their external and internal environment (Pico della Mirandola, 1486; Remotti, 1993).

Humans are able to use culture to adapt to their environment (Allovio, 2015). They are considered undetermined as the individual's active creation of culture ceases at death (Allovio, 2015), giving the role to the community which develop an identity after a person's death. Globally, there are examples of a wide range of actions (or re-action) to death, such as attempts of avoiding, accelerating, mystifying, slowing down, and blocking it. These re-actions can be seen in the use of cremation, giving the body to feed animals, and inhumation and embalming techniques (Favole, 2003; Remotti, 2013). Examples can be found in the Japanese *miira* mummification process (Lobetti, 2007), or Syrian monks' mortification of the body (Filoramo, 2010), and even with the recent development of cryogenic techniques (Bonini, 2007-2008). Importantly, all or some of the above categories are often used by different societies throughout history (Favole, 2003). The human remains become the remains of humanity, as the body is the physical material which has incorporated culture into the biological evidence (Favole, 2003). During their lifetime and in death, humans go through constant change and transformation (Allovio, 2015). Death needs to be perceived not only as a physical event (Hertz, 1907), but has to take the identity of the person into account (Remotti, 1993), considering both biological and archaeological data to better understand its social dimensions (Binford, 1971; Goldstein, 1976; Schiffer, 1987).

Funerary rites are a good example in which to identify differences within and between the societies (Favole, 2003). However, it would be a mistake to tie a rite to a specific population or to try to interpret diversification between the different rites (Tartari, 1996). The same rite can be perceived differently from population to population and, furthermore, this can vary over time. It is also possible that the same beliefs can be expressed via different rites (Tartari, 1996). The perception of the dead and their interaction with the living vary through time and space and between cultures (Rakita, 2005; Rebay-Salisbury, 2010; Cerezo-Roman, 2014). Furthermore, the dead are mourned and buried by the living and can be transformed into something they were not during life (Hodder, 1982a/b; Geertz, 1987) or as a means to serve the purposes of the living (Pearson, 1993). Each burial context needs to be interpreted using an interdisciplinary framework that takes into account social, cultural, and physical information (Howarth, 2007). The separation of the human remains from the context of the burial could lead to a misinterpretation of the original concept (Williams and Giles, 2016). Consequently, each individual burial needs to be analysed as representative of the population from which they came (Williams and Giles, 2016).

The analysis of a skeleton produces unique cultural and biological data not only of the entire lifetime of an individual but can also indicate changes at a community level (Agarwal, 2016). The human remains, together with rites and the artefacts linked to them, are the result of the interaction with the environment and allow the study of the processes within and between populations (Goodman and Leatherman, 1998). Archaeological investigations of human remains from different geographical areas offer new information on cultural diversity. The study of the remains linked to other archaeological data allows for a wider perspective on the lives of past populations. If the body is seen as the result of cultural and biological phenomena, the determination of the biological profiles (sex, age, ancestry) enhances knowledge about demography and life expectations in the past (Sullivan, 2004). The analysis of people's health such as traumatic lesions, pathology, oral health, and stature provide an insight into the evolution and development of a group at a specific time (Mays et al., 2001; Walker, 2001; Armelagos, 2003; Raxter et al., 2006; Cardoso, 2008). The biological data recorded and studied can be then compared to identify an evolutionary trajectory over time (Buikstra and Beck, 2009). The study of biological information through time provides a better understanding of populations and their physical and cultural environment. Biological data are linked with archaeological evidence in order to determine how and why demography, health, funerary rites, and behaviour might have changed through time.

1.2 SARDINIA: ENVIRONMENTAL AND ARCHAEOLOGICAL FRAMEWORK

Sardinia is a Mediterranean island off the western coast of Italy with a long and diverse history. Each era throughout its history is distinguished by a specific material culture, architecture, rites, and behaviour. Archaeology and genetic studies have identified Neolithic (5900-3500 BC) and Phoenician/Punic (900 – 300 BC) eras as key moments in the island's evolution. Henceforth the latter will be referred to as the Punic Era as the Phoenicians were assimilated by the Punics.

Sardinia's position, in the centre of the Mediterranean basin (Figure 1), together with its wealth and varied geography, played an important role in its diversity. The island is located far enough from mainland Europe to be biogeographically isolated and, being strategically centred, has made Sardinia attractive to a wide range of different populations through the millennia. Sardinia is well-located along common ancient sea trade routes. To the east, the Tyrrhenian Sea separates the island from Italy by about 290 km, to the west the distance to Spain is 730 km, approximately 400 km to the Balearic Islands, while the south shore is 220 km from Africa and the north coast is only 25 km from Corsica. The island covers an area of approximately 24,090 km^2 of plains, mountains, and long coastlines. Its biodiversity is typical of the Mediterranean area with some endemic species.

The island was formed during the Palaeozoic Era (up to 500 million years BC). At the end of the Oligocene, Sardinia, Corsica, the Calabro – Peloritano Arch, the Balearic Islands and Kabilidi (North Africa) were part of the south – western European plate. Due to geodynamic events in the Western Mediterranean during the Inferior Burdigalian (20 million years ago), the opening of the Balearic basin forced the stretching of the plate. As a result, Sardinia slowly (4-5 million years) moved to its current position and location (Carmignani et al., 2001).

The 1639 km of coastline is characterised by a large number, and complex variety, of rocks including schist, granite, limestone, and tuff (Carmignani et al., 2001). The long coastlines are punctuated by deep bays, numerous beaches, and various smaller islands off the coast. Most of the central area of the island is characterised by mountains and ranges with multiple caves. The mountains are separated by two large flatlands, the *Nurra* in the north and the *Campidano* in the south. The flatlands include over 1850 km^2 of fertile land. The island has a few major rivers and one natural lake.

The current climate is typical of the Mediterranean with temperatures between 24-30 °C in the summer and 9-10 °C in the winter. Freezing conditions only occur on the highest peak in the centre of the island in winter. The environment changed from the Early Holocene to historic times, resulting in coastal modifications (retreat or advance), and river mouth migrations (Zazo et al., 2008; Melis et al., 2017), followed by socio-economic and cultural changes (e.g., from Mesolithic to Neolithic, from Middle to Late Bronze Age). Information on the climate during the Neolithic is very scarce and is based only on the analysis of vegetation. The limited data available only allow a hypothesis that climate oscillated between warm and cold periods (Beffa et al. 2016). The Punic era was characterised by a very stable climate and favourable conditions, which coincided with the rise of the Phoenician – Punic – Roman cities in the island (Pascucci et al., 2018).

Flora and fauna are very similar in the Mediterranean and Tyrrhenian seas. Due to Sardinia's isolation, it has quite a few endemic species: up to 200 endemic plants and up to 33 endemic animals (Grill et al., 2007). Asteraceae (50 taxa) and Plumbaginaceae (42 taxa) are the most representative plant families for its regional endemism, while hemicryptophytes (118 taxa) and chamaephytes (106 taxa) are the most frequent (Fois, 2022) as is typical of Corsica and the Mediterranean area in general. The fauna of Sardinia includes 370 species including 41 mammals, 18 reptiles, 8 amphibians, and about 300 types of birds both sedentary and migratory. Prominent Sardinian animals are the Giara pony, the donkey, sheep, fox, goshawks, sparrows, and tree frogs (Grill et al., 2007). Noteworthy is the Sardinian pika (*Prolagus sardus)* (Wagner, 1832), an ochotonid closely related to hares and rabbits, which was common in the Middle Pleistocene and went extinct during the Roman age.

The suite of fertile planes, defensive rocky hills and mountains, deep and calm coastlines, as well as temperate weather made Sardinia a suitable place for hunter-gatherers and also for farmers and herders. Sardinia has possibly been occupied since the Final Palaeolithic (20,000 BC) (Modi, 2017) and has a long and diverse history demonstrated by material and symbolic archaeological evidence.

From the beginning of the Neolithic (ca. 5800-3500 BC), pottery of Cardial ware can be found throughout the Mediterranean including in Sardinia (Tykot, 1997; Lugliè, 2006). This testifies to Sardinia's participation in a regional trading network. The studies of obsidian circulation from Monte Arci (Sardinia) indicate even earlier interregional contacts and bidirectional interactions with Corsica, northern Italy, and southern France (Lugliè, 2012). These regional contacts continued during the Copper and Early Bronze Ages (ca. 3200-1800 BC). In the Middle Bronze Age, there is evidence of episodic contact with few imports from the Aegean, such as oxhide ingots, and Mycenaean ceramics. While the Sardinian Recent and Late Bronze Age ceramics have been attested in active relationship with Crete and Cyprus (Gradoli, 2020). In the early 8th century BC, Phoenicians established colonies on the island, followed by the Carthaginians/Punic who gained the entire control of the island by 509 BC (Bartoloni, 2010). The Romans conquered the island in 238 BC, and Sardinia became an important source of grain and minerals in interregional trade networks (Polibio, 206-124 BC; Le Lannou, 1979).

The island's varied archaeological, linguistic, and cultural heritage has attracted researchers since at least the late 19th century. The study of refuse, material culture, and the remains of buildings, such as settlements, tombs, and the traditional *Nuraghe* (Schiffer, 1983, 1987; Kuna, 2015) is well documented and provides evidence of the island's attraction to new populations.

Lugliè (2008) showed how Sardinia participated in the Mediterranean basin's trade network from the Neolithic (5500-3500 BC) and the development of the first settlements. These populations gradually developed and established the Nuragic civilization (1700-700BC) based on cultural and commercial exchange along the Mediterranean which were interrupted by the arrival of new populations (Depalmas, 2010). The succession of conquests starting with the Phoenicians, then the Punic (900-300 BC), followed by the Romans (238 BC-456 AD) demonstrate the importance of the island with regards to controlling the Mediterranean trade routes (Le Lannou, 1979).

The archaeology reveals a story of an island occupied by different populations that settled and changed through time, bringing in new customs, rites, behaviours, and policies. This raises many questions about the dynamics of the series of occupations – were they violent or peaceful? Did they have a social and/or political dimension? Was there mixing of populations or just co-existence?

This study is about the people from two specific sites, one from the Neolithic period and one from the Punic era. These are the sites of *Su Forru de is Sinzurreddus* in Pau, and Monte Luna necropolis in *Senorbì*, respectively (Figure 1). At both sites human remains will be analysed using advanced analytical techniques such as through chemical analyses of specific elements and molecules (i.e., calcium, potassium, iron, and strontium, hydroxyapatite) 3D modelling, and GIS mapping. Additional information about the health of individuals and inferences about rites and funerary behaviour will be presented.

Ancient and contemporary Sardinian genomes have been analysed since the beginning of the 21st century. The isolation of the island makes it ideal for comparative studies with other localities in Europe (Di Gaetano et al., 2014). The island has been hypothesised to have been a refuge for early Neolithic peoples (Chiang et al., 2018) and analyses of genomes have included people from the Neolithic and the Late Bronze and Iron Ages (Caramelli et al., 2007). The mitochondrial RNA of two individuals from the Mesolithic Era (10,000-7,000 BC) have been successfully sequenced (Modi et al., 2017). This allowed a comparison with modern Sardinians, showing signs of a sudden genetic shift with the arrival of the first farmers followed by a period of long genetic isolation. While the genetic pool remained relatively stable from the Neolithic to the end of the Bronze Age, there was a significant diversification with the arrival of the Phoenicians (900-600 BC). They arrived as merchants and integrated with the indigenous population (Bartoloni, 2000). Following the Punics (500-300 BC), the Romans (238 BC-456 AD) challenged their power over the island and founded urban settlements to use the harbours to control the major trade routes between Spain, Africa, and Greece (Bonetto et al., 2014; Sanna, 2019).

Ancient written records also support archaeological and genetic findings. For example, a number of ancient Roman authors refer to Sardinia as an insalubrious island (Tognotti, 2008) and describe an endemic disease consistent with malaria, which was common and long-lasting but not fatal for indigenous people. Brown's (1981; 1986) investigations of Sardinia's geographical limitations and long history of pastoralism and transhumance, suggested connections between cultural adaptations and genetic diseases, such as thalassemia major and favism that spread through the population in response to endemic malaria.

This demonstrates the relevance of combining archaeological and genetic data, and written records when studying human remains. The focus on health, disease, and behaviour using human remains from prehistoric and historic Sardinia, adds significant new information on how these people changed and adapted during the period of isolation through to when it became a more diverse region with the influence of new populations. Following Black (2018, p.1), "All that remains is life in death", this investigation aims to apply anthropological standards in combination with advanced analytical techniques. New technologies have proven to be useful to detect new information leading to a more holistic understanding of past lives. Archaeological studies have generally prioritised the study of grave goods and ancient buildings, with a focus on production rather than the producer. This has resulted in a high volume of reports on archaeological data from a wide range of areas and populations. In contrast, the aim of this work is to focus on the producers, the people who actually created the archaeological record and show cultural adaptations to the natural environment. While genetics has been helpful in the study of human remains, it is a destructive technique. The sample size of human remains is small often even preventing replication of analyses. Consequently, access to human remains is tightly controlled and approvals are difficult to obtain. Using a combination of standard techniques and advanced new technologies may lead to new discoveries when studying human remains. The new findings may even be relevant with regards to decisions as to whether the use of destructive techniques is warranted.

1.2.1 Snapshots in time: Su Forru de is Sinzurreddus and Monte Luna

The second half of the Middle Neolithic (second half of the 5th millennium BC) cave burial of *Su Forru de is Sinzurreddus* in Pau, in the *Mount Arci* area, is located near one of the largest known obsidian sources and workshops (Luglié, 2008). This region is located less than 20 km from the Gulf of Oristano. Archaeological research conducted on Sardinia is aimed at reconstructing ancient population profiles and their interactions with mainland Europe and the wider Mediterranean basin. The research is based on the analysis of human remains, material culture and symbolic, ritual and social dimensions of the populations. New technologies and advances in archaeological methodologies have enabled the scientists to gain additional valuable insights into the development of the prehistoric and historic cultures in Sardinia.

The Punic necropolis of Monte Luna (VI century BC – II AC) is linked to the urban settlement of *Santu Teru.* The Acropolis of *Santu Teru* is of significant interest from a cultural perspective because the city eventually ruled over of the entire area of Trexenta, in which it is located, and was managed by the main settlement of KRLY (Cagliari’s Punic name). Both cities were under the control of Carthage, the main Punic city in the Western Mediterranean, northern Africa (Todde, 2020), Furthermore, the necropolis represents a snapshot of the time when Punics and Romans were fighting for control over the Mediterranean basin, it is further attested to be lived during Republican and Imperial ages, and the necropolis also probably survived beyond the end of the Roman Empire (Forci, 2011). Although archaeological data are sparse, written records and the use of cutting-edge scientific approaches have provided new evidence on health, trauma, behaviour, and the perception of social structure at this time of change.

1.3 RESEARCH APPROACH

The human remains from the Neolithic cave of *Su Forru de is Sinzurreddus* and the Punic *Monte Luna* Necropolis are the focus of the present study. The bioarchaeological approach is applied to interpret the remains as system interconnected with their society (Ingold, 1998; Sofaer, 2006; Gravlee, 2009). The characteristic of the island of Sardinia makes it an ideal area to examine the biological profile of the peoples who have inhabited the island over time.

The importance of environmental and behavioural influences will be shown through the application of a life course concept (Gowland, 2016). The connection between lives and social/historic contexts is drawn through integration of archaeological, historical, and ethnographic information (Buikstra and Beck, 2006).

Bone structure and function are influenced during the entire lifetime by a wide range of factors such as diet, health, disease, and general quality of life, (Mays, 1998). Health data can show the complex relationship of people with their culture, natural environment, and history and is used to assess the populations social perspective (Gowland and Knüsel, 2006), evolution of medical practices, pathology, genetic traits, and trauma (Coppa and Rubini, 1996; Ortner, 2003; Barnes, 2012; Mann and Hunt, 2012, 2016). Health profiles of individuals may provide an insight into the level of medical care an individual received based on their status. This also assists to understand the structure of the society in a particular period.

The study will follow the guidelines of the bioarchaeological approach carrying out an estimation of the demography (Hoppa Venpel, 2002; Sullivan, 2004) through calculation of the minimum number of individuals (MNI), sex, and age-at-death (Buikstra and Ubelaker, 1994) to identify the presence of patterning between social construction and the human remains. An analysis of the evidence for oral pathology, such as caries, periapical lesions, antemortem tooth loss (AMTL), will provide comparative information on general health both within and between both periods (Mays et al., 2001; Anderson, 2003; Mitchell, 2003). Variations in enamel hypoplasia (EH) and stature will be used to reconstruct the life history and health status of individuals (Brothwell, 1981; Goodman and Rose, 1998; Schillaci and Stojanowski, 2002; Hillson, 2005; Mariotti, 2004, 2007; Ruff, 2012).The remains will be interpreted in relation to the landscape and artefacts to better contextualise the social context (Thomas, 1993; Richards, 1993; Tilley, 1994; Bender, 1997, 2002).

The bioarchaeological approach will help to better understand the introduction of new funerary rites, and how health and its perception evolved based on the physical and cultural environment throughout these two key transitional periods in the history of Sardinia.

1.3.1 A (bio)spatial point of view

The analysis of the geo-terrestrial space (Van Leusen, 1993; Falkner et al., 2002) and 3D modelling (Errickson et al., 2017) will be undertaken to develop a better understanding of the settlements and the location of the tombs. The maps obtained will allow a study of the distribution of human remains in terms of MNI, age-at-death, health, and trauma cross-referenced with archaeological data (for example, stratigraphy and grave goods). The biospatial analysis helps to contextualise the results in the wider cultural setting. Moreover, a study of the rites and customs is also carried out to more comprehensively understand the biological and cultural environment in which the people lived.

1.4 OBJECTIVES

The aim is to uncover patterns and trends that indicate how humans and their environment interacted with each other over two key time periods in Sardinia's past, in order to gain insight into the dynamics of each system (Franklin, 2002). The estimations and diagnoses of the remains will be useful to make a comparison within and between the time periods and between individuals and groups (Soafer, 2006). The aim is to explore biological and social processes by using archaeological and anthropological techniques, combined with chemical analysis of human remains and geo-terrestrial imaging. This may bring to light new information of materials and remains from excavations undertaken before the development and application of advanced bioarchaeological techniques. Moreover, the study will be applicable to other geographical areas, and time periods. This approach will be beneficial to further research and will integrate with knowledge gained by destructive analytical methods such as chemical and genomic procedures.

The application of new technologies will provide an insight into the evolution of customs through time. This will provide new information on the history of the island and the development of the Mediterranean. The study aims to identify how populations influenced each other, and to what degree they intermixed.

These results will be made readily available on multiple digital platforms, not only to facilitate future research but also to encourage wider public engagement in accordance with current European policies on data sharing (European Commission Data Governance Act, 2020; European Commission Data Act, 2022).

The broad aim can be divided into the following objectives:

- Undertake an analysis of the demography, paleopathology, and metric variables of the skeletal remains at Pau and Monte Luna, focusing on their specific archaeological, cultural, and environmental context to investigate the life histories of the people.
- Apply new technologies, such as spectrophotometry, X-Ray fluorescence, and FTIR-ATR to understand burial rites through the analysis of physical changes of bone due to the effect of fire. Results are contextualised in the biological, social, and environmental contexts.
- Use 3D modelling, GIS mapping, and aerial photogrammetry to comprehend the locality in which people lived, how they modified the area, and how they were modified by it.
- Produce a wider synthesis of lifeways within and between people of the Neolithic and Punic Era. Furthermore, as first comprehensive study of past population over the island will be compiled suitable for the study of other cultural and temporal environments across Europe, particularly where skeletal collections are poorly preserved and/or commingled.

1.5 THESIS STRUCTURE

This thesis is comprised of both published articles and research that is still to be submitted. Chapter Two provides information about the excavations and archaeological methodologies used at Su Forru de is Sinzurreddus and the Monte Luna necropolis. Chapter Three presents information on the preservation of human remains and the demographic profile of Pau and Monte Luna. Chapter Four explores the application of chemical analyses in a collective burial of Pau characterised by a high level of fragmentation of the human remains (this chapter has been published in the *Journal Archaeological Science: Reports)*. Chapter Five compares the oral health of individuals from both Pau and Monte Luna. The oral health section includes a tooth count analysis, study of caries, periapical lesions, and ante mortem tooth loss. Chapter Six examines the physiological health in the groups from Pau and Monte Luna via indicators of stress: enamel hypoplasia and stature. The results are compared between the two sites. Chapter Seven provides an osteobiography of Tomb 27 in Monte

Luna (this chapter has been published in the *Journal Archaeological Science: Reports)*. A multi-disciplinary approach to interpret biological data in the archaeological framework and historical sources is proposed. Chapter Eight presents an analysis of the remains in the landscape of Pau and Monte Luna. Archaeological findings, type of burials, age, sex, and pathological and traumatic profiles, are linked to the landscape. Chapter Nine addresses the outcomes of each of the objective, integrating the results of the study with that of previous research. The Appendices will provide additional information as follow: Appendix A shows Monte Luna's 16 individuals and their preservation; Appendix B presents Monte Luna's bones measurements; Appendix C Monte Luna's teeth by individual; Appendix D enamel hypoplasia additional tables for both Pau and Monte Luna; Appendix E contains supplementary files; and Appendix F presents the publications as published and details the contribution by co-authors and presents other research conducted during the PhD.

2 ARCHAEOLOGY: CONTEXTUALISING SU FORRU DE IS SINZURREDDUS AND MONTE LUNA NECROPOLIS

This chapter focuses on the archaeological context of the human remains of Pau and Monte Luna. The focus is on the role of archaeology within a bioarchaeological framework and how the archaeological context in terms of material culture, settlements, and tomb types, is fundamental for the analysis of human remains. Archaeology provides a long-term record of broader social practices and trajectory of interpretations. The past can be at least partially reconstructed through the analysis of a wide range of archaeological productions such as locations, buildings, and tools. The focus of archaeology is people and their behaviour, beliefs, and societal structure. The interpretation of past population movements and regional and interregional connections is vital in order to understand the present. Over the past two decades the archaeological approach has overcome the constraints of New Archaeology (Binford, 1964, 1971, 1981) which constructed interpretative frameworks with particular reference to how the archaeological record formed (Schiffer, 1983). The formation processes approach takes into consideration cultural and non-cultural domains, leading to a collaborative interpretation of archaeological records via a cultural and scientific approach.

Archaeological practice is based on recovery, analysis, and interpretation which incorporates the new methodological framework. It is important to understand recovered cultural material as being the result of cultural and non-cultural processes. The inclusion of agency in the interpretation of the archaeological record (Schiffer, 1987) fosters an understanding of human behaviour and organisational capacities of past societies. The life cycle of artefacts goes through a primary, secondary, and tertiary phase (Schiffer, 1983, 1987). In the first phase the artefact is used, and in the secondary phase either a complete artefact, or a damaged or destroyed one is intentionally deposited.

Finally, the third phase refers to damaged or destroyed artefacts that are deposited in a particular location out of context (Kuna, 2015).

New Archaeology has also had a great influence on the way in which archaeological finds are interpreted. Its application has extended beyond the traditional artefact analysis, to include an understanding of the relationship between the living and the dead. The life cycle of an object includes the idea of the artefact, its creation, and its application towards a specific concept (Kuna, 2015). An object can be interpreted with an all-new purpose, or maintaining the original one, and be the messenger of a status linked culturally to the living world, to emphasize the continuity between the living and the dead (Kuna, 2015). In this field, the deposition analysis which has an overview of the relationship between a person's living and dead status, bioarchaeological research has become increasingly important in interpreting the remains of people who lived in the past. This type of analysis has been particularly useful for interpreting burial sites, as it takes into account not only the artefacts found in the grave, but also the environment in which the grave was found, and the people who were buried in it. Bioarchaeological analysis involves looking at the physical remains of individuals; the body represents one more piece to include in the analysis of what was left behind.

The perception of the living and dead and their interactions with the environment are affected by time and space. These variations shape the person and personhood, which are both reflected into continual revisions of social interactions and perspectives (Mauss, 1950; Fortes, 1987; Gilliespie, 2001; Rakita, 2005; Rebay-Salisbury, 2010; Cerezo – Roman, 2015). The archaeological record can be categorised into active and inactive products. The former is made up of material culture (objects, buildings) whereas the latter refers to human remains.

2.1 ARCHAEOLOGICAL OVERVIEW

A summary of the main chronological periods of Sardinia is shown in Table 1. The initial occupation of Sardinia was previously thought to date to the Neolithic, very late compared to mainland Italy (Lilliu, 1988). However, the discovery of stone artefacts assigned to the Clactonian technocomplex at numerous sites (*e.g. Sa Coa de Sa Multa* and *Sa Pedrosa Pantallinu* (Martini, 2009), shifted the date of first arrival to the island to the Middle Pleistocene (2,58 My – 11,700 My). The earliest human remains attributed to *Homo sapiens* is a partial hand phalanx found in *Corbeddu* Cave (Oliena – Nuoro) dated to 20,000 years ago (Upper Palaeolithic) (Sondaar et al., 1993; Sanna, 2009; Martini, 2009). However, since the bone has yet to be radiocarbon-dated and the chronology of the samples disagrees with their stratigraphic position, the date remains controversial (see, e.g., Cherry 1990, 1992; Lugliè 2009; Cherry and Leppard 2017; Lugliè 2018).

Table 1 Sardinia. Chronology. Revised from Tykot 1994.

Periodo		Datazioni
Paleolithic	Inferior	> 150,000 BC
	Middle	
	Superior	15,000-11,000 BC
Mesolithic		11,000-6,000 BC
Neolithic	Early	6,000-5,300 BC
		5,300-4,900 BC
	Middle	4,900-4,000 BC
	Late - Final	4,000-3,500 BC
Eneolithic	Early	3,500-2,700 BC
	Advanced	2,700-2,200 BC
	Late - Final	
Bronze Age	Early	2,200-1900 BC
	Middle	1,900-1,600 BC
		1,600-1,300 BC
	Recent	1,300-1,150 BC
	Late - Final	1,150-900 BC

Iron Age	Geometric	900-730 BC
	Oriental	600-510 BC
	Arcaic	580-500 BC
Historic Era	Punic	510-238 BC
	Roman	238 BC-1 AD
		1-476 AD

A series of glaciations during the Pleistocene shortened the seafaring route by 100 to 130 meters (Klein Hofmejer et al., 1987, 1988; Ulzega, 1999; Sanna, 2006), which facilitated the migration of humans to Sardinia (Sanna, 2009). Sardinia and Corsica were originally formed as one landmass separated from the Tuscan archipelago by about 32 km (Klein Hofmejer et al., 1987-88; Martini e Ulzega, 1989-90; Martini, 1999a; 2009). In the Upper Palaeolithic (24-15 My), there was a major regression of the sea, shortening the distance between Tuscany and Corsica to about 8 km (Broglio, 2003). This is considered to be the most likely period for the first human migration to Sardinia (Sanna, 2006, 2009). The oldest, albeit fragmentary, evidence of human remains at the site of Su Carroppu (Carbonia) dates to the Mesolithic (Lugliè, 2009, 2014). A partial maxilla and a temporal bone attributed to the 9th millennium BC were found at *Su Corbeddu* Cave (Klein Hofmejer et al., 1987-88; Martini, 2009). However, the permanent presence of humans on the island is dated to the Neolithic (Sanna, 2006, 2009; Lugliè et al., 2007; Pittau et al., 2012).

During the Neolithic, agriculture was introduced as well as ovicaprines, pigs, and cattle. There is evidence for new types of chipped tools made from obsidian and flint, and new types of pottery and textile production, resulting in a revolution of technology, industry, and concomitant socio-economic developments (Sanna, 2006; Lugliè, 2017; Fanti, et al., 2018). During Neolithic times in Europe, the linear pottery culture is concentrated in the northern regions, and the impressed ceramics culture is mainly found in the Mediterranean. It is unclear if this division happened due to a cultural or a demic diffusion model (Chikhi et al., 2002; Rubini e Mogliazza, 2005; Sanna, 2009; Pinhasi and Von Cramon – Taubadel, 2009; Von Cramon – Taubadel and Pinhasi, 2011; Pinhasi et al., 2012). Lugliè

(2009). Evidence consistent with the demic diffusion model suggests that the Neolithic communities represent the very first population of the island that underwent rapid development.

The Neolithic is subdivided into the Early Neolithic (6000-4900 BC), Middle Neolithic (4900-4000 BC), and Late-Final Neolithic (4000-3500 BC) (Tykot, 1994; Tanda, 1998; Lugliè, 2009, 2018; Manen et al., 2018). The Early Neolithic is characterised by cardial impressed pottery in *Su Carroppu*, in the *Filiestru* Cave, and subsequent epicardial and linear carved pottery (Lugliè, 2009). Most of the findings are located in the central-south area of the island. The inland region is not excluded but there are less findings to date. Findings are characterised by both open-air and cave settlement (Lugliè, 2009). Most of the artefacts have been found in caves, although they are often poorly preserved (Lugliè, 2009). During this period, economic activity was focused on farming ovines, caprines, and pigs, as well as gathering and agriculture (Lugliè, 2009). The Middle Neolithic is subdivided into two main culture *facies*: *Bonu Ighinu* (Middle Neolithic A), and *San Ciriaco* (Middle Neolithic B). The oldest artefacts of the *Bonu Ighinu* culture have been found in the *Sa Ucca e Su Tintirrioulu* Cave (Sassari). People of this culture were mostly cave-dwellers with only a few open-air settlements found so far (Santoni, 1982a; 1982b; 1995; Usai, 2009). Small statues, possibly portraying females, are characteristic of the *Bonu Ighinu* culture. It is not known what these statues represent although it is conceivable that they personify a divine being or a very important ancestor (Lugliè, 2018). The statues are always found in sepulchres along with funerary objects. The site of *Cuccuru is Arriu* (Cabras) is comprised of twenty depositions of mixed typologies, mainly hypogea (thirteen) but also a rock pit and, possibly, a simple ground pit. Most tombs contain a single adult, with only two hypogea containing two individuals. In one of these tombs, both an adult and a subadult were interred. Individuals were deposited in a left lateral decubitus position, together with funerary objects such as pottery dishes and vessels, and the above–mentioned statues (Germanà and Santoni, 1992). The *San Ciriaco* Culture, named after the locality in which the first evidence was recovered, in the area of Terralba (Oristano), is characterised by an intensification of obsidian production with the main centre being in the *Monte Arci* area (Lugliè, 2012; Orange et al., 2016). The *Ozieri* or *San Michele* (Tanda, 2009) culture appear during the Late-Final Neolithic. People of this culture lived mostly in open-air settlements, using caves much less frequently. They also introduced the *domus de janas,* carved hypogeic graves, in which to bury human remains (Tanda, 2009).

The Eneolithic phase (4th-3rd millennium BC) has a high degree of continuity with the Neolithic with similar settlement types and burial practices. However, there was some evolution in tools and ceramic production (Tanda, 1998; Ugas, 1998; Melis, 2009), with local distinctions between the north and the south part of the island (Moravetti, 2009). Respectively*, domus de janas* and cave depositions; and exclusive hypogeum, lithic cysts, pit, and cave tombs. The Metal Ages (1800-500 BC) are subdivided based on archaeological stratigraphy and findings. The Nuragic civilisation showed a vibrant cultural and socio-economic development with the production of new tools, and improvements in agriculture and farming techniques (Contu, 1982, 1985; Lilliu, 1990; Tykot, 1994; Ugas, 1998; Melis, 2003). This period is noted for the grandeur of the villages, built with at least seven thousands of corbelled domes, still visible today, for instance, in the complex of *Su Nuraxi* (Barumini) and *Genna Maria* (Villanova Forru) (Depalmas, 2009; Ugas, 2009). The tools produced in Sardinia, such as pottery, ornaments, obsidian, and flint, were found in other Mediterranean regions, attesting the cultural ferment of this time. During this period, funerary practices used only one of two types of tombs. Initially, Sardinian megalithic graves built during the Bronze Age by the Nuragic civilization, were either carved out of or built with rocks, with one or multiple chambers and aisles for collective burials (Depalmas, 2009). Much later in the Iron Age, at *Monte Prama* (Cabras), individual pit tombs were used, these were dug in the ground and sometimes covered with rock and associated with statues (Fonzo and Pacciani 2014).

During the Iron Age (900-500 BC), there was lively cultural contact between Sardinia and their neighbours in the Mediterranean, specifically with the Phoenicians and Etruscan (725-600 BC), and

Oriental-Greek populations (600-510 BC) (Ugas, 2009). Phoenicians first settled in the northern part of the island in *Sant'Imbenia* (Alghero) and founded local communities based on the wine trade along the Mediterranean and Atlantic routes (Bernardini, 2009). Around the first half of the 8th century BC, the Phoenicians established cities along the south-western coast of the island such as Sulky, San Giorgio, San Vittore, Monte Sirai (Sulcis), Othoca, Tharros (Oristano), Nora, and Bithia (Cagliari) (Bernardini, 2009). The interconnection between Nuragic, Greek, Etruscan, and Phoenician cultures is evidenced by the material culture found in necropoli, sanctuaries, and cities. The traditional funerary rite was cremation, with only a few cases of inhumation recorded (Bartoloni, 1998; Guirguis, 2011; Pusceddu et al., 2012). The 6th century BC is characterised by the expansion of Carthaginian or Punic influence along the Mediterranean. The Romans acknowledged the power of Carthage over the island of Sardinia in 590 BC (Moscati, 2000). The main assets were the control of areas for both agriculture (*i.e.* Monte Luna) and mining (i.e. Antas) and establishing new sea routes through the improvement of the coastal Phoenicians' settlements into commercial harbours (Bernardini, 2009). Funerary rites see a change to inhumation in tombs carved in the ground or in the rock, accompanied by rich funerary assemblages of pottery, jewellery, and tools (Costa, 1990; Todde, 2020). The decline of the Punic empire over the island begins around 238 BC when the Sardinians eventually join up with the Romans and defeat the Punics at the battle of *Cornus* in 215 BC (Mastino et al., 1991). However, a small Punic presence may have continued according to written sources from as late as the 4th century AD (Mastino et al., 1991).

2.2 Theoretical Approach

The Neolithic site of Pau highlights the start of the establishment of a complex network of human activity and interactions, while the Punic site of Monte Luna represents an already well-organised and elaborate system of governance based on an intricate trade network. In both cases, inter-regional interactions are in place, and play a great part in the development of both sites' cultural context and behaviour. The wider concept of globalisation allows to interpret sociocultural connections such as trade, migration, internationalism, and diffusion through the networks that created and maintained them (Hodos, 2017). In this approach, time and space are inter-dependent and foster the process of development and inter-cultural awareness. At each point in time and space there are shared practices and an awareness of local differences (Hodos, 2017).

2.3 The Neolithic and the site of Su Forru de is Sinzurreddus in Pau

At the beginning of the Neolithic, trading of obsidian from four main sources in the Mediterranean (Pantelleria, Lipari, Palmarola and Monte Arci (Sardinia) (Tykot, 1996; Lugliè, 2009)) becomes established. The Monte Arci area is characterized by an initial exchange (Early Neolithic) to develop a proper trade along the Middle Neolithic: the development of a local economy based on obsidian to a wider concept of "globalisation" (Hodos, 2017) is reflected by an increase in volume and rhythm of work (Lugliè, 2012). In the 5^{th} millenium BC, the raw material is collected with no preference almost exclusively from two sources with a specific chemistry of the glass called SA and SC from Masullas, and Pau, respectively (Tykot, 1996; Lugliè et al., 2011). It is likely due to the qualitative and quantitative abundance of these deposits that settlements are established nearby, and trading occurs (Lugliè et al., 2006; Lugliè, 2012). Furthermore, this period sees an evolution in the production system with the raw material initially being processed in proximity to the sources. This resulted in the creation of stable production centres specialising in producing transportable blanks of obsidian, which are then shaped into useful artefacts in the main settlements (Tanda et al., 2006; Lugliè, 2012). Trade of these artefacts flourished, and they can be found as far as Tuscany, French Midi, and Catalunya (Gibaja Bao et al., 2013; Tanda et al., 2014).

There are several areas of interest in Pau regarding the gathering and working of the raw material (Lugliè, 2003). In 2001, a natural cavity 500 meters above sea level with a floor area of about 20 m^2 was found. It has a characteristic dome vault and in the local language is called Su *Forru de is Sinzurreddus* meaning "the oven of the bats" (Lugliè et. al., 2019). The 2002 excavation found evidence of people living outside the cave in modern times. The excavation of the inside of the cave found a stratigraphic sequence formed by alternate layers of heavy blocks of rocks and ground dust. It was hypothesised that the thick accumulation of the blocks in front of the entrance of the cave showed that the original external level was a couple of meters lower than the contemporary cave surface. Inside the cave there was evidence of numerous rock falls and stashes of rocks, including evidence of contemporary human and animal presence on the site (Lugliè et. al., 2019). In this complicated scenario, the findings were mainly human bones rather than artefacts made from obsidian. The bones were highly fragmented and showed evidence of thermic alteration possibly due to a secondary deposition ritual (Lugliè et. al., 2019). More than 50,000 fragments of bone were located via a systematic application of three-dimensional techniques and recorded using GPS station coordinates. This led to the detection of a small number of obsidian splinters, a few ornaments associated with the known funerary practice in Li Muri (Arzachena), and a large number of pottery fragments showing morphologic and manufacturing features consistent with the San Ciriaco culture (Lugliè et. al., 2019). This evidence indicated the site was the first established and long-term settlement near the area of mass production of obsidian artefacts. The presence of human remains suggests that people were permanently settled in Monte Arci and controlled the area of extraction and production of obsidian (Lugliè et. al., 2019).

The pottery found mostly comprised fragments of thin walls (< 5 mm), rims, bases, and a few handles. The morpho-typology analysis showed the findings to be of the San Ciriaco culture characterised by very standardized thin pottery with no inclusions in the fabric which appeared smooth, compact, and clean. A dominant feature of the pottery is the shiny and bright appearance of the polished internal and external walls (Santoni, 1982; Ugas, 1990; Santoni et al., 1997; Lugliè, 1998; Alba 2000; Lugliè 2003a; Usai, 2009; Lugliè, 2017; Fanti et al., 2018). The most common shape recovered is the carinated bowl, typical of this time period, characterised by a narrower opening than the maximum diameter of the bowl. There are also a few dishes and some medium sized pottery (Lugliè, 2003a, Figure 3 e Fanti et al., 2018). The pottery and lithic artefacts are consistent with the assemblages found at coeval sites in the northern part of the island and in Corsica (Lugliè 1998, 2003a; Tramoni et al., 2007; Tramoni and D'Anna, 2016).

2.4 The Punic Era and the site of Monte Luna Necropolis in Senorbì

The middle of the 6th century BC marks the actual chronological distinction between Phoenician and Punic dominance. This is evident in the increasing prevalence of Punic urban fabric and material culture as they expand along the western Mediterranean. The attraction of Sardinia related to its agricultural and mineral resources. Recent studies have pointed out a high variation in identities at the local level (Roppa, 2014). Interestingly, the smaller the case studies the larger the variation encountered (Queen and Vella, 2014), opening a debate with regards to the evolution of Punic hegemony. The newest studies on this matter focus on specific Sardinian communities and explore the formation of their cultural identity through archaeological analysis of settlement patterns (Roppa, 2014). The sites of *Monte Sirai* and *Villasimius* have been interpreted as Carthaginian sites (Marras et al., 1989; Moscati et al., 1997; Bartoloni and Bernardini, 2004). This is based on new forms of pottery, and the change in burial practices from cremation to inhumation in cut chambers or stone cists (Perra, 2001; 2005; Bartoloni and Bernardini, 2004; Moscati et al., 1997). However, the analysis of the burial practices shows a more nuanced picture. Stiglitz (1999) found funerary wall-paintings in Sardinia that pre-date the North African examples that supposedly influenced them. Changes and development of funerary practices need to be analysed on a case-by-case basis (Roppa, 2014).

The Monte Luna Necropolis presents a case-in-point in the contemporary debate between traditional and new interpretations about the cultural diversity on the island (Roppa, 2014). The necropolis is located in the southeastern area, 10 meters from the settlement of Santu Teru (Costa, 1980). The main excavation campaign (1977 – 1981) brought to light a total of 120 tombs, some of which had been opened and scavenged sometime in the past. Moreover, the opening of a tunnel for road development on the eastern side damaged several tombs resulting in the loss of their contents including human remains and funerary objects. The arrangement of tombs is very much dictated by the landscape to maximise the use of space, which is consistent with practices in other Punic necropoli (Costa, 1980; 1983a – b – c).

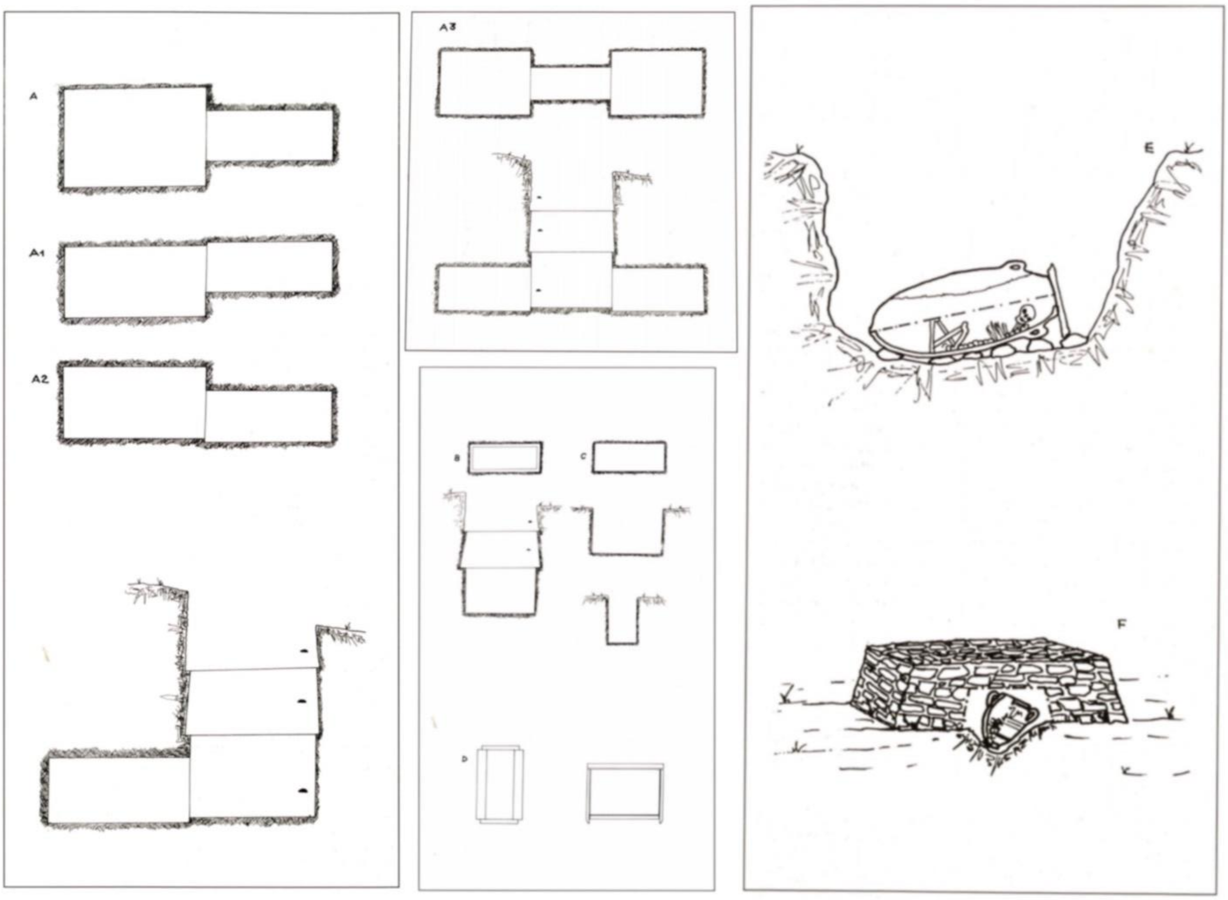

Figure 2 Monte Luna. Tomb Types. A (1, 2, 3): hypogeum, single or double chambers. B, C, D: pits. E, F: enchytrismos, burial with urn (Costa, 1980; 1983).

Costa (1980; 1983) documented the types of tombs excavated (Figure 2). The majority are of the 'A' pit tomb type with the hypogea room opening on the shorter side. Type A tombs show variations in terms of the position and number of rooms (A1, A2, A3) and are typically either rectangular or trapezoidal. The carved walls usually allow for easy access to pits with a typical depth of 6 metres. The Type A pit tomb entrance is usually closed off with a limestone slab on top or at the short side, however, sometimes rocks are cemented together using mud. The internal part is decorated with geometric patterns and there are reports about two cases of walls coated with plaster, refined paintings, and a stucco finish (Costa, 1981). Due to the generous size of the chambers, some of them were even furnished with small tables or votive areas. One and two-chambered pits typically contain one and two bodies, respectively. Where multiple depositions are encountered within a chamber, they are a reflection of the tomb having been reused, rather than multiple burials occurring at the same time. Type B pit tombs do not contain a separate chamber, or a stone lid and the body is simply placed at the bottom of the pit which is deep, as deep as a hypogeum. Over time, the population developed a preference for the simpler, shallower Type C tomb in the ground, dug both in new areas and as replacements for older tombs. Some other burials, similar in the shape to the rectangular Type A tombs, have been found carved into the rock instead. Type D pit tombs contain wooden trunks, and the walls are covered with limestone slabs. Many *enchytrismòs* (jars) (Type E) and smaller urns, containers for cremated human remains, have been damaged due to their superficial deposition, as were most of the other types of cremation containers (Type F). There is also evidence that each burial was marked by rocks. The tomb types can be chronologically arranged as follows: the pit tomb with hypogeum (A1 and A2) and simple pits (C) are the most ancient type dating to the 5th - 4th century BC; the end of the 4th and the 3rd century BC are characterised by tombs with a hypogeum and the pit in the ground (A3). During the 3rd century this type became more prominent eventually completely displacing pits with chambers (A3). The analysis of funerary sets showed a correlation between the type of tomb and the funerary objects over time indicating a slow decline and eventual total abandonment of the city of Santu Teru through the reduction in precious artefacts, such as jewellery

(Figure 3), and self-care tools (i.e. *strigile*: body scraper) (Todde, 2021). This is consistent with the historical contest between the Punics and Romans to gain dominance over the Mediterranean.

Figure 3 Monte Luna. Jewellery and talisman (Todde,2019). From left acorn necklace; Ra ring; Horo Ra amulet in bone; gold leaf ornament.

Inhumations are the most common funerary practice in the 5^{th} – 4^{th} century BC. Cremations started to become more common in the middle of the 4^{th} century and dominated during the 3^{rd} century BC probably due to economic or spatial constraints (Costa, 1980; 1983). Inhumations took various forms, such as placing the well-dressed and painted body on wooden tables or on the ground covered by a *sudarium* (cloth). The body was placed in a supine position with the head oriented to the end of the chamber. In the case of multiple burials, the male was deposited on the left, with women and subadults on the right. The male usually had their head pointing to the end of the chamber, while women and subadults were oriented with the head facing the entrance. There is also evidence of subadults being placed on the belly of the women or between their legs (Costa, 1980; 1983; Usai, 1981).

Funerary objects from the city of Santu Teru are often well preserved. The main item found is pottery, which is largely the Punic type with some imported wares (Costa, 1980; 1983; Todde, 2019). The Punic type consists mostly of decorated commercial amphorae, and pitchers and jugs of medium size. Large amphorae with floral decorations are also present but rare, in contrast to dishes, cups, and oil lamps. There are also a few examples of Attican production from the period 4^{th} - 3^{rd} BC. The wealth of the city is showcased by the presence of jewellery such as necklaces, bracelets, earrings, and dioramas in gold, silver, and other metals. Particularly noteworthy is a very well manufactured, large gold necklace with an acorn found in Tomb 87 (Costa, 1980; 1983; Pisano, 1996; Aquaro, 2009, 2011; Solinas, 2011; Todde, 2019) (Figure 3). The iconography and material of the artefacts show considerable variation. The rings are decorated with female, male, Greek, or Egyptian symbols (Ra eyes, beetle), and there are dioramas with gold leaves, pendants with green diaspore, carnelian, and chalcedony (Figure 3). There are amulets made of glass, silver, bone, amber, and hard or siliceous paste, with iconographic representations of Horo Ra, Horo hawk, cat, Pthat–pateco, ugiat eye, heart or other body parts, and zoomorphic motifs (Figure 3). Artefacts carved from bone formed mainly buttons, masks, amulets, combs, picks, and instrument parts. There are also glass beads and bronze were used to make razors, bells, mirror, and *strigile* (tool for cleansing the body). Moreover, several coins from the Punic era and some reused in Roman times, were also found (Costa, 1980; 1983; Pisano, 1996; Aquaro, 2009, 2011; Solinas, 2011; Todde, 2019). The analysis of type of burials, funerary sets, and depositional area provides the context in which the human remains were buried in order to have a better interpretation of the social system, and social perspective at the time of deposition.

3 THE HUMAN REMAINS: A LIFE IN DEATH AT SU FORRU DE IS SINZURREDDUS IN PAU AND MONTE LUNA NECROPOLIS

This chapter will describe the preservation of human remains for both Pau and Monte Luna. The following section will introduce the methods used to carry out the investigations. The demographic profiles for both Pau and Monte Luna will then be presented, followed by a section about limitations and biases.

3.1 MATERIALS

3.1.1 Su Forru de is Sinzurreddus

The human remains recovered in the cave of *Su Forru de is Sinzurreddus* in Pau are represented by more than 50,000 fragmented human bone elements, many with evidence of possible cremation. Due to the high level of fragmentation, most of the elements were only able to be allocated to a macro-anatomical area (cranial, axial, or appendicular skeleton). Where possible, the skeletal element was identified, sided, sexed, and aged using anthropological standards (Buikstra and Ubelaker, 1994; White and Folkens, 2005). Among the 50,000 fragments, 565 teeth and 500 hand and foot phalanges were selected from the stratigraphic units. They were sorted according to ID number, date of collection, stratigraphic unit, state of preservation, skeletal element, whether they were burnt or unburnt, and any specific traits. Teeth were studied for dental wear (Scott, 1979; Brothwell, 1981; Lovejoy, 1985), dental health, and stress markers (calculus, caries, enamel hypoplasia) (Hillson, 2005), and age-at-death was estimated using either dental calcification for subadult teeth and dental wear seriation for adult teeth. Phalanges were allocated either to the hand or foot, digit number/position, side of the body, and age estimation when possible (Buikstra and Ubelaker, 1994; Scheuer and Black, 2005; Garrido Varas and Thompson, 2011). The preservation of the skeletal elements was very poor, and, as such, no sex estimation was possible, and no bones were able to be confidently grouped as belonging to an individual. The remains were, therefore, analysed as a commingled collection.

3.1.2 Monte Luna Necropolis

The Monte Luna necropolis originally contained 120 tombs. However, due to a combination of looting and inadequate storage, bones were only recovered from 70 tombs. The majority of the 70 tombs were used multiple times, with between two to 12 adults buried within a single tomb. When subadults and young children were present, there were only a maximum of two individuals within a tomb. The details of removal and storage of human remains varied. In some tombs, all bones were collected and stored with no distinction between individuals, leading them to being considered as commingled burials during post-excavation analysis. In other tombs, bones were removed and stored separately based on stratigraphy, which individual they belonged to, and positional information based on cardinal points. In a subsequent analysis, the bones of commingled burials were sorted by anatomical region and side of body, and, where possible, both upper limb bones (humerus, radius, and ulna) and lower limb bones (os coxae, femur, tibia, and fibula) were pair-matched to re-create individual skeletons.

3.2 AGE-AT-DEATH ESTIMATION METHODS

The Pau and Monte Luna samples were studied using a multifactorial approach to estimate age-at-death. Due to the high level of fragmentation and commingling, it was difficult to determine the precise number of individuals present, this, a method of seriation was applied (Lovejoy et al., 1985). This is done by measuring the age-sensitive features of the skeleton such as the degree of tooth eruption and wear, cranial suture closure, epiphyseal fusion, and other skeletal changes that occur as a person ages, and comparing them to known age standards. Following that, the bones are arranged in ascending order according to their age (White et al., 2011). The resulting age sequence is used to estimate the age of each bone element in the series.

Estimation of age for younger individuals has been shown to be more accurate and to provide narrower age ranges. This is due to many changes occurring in the growing body at regular intervals and at known rates (Buikstra and Ubelaker, 1994; Scheuer and Black, 2009). Foetal, infant (0-9 years old) and subadult ages (10-15 years old) are based on tooth development and bone growth. Tooth formation, calcification, and eruption were assessed (Ubelaker, 1989), bone length, epiphyseal fusion, and ossification centres were observed to assess foetal and infant age (Flacker, 1942; Winter et al., 1988; Oliver and Pineau, 1960; Fazekase Kosa, 1978; Buikstra and Ubelaker, 1994; Huxley, 1998; Scheuer and Black, 2009), and subadult age (Garuet al, 1972; Brothwell, 1965; Stloukale Hanakova, 1978; Ubelaker, 1989; Borgognini Tarli and Pacciani, 1993; Buikstra and Ubelaker, 1994; Scheuer and Black, 2009). However, in subadults it is essential to consider individual variability of changes in timing and rates of growth that could be discontinuous and hence saltatory (Lampl et al., 1992), or influenced by disease and malnutrition (Sherwood et al., 2000).

Age-at-death estimation methods in adults only allow for a wide age range estimate because techniques are based on bone resorption, deposition, remodelling, and, ultimately, degeneration (Mays, 1998; Buikstra and Ubelaker, 1994). Until the age of about 30 years, some bones are still growing and some epiphyses are still fusing. However, at ages beyond 30 years, age-at-death methods follow stages of degeneration based on wear and tear of the body over time. These degenerative processes commonly follow a less regular progression and show high individual variability (Mays, 1998) as they are also influenced by behaviour, activity, and environmental factors, and need to consider how populations can differ in the timing of the degenerative process (Mays, 1998; Buikstra and Ubelaker, 1994; Hoppa, 2000; White et al., 2011). Where possible, dental wear (Brothwell, 1981; Smith, 1984; Lovejoy, 1985; Buikstra and Ubelaker, 1994), late epiphyseal union (Borgognini Tarli and Pacciani, 1993), skull endocranial and ectocranial suture closure (Acsadi and Nemeskéri, 1960; Meindl and Lovejoy, 1985), pubic symphysis and auricular morphology scores (Todd, 1921; Meindl and Lovejoy, 1985; Suchey-Brooks, 1990), and variation of the fourth rib's sternal end (Işcan et al., 1984) were used for age estimation.

The above-mentioned standard methods all have some limitations which can affect their reliability. The degree of imprecision in aging skeletal remains is tied to the control samples on which the methods were originally based. The control samples have inherent biases as they were usually based on a selection of a deceased population. The assumption is that the examined features of the remains of interest follow the same pattern observed in the control samples. Understanding the accuracy of this assumption is essential in order to arrive at a more reliable and precise estimation of age-at-death of the population being studied (Priya, 2017). Dental wear has been considered a useful indicator for determining age-at-death as it can be seriated within the population being studied (Lovejoy et al., 1985; Mays, 2002; White et al., 2011). The quantification of tooth wear in this study was performed according to Lovejoy (1985).

Analysing the morphology of the pubic symphysis and auricular surface is considered the most reliable method to estimate age (Todd, 1920; Suchey, 1986; Brooks, 1990). Even after other epiphyses have fused and the body is fully grown, age-related changes continue in the pubic symphysis and the auricular surface. These changes have been measured and described are known to result in changing degrees of porosity, granularity, billowing, and bone density. Both bone regions are highly sexually dimorphic (Todd, 1920; Suchey, 1986; Brooks, 1990; Priya, 2017), and the auricular surface is more reliable in aging older individuals (Hartnett, 2010).

The chest plate is affected by progressive ossification of the sternal end of the ribs, which is indicative of both age and sex. Işcan et al., (1984) standardised a methodology based on the scoring of the costochondral joint of the fourth rib, noting specific changes to the joint walls, rim, morphology of the joint surface, and bone texture and density. This method is based on morphological changes that are highly influenced by age, sex, pathology, and physical activity and, therefore, can only provide a general indication of age-at-death.

Cranial suture closure is one of the least reliable methods due to high intra-sutural variability (Buikstra and Ubelaker, 1994). Both endocranial (Acsadi and Nemeskéri, 1960) and ectocranial (Meindl and Lovejoy, 1985) closure analysis are based on a scoring system ranging from open to obliterated. Age-at-death is estimated based on the measurement of ten sample points, which is correlated with a mean age and age range.

The estimation of age-at-death of adult skeletal remains should consider all measurable age indicators followed by multifactorial analysis. This is, of course, dependent on the level of completeness of individual skeletons. The Pau and Monte Luna skeletal samples are characterised by a high level of fragmentation and disarticulation and this multifactorial approach could only be followed through in a small number of more complete individuals.

3.3 SEX ESTIMATION METHODS

The estimation of biological sex is challenging on subadult skeletal remains. Morphological methods for determining sex are often unreliable in immature individuals because the level of sexual hormones is lower than in adults. As hormones are key in the development of certain morphological features, such as the size and shape of the skull and pelvis, these features may not be as pronounced in immature individuals (Scheuer and Black, 2009). Therefore, it can be difficult to accurately differentiate between males and females based on morphology. Thus, in this study, the determination of biological sex was only attempted for adults aged 20 years and older. Sexual dimorphism was scored for cranial (Bass, 1995) and pelvic (Bruzek, 2002; Murai et al., 2005) morphology and long bone measurements were taken. Cranial and pelvic morphology was of use in only a small number of individuals. The metric results, such as long bone measurements, from these individuals were then compared with the metrics from other commingled bones. Thus, section point analyses from the metric data of the sexed individuals was able to be used to estimate the sex of some long bones. This increased the minimum number of individuals facilitating the development of a demographic model of the Monte Luna population. This method is described and discussed in Chapter Six, together with an analysis of stress in childhood via estimation of stature and linear enamel hypoplasia.

3.4 RESULTS AND DISCUSSION

3.4.1 Pau

The health of the population of Pau is presented only through the analysis of 565 teeth (Table 2) as bone samples were poorly preserved. The tooth assemblage included 55 deciduous teeth and 461 permanent teeth (Table 3, 4). Sex estimation was not possible due to the commingling and high level of fragmentation. The complete upper right incisors, both permanent and deciduous, were used to establish the minimum number of individual (MNI) present, which was calculated to be 18 adults and six subadults.

Only 516 of the 565 teeth were sufficiently preserved (*i.e.* at least 75%) to determine their identity and position in the dentition, their wear, and health. The analysis of dental wear using seriation (Brothwell, 1981; Smith, 1984; Lovejoy, 1985; Buikstra and Ubelaker, 1994) was performed to assess age ranges (of individual teeth. Subadults were classified as either 0-9 yo, 10-15 yo based on the type of tooth, tooth wear, and development. Adults were grouped as young adult (16-25yo), adult (26-35yo), mature adult (36-45yo), old adult (45+yo), and an unknown age category for teeth with no recordable wear (Table 2).

The proportion of teeth within each age-at-death category showed a total of 31.4% of teeth that were classified as subadults, with 14.9% in the 0-9 yo and 16.5% in the 10-15 yo category. The majority of the adult teeth were identified to be from young adults (16-25 yo, 19.6% of the total sample) and a total of 39% of teeth could not be aged (Table 2, Figure 4).

Table 2 Pau. Total number of teeth per age class.

Age class	Age subclass (years)	Total teeth (%)
Subadult	0 - 9	77 (14.9)
	10 -15	85 (16.4)
Adult	16 - 25	101 (19.5)
	26 - 35	19 (3.6)
	36 - 45	21 (4.0)
	45 +	12 (2.3)
Unknown		201 (38.9)
Total		516

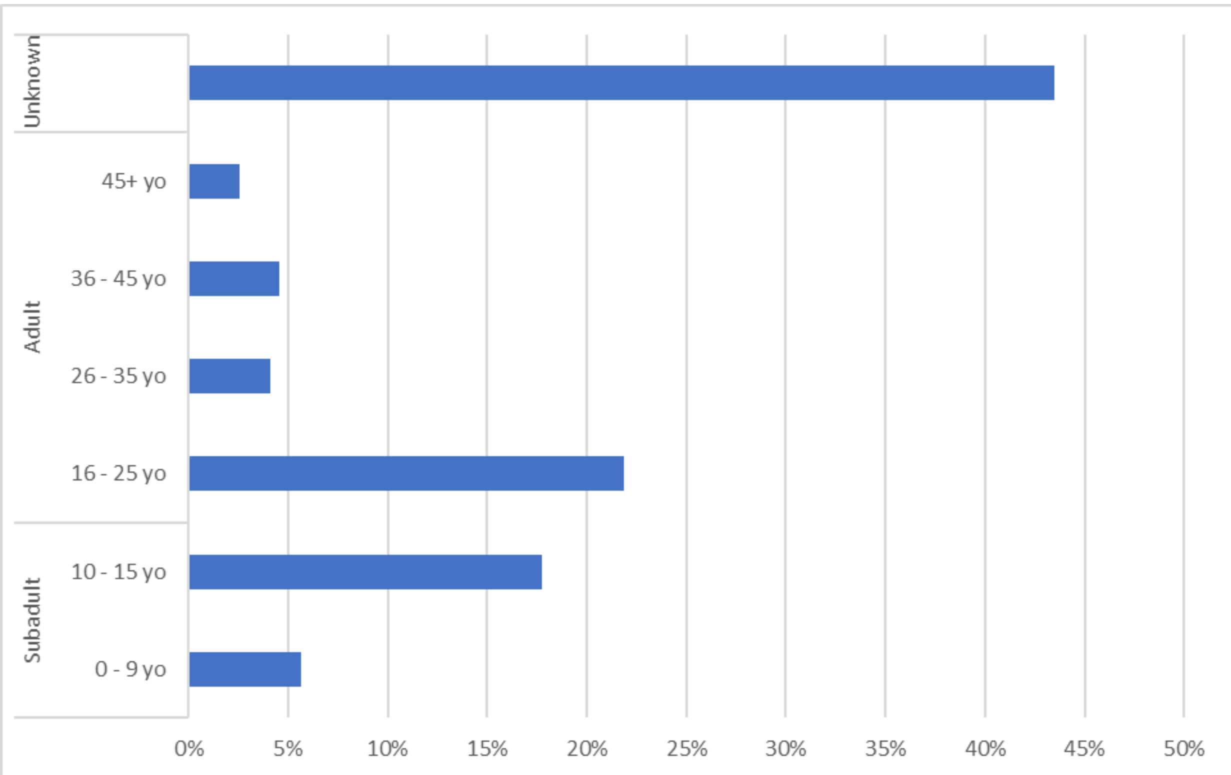

Figure 4 Pau. Demographic profile of the teeth of the Pau assemblage.

The majority of the deciduous teeth (89.1%) were aged within the 0-9 yo group (Table 3). Many of the permanent teeth were from individuals aged 10-15 yo and 16-25 yo (Table 4).

Table 3 Pau. Deciduous teeth.

	Deciduous Teeth			
	Incisors	Canines	Molars	Tot (%)
0 – 9 yo	28	7	14	49 (89.0)
10 – 15 yo	2		1	3 (5.4)
Unknown				3 (5.4)
Tot (%)	30 (54.5)	7 (12.7)	15 (27.2)	55

Table 4 Pau. Permanent teeth count.

	Permanent Teeth				
	Incisors	Canines	Premolars	Molars	Tot (%)
0 – 9 yo	5	3	7	10	25 (5.46)
10 – 15 yo	7	6	36	33	82 (17.79)
Young Adult (16 – 25 yo)	25	7	29	40	101 (21.91)
Adult (26 – 35 yo)	11	0	1	7	19 (4.12)
Mature Adult (36 – 45 yo)	2	3	5	11	21 (4.56)
Old Adult (45+ yo)	2	2	2	6	12 (2.60)
Unknown	28	25	56	92	201 (43.60)
Tot (%)	80 (17.35)	46 (9.98)	136 (29.50)	199 (43.17)	461

Deciduous incisors were the most commonly preserved teeth (54.55%). Among the permanent teeth, molars (43.17%) were most commonly preserved, followed by premolars (29.50%) (Figure 5).

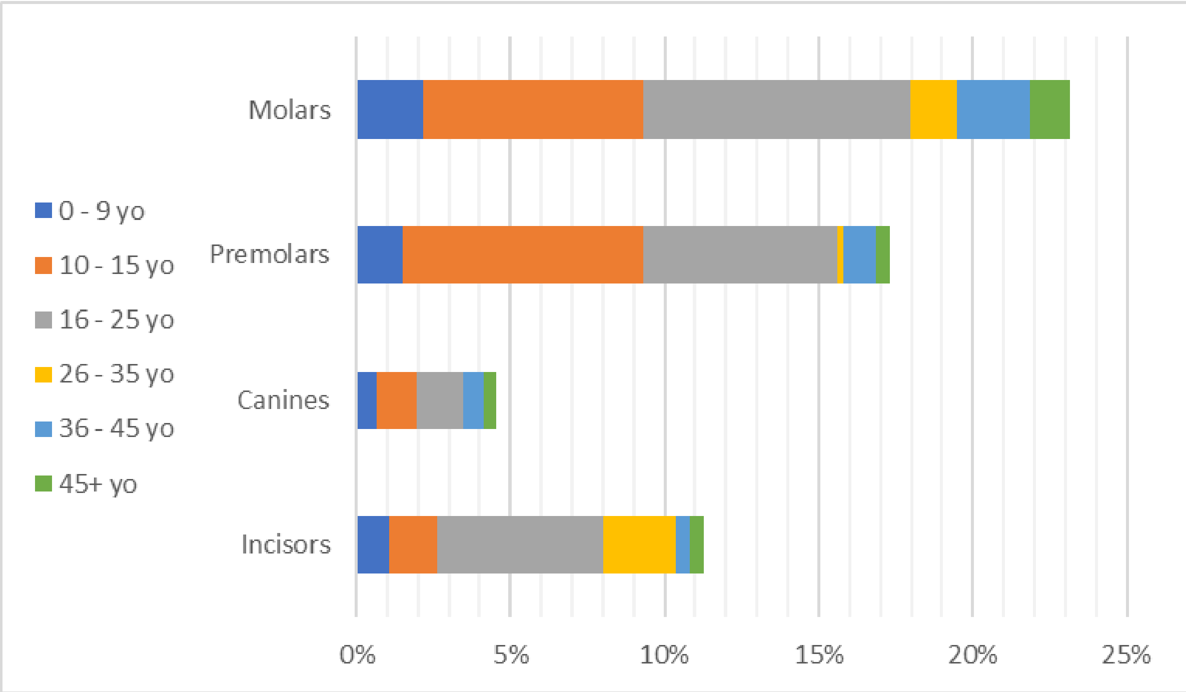

Figure 4 Pau. Prevalence of the type of permanent tooth in subadults and, adults.

3.4.2 Monte Luna

The MNI was calculated based on the repeated elements *within* each of the 70 tombs. The MNI is 227 adults, with 21 females and 16 males identified to be older than 15 years, and 59 subadults grouped in the 1 to 15 years age class. No subadults of less than 1 year of age were found.

Figure 5 Monte Luna. Examples of level of fragmentation and sorting process through anatomical regions.

A total of 733 cranial and postcranial elements were identified, sided, sexed, measured, and assessed for presence of traumatic and pathological evidence (Figure 6 and 7). In the total sample, fifty crania were able to be estimated for sex, with 34% identified as male and 22% as female.

Figure 6 Monte Luna. Example of the preservation of one individual (Paba, R.).

Table 5 Monte Luna. Identified elements based on anatomical regions.

	Individuals (%)[1]	Cranium (%)[1]	Axial skeleton (%)[1]	Upper Limbs (%)[1]	Lower Limbs (%)[1]	Tot (%)[1]
Male	16 (7.04)	17 (34.00)	2 (4.65)	13 (8.55)	19 (7.28)	67 (9.14)
Female	21 (9.25)	11 (22.00)	10 (23.26)	18 (11.84)	15 (5.75)	75 (10.23)
Unknown	190 (39.65)	22 (44.00)	31 (72.09)	121 (79.61)	227 (86.97)	591 (80.63)
Tot (%)[1]	227 (30.97)	50 (6.82)	43 (5.87)	152 (20.74)	261 (35.61)	733

[1] Percentage of the total amount of cases based on the total amount of observations.

Table 6 Monte Luna. Identified elements in the post-cranial skeleton.

Element	Male (%)[1]	Female (%)[1]	Unknown (%)[1]	Tot (%)[2]
Clavicle (%)	2 (6.45)	5 (16.13)	24 (77.42)	31 (6.81)
Humerus (%)	9 (11.11)	11 (13.58)	61 (75.31)	81 (17.80)
Radius (%)	3 (6.98)	4 (9.30)	36 (83.72)	43 (9.45)
Ulna (%)	1 (3.70)	3 (11.11)	24 (88.89)	27 (5.93)
Femur (%)	6 (8.22)	3 (4.11)	64 (87.67)	73 (16.04)
Tibia (%)	4 (11.76)	2 (5.88)	28 (82.35)	34 (7.47)
Fibula (%)	1 (33.33)	0 (0)	2 (66.67)	3 (0.66)
Patella (%)	4 (4.04)	2 (2.02)	93 (93.94)	99 (21.76)
First Metatarsal (%)	4 (7.69)	8 (15.38)	40 (76.92)	52 (11.43)
Pelvis (%)	0 (0)	5 (41.67)	7 (58.33)	12 (2.64)
Tot (%)[2]	34 (7.47)	43 (9.45)	379 (83.30)	455

[1]Percentage of the observed trait among same element based on the total amount of same element counted.
[2] Percentage of the total amount of observed trait among all the elements based on the total amount of elements (455).

There were 455 postcranial elements identified, with patellae the most commonly preserved bone (21.8%), followed by humeri (17.8%), femora (16.0%), and first metatarsals (11.4%) (Table 6). The allocation of sex with 9.45% identified as female and 7.47% as male was based on an analysis of the cranium and pelvis (Table 5).

The preservation of the dentition (teeth and tooth positions)

The details of the preservation status of the teeth and associated tooth positions (preserved bony tooth socket with or without a tooth) are presented. This overview of the entire assemblage of teeth is then used to analyse the dental pathology of the population in Chapter Five.

A total of 2364 teeth (134 deciduous and 2228 permanent) and 3851 tooth positions (bone only) were preserved (Table 7). The most numerous teeth are from young adults, representing over half of the teeth examined (53.9%) (Figure 8). This may mean the sample is somewhat biased towards young adults and, since dental health is strongly age-progressive, it may distort the results. As mentioned above, sex estimation was not possible for the majority of teeth. There are 3851 tooth positions (Table 7) of which the majority (64.4%) is from young adults (16-25 yo). This sample is considerably smaller compared to the whole tooth sample as the bone was poorly preserved, and many teeth were unassociated with a mandible or maxilla. The distribution of the small sample of deciduous teeth (n=134) by tooth type indicates that molars (50.75%) were most frequently preserved, followed by canines (26.1%) and then incisors (23.1%) (Table 8). The distribution of permanent teeth (n=2228) (Table 9) by age indicates that molars (39.6%) are most frequently preserved, followed by premolars (23.1%) incisors (22.8%) and canines (14.3%) (Table 9). In both the deciduous and permanent tooth samples the posterior teeth are most likely to be preserved with molars being most numerous in both samples t (DT 50.7%; PT 39.6%) (Tables 8 and 9). In contrast, the pattern of preservation in the anterior dentition differs between deciduous and permanent teeth. In the former, canines are most represented (26.1%), while incisors have the lowest level of preservation (23.1%). In the latter incisors are most numerous (22.8%), with the canines showing the lowest level of preservation (14.3%).

The tooth count method shows a prevalence of 53.8 % of total teeth belonging to young adults (16-25 yo) (Table 7; Figure 8).

Table 7 Monte Luna. Total number of teeth and tooth positions in the sample per age-at-death and sex.

Age class	Age subclass (years)	Total teeth (%)	Total tooth positions (%)
Subadult	0 - 9	201 (8.5)	100 (2.6)
	10 -15	70 (2.9)	150 (3.9)

Adult	16 - 25	1273 (53.8)	2480 (64.4)
	26 - 35	252 (10.6)	480 (12.4)
	36 - 45	112 (4.7)	257 (6.6)
	45 +	159 (6.7)	384 (9.9)
Unknown		296 (12.5)	
Tot		2363	3851

Partially complete teeth are included in the count when their position within the dentition could be identified. Tooth position is determined by analysis of the tooth socket including post-mortem loss, unremodelled, and remodelled sockets.

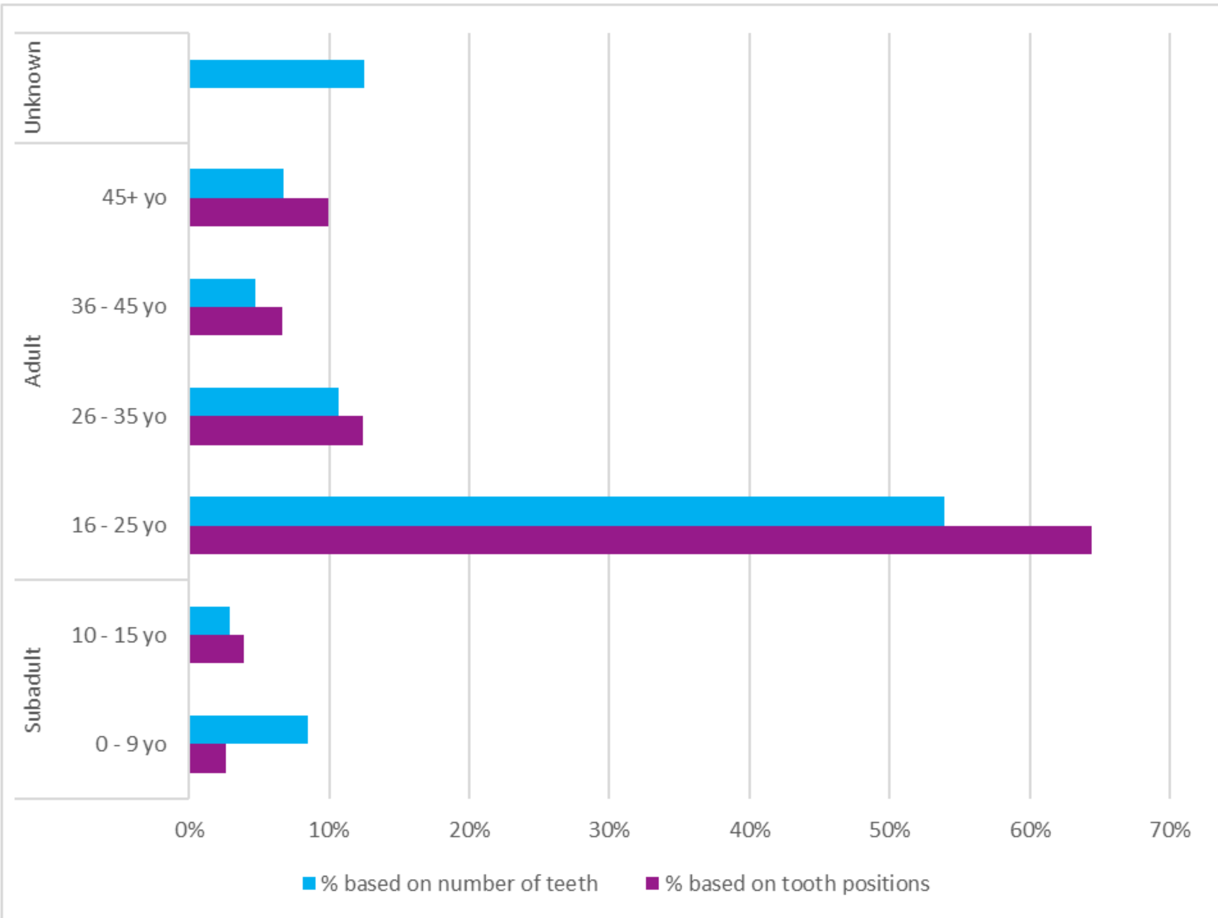

Figure 7 Monte Luna. Demographic profile of the teeth and tooth positions of the Monte Luna assemblage.

Table 8 Monte Luna. Deciduous teeth count.

	Deciduous Teeth			
	Incisors	Canines	Molars	Tot (%)
0 – 9 yo	31	35	47	113 (84.3)
Unknown			21	21 (15.6)
Tot (%)	31 (23.1)	35 (26.1)	68 (50.7)	134

The majority of deciduous teeth (84.3%) were from individuals aged between 0-9 yo (Table 8), while most of the permanent teeth (57.1%) belonged to young adult individuals (16-25 yo) (Table 9).

Table 9 Monte Luna. Permanent teeth.

	Permanent Teeth				
	Incisors	Canines	Premolars	Molars	Tot (%)
0 – 9 yo	16	10	18	56	100 (4.4)
10 – 15 yo	8	8	11	31	58 (2.6)
Young Adult (16 – 25 yo)	389	221	281	382	1273 (57.1)
Adult (26 – 35 yo)	34	34	50	134	252 (11.3)
Mature Adult (36 – 45 yo)	8	11	32	60	111 (5.0)
Old Adult (45+ yo)	30	16	36	77	159 (7.1)
Unknown	25	19	88	143	275 (12.3)
Tot (%)	510 (22.8)	319 (14.3)	516 (23.1)	883 (39.6)	2228

In the assemblage of deciduous teeth, molars were the most commonly preserved type of tooth (50.7%). In the permanent dentition, the highest level of preservation was found for molars (39.6%) and premolars (23.1%), followed by incisors (22.8%) and canines (14.3%) (Figure 9). The highest repetitive element in the deciduous and permanent dentition were molars (Rd_5 = 7) and incisors (RI^1 = 170), respectively.

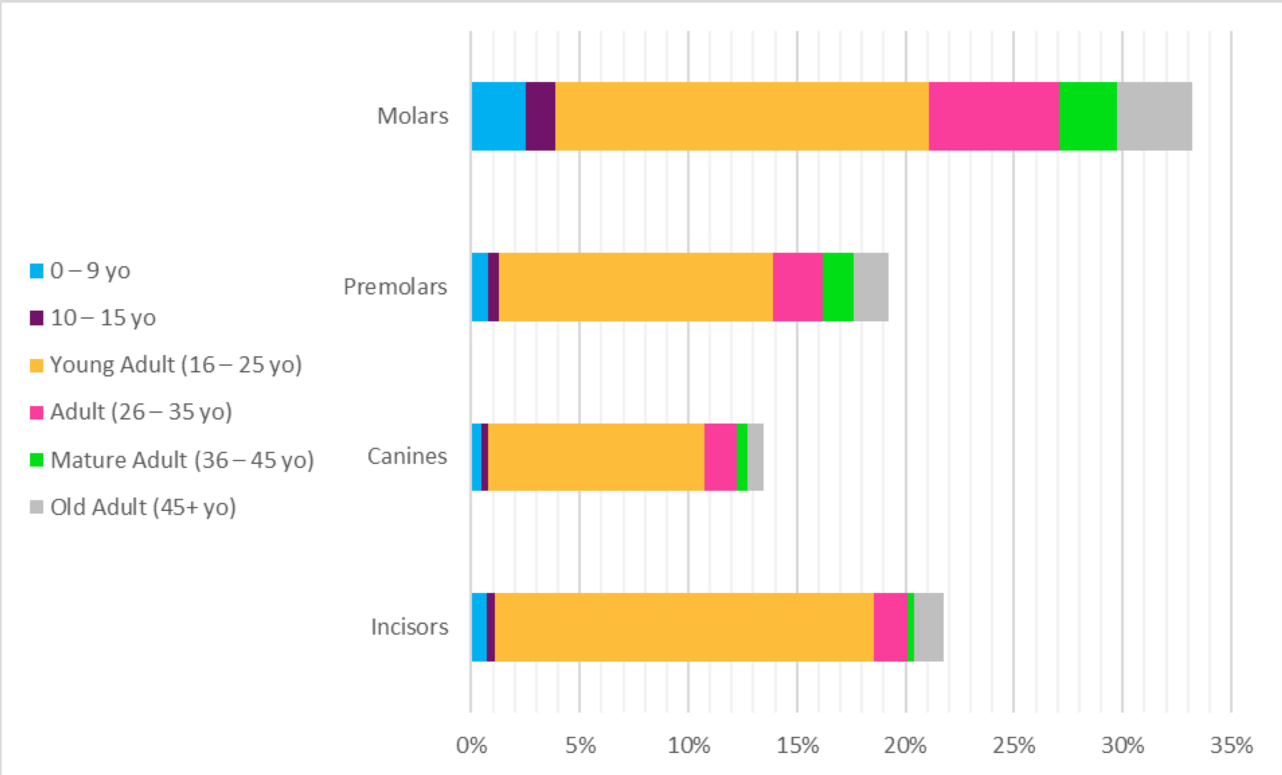

Figure 8 Monte Luna. Prevalence of type of permanent teeth among subadult, adults, and unknown age ranges.

3.5 DISCUSSION

The demographic data presented in this study can help to understand the population structure of the Pau and Monte Luna communities, leading to an improved understanding of population dynamics of past societies. This also provides further insight into the social and cultural practices in place at the time. Identifying anomalies in the age-at-death and male to female ratio within a sample is also important. For example, a high percentage of males in a cemetery could suggest that they were more vulnerable to death than females. However, when considered within the broader archaeological context an alternative explanation may become apparent, such as the cemetery being a military burial site (eg. Ugas, 1990). Furthermore, demographic data can assist in identifying any age gaps in the sample, which could indicate that certain groups or people were under-represented or absent from the site. Demographic non-stationarity can affect the estimation of age-at-death distributions in several ways (Wood et al., 1992). First, mortality patterns in a growing population may differ from those in a stable population, resulting in distortions of the age-at-death distribution if a model based on a stationary population is used. Secondly, the age-at-death distribution can be affected by changes in the sex ratio over time, as mortality rates vary by sex (DeWitte and Stojanowski 2015). Thirdly, the age-at-death distribution may be affected by changes in the age structure of the population, which can result in changes in mortality rates of different age groups. Finally, using age-at-death as a proxy for the number of individuals dying within an age interval may lead to inaccurate estimates if the age distribution of the population is not homogeneous (Wood et al., 1992; DeWitte and Stojanowski 2015).

Burial sites are often disturbed by human activity such as construction, development, or looting. The arrival of a new population may have resulted in re-use, or disruption of a cemetery. Natural processes, such as erosion and weathering, taphonomic changes, and animal activity can also cause damage, and affect preservation in burial sites over time (Mays, 1992; Waldron, 1994). In addition, during an archaeological survey, excavation, or analysis of some of the fragile remains may be lost due to inappropriate handling (Waldron, 1994). It is also vital to maintain an awareness that dead populations differ from living ones (Mays, 1992; Waldron, 1994).

The demography of Sardinia is not well understood due to a paucity of data. The available data are, to date, based on genetic analyses. During the advanced Neolithic (4500-3500 BC), the population of Sardinia was estimated as numbering only in the tens of thousands (Calò et al., 2021). The Phoenician and Punic eras were characterised by female mobility and genetic diversity, reflecting the inclusive and multicultural nature of the society (Matisoo-Smith et al., 2018). However, further site-based studies are necessary to shed light on the demography of the island, particularly changes in the age and sex distribution through time.

The Pau and Monte Luna samples are characterised by a high level of fragmentation. Therefore, the demographic profiles can only be presented in terms of the minimum number of individuals (MNI), age ranges, and sex distribution (Monte Luna only). The samples from Pau and Monte Luna contained a similar proportion of subadults, with 33.3% (6/18) and 25.9% (59/227), respectively. The subadults in Pau included bones from foetal and neonatal individuals (evidence of post-cranial bones), infants, and older subadults. Notably, in Monte Luna there was no evidence of subadults aged younger than 1 year of age (+/-3 months), which may have been due to decay and fragmentation of the very fragile foetal and /infant bones at that location. It is also possible, the very young were buried elsewhere).

In both samples, the majority of adults were in the young age range (16-25yo) (based on the available dental samples). Only 2.6% of the Pau sample and 7.13% of the Monte Luna were from individuals classified as older adults. Historically, infants and subadults suffered high rates of mortality (Trinkaus, 1995; Volk and Atkinson, 2013), and even as adolescents and adults, people still faced a range of health risks that could lead to premature death. For example, accidents and injuries were more common because of a lack of safety standards, medical knowledge, and technological evolution. Additionally, diseases were often fatal especially in populations with weakened immune systems due to either malnutrition or health problems.

It is possible to investigate potential differences in health and wellbeing among the two populations by analysing the demographic data. This information can help to create a regional profile that provides insight into the health status of a specific group, including aspects such as disease patterns, life expectancy, and nutritional status. Comparing demographic data from the Neolithic and Punic era can help to identify trends and changes in health outcomes over time. This, in turn, can be combined with genetic data to gain an understanding of historical trends. Additionally, the demographic data can be compared with that of different European populations to identify local patterns of disparities and inequalities of health. Further chapters will analyse and discuss the Pau and Monte Luna samples to interpret funerary behaviour, health, and stress indicators. Finally, the discussion at the end of this thesis will integrate all information gained to develop an interpretation of life in Sardinia during the Neolithic and Punic era.

3.6 LIMITATIONS AND BIASES

The bioarchaeological approach assumes that a sample of human remains is representative of the living group to which the person belonged. The whole community is interpreted through the observation of the available samples. There are many potential issues interfering with a sample following interment, excavation, and subsequent curation. When using the dead to deduce information about the population as a whole, four factors have to be taken into account (Waldron, 1994):

- The proportion of dead that were buried;
- The proportion of those buried whose remains were preserved enough to be discovered;
- The proportion discovered;
- The proportion recovered.

Due to the extrinsic effects of the natural and cultural environments, the samples of Pau and Monte Luna are poorly preserved with a high level of fragmentation.

The sample from Pau is made up of isolated elements, partly with evidence of cremation and with only isolated teeth providing valuable information. However, the data are suitable to provide some information on the population's culture and funerary behaviour.

The sample from Monte Luna is characterised by skeletal elements from 70 tombs out of a total of 120 burials identified; not all were excavated. Each of the tombs contained multiple depositions and cremations with mostly isolated elements recovered, though a number of more complete individuals were recovered.

The only archaeological artefacts of the period are stored at the MADN (*Museo Archeologico Sa Domu Nosta*) and the Archaeological National Museum in Cagliari. The artefacts found inside the tombs provided valuable information about the culture of the time.

Estimation of demography and MNI using standards based on modern subadult and adult people of known age (Mays, 1998), have to consider the following limitations:

- A single burial may not be indicative of particular characteristics of the population at the time.
- The natural variability of some skeletal features of different populations will influence both the developmental and degenerative processes in a person, due to environmental (climate, diet) and genetic (osteogenesis and dental eruption times) factors.
- Standards based on modern populations assume that ancient skeletons followed similar chronological events. It is essential to consider that there is a certain degree of variation of standards both at an individual and population level. Furthermore, external factors such as diseases, and malnutrition, can affect the development, degeneration, and decay of a skeleton.

- It is more reliable to use at least two or more methods of analysis to estimate demography.

An ideal model of analysis is based on complete skeletal remains which would allow for more precise estimations of aspects of the biology of individuals. It is considered good practice to combine at least four methods of analysis to gain an understanding of a population. (Acsadi and Nemeskéri, 1960**;** Sjovold, 1975; Buikstra and Ubelaker, 1994) However, ancient human remains are commonly highly fragmented and, therefore, other methods to study partially (25 % - 50 % - 75 %) preserved skeletons have been developed.

The presence of 17 partially preserved individuals (75% completeness) of both subadult and adult age ranges at Monte Luna, allowed a combination of multiple methods of analysis to be carried out and to verify their validity on a Sardinian population. The different methodologies produced consistent estimates and are therefore considered to be reliable (Appendix – Individual's biological profile estimation).

The limitations outlined above may distort the results and hence interpretation of the demography and health status of the populations and are carefully addressed in the following chapters.

4 Rising from the ashes: a multi-technique analytical approach to determine cremation. A case study from a Middle Neolithic burial in Sardinia (Italy)[1]

4.1 Introduction

The study of cremated human remains from archaeological contexts has traditionally been viewed as less valuable than the study of inhumed bodies, due to the complexity of the adulterated material and the false belief that little survives the burning process (Thompson, 2016). This lack of attention is being remedied more recently through several publications (e.g. Mayne Correia, 1997; McKinley, 2000; Fairgrieve, 2008; Schmidt and Symes, 2008), summaries (e.g. Ubelaker, 2009; Goncalves, 2012), and frequent continuous research (e.g. Thompson, 2002, 2004, 2005, 2009; Goncalves, 2011, 2013a, 2013b; Sandholzer et al., 2013, 2014). Recent methodological and theoretical developments aiming to reconstruct the taphonomic transformation of the human body during cremation have highlighted their potential for understanding past funerary and cultural practices. State of the art technologies show some benefit. Shipman's work (1984) started the study of considering colour change in burnt bone and now it is possible to study the chemical composition of the bone and burnt through X-Ray Fluorescence (XRF), X-Ray diffraction (XRD) and Fourier-Transform Infrared spectroscopy (FTIR). The application of these methods has usually combined XRF, XRD and FTIR

[1] *This chapter is written as a standalone journal article, published by the Journal of Archaeological Science: Reports 36 (2021) 102855, doi: https://doi.org/10.1016/j.jasrep.2021.102855. As such, there will be some repetition from previous sections particularly in regard to context and materials.*

(Dal Sasso et al., 2014, 2016; Stiner et al., 1995, 2001; Piga et al., 2009), or XRD and FTIR (Piga et al., 2016).

Traditionally, the archaeological context of cremation presented in many studies is usually derived from either the presence of a container such as an urn or of a distinct burial. In complex multiple burials, due to the difficulty of identifying each individual, the study of cremated remains is more challenging. This is the case for the Middle Neolithic (MN) collective burial studied here. This burial was brought to light inside the Su Forru de is Sinzurreddus cave (Sardinia, Italy), during excavations carried out during the Monte Arci research project, which aimed to identify the diachronic trend of obsidian exploitation from the Early Neolithic to the Late Bronze age (Figure 10, Lugliè, 2003b).

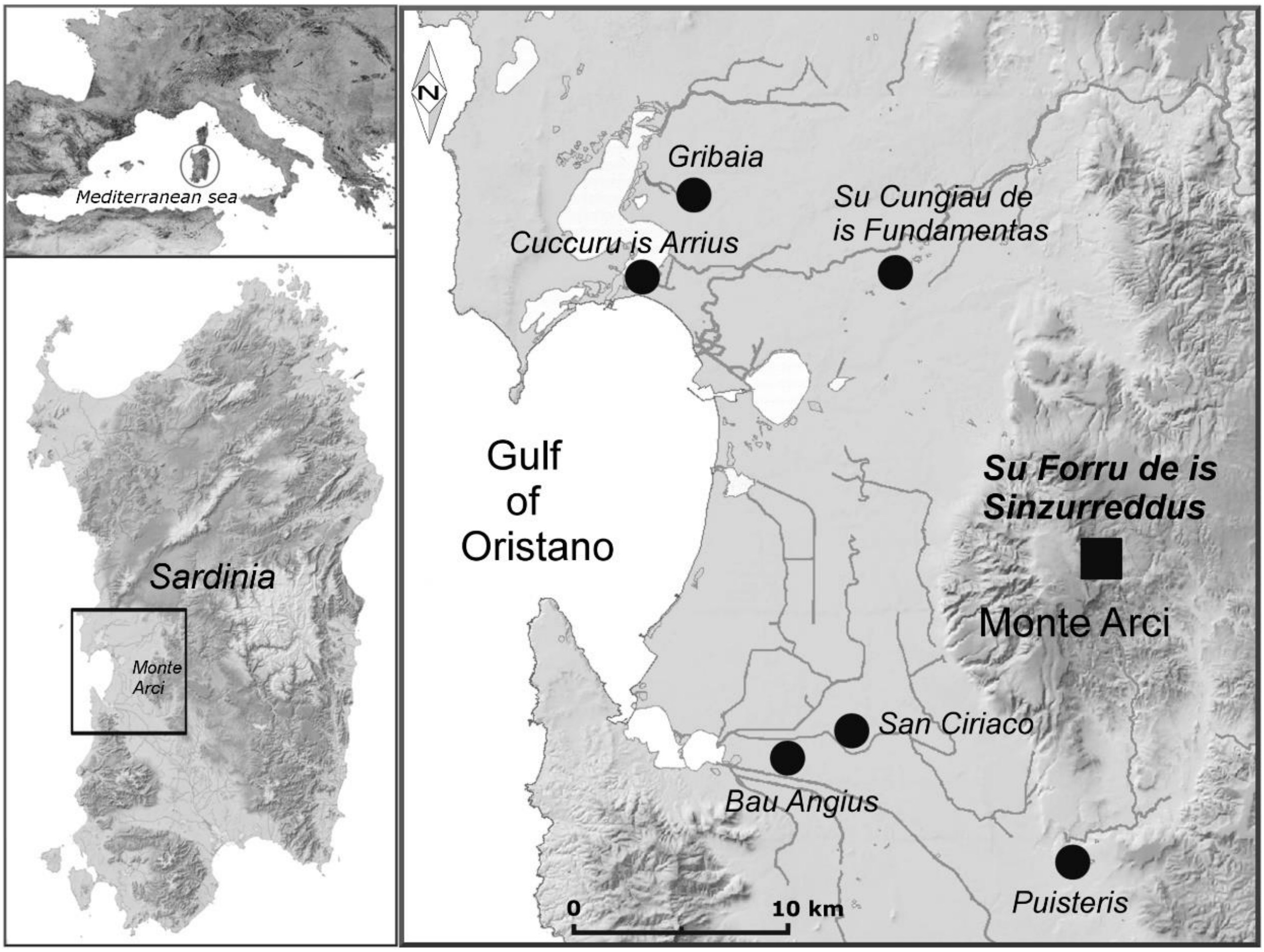

Figure 9 General map of central-western Sardinia (Italy) with Su Forru de is Sinzurreddus-Pau (OR) and other major Middle Neolithic sites. (Map: C. Lugliè, L. Fanti)

During the excavation it was clear that most of the approximately 50,000 skeletal fragments recovered showed to have been affected by thermal alterations with different degrees of combustion (Figure 11).

Figure 10 Heat induced colour change on archaeological human bones from stratigraphic units 1064 and 1070. (Photo: C. Luglié, R. Paba).

Nonetheless, no evidence of firing inside the cave has been recorded. This peculiar archaeological context raised an unexpected issue: were we facing a secondary burial rite through the systematic cremation of several individuals? If this was the case, it would be the oldest and only example in Sardinian Neolithic. Very few examples of cremation even appear in coeval sites abroad (Bernabò

Brea et al., 2010). Such a crucial shift of ritual behavior from primary inhumation to body cremation in the interregional MN required greater understanding of this specific symbolic behavior.

The anthropological material was affected by high fragmentation, and in the dispersal of both artefacts and human remains, a key role was clearly played by the natural exfoliation of the cave roof. Thus, it is very difficult to rely only on the spatial analysis and the evaluation of taphonomic processes to determine the funerary practices. This context required the application and integration of several analytical methods, in order to understand the ritual and post-depositional distribution of thousands of fragmented humans remains. As a consequence, a multidisciplinary approach, combining, for the first time, the application of spectrophotometry, XRF, and FTIR was undertaken.

The approach is articulated in the following steps:

- Selection and spatial distribution analysis of the MN artefacts and anthropological materials by GIS;
- Analysis of bone's colour change (and by association, temperature) through spectrophotometry;
- Characterization of the elemental composition of bone by means of XRF;
- Molecular composition and Crystallinity Index analysis of bone through FTIR.
- All the data were then statistically analysed, according to each technique. They underwent statistical analysis via T-test and correlation measures.

This aims to develop a methodological tool suitable to apply to similar cases and encourages the study of cremated human remains in collective burials to understand their relevance to funerary symbolic behaviour in the Mediterranean and European context.

4.2 ARCHAEOLOGICAL SETTING

4.2.1 Geographic and cultural context

The site of Su Forru de is Sinzurreddus is situated in Sardinia, a 24.1 km^2 island far from the mainland that in prehistory was reached exclusively by seafaring. Consequently, every new arrival of human groups was striking because it introduced clear innovation that is recorded in the archaeological realm both in the material and in the symbolic record. Since the first population on the island during the Early Neolithic (VI millennium BCE), interregional contacts and bidirectional interactions ensured a symmetrical cultural evolution of the human communities settled on the island with those in the surrounding western Mediterranean (Lugliè, 2018a). Among the few raw materials, obsidian gives evidence of human displacements from the island towards the Italian peninsula and the north-western seashores of the Mediterranean. In fact, from the Monte Arci volcanic complex, in the immediate central-west backshore of Sardinia, several discrete obsidian sources of this rare volcanic glass were exploited and distributed (SA, SB1, SB2 and SC geochemical groups: Tykot, 1997; Lugliè et al., 2006; Lugliè, 2009) (Figure 7). Between the VI and V millennium BCE, the exchange of polished stone rings linked the island with the north of Italy (Tanda, 1977), strengthening the building of interregional exchange networks, according to the internal development of social organization.

On the other hand, the transmission of symbolic behavior is almost exclusively confined to the figurative expressions of pottery decoration, to scant convergences in lithic technology and, more weakly, to funerary rituals. In the late V millennium BCE, for instance, several traditional pot types belonging to the advanced MN *San Ciriaco* culture, previously undecorated, show the adoption of carved graphic schemes like wavy lines and spirals that marked a wide dissemination in the coeval Square-Mouthed-Pottery (SMP) culture of the Po Plain (Bagolini and Biagi, 1976). This cultural horizon was certainly in contact with the Tyrrhenian region due to the bidirectional distribution of obsidians and metamorphic (steatite) small stone beads between Sardinia and several workshops in the Apennine between Tuscany and Emilia (Micheli, 2012; Micheli and Mazzieri, 2012).

As to the funerary practice, by contrast, evidence from Sardinia gives very little information to date, limited exclusively to the case of the hypogeal necropolis at Cuccuru is Arrius - Cabras. Belonging to the earlier MN-A *Bonu Ighinu* culture, a series of nine small underground chambers, dated to around the middle of the V millennium BCE, showed a specific ritual of individual primary burial with the body lying along the left side and flexed like in fetal position (Santoni, 1982b; Lugliè and Santoni, *in press*). Pots, obsidian artefacts and sometimes food may be buried with the body, yet from one to three human figurines made in stone are always placed in the burial. This ritual and specific symbolic behavior matches the usual funerary SMP culture in many sites of the Po Plain (Bernabò Brea et al., 2010). Surprisingly, during the following and more widespread MN-B *San Ciriaco* phase, this burial practice is almost totally unknown. With the exception of the conjectural attribution to this culture of the stone circle necropolis at *Li Muri* near Arzachena (Antona, 2003), where ritual was not identified due to the lack of preservation of the human bones, there are no other funerary custom discovered thus far.

4.2.2 The collective burial of the Su Forru de is Sinzurreddus

The Su Forru de Is Sinzurreddus burial site is located at 508 meters above sea level on the eastern flanks of the Monte Arci volcanic massif in the district of Pau, province of Oristano (central west Sardinia) (Figure 10). The funerary locus is a small cave (around 17 m2) opening onto a steep fault which runs through a massive rhyolitic dome with a main SW-NE direction. Before the long-term backfilling of the fault, the original entrance of the cave was several meters above the Neolithic ground level, thus providing a protected and barely accessible space (Figure 12 and 1).

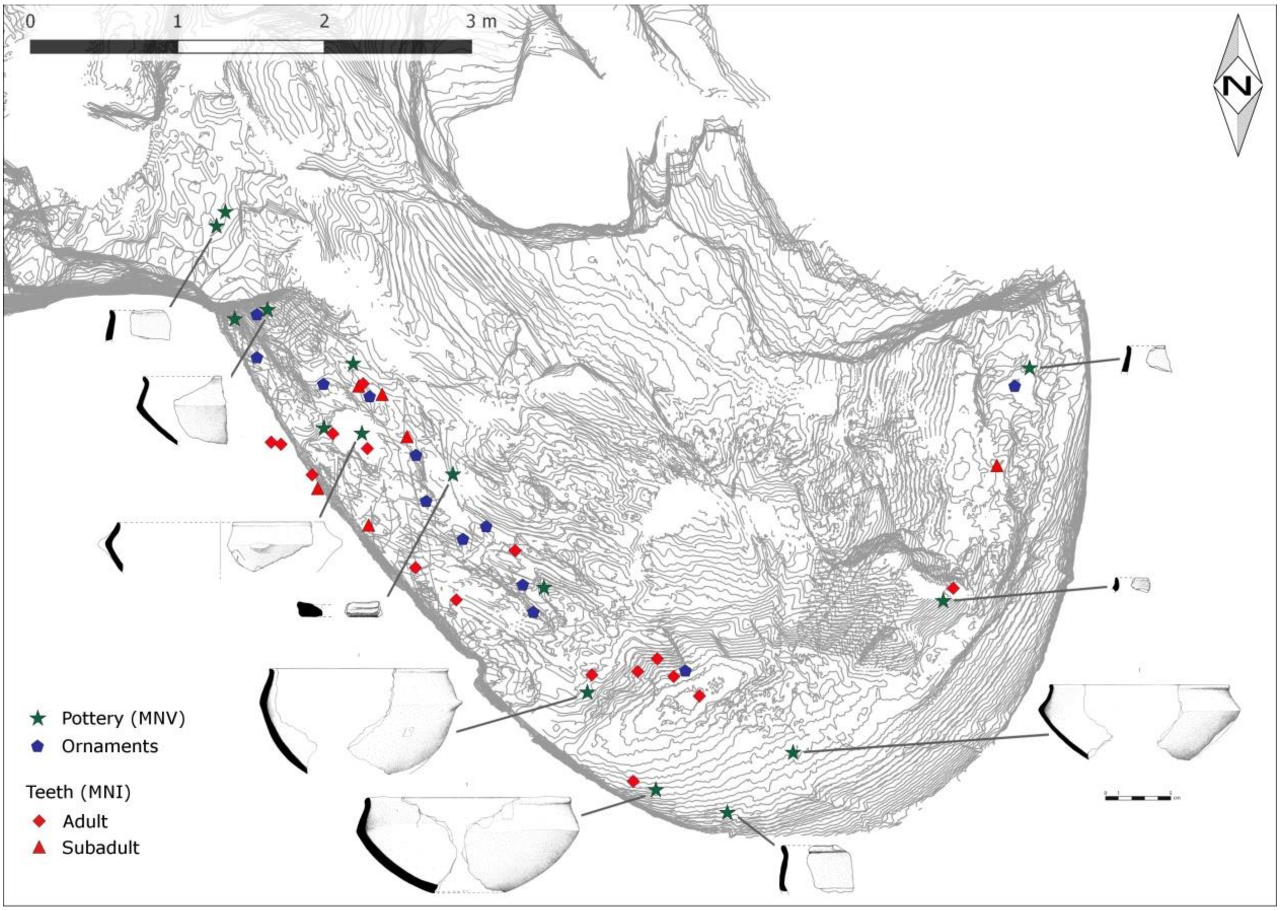

Figure 11 Spatial distribution of MN-B San Ciriaco pottery vessels (MNV: minimum number of vessels identified, with drawings of the main vessel profiles), ornaments (beads) and human teeth selected for determining the minimum number of individuals (MNI). (Map: C. Lugliè, R. Paba, L. Fanti; vessel drawings: L. Fanti, C. Lugliè)

A long-term excavation (2003-2015) of the stratigraphic sequence inside the shelter revealed the succession of several phases of massive vault collapse and human frequentations, spanning from the MN to the present. The first and main phase of occupation belongs to the MN-B San Ciriaco culture, dated back to the second half of the V millennium BCE. Therefore, Su Forru de is Sinzurreddus bears the oldest direct evidence of a long-term human presence on Monte Arci. Further settling of the cave during the Copper Age and Nuragic Middle Bronze Age were almost episodic, possibly due to the progressive reduction of the room, because of the filling and obstruction following the vault collapse events. The anthropogenic layers brought to light bore a very thin and powdery matrix, inserted between large rhyolite boulders and slabs, which resulted in a cautious, thorough and lengthy excavation.

Su Forru de is Sinzurreddus is located near the eastern border of the *Sennixeddu* which is on an outcrop of SC obsidians, its relationship with this raw material exploitation may be asserted. This inference is supported by the presence of obsidian flakes inside the cave, in stratigraphic association with the MN human remains. The same stratigraphic position of a few ornaments and, mainly, of several pottery sherds exclusive of the MN-B *San Ciriaco* culture led, firstly, to assign the graves to this horizon and, secondly, to confirm that during the second half of the V millennium BCE the systematic and massive exploitation of the SC obsidian primary deposits on the mountain took place (Lugliè, 2012). All the diagnostic artefacts were displaced randomly but mainly along the western and south/south-eastern walls of the cave, entangled in a huge amount of hyper-fragmented human bones and intermingled with several areas of concentrated human remains (Figure 13 and 14).

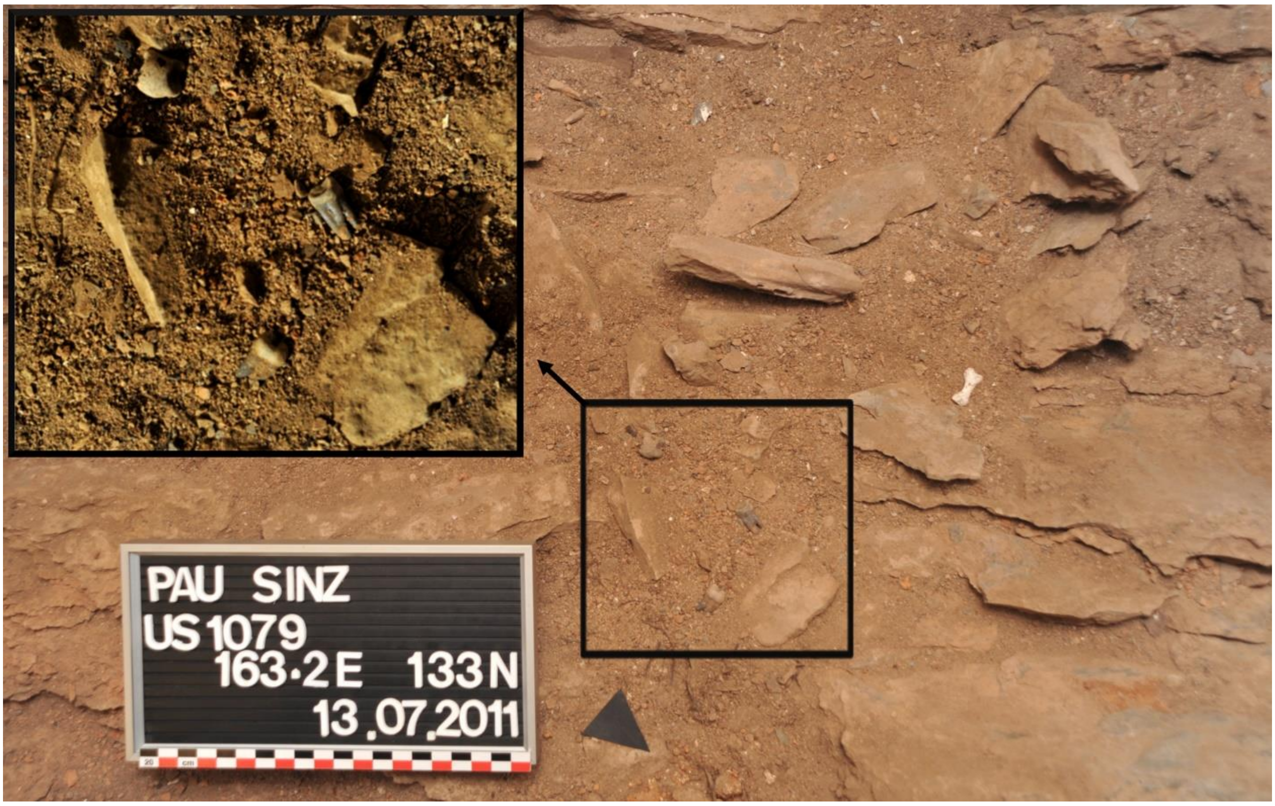

Figure 12 Excavation of the stratigraphic units in the Su Forru de is Sinzurreddus cave, with detail of dispersion of burnt bones, notably teeth (detail in the focus window). (Photo: C .Luglиè; image: L. Fanti)

Figure 13 Excavation of the stratigraphic units in the Su Forru de is Sinzurreddus cave, with detail of a MN-B San Ciriaco bowl (white arrow). (Photo: C. Lugliè; image: L. Fanti)

Pottery is the most reliable cultural and chronological indicator of the archaeological burial context at Su Forru de is Sinzurreddus. It appears within all the stratigraphic anthropogenic layers, matching the distribution of human bones along the southern and western walls of the cave (Figure 12).

Despite the relatively high fragmentation of the assemblage and the small dimensions of many sherds, the morphology of vessels with well-preserved profiles (mainly carinated bowls) and the technological features shared by all the pottery assemblage are clearly recognizable as distinctive of MN-B *San Ciriaco*. This pottery is characteristic of numerous contemporaneous sites across the island (Figure 12; Santoni, 1982a-b; Ugas, 1990; Santoni et al., 1997; Lugliè, 1998, 2003a; Usai, 2009; Lugliè, 2017, 59-63, Figure 19-22; Fanti et al., 2018, Figure 1 and 10; Fanti 2019, Figure 8). Based on a count of rim types and family sherds from the study of all the assemblage (Rice, 1987, 292-293; Voss and Allen, 2010, 1-2), a minimum number of 15 vessels has been assessed.

Alongside the closest morpho-typological similarities among the vessels from Su Forru de is Sinzurreddus and pottery from the sites located along the main approaches to the Monte Arci massif, notably Puisteris-Mogoro (Meloni, 1994; Santoni et al., 1997), and in the central-western Sardinia area surrounding the gulf of Oristano, such as Gribaia-Nurachi, Bau Angius-Terralba and the eponym site of San Ciriaco-Terralba (Figure 10; Lugliè, 2003a, 2017; Fanti et al., 2018), the spectrum of comparisons connects the pottery assemblage of this funerary site to a broader scenario which reflects a wide network of relationships and contacts, encompassing and overtaking the regional domain towards the near island of Corsica and the north Tyrrhenian area (Tramoni et al., 2007; Le Bourdonnec et al., 2011; Tramoni and D'Anna, 2016; Lugliè, 2017).

4.3 Materials and Methods

4.3.1 Human remains

Besides a restricted number of contemporary, not-burnt, small faunal bones, the number of pieces of human remains found is more than 50,000, characterised by a high level of fragmentation. During the recovery, it was observed that these remains were partially inhumed but a consistent number of them had been exposed to fire (as evidenced through colour change) (Figure 11). In fact, the remains were characterised by heat-induced fracture patterns, bone warping, shrinkage and chromatism described in the literature (Bonucci and Graziani, 1975; Shipman et al., 1984; Reverte Coma, 1985; Holck, 1986; McCutcheon, 1992; Mays, 1998; Wahl, 2008; Walker et al., 2008; Gonçalves et al., 2011). For this study teeth (565) and phalanges (500) were selected from all the excavated Stratigraphic Units, because they are the only complete elements in the excavated sample. A further selection of mixed fragmented humans remains from stratigraphic units 1070 and 1064 (372) was studied to confirm the presence of burning. These bones were found underneath a stone slab from the collapse of the roof and have been associated with a well-defined chronology, based on the associated pottery. Teeth, phalanges and the mixed material were recorded following standard methods (Buikstra and Ubelaker, 1994; White and Folkens, 2005). The fragments were sorted according to skeletal area (cranium, axial or appendicular skeleton) and then identified to skeletal element or assigned to an 'unidentified' category.

4.3.1.1 Minimum number of individuals and health conditions

Teeth and phalanges were the only whole skeletal elements recovered and were used to estimate the minimum number of individuals. They were sorted by name, date, stratigraphic unit, present state, skeletal element, burnt/unburnt, and then each category for specific traits. Teeth were studied for dental wear (Brothwell, 1981; Lovejoy et al., 1985), dental health (hypoplasia, calculus, caries) (Hillson, 2005), and age estimation. Phalanges were recorded by hand/foot, number, side, age estimation, and some measurements were taken (for the first proximal phalanx of the hand) (Garrido Varas and Thompson, 2011).

4.3.1.2 Heat-induced colour change

Colour change is a well-known indicator of cremation (Shipman et al., 1984; Gonçalves et al., 2011; Ellingham et al., 2014). The coloration varies with temperature as follows: a yellow brown at 200°C, a dark brown-black at 300°-400°, an ash-grey at 500°-600°C, chalk-white over than 700°C, and white with blue/yellow shades between 800°-1000°C. Therefore, the selected samples from stratigraphic units 1070 and 1064 underwent spectrophotometry (XRite, Ci 6X) to assess colour. The equipment was calibrated with white, black and green blanks supplied by the company. The osteological controls and the selected samples were recorded in Munsell and CIELAB (Munro et al., 2007; Ellingham et al., 2013). The samples were cleaned with a brush to create a 7mm diameter space, enough to be covered by the spectrophotometer lens. The measurement was taken on the colour which equated to the highest temperature of burning. Each sample was recorded three times at the same point and the mean result used. The averages were exported to Excel Office365 and SPSS (v23).

4.3.1.3 Osteological Controls

The effective analysis of heat-induced change in bone from archaeological sites requires comparison to experimentally burned bone in order to validate the features observed in the field. As such, a signifşt amount of sheep bone (an accepted animal analogue) has been burned, both fleshed and defleshed, at known temperatures (100 to 1100°C, in 100°C intervals) for specified durations (60mins). Samples were crushed and combined together to produce a composite sample for fleshed and defleshed at each temperature interval (Figure 15).

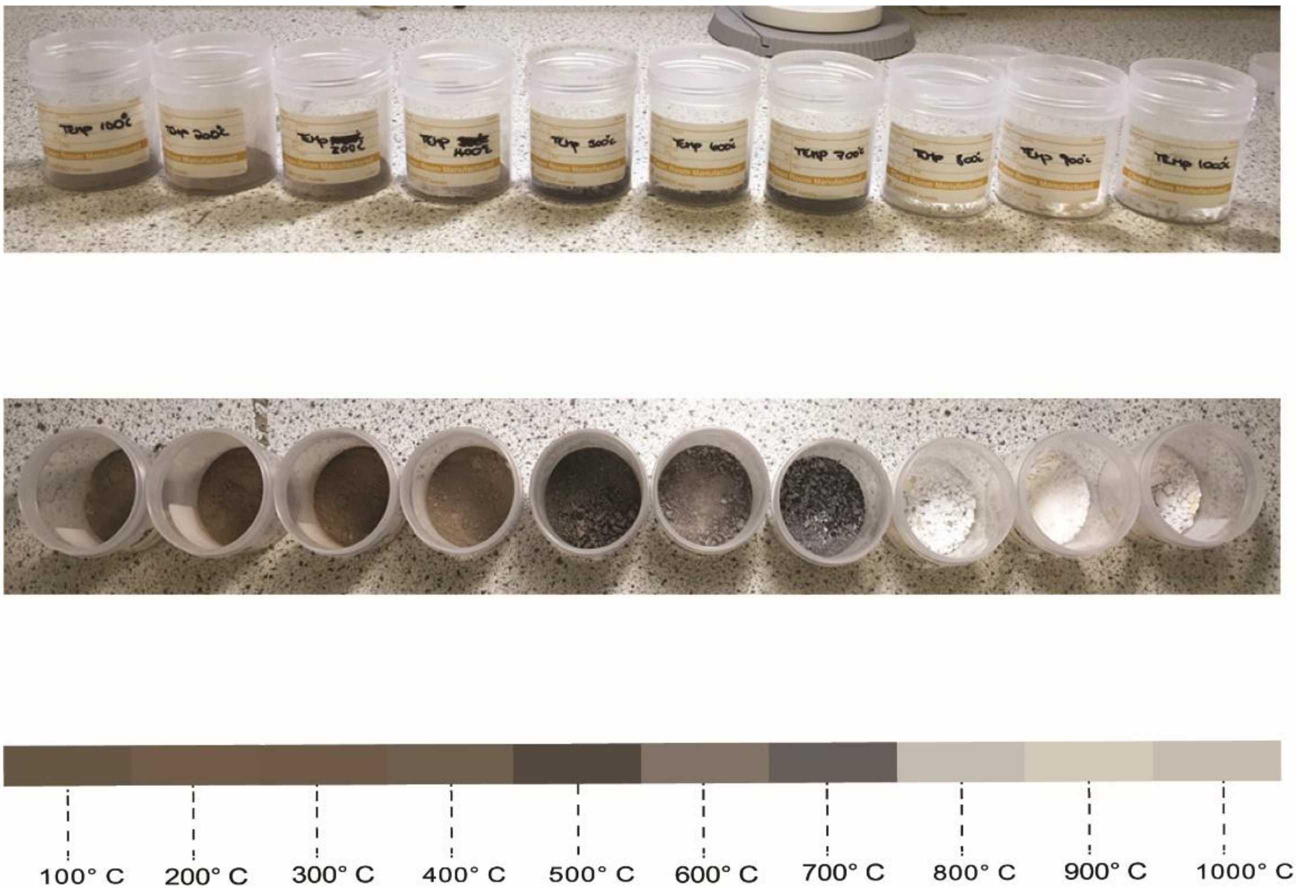

Figure 14 Osteological controls of sheep bones burnt at known temperatures (Controls: T.J.U. Thompson; photo: R. Paba)

These experimental studies (documented for example in the likes of Ellingham et al., 2014; Ellingham et al., 2016; Piga et al., 2008; Thompson, 2005; Thompson et al., 2013; Thompson et al., 2016, Marques et al., 2018) permit an understanding of the effect of temperature, oxygen, timing, the presence of soft tissues, clothing, etc on heat-induced changes visible on the skeleton. Once burned, the samples were subjected to FTIR, XRF and colour analysis to create standards for use in the field. Results and application of these experimental studies can be seen in the likes of Thompson et al., 2016.

4.4 XRF

X-Ray fluorescence (XRF) has shown promise in the study of fire use in archaeology (Reidsma et al., 2016) and in determining whether a set of remains belongs to a single or multiple individuals by analysing elemental concentrations in human bones (Gonzalez-Rodriguez and Fowler, 2013). A portable X-Ray Fluorescence Niton XL3t GOLDD+ Spectrometer analyser from Thermo Scientific (UK) was used. After the calibration and safety control protocol was performed, it was set up under Mining exploration and Geochemical analyses to detect all the elements. First, the osteological controls were performed, then the sample from the chosen stratigraphic units. The samples were cleaned to minimize surface contamination; however, surface contamination should be minimal because X-Rays penetrate a few millimetres beyond the surface (Shackley and Dillian, 2002; Shackley, 2011). All recordings were taken three times and the averages were exported to Excel and SPSS.

4.5 FTIR

Fourier Transform Infrared Spectroscopy (FTIR) is the latest technology to be used in the study of burnt human remains. It has shown how changes in the Crystallinity Index (CI), C/P and CO/P ratios are useful to estimate temperature (Goncalves et al., 2018; Thompson 2015, 2016; Thompson et al., 2009; 2011; 2015). The scans were undertaken by a Bruker Alpha II Platinum ATR controlled by OPUS software and calibrated using previous known data from the same equipment. For each sample, a portion of 0.5 g fragment was selected, then background spectra were collected. The diamond stage was cleaned with propanol before all use. The spectra for each sample were recorded three times following published methods (Squires et al., 2011; Thompson et al., 2013) between 2000cm^{-1} and 200 cm^{-1} at a resolution of 4cm^{-1} with 32 scans in each analysis. Because the positions on the FTIR spectra and the ratio themselves examine different aspects of burning intensity, in this study measures proposed by Thompson et al. (2013) were used:

$CI = (565cm^{-1} + 605cm^{-1})/595cm^{-1}$

$C/P = (1415cm^{-1}/1035cm^{-1})$

$CO/P = (1650cm^{-1}/1035cm^{-1})$

Therefore, CO/P describes low temperature, 100°-500°C; CI middle intensity, 500°-800°C and C/P high intensity burning events, 800°-1000°C (Thompson et al., 2013).

4.6 RESULTS AND DISCUSSION

4.6.1 MNI

Analysis of the teeth allowed four age ranges to be defined (Brothwell, 1963; Bouville, 1983; Lovejoy, 1985): subadult, 0-12 y; young adult, 12-24 y; mature adult, 24-40 y; old adult, 40-55 y. The incisors, both permanent and deciduous, estimate the minimum number of individuals at 18 adults between 12 and 55 yr, the majority of which were between 12 and 24 yr, and the presence of six subadults between 0-7 yr (Figure 10). Furthermore, 18 teeth of young adults showed hypoplasia of which 13 were consistent (level 2, 3) (Brothwell, 1981); seven young adult's teeth were recorded with dental calculus at level 1 (Brothwell, 1981); 45 caries were observed in teeth of all age ranges, of which the age group with the most caries is between 12-24 y (Table 10). Hand and foot bones supported the MNI and the presence of different age ranges (Table 11).

Table 10 Su Forru de is Sinzurreddus teeth analysis. RI1: Upper right permanent incisor; Rdi1: Lower right deciduous incisor.

	Total n	RI^1	Rdi^1	Hypoplashia	Calculus	Caries
Teeth	565	18	6	24	7	45

Table 11 Su Forru de is Sinzurreddus phalanges analysis. Proximal left and right phalanges have been sided following Garrido Varas and Thompson, 2010.

	Total		Hand		Feet	N/D
n	500*		280		174	46
		Metacarpals	**Prox. Lx phalanges**	**Prox. Rx phalanges**	**Metatarsals**	
n of identified bones		16	10	7	34	

*: of which 71 are subadults

4.6.2 Heat-induced changes

Due to the high level of fragmentation, 131 samples were recorded in CIELAB and Munsell colour data. Here, the prevalence of darker and lighter-shade colours indicates that most of the individuals were burned at temperatures over 400°C (Mays, 1998; Ellingham et al., 2014; Goncalves et al., 2018). The 3D chart shows that most of the sample was burnt around 400° and 1000°C (Figure 16).

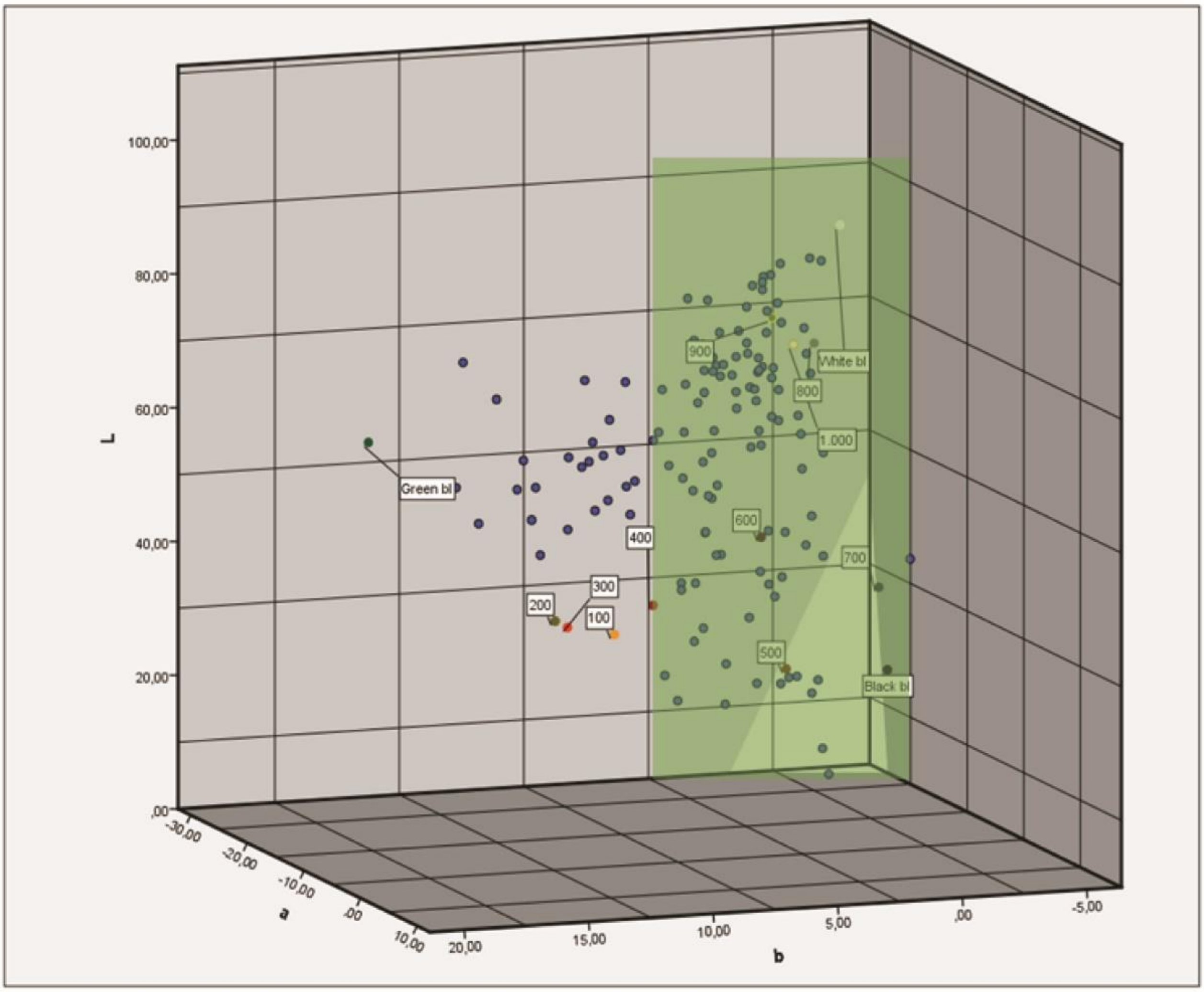

Figure 15 CIELAB 3D chart of controls (labels) and bones sample (blue dots) from stratigraphic units1064 and 1070. The part in green indicates that most of the sample was burnt around 400° and 1000°C. (Graph: R. Paba)

4.6.3 Elemental composition

The elemental composition of 157 fragments from the original sample were able to be analysed. Thirteen elements were detected in high enough concentrations to be measured: calcium (Ca), aluminium (Al), silicon (Si), phosphorus (P), sulphur (S), chlorine (Cl), potassium (K), titanium (Ti), chromium (Cr), manganese (Mn), iron (Fe), strontium (Sr), and hafnium (Hf). High levels of silicon suggest that the bone mineral composition has been affected by soil adhering (Burton and Price, 2000; Perrone et al., 2014). The presence of Al, used to package the human remains after the excavation, has also affected the results. Subsequently, following the previous studies (Christensen et al., 2012; Fulton et al., 1986; Gonzalez-Rodriguez and Fowler, 2013) it was decided to focus on Ca, P, Sr, Fe and K. Lead and zinc were not detected in the samples. Still, the controls show that a percentage of Ca, P, Fe and Sr can be find in burning beyond 300° and 490°C (Figure 17).

Figure 16 Controls element percentage of Ca, P, Fe and Sr. Where X axis shows temperature and Y axis elemental presence in percentage. The red bars define the point over which is reached a temperature over 300° and 490°C, based on the elements. (Graph: R. Paba)

K shows a nonlinear evolution through the increasing of the temperature. The ratio Ca/P is stable at 2:1 for the majority of temperatures and Sr/Ca shows lower levels with the increase of the temperature. This indicates that the application of XRF on cremated bones, associated with colour examination, gives enough information that this method could be used in the cases where destructive techniques on the samples are not permissible. Furthermore, nutritional information deduced by the Ca/P and by the Sr/Ca ratio suggests an omnivore balanced diet (Elias et al., 1982; Sillen et al., 1982; Lambert and Weydert-Homeyer, 1993) with most of the contribution from vegetable proteins, because of the minimum presence of calculus. This is consistent with the study of the food content residues in coeval pottery from the nearest settlements (Fanti et al., 2018).

4.6.4 Fragment composition

FTIR was applied to 253 samples, again due to the fragmentation of the sample, of which, 124 were also analysed by the XRite and XRF (Table 12).

Table 12 Su Forru de is Sinzurreddus sample from stratigraphic units 1064 and 1070 analysed by the multi-technique approach.

	Total	XRite	XRF	FTIR	XRite+XRF+FTIR
n	366	131	157	253	124

The osteological control measurements of CI, C/P and CO/P follow the trends provided by Thompson (2013; 2015), which suggest the reliability of the dataset. The 124 values show that 53.71% of the sample has been burnt at high temperature, 38.40% at middle temperature and 14.87% at low temperature. The remaining sample is consistent with this trend (Figure 18). As per Berna et al., (2012), the presence of the peak at 630 confirms that the burning happened above 500° and allow diagenesis to be excluded.

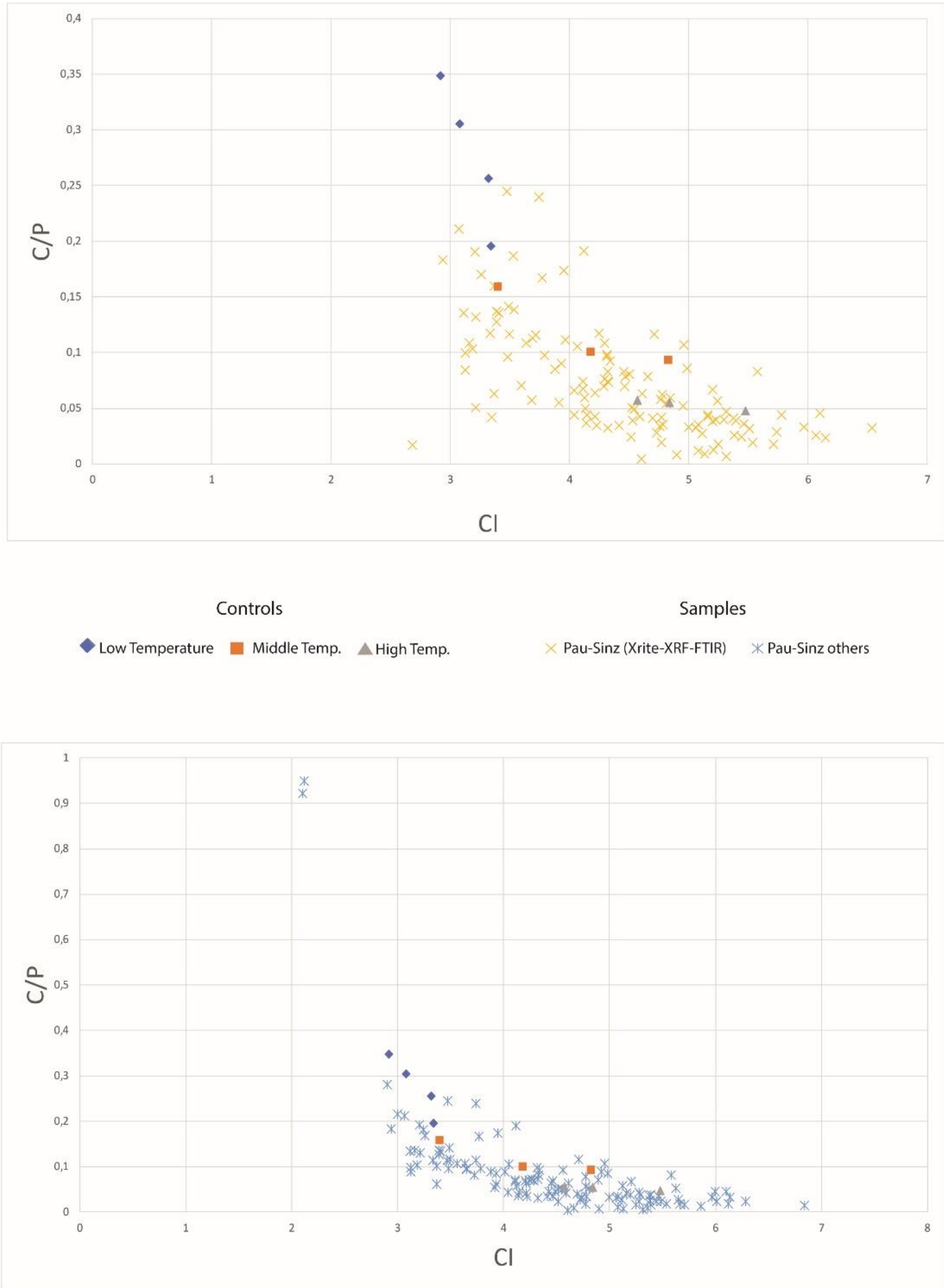

Figure 17 CI/CP chart of controls and selected bones: most of the sample lies around mid-high intensity temperature. (Graph: R. Paba)

The results here suggest an intensity of heating that is not consistent with accidental burning (Carrol and Smith, 2018), absolutely excluded even by the archaeological evidence from Su Forru de is Sinzurreddus cave. As such, it was possible to confidently analyse the remains by anatomical regions to better clarify bodily position within the funerary practice (Table 13).

Table 13 Identified anatomical regions in sample from stratigraphic units 1064 and 1070 analysed by the multi-technique approach.

	Total	ND	Skull	Ribs	Vertebras	Up. Limbs	Lw. Limbs	ND Limbs
n	174	91	18	22	16	5	4	18

Based on the results, it is clear that the limbs and skull were frequently burned at the highest temperature, this suggests the position of the body relative to the fire, accounting for the presence on soft tissue. This is consistent with the statistical correlation performed by SPSS. Following this, seven sided ribs (4 left, Lx; 3 right, Rx) and one Rx humerus fragment were analysed and indicated that the left side of the body was most impacted by high intensity temperature, leading to the assumption of a left lateral decubitus position relative to the source of fire (Figure 19).

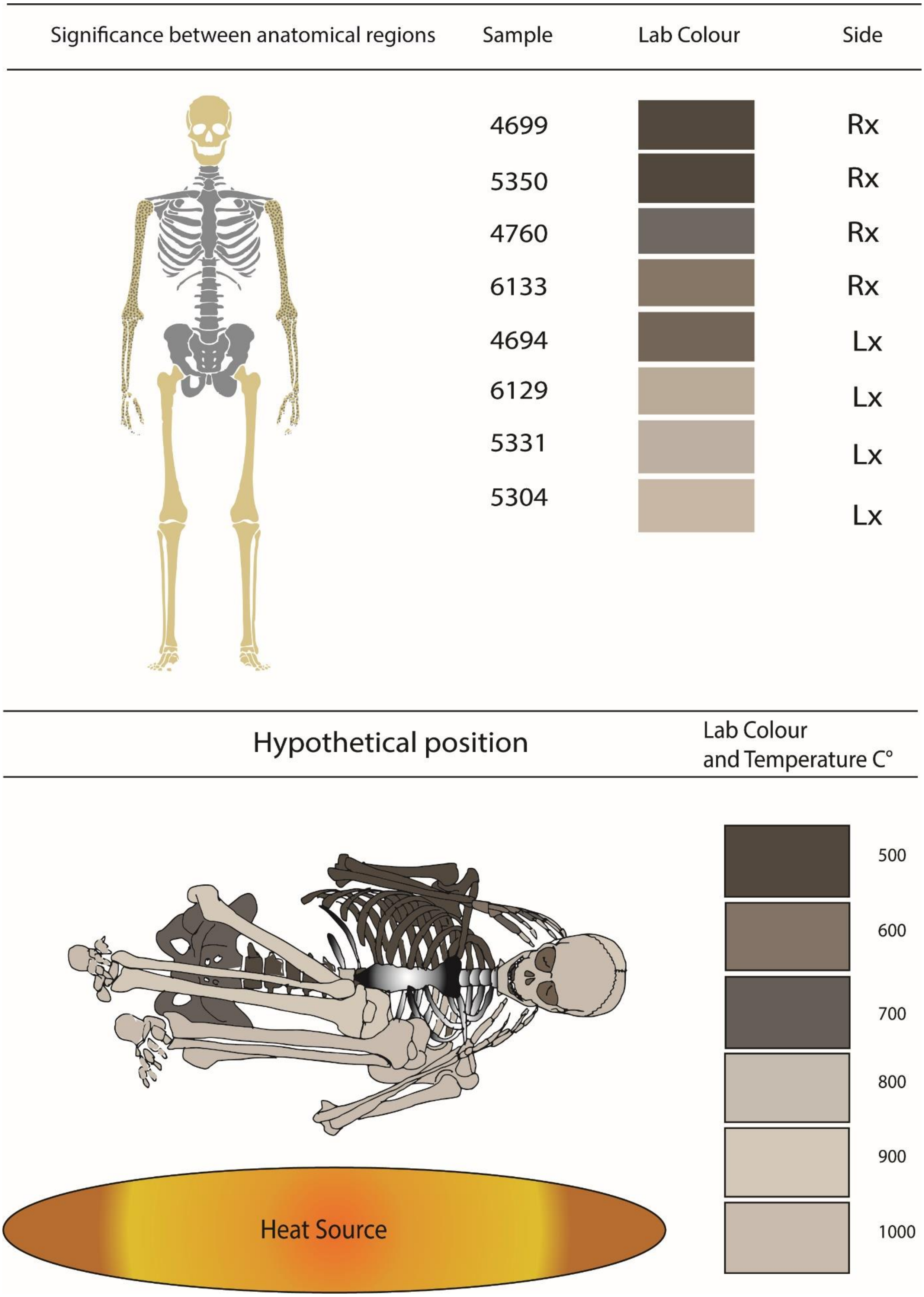

Figure 18 Graphic representation of the correlation between anatomical regions. Ribs table with colour in CIELAB and hypothetical position. (Image: R. Paba)

4.7 UNDERSTANDING FUNERARY RITUALS IN THE MIDDLE NEOLITHIC

These results show a ritual of secondary interment specific to the San Ciriaco cultural horizon, as suggested by the combined findings of typical pottery and ornaments. In fact, to date, no specific San Ciriaco burial ritual was known in Sardinia; this cultural horizon spans almost entirely the second half of the V millennium BCE. This study revealed that the individuals buried inside Su Forru de is Sinzurreddus cave during the advanced MN were intentionally cremated elsewhere, undoubtedly outside of the hypogeum. During the cremation phase, the results suggest the bodies of the dead were placed on the fire with a left side decubitus, possibly keeping the traditional disposition of the buried individuals as in the MN-A Cuccuru is Arrius graves (Santoni, 1982b). Afterwards, carbonized bones and ashes were collected and placed along the walls of the cave, possibly inside some container of perishable material, together with a fragment of a pot. Small lithic beads, according to the MN-A Cuccuru is Arrius graves (Santoni 1982b), were probably part of the personal items of the deceased, due to the apparent lack of thermal alteration on their surfaces. Finally, it has been possible to establish that this uncommon rite was followed without any selection of the buried people as to age and, possibly, to sex.

The adoption of secondary burial after thermal treatment of the body clearly lies out of the local regional tradition. Earlier (Bonu Ighinu) and later (San Michele di Ozieri) funerary norms and practices seem to be exclusively primary – individual and collective, respectively- depositions into artificial hypogea. So far, in Sardinia and the near island of Corsica, there is no evidence of cremation both in EN and MN burials. Secondary depositions of burnt bones have been recorded in a few MN funerary contexts of Northern Italy: at Ponte Ghiara, Fidenza (Parma) and at Le Mose (Piacenza) belonging to the former Square Mouthed Pottery (SMP) 1 in the Po Valley and at Gaione - Cascina Catena (Parma), assigned to the following SMP 2 phase. At Ponte Ghiara di Fidenza, a unique secondary deposition of selected bones (grave n. 2) belonging to a cremated woman was associated with some remains of a dog and a single cylindrical calcite bead (Bernabò Brea et al., 2010). It has been suggested that burnt human remains were possibly contained by a receptacle made of organic material. At Ponte Ghiara, other burials of the same dwelling phase show both individual and collective primary inhumations placed inside pits, with bodies lying in several different positions including the contracted posture on the left side. Similarly, at Le Mose site up to 39 MN burials have been recognized scattered between the dwelling units, revealing a wide range of funerary rituals. Primary male and female inhumations are largely dominant (many of them in a contracted position lying on their left side), yet two possible females of the SMP1 phase (graves n. 27 and 34 in the Generali site), buried without any accompanying items, bear evidence of some ritual cremation. At the site of Gaione at least four graves including cremation evidence were recorded. Two of them (graves n. 16, 18) were identified as female and a rich series of small, ornamental, cylindrical steatite beads were recovered from the cremated body (Bernabò Brea et al., 2010). Strikingly, even at Su Forru de is Sinzurreddus, small beads are among the personal items associated with the cremated remains, though in this case, because of the high fragmentation rate of the bones, it was not possible to identify the gender of the cremated individuals. All the above-mentioned cremations from the Emilia territory were supposed to have gone over the temperature of 600°C, due to patent bones' calcination (Bernabò Brea et al., 2010: 92). In the Northern Tyrrhenian region, further evidence of cremation of several individuals during the MN was recorded in the funerary cave of Grotta della Matta (also known as Grotta del Sanguineto) in the Orco Feligno town, Savona (Liguria) (Delfino, 1981). Similarly, in Southern Italy a ritual of collective burial including at least 20 cremated subadults showing possible calcinated bones has been identified at Grotta Pavolella near Cassano Jonio (Cosenza): bodies were associated with painted pottery of the early MN and lithic artefacts, including some sickle blades. In the latter case, the ritual of cremation was clearly performed inside the cave, burning the bodies placed above previous burials of inhumated that were consequently affected by thermal alteration apparent in the periosteum of the bones (Carancini and Guerzoni, 1987).

This patchy geographic distribution of the occurrence of MN cremations, spanning virtually all the V millennium BCE, is possibly the result of inconsistent archaeological excavation approaches.In the past the scanty and scattered remains from this specific ritual were frequently disregarded, whenever ashes are not preserved by a resistant long-lasting container like pottery. In particular, this seems to be the case in Sardinia, considering the lack of information about the San Ciriaco funerary behaviour, despite the number of dwelling sites identified thus far. Since a close cultural tradition between the MN-A Bonu Ighinu and the MN-B San Ciriaco aspects has been argued in settlement strategies and, more clearly, in pottery production (Lugliè, 2003b, 2017; Fanti et al., 2018), the sharp shift in funerary rituals with the sudden appearance of cremation still deserves a sound explanation. The matching of both the circulation of obsidian and steatite beads and the ritual of cremation between Sardinia and the SMP 2 facies of the Po Plain, suggests that the north of Italy might have played a central role in the diffusion of this practice. The previous and coeval ritual of inhumations with contracted bodies placed on the left side may be considered another point of convergence and a bridge between the local tradition and the SMP 2 community, since this study revealed that Su Forru de is Sinzurreddus individuals have been cremated with their bodies lying in the same position. If further archaeological investigation will not foster the degree of adoption of cremation by the San Ciriaco groups at the regional scale, we must try to reconstruct the socio-economic role played by the specific community buried at Su Forru de is Sinzurreddus in the frame of the birth and development of the Monte Arci obsidian system of production and of its integration into the complex exchange networks encompassing Sardinia, Southern France and the North of the Italian mainland (Lugliè, 2009). A systematic application of the integrated analytic approach presented in this study to other cremated bones from the few MN sites known to date in the Po Plain will possibly shed a new light on the origin and circulation of this funerary ritual at the interregional level**.**

4.8 CONCLUSIONS

The application of this multidisciplinary approach to the study of the considerable amount of dispersed and fragmented bones in the Su Forru de is Sinzurreddus burial led to several crucial points raised regarding the recent prehistory not just of Sardinia but of a wider interregional context, encompassing the western Mediterranean. The integration between Spectrophotometry, XRF and FTIR has been shown to be a powerful tool for such demanding sites, which could be applied in the future to better understand them and improve inferences on some symbolic attitude of Neolithic human groups. This approach allowed the successful examination of cremation-specific behaviour, with the estimation of the temperature reached by different anatomical regions during the burning. Subsequently, this led to suggest at least one case of the body position during the exposition to fire, making it possible to further infer ritual behaviour. This is a significant step forward in our attempts to formulate a bioarchaeology of cremation in the past. Despite the success of this work, there are some limitations. The study would benefit from a greater array of comparative archaeological samples, and greater uptake of the methods in archaeological investigations would provide more confidence in our results. Future experimental studies would also support our key conclusions.

5 DENTAL HEALTH

This chapter will focus on the oral health of the people buried at the site of Pau and Monte Luna. Focusing on oral health in past populations is essential for the interpretation of general health and well-being of individuals and at a population level.

From a bioarchaeological perspective, the study of health and disease helps to understand the events that have shaped the life of individuals and communities over time. Health and disease are complex issues and influenced by a combination of both biological and cultural elements (Elder, 1998; Giele and Elder, 1998; Prowse, 2011). By examining the bioarchaeological evidence, researchers can gain insight into the health and disease status of past populations (Goodman and Leatherman, 1998), which can then also be used for comparative purposes with other cultures and populations (Buikstra and Ubelaker, 1994; Brickley and McKingley, 2004).

Social change, social structure, and individual behaviour have an effect on the life of an individual or a group of people within larger historical contexts and, in turn, also affect bioarchaeological data (Elder, 1998; Giele and Elder, 1998; Prowse, 2011). Culture is perceived as an entity of multiple aspects such as customs, beliefs, religious practices, taboos, family lineage, perceptions, which need to be included in the historical analysis of health and disease in a population. (Goodman and Leatherman, 1998). Subsequently, the bioprofiles of individuals with and without lesions are used to compare variation within and between skeletal assemblages in different times and places (Buikstra and Ubelaker, 1994; Brickley and McKingley, 2004).

The study of oral health can provide insight into the general health status of a population and also document changes in oral health over time. Globally, many factors have been identified that affect oral health such as diet (including nutrition), demography (fertility, age, biological sex), and genetics (predisposition to disease, composition of oral microbiome). Moreover, these factors are, in turn, influenced by the broader community that the individual lived in, including their subsistence strategies and socio-economic status.

5.1 FOOD AND DENTAL HEALTH

Many studies have pointed to the role of food in the development of oral pathologies. Food ingestion can lead to plaque formation and subsequent periodontal diseases. Bacteria breaking down carbohydrates also demineralise the enamel of the teeth causing carious lesions. This in conjunction with high dental attrition can damage the pulp chamber making it susceptible to infection and eventual periapical lesions and antemortem tooth loss (AMTL) (Hillson, 2005). While oral pathologies are correlated with the carbohydrate content of food (Kandelmann, 1997), it appears that the frequency of their consumption has a more significant effect (Krasse 2001; Marshall et al., 2005). The relationship between diet and oral health is discussed further below.

5.2 AGE AND SEX AND DENTAL HEALTH

The sex and age of an individual are important variables to consider when analysing dental health. Generally, oral health declines with age but the variation in the rate of caries, for example, between sexes reflects underlying cultural, biological, and physiological differences such as social disparities and sexual divisions of labour affecting access to food (Lukacs and Largaespada, 2006). Furthermore, sex-specific differences in hormone levels, as well as their changes in females during puberty, pregnancy, and menopause may affect the microbial balance in the oral cavity and lead to detrimental changes in oral health (Willis and Oxenham, 2013). Sex hormones may also play a role in modulating the immune response to oral pathogens, and thus influence the risk of oral diseases (Lagler and Menaker, 1980; Laine et al., 1988). Finally, there are also sex-specific differences in dental anatomy and dental plaque formation due to salivary gland size, saliva composition, and flow rate (Percival et al., 1994).

5.3 Dental pathologies

Caries, periapical lesions, and tooth loss are the most common dental pathologies reported in the literature. The main cause of periapical lesions and tooth loss in the past are deep caries and severe attrition demonstrating a causal relationship between these three pathologies. A carious lesion, appearing as a cavity in either the crown or roots, is a demineralisation of the enamel/dentine/cementum of a tooth caused by the bacteria contained in plaque (Soames and Southam, 1993; Hillson, 2001, 2005). The cavities can expose the pulp chamber leading to infections and eventually to periapical lesions and antemortem tooth loss.

The types of food eaten, cooking techniques, frequency of consumption, and how food was shared can inform on the subsistence strategies, cultural regulations, and history of a population (Lanfranco and Eggers, 2010). The analysis of the relationship between dental lesions and subsistence lifeways suggests an underlying biocultural influence on to the incidence of dental pathogenesis and its progression (Marklein et al., 2019). It is important to consider the context of the individual's life history and the social, economic, and environmental factors that may have influenced the development of dental pathologies such as caries. Investigating the life history of an individual may help to identify risk factors that contribute to the development and recurrence of caries. Furthermore, understanding the interaction between, and progression of, oral pathologies may provide a better understanding of the aetiology of caries and the influence of environmental factors (Hillson, 2001).

5.3.1 Subsistence/agriculture and dental health

Dental lesions have been observed to show a non-linear relationship with subsistence lifeways (Marklein et al., 2019). The initial paradigm suggested that the development of agriculture and permanent settlements saw an increase in food production. Research was then focused on identifying the specific dietary and lifestyle patterns of populations, which may be associated with the occurrence of carious lesions (Domett, 2001; Lukacs, 2008; Domett and Oxenham, 2011).

While early studies suggested that the introduction of agriculture resulted in an overall increase in oral pathologies, recent studies have focused on the relationship between subsistence lifeways, oral hygiene practices, and oral health (Marklein et al., 2019; Smith et al., 2022). This more complex approach has identified that oral health is determined by a number of factors, only one of which is diet.

Early bioarchaeological studies noted a shift in oral health with the introduction of agriculture, which was originally interpreted as a decrease in quality of life and lifestyles (Childe, 1951, 1957; Cohen, 1977, 1989). However, this was disputed by later studies (Cohen, 1977, 1989; Cohen and Armelagos, 1984; Armelagos, 2003) which showed an increase in palaeopathological lesions, including dental health and specifically caries, following agricultural introduction and intensification (Turner, 1979; Larsen, 1983, 1997, 2015; Kelley et al., 1991; Larsen et al., 1991; Lukacs, 1992; Lukacs and Minderman, 1992; Temple and Larsen, 2007; Watson et al., 2010). Bioarchaeological studies were focused on the relationship between oral pathologies and diet to make inferences about the lifestyle and health of both individuals and populations (Zuckerman and Armelagos, 2011). Oral health is affected by a combination of the types of food consumed and oral hygiene practices, with poor oral hygiene practices and prevalence of nutrient-poor food resulting in poor oral health. Consequently, the introduction of agriculture did not necessarily result in a general deterioration in oral health. It appears that the pattern was more complicated with certain populations showing an increase in dental pathologies, while other populations maintained the same level or even improved oral health (Smith et al., 2022).

Studies on oral health demonstrated a contrast between hunter-gatherers and agricultural populations. One of the main topics discussed is the introduction of domesticated crops resulted in a shift in available food sources with the observed higher frequencies of oral pathologies interpreted as a direct result thereof. This area of study has interpreted this shift as an indicator to produce the dental health profiles of past populations (Lukacs, 1996; Larsen, 1997; Hillson, 1996, 2001). For example, the low frequencies in oral pathologies in the Italian Neolithic is hypothesised to be the result of a late introduction of agriculture (Marinelli et al., 2017). In later periods, the more consistent frequencies of carious lesions are interpreted as populations slowly adapting to a carbohydrate-rich diet (Marinelli et al., 2017; Turner, 1979). Many studies on the cariogenicity of carbohydrates have noted that the introduction and adoption of agriculture has negatively affected oral health (Hillson, 2008). The dietary change in the transition to agriculture became considered synonymous with higher prevalence of caries due to carbohydrates consumption (Roosevelt, 1984; Rose et al., 1984; Temple and Larsen, 2007). Although the evidence for cariogenicity associated with cultigens is not consistent (Tayles et al., 2000; Domett, 2001; Oxenham, 2006), studies have shown an increase in caries due to consumption of maize (Cohen and Armelagos, 1984; Larsen, 1997). Generally, the incidence of caries increases with ageing, and is also more prevalent in the posterior dentition, and in females (Lukacs, 2008; Willis and Oxenham, 2013). While there is no stable pattern observable in populations cultivating rice (Powell, 1985; Cucina et al., 2011), Lukacs (2011) and Willis and Oxenham (2013) agree that there is a higher prevalence of caries and tooth loss in both females and the elderly in the rice-farming populations of Southeast Asia. This illustrates that understanding the variation among different populations is necessary to understand the nuanced indicators of lifeways (Marklein et al., 2019).

5.3.2 Fertility and dental health

Advances in agriculture were concurrent with population increases and extended life expectancies (Cohen and Armelagos, 1984; Steckel and Rose, 2002). The Neolithic Demographic Transition

(NDT) from a hunter-gatherer to a sedentary lifeway affected the connection between food and human health. The two main effects of the NDT are changes in diet, lifestyle, and mobility on the one hand, and higher levels of fertility on the other (Lukacs and Largaespada, 2006; Lukacs, 2008). In the last decades, studies have shown that pregnant women may be more prone to dental lesions due to hormonal changes and changes in oral hygiene habits associated with pregnancy. Lesions can include gingivitis, periodontal disease, and tooth decay (Lukacs and Largaespada, 2006; Lukacs, 2008; Fields et al., 2009; Ferraro and Veira, 2010 Watson et al., 2010).

The NDT is characterised by an increase in fertility, subsequent population increase, and extended life expectancies (Cohen and Armelagos, 1984; Steckel and Rose, 2002). Moving from a nomadic lifestyle to sedentism, and the accompanying change in diet, positively influenced levels of fertility (Domett and Oxenham, 2011; McFadden and Oxenham, 2018) having an effect in reducing birth intervals (Bocquet-Appel and Naji, 2006; Bellwood and Oxenham, 2008). Despite oral pathologies being age-progressive, they have been shown to be more prevalent in areas of high rates of fertility (Lukacs, 2008; Willis and Oxenham, 2013). In areas where the transition was more gradual, the increase in dental caries will be small and insignificant. In contrast, in areas where the transition was more abrupt, the increase in caries will be much more significant due to the dramatic changes in diet and fertility (Willis and Oxenham, 2013).

5.3.3 Dental health in Pau and Monte Luna

Caselitz (1998) showed dental lesions increased gradually from the Neolithic up to modern times in Europe and specifically in the Mediterranean area. To understand the effect of different lifeways and climate regimes on dental pathologies, a detailed analysis of the different contributing societal and environmental factors is necessary (Marklein et al., 2019).

In this chapter, the oral health of both populations is analysed focusing on the prevalence of dental caries, periodontal disease, and AMTL. The archaeological samples of Pau and Monte Luna provide a unique opportunity to analyse and compare the dental health of Neolithic and Punic populations.

The study of dental lesions in Pau and Monte Luna also provides information on the environmental and lifestyle factors that influence oral health such as diet, hygiene, and cultural practices. In addition, this research can provide insight into the ability of Sardinian populations to adapt to changing environments and the impact of human mobility on health. A population's life course perspective considers how humans interact with their environment and how the environment affects their oral health. It is applied through the analysis of oral health considering period, Middle Neolithic and Punic Era, environment, in Sardinia, timing of life, such as young or adult age, and human agency, such as food and hygiene habits linked to sex and eventually societal differences (Elder, 1994, 1998).

The analysis of oral health emphasises the connection between individuals and groups within a pre-historic and a historic context in the same geographical area. Each social and cultural context is interpreted through a thorough analysis of dental lesions to understand a population's life course. Subsequently, they are compared, taking into account both disparities and similarities in each period, towards a better interpretation in terms of a life course perspective (Prowse, 2011). Following Elder (1994, 1998), the chapter presents the analysis of oral health taking into account the cultural, social, and technological changes which occurred in Pau and Monte Luna. The key role of individuals is outlined through the analysis of the remains in terms of individual behaviour and oral health status. This also considers the age of the individual and compares individual results within the group. This is consistent with the bioarchaeological approach that emphasises the relationship between biological and social processes. The aim is to investigate the connections between different periods of life in the Sardinian population. The archaeological samples of Pau and Monte Luna represent a suitable case study to obtain information on the distribution of oral diseases and on the quality of life of Neolithic and Punic populations on the island. The relationship between dental lesions of a population and their lifeway at sensitive times of change enhances the knowledge on geographical and chronological trends in the Mediterranean.

The analysis of oral health at Pau provides an insight into a community representing the transition from a hunter–gatherer society to permanent settlements. Access to food, and the way of consuming it, is influenced by social, political, and economic factors (Prowse, 2011). Recent studies have provided valuable insight into new materials, food, and behavioural patterns (Fanti et al., 2018; Lugliè et al., 2019; Paba et al., 2021) which can assist in the understanding of the impact of oral health.

The sedentary population at Monte Luna lived at a key moment in history when the power over the Mediterranean by the Roman Empire was challenged. The presence of elaborate burials, a variety of high-status material culture, and the presence of complex social networks all suggest that the settlement had a high level of social status (Todde and Byrsa, 2021) whose oral health is investigated in the present study.

Dental biomarkers can be used to measure the changes in dental health due to food supply, quality and quantity, hormones, fertility, and pregnancy. Tooth development (Buikstra and Ubelaker, 1994; Scheuer and Black, 2000; Al Qahtani et al., 2010) and dental wear (Lovejoy, 1985; Buikstra and Ubelaker, 1994) were used to estimate age-at-death, and oral pathologies such as caries, periapical lesions, and antemortem tooth loss were recorded using well-established standardised methods (Brothwell, 1981; Lukacs, 1989; Hillson, 2005). The frequency and distribution of oral pathologies is analysed by age and sex where possible. The comparison within and between the two populations could indicate that oral health changed over time or, alternatively, that the profile of oral health and lifestyle in the Sardinian population remained constant.

5.4 MATERIALS AND METHODS

The dentition of human remains from Su Forru de is Sinzurreddus in Pau and Monte Luna necropolis are investigated in this study. As detailed in Chapter 3, the collections consist of isolated bones including mandibular and maxillary bones which cannot be assigned to particular individuals. The fragmentation and post-mortem tooth loss (PMTL) were also very high due to looting, excavation, and curation processes. Due to these limitations, the tooth count method has neem applied which increases the power of statistical analysis. The tooth count method calculates the prevalence of dental caries, periapical lesions, and antemortem tooth loss (AMTL) in each tooth class. The main limitation of this method is the inability to assign teeth and thus dental pathologies to individuals. The individual count method was able to be used only a small sample. All the remains were either carefully brushed or washed taking care to preserve the calculus and bone flakes. Following that, the teeth underwent a macroscopic examination to estimate dental wear, frequency and severity of caries, periapical lesions, and antemortem tooth loss as detailed below (Brothwell, 1981; Goodman and Rose, 1994; Hillson, 2008).

5.4.1 Age-at-death and sex estimation

Buikstra and Ubelaker's (1994) standards and Lovejoy's (1985) dental wear scoring technique were used to estimate age-at-death. Where the dentition was associated with a partial or complete skeleton, dental wear and tooth development were combined with age estimates from pubic symphysis morphology and the state of epiphyseal fusion. Both deciduous and permanent teeth were assessed using the methods of Buikstra and Ubelaker's (1994) and Scheuer and Black's (2000) dental development data. In addition, for isolated deciduous teeth age was estimated using the dental formation stages developed by Priyadarshini et al., (2015).

The methods allowed the classification of teeth belonging to either subadults, adults, or of unknown age. Subadults were further divided into two age ranges (0-9 yo and 10-15 yo) based on type of tooth and tooth development and wear. Adults were divided into four age ranges namely young adult (16-25yo), adult (26-35yo), mature adult (36-45yo) and old adult (45+yo) based on tooth wear and development as detailed in Chapter 3.

Sex was estimated based on morphological features of the pelvis, cranium, and mandibles (Buikstra and Ubelaker, 1994) (See Chapter 3). For most of the sample this was not possible as there were many incomplete skeletons, or there was insufficient information to link the dental remains to an individual. Where possible, the adult remains were grouped as females, males, and unknown sex. Subadults in the sample are all considered to be of unknown sex.

5.4.2 Dental pathology

Dental health was assessed by recording dental wear, frequency of caries, periapical lesions, and antemortem tooth loss. As most dental pathologies are age-progressive, the results were grouped according to their age. These data were then used to compare the dental pathologies of the Pau and Monte Luna populations.

A number of methods were used to assess different characteristics of the wear on each single tooth (Scott, 1979; Brothwell, 1981; Smith, 1984; Lovejoy, 1985; Buikstra and Ubelaker, 1994). The method of Scott (1979) and Brothwell (1981) is most applicable to molars, while Smith's (1984) analytical method is more suitable for incisors, canines, and premolars. In contrast, Lovejoy (1985) provides an assessment based on the full dentition of a sample of Libbean agriculturalists. Combining the information from all three analytical systems provides the most comprehensive assessment of each tooth.

Caries was identified following Hillson (2008), who describes it as a progressive demineralisation of enamel, cementum, and dentin that can eventually lead to cavities in the crown and roots. Carious lesions develop most frequently in premolar and molar occlusal crowns and can also form at the contact points on both mesial and distal surfaces (interproximal caries). They rarely occur on the smooth crown surfaces. Root surface caries are reported to appear more commonly later in life (Gati, 2011). All erupted teeth, deciduous and permanent, were examined for both crown and root lesions and classified as either Grade 1 (superficial evidence), Grade 2 (caries that had reached the dentine), or Grade 3 (perforation) (Brothwell, 1981). Teeth with two or more separate carious lesions were counted as having one lesion only, however, the higher severity of the infection was recorded.

Periapical lesions, sometimes also known as abscesses, were observed either as an apical root lesion (drainage channel of the abscess) (Buikstra and Ubelaker, 1994) or where there was osteolytic removal of the alveolar bone with exposure of the tooth root (Hillson, 2008). The results were calculated as the proportion of periapical lesions in the total number of *tooth positions* with intact alveolar bone.

Antemortem tooth loss (AMTL) is defined as the absence of a tooth associated with the presence of remodelling or healed bone in the surrounding alveoli (Lukacs, 1989). AMTL were also calculated as a proportion of the total number of tooth positions.

5.4.3 Statistical approach

Fisher's exact tests (FET) with significance set at $p < 0.05$, were performed in Graph Pad Prism (V. 9.5.0) to determine if there were any significant differences in the frequency of dental pathologies. However, due to the small size of some sub-samples, FET could not be performed where two or more values were less than 5 (*e.g.* FET is possible if 0/5 vs 5/16 but 0/13 vs 3/69 does not allow for comparison) (Cohen, 1988; Bewick et al., 2004; Kim, 2017).

5.5 RESULTS: PAU

5.5.1 Preservation of teeth at Pau

The sample contains 561 isolated deciduous and permanent teeth without an associated mandible or maxilla, preventing analysis of periapical lesions and AMTL. The complete upper right incisors, both permanent and deciduous, were used to establish the MNI estimated to be 18 adults and six subadults (See Chapter 3). A high number of teeth (38.95%) had an unknown age-at-death and sex. There was a very similar presence of teeth in the two subadult age groups (14.92 % and 16.47%, respectively), and young adults (19.57 %). Adult, mature, and old adults were present in much lower numbers (3.68%; 4.07%; 2.33%).

5.5.2 Caries at Pau

Only one deciduous tooth was affected by caries (1/55, 1.8%) in the small sample. The carious lesion (Grade 1) was in an incisor crown (Table 14 and 15).

Table 14 Pau. Deciduous teeth affected by caries.

	Caries/Deciduous Teeth (A/O)[1]			
	Incisors	Canines	Molars	Tot (%)
0 – 9 yo	1/28 (3.5)	0/7	0/14	1/49 (2.0)
10 – 15 yo	0/2		0/1	0/3
Unknown				0/3
Tot				1/55 (1.8)

[1] A=Affected; O=Observed

Table 15 Pau. Caries distribution in deciduous teeth using Brothwell's (1981) grading of lesions and separated by crown and root.

	0 – 9 yo (N=1)						
	Crown caries			Root caries			
	1	2	3	1	2	3	Tot (%)
Incisors	1						1 (2.1[1])

Canines
Premolars
Molars

[1] Percentage is is calculated per tooth type as the number of affected teeth as a proportion of total teeth present (46).

In the permanent teeth, 10.30% (45/437) were affected by caries (Table 16). Generally, the prevalence of caries increased with age, reaching a maximum frequency of 41.6% in old adults (45+ yo). Caries was recorded significantly more frequently in the posterior dentition compared to the anterior dentition (FET p-value <0.0001) (Table 17). The highest frequency of caries was found in molars (32/190, 16.8%) followed by premolars (12/129, 9.3%) (Figure 20).

Table 16 Pau. The prevalence of caries in permanent teeth

	Caries/Permanent Teeth (A/O)[1]				
	Incisors	Canines	Premolars	Molars	Tot (%)[2]
Subadult (10 – 15 yo)	0/7	0/6	1/36 (2.7)	2/33 (6.0)	3/82 (3.6)
Young Adult (16 – 25 yo) (%)[3]	0/25	1/7 (14.2)	6/29 (20.6)	16/40 (40)	23/101 (22.7)
Adult (26 – 35 yo) (%)[3]	0/11	0/0	1/1 (100)	2/7 (28.5)	3/19 (15.7)
Mature Adult (36 – 45 yo) (%)[3]	0/2	0/3	1/5 (20)	4/11 (36.3)	5/21 (23.8)
Old Adult (45+ yo) (%)[3]	0/2	0/2	0/2	5/6 (83.3)	5/12 (41.6)
Unknown (%)[3]	0/28	0/25	3/56 (5.3)	3/92 (3.2)	6/201 (2.9)
Tot (%)[4]	0/75	1/43 (2.3)	12/129 (9.3)	32/189 (16.9)	45/436 (10.3)

[1] A=Affected; O=Observed
[2]= The percentage is calculated as the number of caries as a proportion of the total number of teeth per age range
[3]= The percentage is calculated per tooth type in each age range as the number of caries as a proportion of the total number of teeth present age range
[4]= The percentage is calculated per tooth type as the total number of caries as a proportion of the total number of teeth present

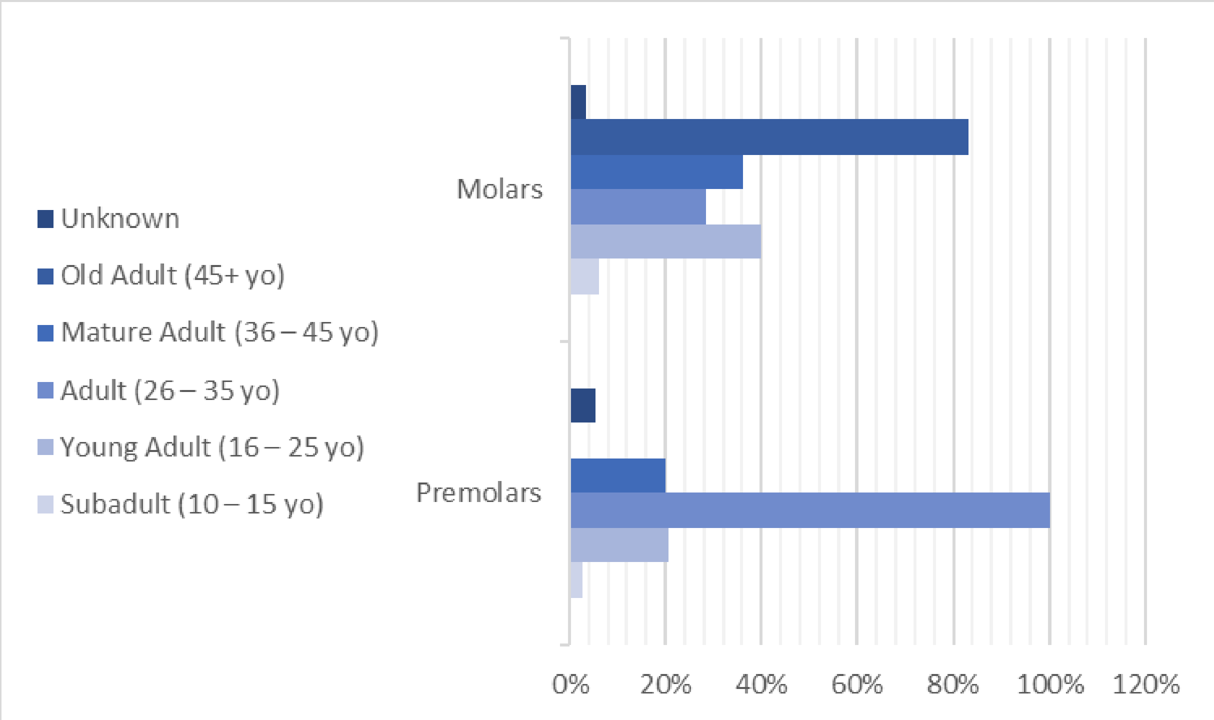

Figure 19 Pau. Prevalence of caries by tooth type and age.

The frequency of carious lesions in young adults (16-25 yo) at Pau was significantly higher in the posterior dentition compared with that of the anterior dentition (FET p-value <0.0008) (Table 17).

Table 17 Pau anterior and posterior dentition.

	Pau		
	Anterior Dentition	Posterior Dentition	Ant/Post Dentition Differences FET p-values
Subadult (10 – 15 yo) (%)	0/13	3/69 (4.3)	
Young Adult (16 – 25 yo) (%)	1/32 (3.1)	22/69 (31.8)	**0.0008***
Adult (26 – 35 yo) (%)	0/11	3/7 (42.8)	**0.0297***
Mature Adult (36 – 45 yo) (%)	0/5	5/16 (31.2)	0.2776
Old Adult (45+ yo) (%)	0/4	5/8 (62.5)	0.0808

Tot (%)	1/65 (1.5)	38/169 (22.4)	**<0.0001***

*Statistically significant p-value <0.05.

Grade 1 crown caries, were evident in 53.3% of the total lesions (24/45) (Table 18), Grade 3 crown caries in 33.3% (15/45) and only a small percentage of Grade 2 crown caries were present. Molars were most frequently affected by Grade 3 caries with 35.5% in young adults (16 – 25 yo), followed by 11.1% in old adults (45+ yo), and 8.89% in the mature adults (36 – 45 yo) (Figure 21).

In contrast, root caries were rare with only two teeth showing Grade 3 (2/45, 4.4%) caries both located in premolar roots.

Table 18 Pau. Prevalence of caries as recorded by level of severity (grade 1, 2, 3) for crown and root lesion and as divided by tooth type and age category.

		Crown caries			Root caries			
Age Ranges		1 (%)[1]	2 (%)[1]	3 (%)[1]	1 (%)[1]	2 (%)[1]	3 (%)[1]	Tot (%)[2]
Subadult (10 – 15 yo) (N=3)	Incisors							
	Canines							
	Premolars	1 (33.3)						1 (2.2)
	Molars	1 (33.3)		1 (33.3)				2 (4.4)
Young Adult (16 – 25 yo) (N=23)	Incisors							
	Canines	1 (4.3)						1 (2.2)
	Premolars	4 (17.3)		2 (8.7)				6 (13.3)
	Molars	11 (47.8)	1 (4.3)	4 (17.3)				16 (35.5)
Adult (26 – 35 yo) (N=3)	Incisors							
	Canines							
	Premolars	1 (33.3)						1 (2.2)

	Molars	2 (66.6)				2 (4.4)
Mature Adult (36 – 45 yo) (N=5)	Incisors					
	Canines					
	Premolars			1 (20.0)		1 (2.2)
	Molars	1 (20.0)	1 (20.0)	2 (40.0)		4 (8.8)
Old Adult (45+ yo) (N=5)	Incisors					
	Canines					
	Premolars					
	Molars		2 (40.0)	3 (60.0)		5 (11.1)
Unknown (N=6)	Incisors					
	Canines					
	Premolars	1 (16.6)			2 (33.3)	3 (6.6)
	Molars	1 (16.6)		2 (33.3)		3 (6.6)
Tot (%)[2]		24 (53.3)	4 (8.8)	15 (33.3)	2 (4.4)	45

[1]Percentage is calculated per tooth type in each age range as the number of affected teeth as a proportion of total number of teeth present

[2]Percentage is is calculated per tooth type as the number of affected teeth as a proportion of the total number of teeth present (45).

The severity of caries in maxillary and mandibular molars was not significantly different (Table 19).

Table 19 Pau maxillary and mandibular molars in comparison.

	Pau		
	Maxillary M1, M2, M3 (N = 14)	Mandibular M1, M2, M3 (N = 17)	Maxillary/Mandibular FET p-values
1(%)*	9 (64.2)	8 (47.0)	0.4730
2(%)*	2 (14.2)	2 (11.4)	>0.9999
3(%)*	3 (21.4)	7 (41.1)	0.2802

*Percentage is A/O (Affected/Observed)

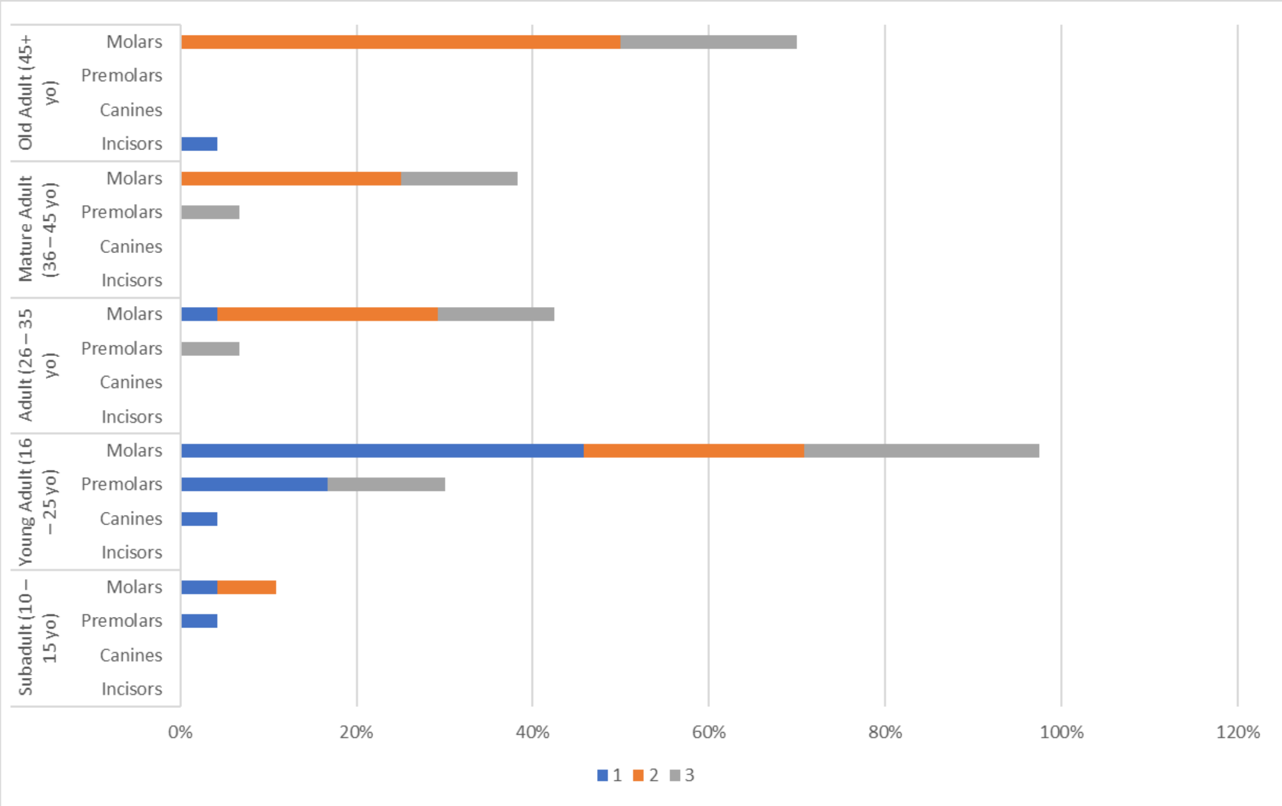

Figure 20 Pau. Distribution of crown caries based on severity, tooth position, and age.

As mentioned above, all teeth from Pau were isolated, preventing the recording of tooth positions, periapical lesions, and AMTL. These constraints limit the ability to compare the data with that of Monte Luna.

5.6 Results: Monte Luna

5.6.1 Preservation of teeth at Monte Luna

There were a total of 2363 deciduous and permanent teeth in the Monte Luna (Table 23) sample, with the majority being isolated teeth. Data on tooth positions, periapical lesions, and AMTL, was recorded and sex determination was also available for a small sample of individuals. A small number of teeth (12.5%) have an unknown age-at-death. Young adults (53.8%) are the dominant age group, and there were low numbers of teeth for adults, mature, and old adult groups present (10.6%, 4.7%, and 6.7%, respectively).

5.6.2 Caries at Monte Luna

Only two deciduous molars were affected by caries (2/134, 1.5%) (Table 20), with both carious lesions in the crown classified as Grade 3 (Table 21).

Table 20 Monte Luna. Deciduous teeth affected by caries.

	Caries/Deciduous Teeth (A/O)[1]			
	Incisors	Canines	Molars	Tot (%)
0 – 9 yo	0/31	0/35	2/47	2/113 (1.7)
Unknown			0/21	0/21
Tot	0/31	0/35	2/68	2/134 (1.4)

[1] A=Affected; O=Observed

Table 21 Monte Luna. Caries distribution using Brothwell's (1981) grading of lesions and separated by crown and root.

	0 – 9 yo (N=2)						
	Crown caries			Root caries			
	1	2	3	1	2	3	Tot (%)
Incisors							
Canines							
Premolars							
Molars			2				2 (2.6[1])

[1] Percentage is is calculated per tooth type as the number of affected teeth as a proportion of the total number of teeth present (75).

In the permanent teeth, 3.5% (73/2071) were affected by caries (Table 22). The frequency of caries generally increases with age, reaching a maximum of 8.8% in old adults (45+ yo). However, when looking at caries per tooth type, the pattern only holds for molars (Figure 22). Moreover, the highest rate of caries is also found in the posterior dentition (molars) (47/914, 5.1%), followed by the premolars (15/516, 2.9%) and the incisors (5/510, 1.0%).

Table 22 Monte Luna. The prevalence of permanent teeth affected by caries.

	Caries/Permanent Teeth (A/O) [1]				
	Incisors	Canines	Premolars	Molars	Tot (%)[2]
Young Adult (16 – 25 yo) (%)[3]	2/389 (0.5)	2/221 (0.9)	4/281 (1.4)	21/382 (5.5)	29/1273 (2.2)
Adult (26 – 35 yo) (%)[3]	0/34 (0)	2/34 (5.8)	5/50 (10)	10/134 (7.46)	17/252 (6.7)
Mature Adult (36 – 45 yo) (%)[3]	1/8 (0.1)	1/11 (9.0)	2/32 (6.2)	5/60 (8.3)	9/111 (8.1)
Old Adult (45+ yo) (%)[3]	2/30 (0.07)	1/16 (6.2)	3/36 (8.3)	8/77 (10.3)	14/159 (8.8)
Unknown (%)[3]	0/25 (0)	0/19 (0)	1/88 (1.1)	3/143 (2.1)	4/275 (1.4)
Tot (%)[4]	5/486 (1.03)	7/301 (2.33)	15/487 (3.0)	47/796 (5.9)	73/2070 (3.5)

[1] A=Affected; O=Observed

[2] = The percentage is calculated per age group as the number of affected teeth as a proportion of the total number of teeth present

[3]= The percentage is calculated per age group as the number of affected teeth as a proportion of the total number of teeth present

[4]= The percentage is calculated per age group as the number of affected teeth as a proportion of the total number of teeth present

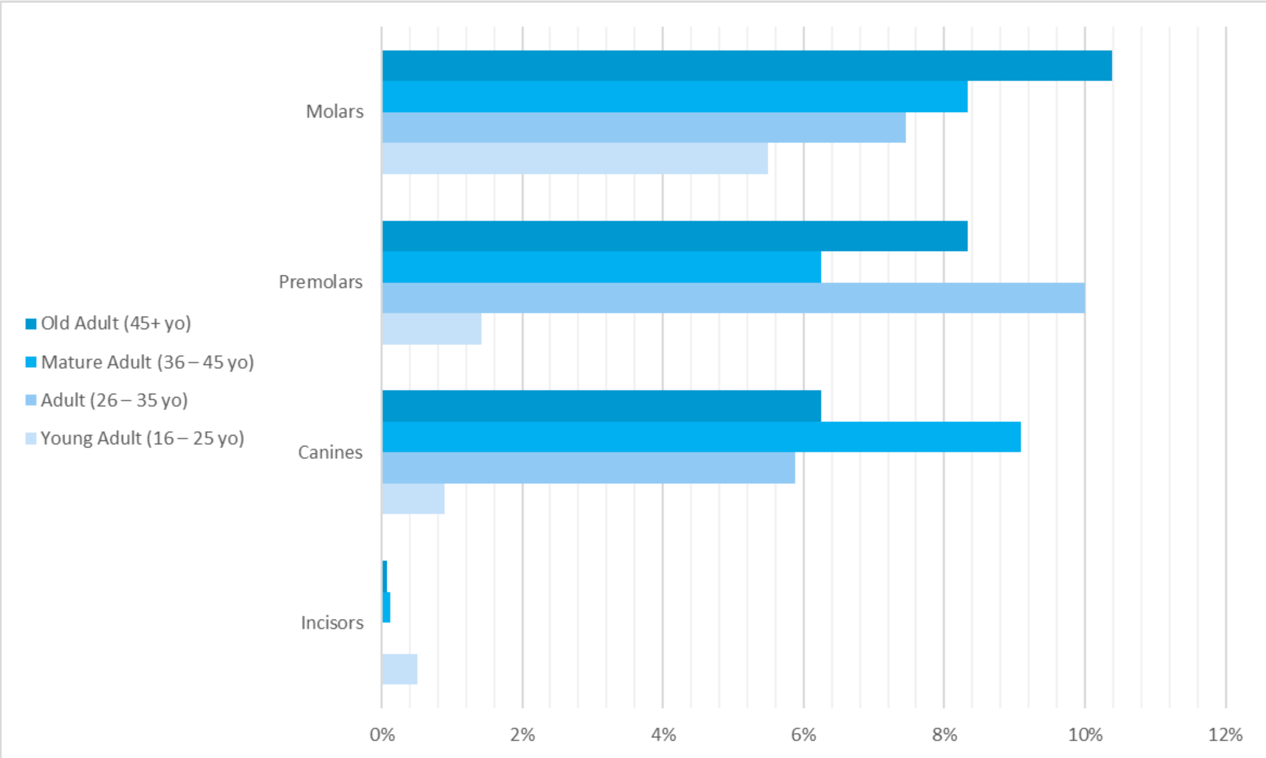

Figure 21 Monte Luna. Prevalence of caries per tooth type and age.

In the Monte Luna sample, the sex of only 20 females and 12 males could be determined. There were no carious lesions in male teeth and the frequency of caries in females was 4.6% (FET p-value = 0.1242) (Table 23). Within the female group, the frequency of caries increased with age, with older females showing the highest levels of caries (5/24, 20.8%) (Table 23).

Table 23 Monte Luna. Proportion of caries in teeth

	Male (n/N)	Female (n/N)	FET values	Unknown Sex (n/N)	Tot
Young Adult (16 – 25 yo) (%)*	0/27	3/143 (2.10)	>0.9999	26/1103 (2.3)	29/1273 (2.2)
Adult (26 – 35 yo) (%)*	0/7	0/25		17/220 (7.7)	17/252 (6.7)

Mature Adult (36 – 45 yo) (%)*	0/25	2/26 (7.6)		7/60 (10.0)	9/111 (8.1)
Old Adult (45+ yo) (%)*	0/9	5/24 (20.8)	0.2900	9/126 (7.1)	14/159 (8.8)
Unknown (%)*	0/0	0/0		4/275 (1.4)	4/275 (1.4)
Tot	0/68	10/218 (4.5)	0.1242	63/1784 (3.5)	73/2070 (3.5)

n=number of teeth with caries;
N = total number of observable teeth;
*Statistically significant p-value <0.05.

Table 24 Monte Luna. Proportion of caries in the anterior and posterior dentition.

	Monte Luna		
	Anterior Dentition n/N (%)	Posterior Dentition n/N (%)	Ant/Post Dentition Differences FET p-values
Subadult (10 – 15 yo) (%)	0/8	0/42	
Young Adult (16 – 25 yo) (%)	4/610 (0.6)	25/663 (3.7)	**0.0002***
Adult (26 – 35 yo) (%)	2/68 (2.9)	15/184 (8.1)	0.1691
Mature Adult (36 – 45 yo) (%)	2/19 (10.5)	7/92 (7.6)	0.6500
Old Adult (45+ yo) (%)	3/46 (6.5)	11/231 (4.7)	0.7099
Tot (%)	11/743 (1.4)	58/1212 (4.7)	**<0.001***

n=number of teeth with caries;
N = total number of observable teeth;
*Statistically significant p-value <0.05.

In terms of the severity of infection, Grade 1 caries were evident in 54.7% of the total lesions (40/73), Grade 3 in 37.0% (27/73), and only a small percentage of Grade 2 was present (Table 25). The molars were most frequently affected by Grade 3 caries, with 35.3% of teeth affected in adults (26-35 yo), 31.0% in young adults (16-25 yo), and 22.2% in mature adults (36-45 yo) (Figure 23). In contrast, root caries, was rare with only four teeth showing either Grade 1 (1/73, 1.37%) or Grade 3 (3/73, 4.1%) caries. Three of the four root caries were located in molars (Table 25, Figure 23).

Table 25 Monte Luna. Frequency of caries as recorded by level of severity (grade 1, 2, 3) for crown and root lesion per tooth type and age category.

		Crown caries			Root caries			
Age Ranges		1 (%)[1]	2 (%)[1]	3 (%)[1]	1 (%)[1]	2 (%)[1]	3 (%)[1]	Tot (%)[2]
Young Adult (16 – 25 yo) (N=29)	Incisors	2 (6.9)						2 (2.7)
	Canines	1 (3.4)		1 (3.4)				2 (2.7)
	Premolars	4 (13.7)						4 (5.4)
	Molars	11 (37.9)		9 (31.0)			1 (3.4)	21 (28.7)
Adult (26 – 35 yo) (N=17)	Incisors							
	Canines	1 (5.8)		1 (5.8)				2 (2.7)
	Premolars	5 (29.4)						5 (6.8)
	Molars	3 (17.6)		6 (35.2)			1 (5.8)	10 (13.7)
Mature Adult (36 – 45 yo) (N=9)	Incisors			1 (11.1)				1 (1.3)
	Canines	1 (11.1)						1 (1.3)
	Premolars	1 (11.1)		1 (11.1)				2 (2.7)
	Molars	2 (22.2)		2 (22.2)	1 (11)			5 (6.8)
Old Adult (45+ yo) (N=14)	Incisors	1 (7.1)		1 (7.1)				2 (2.7)
	Canines		1 (7.1)					1 (1.3)
	Premolars	1 (7.1)	1 (7.1)	1 (7.1)				3 (4.1)
	Molars	7 (50)		1 (7.1)				8 (10.9)

Unknown (N=4)	Incisors						
	Canines						
	Premolars					1 (25)	1 (1.3)
	Molars			3 (75)			3 (4.1)
Tot (%)[2]		40 (54.7)	2 (2.7)	27 (36.9)	1 (1.3)	3 (4.1)	73

[1]: Percentage is based on the total amount of type of affected teeth for each tooth type based on the total amount of affected teeth in each age ranges.
[2]: Percentage is based on the total amount of type of affected teeth for each tooth type based on the total amount of affected teeth in the sample (73).

The severity of caries between the Monte Luna maxillary and mandibular molars was statistically significant with more Grade 1 lesions in the mandibular molars and more Grade 3 lesions in the maxilla (FET p-value <0.0077 and FET p-value <0.0077, respectively) (Table 26).

Table 26 Monte Luna. Caries in the maxillary and mandibular molars.

	Monte Luna		
	Maxillary M1, M2, M3 (N = 22)	Mandibular M1, M2, M3 (N = 25)	Maxillary/Mandibular FET p-values
1(%)*	14 (63.6)	24 (96.0)	**0.0077***
2(%)*	0	0	
3(%)*	8 (36.3)	1 (4.0)	**0.0077***

*Statistically significant p-value <0.05.

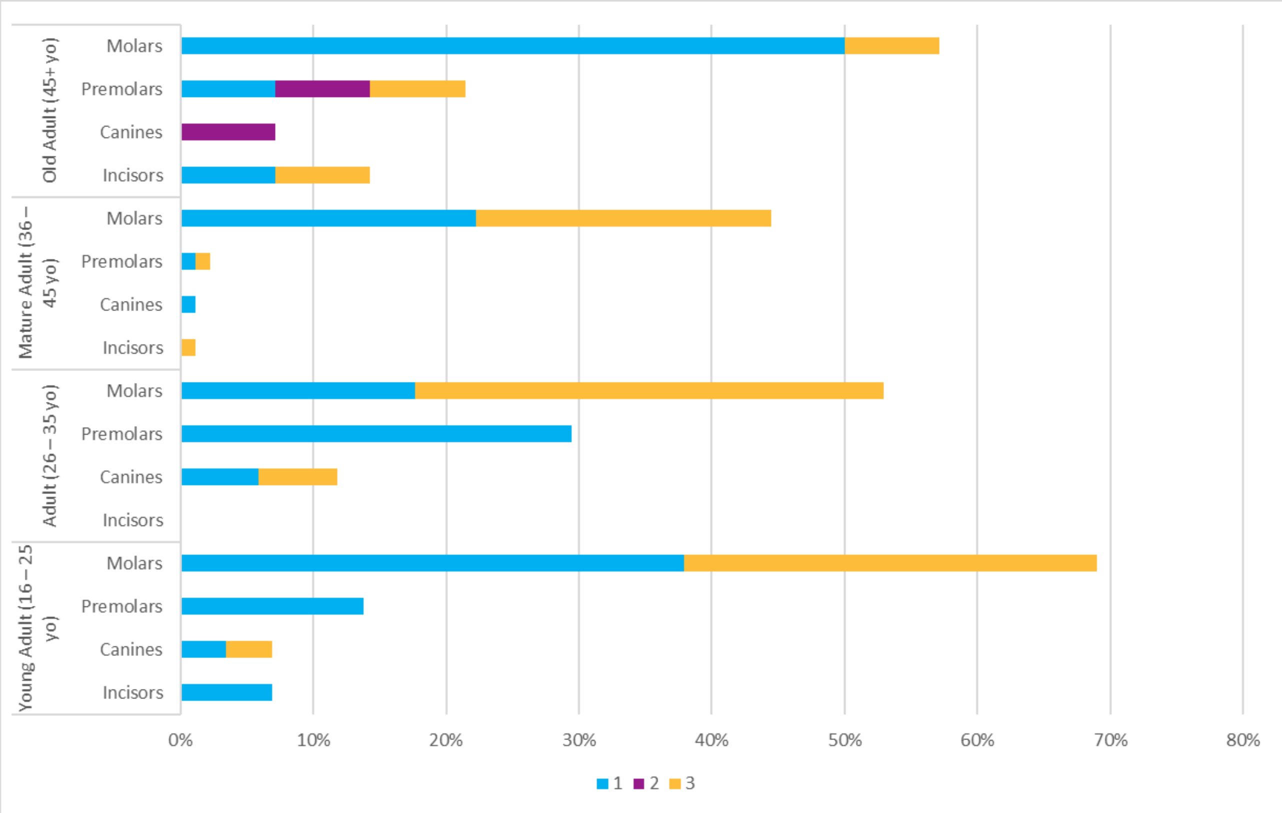

Figure 22 Monte Luna. Distribution of crown caries based on severity, tooth position, and age.

5.6.3 Periapical Lesions and Antemortem tooth loss at Monte Luna

Only a small number of tooth positions were affected by periapical cavities (12/650, 1.8%) (Table 27). The majority of these (5/80, 6.2%) were in males, with only 1.82% in females (4/220), but the difference was not significant (FET p-value = 0.0602). Periapical lesions were most commonly seen in old adults (11.2%, 7/62), with old adult males having a non-significantly higher frequency (18.5%) than old adult females (7.1%), (FET p-value = 0.2516). However, it has to be emphasised that this analysis was based on a small sample size only.

Antemortem tooth loss was evident in 8.15% (53/650) of the sample (Table 27). The frequency of AMTL was very similar in males and females (12.5% and 11.8%, respectively) (FET p-value =

0.8431). Consistent with periapical lesions, the AMTL evidence was more frequent in old adults (58.06%), however, old adult females were non-significantly more affected (57.1%) compared with old adult males (37.0%) (FET p-value = 0.1799). High rates of AMTL were also evident in mature age females (64.2%).

Figures 24 and 25 show a high proportion of both periapical lesions and AMTL in older males.

Table 27 Monte Luna. The frequency of periapical lesions and ante mortem tooth loss (AMTL).

	Periapical lesions					AMTL				
	Male	Female	Sex diff. p-value (FET)	Unknown	Tot	Male	Female	Sex diff. p-value (FET)	Unknown	Tot
Young Adult (16 – 25) A/O (%)	0/34	2/170 (1.1)		1/114 (0.88	3/318 (0.9)	0/34	1/170 (0.5)		4/114 (3.5)	5/318 (1.5)
Adult (26 – 35) A/O (%)	0/4	0/0		0/23	0/27	0/4	0/0		0/23	0/27
Mature Adult (36 – 45) A/O (%)	0/23	0/14		0/37	0/74	0/23	9/14 (64.2)	**<0.0001***	0/37	9/74 (12.1)
Old Adult (45+) A/O (%)	5/27 (18.5)	2/28 (7.1)	0.2516	0/10	7/62 (11.2)	10/27 (37.0)	16/28 (57.1)	0.1799	10/10 (100)	36/62 (58.0)
Unknown A/O (%)	0/0	0/0		2/163 (1.2)	2/163 (1.2)	0/0	0/0		3/163 (1.8)	3/3 (1.8)
Tot A/O (%)	5/80 (6.2)	4/220 (1.8)	0.0602	3/350 (0.8)	12/650 (1.8)	10/80 (12.5)	26/220 (11.8)	0.8431	17/350 (9.0)	53/650 (8.1)

*Statistically significant p-value < 0.05.

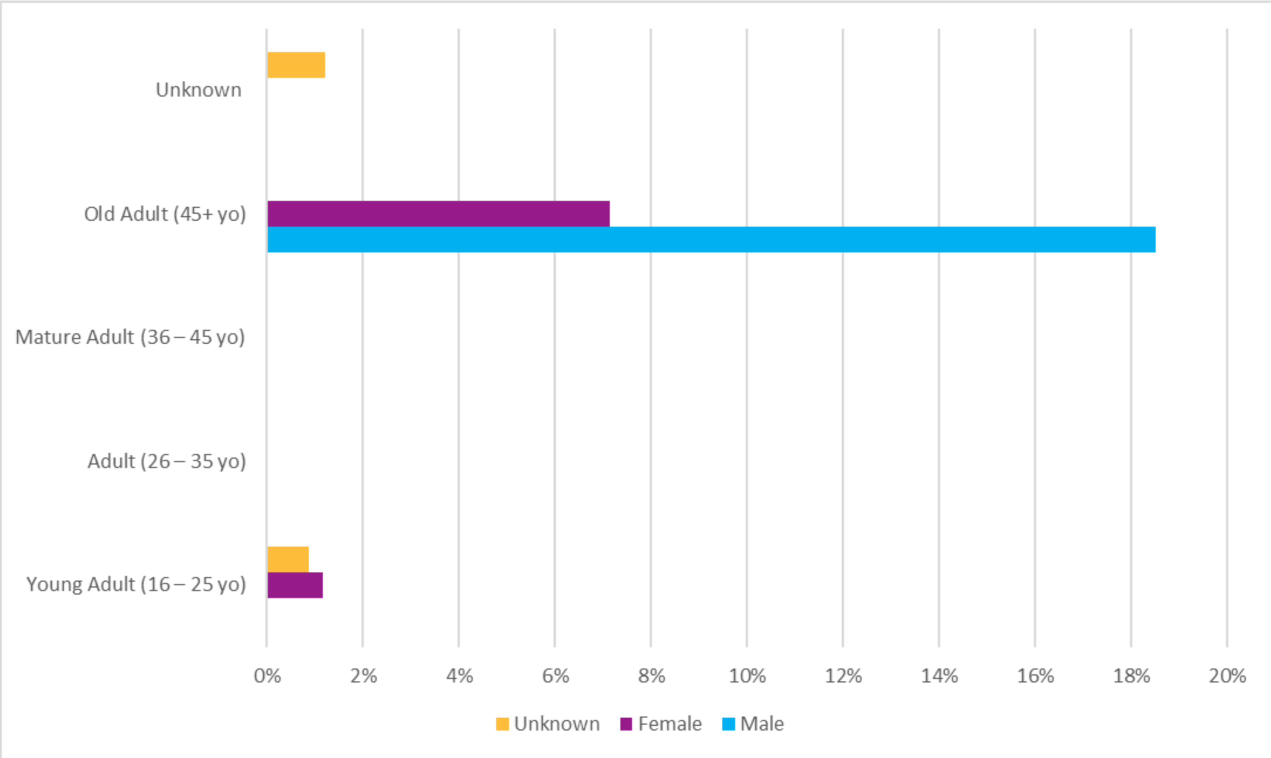

Figure 23 Monte Luna. Periapical lesions distribution based on tooth count position, sex, and age.

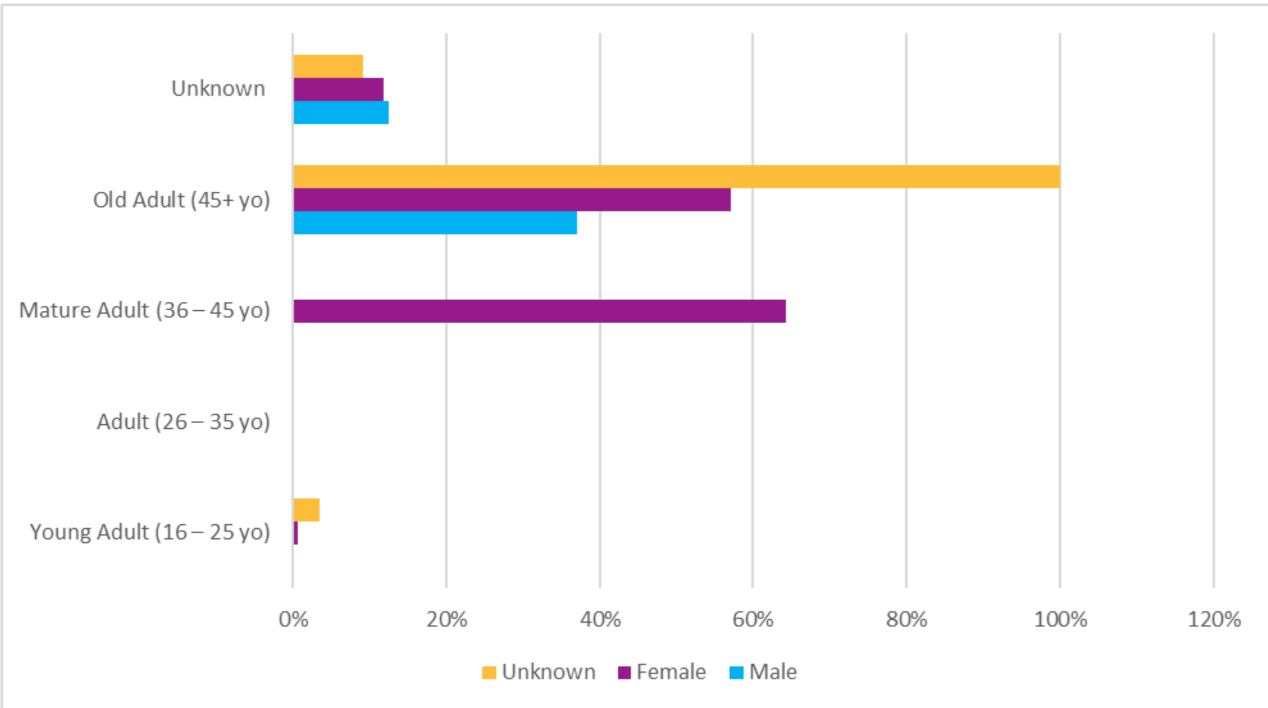

Figure 24 Monte Luna. AMTL distribution based on tooth count position, sex, and age.

5.7 COMPARISON OF DENTAL HEALTH IN PAU AND MONTE LUNA

5.7.1 Demography of the samples

The dental samples of Pau and Monte Luna able to be recorded are substantially different with a much higher number of teeth preserved from Monte Luna (n=2363) compared to Pau (n=516) (Table 28). This difference could bias the analyses and will be considered when comparing the results. Both samples had a higher proportion of teeth from young adults. Furthermore, as stated previously, sex, tooth count positions, periapical lesions, and AMTL could not be estimated in the Pau samples due to the absence of maxillary and mandibular bones. With this caveat in mind, this section will compare the data on caries per age group and type of tooth.

Table 28 Pau and Monte Luna teeth samples.

Tooth count and age classes			
		Pau	Monte Luna
Age class	Age subclass (years)	Tot (%)	Tot (%)
Subadult	0 – 9	77 (14.9)	201 (8.5)
	10 – 15	85 (16.4)	70 (2.9)
Adult	16 – 25	101 (19.5)	1273 (53.8)
	26 – 35	19 (3.6)	252 (10.6)
	36 – 45	21 (4.0)	112 (4.7)
	45 +	12 (2.3)	159 (6.7)
Unknown		201 (38.9)	296 (12.5)
Tot		516	2363

5.7.2 Caries

The sample from Pau had a significantly higher frequency of caries (10.3%) compared to the Monte Luna sample (3.1%) (FET p-value <0.001). At both Pau and Monte Luna, caries increased with age, reaching a maximum in the old adult category (45+ yo) (41.6% and 8.8%, respectively). Consistently, both samples showed the highest rates of caries in the molars, with Pau having a significantly higher prevalence (16.9%) compared to Monte Luna (5.6%) (FET p-value <0.001) (Table 29) (Figure 26).

Table 29 Pau and Monte Luna. The prevalence of permanent teeth affected by caries.

	Incisors			Canines			Premolars			Molars			Tot (%)[2]		
	Pau	Monte Luna	FET p-values	Pau	Monte Luna	FET p-values	Pau	Monte Luna	FET p-values	Pau	Monte Luna	FET p-values	Pau	Monte Luna	FET p-values
Subadult (10 – 15 yo) (%)[3]	0/7	0/8		0/6	0/8		1/36 (2.7)	0/11		2/33 (6.0)	0/31		3/82 (3.6)	0/58	
Young Adult (16 – 25 yo) (%)[3]	0/25	2/389 (0.5)		1/7 (14.2)	2/221 (0.9)	0.0897	6/29 (20.6)	4/281 (1.4)	**<0.001***	16/40 (40.0)	21/382 (5.5)	**<0.001***	23/101 (22.7)	29/1273 (2.2)	**<0.001***
Adult (26 – 35 yo) (%)[3]	0/11	0/34 (0)		0/0	2/34 (5.8)		1/1 (100)	5/50 (10.0)	0.1176	2/7 (28.5)	10/134 (7.4)	0.1099	3/19 (15.7)	17/252 (6.7)	0.1551
Mature Adult (36 – 45 yo) (%)[3]	0/2	1/8 (0.1)		0/3	1/11 (9.0)		1/5 (20.0)	2/32 (6.2)	0.3616	4/11 (36.3)	5/60 (8.3)	**0.0274***	5/21 (23.8)	9/111 (8.0)	**0.0465***
Old Adult (45+ yo) (%)[3]	0/2	2/30 (0.07)		0/2	1/16 (6.2)		0/2	3/36 (8.3)		5/6 (83.3)	8/77 (10.3)	**0.0002***	5/12 (41.6)	14/159 (8.8)	**0.0048***
Unknown (%)[3]	0/28	0/25 (0)		0/25	0/19 (0)		3/56 (5.36)	1/88 (1.1)	0.2991	3/92 (3.2)	3/143 (2.1)	0.6813	6/201 (2.9)	4/275 (1.4)	0.3348
Tot (%)[4]	0/75	5/494 (1.0)	0.3644	1/43 (2.3)	7/309 (2.2)	>0.9999	12/129 (9.30)	15/498 (3.0)	**0.0024***	32/189 (16.9)	47/827 (5.6)	**<0.001***	45/436 (10.3)	73/2128 (3.4)	**<0.001***

[1]A=Affected; O=Observed

[2]= The percentage is the proportion between the total amount of caries on the total amount of teeth counted in each age ranges.

[3]= The percentage is the proportion between the total amount of caries of each tooth type on the total amount of the same tooth type for each age ranges.

[4]= The percentage is the proportion between the total amount of caries of each tooth type on the total amount of the same tooth type in the all sample.

*Statistically significant p-value <0.05.

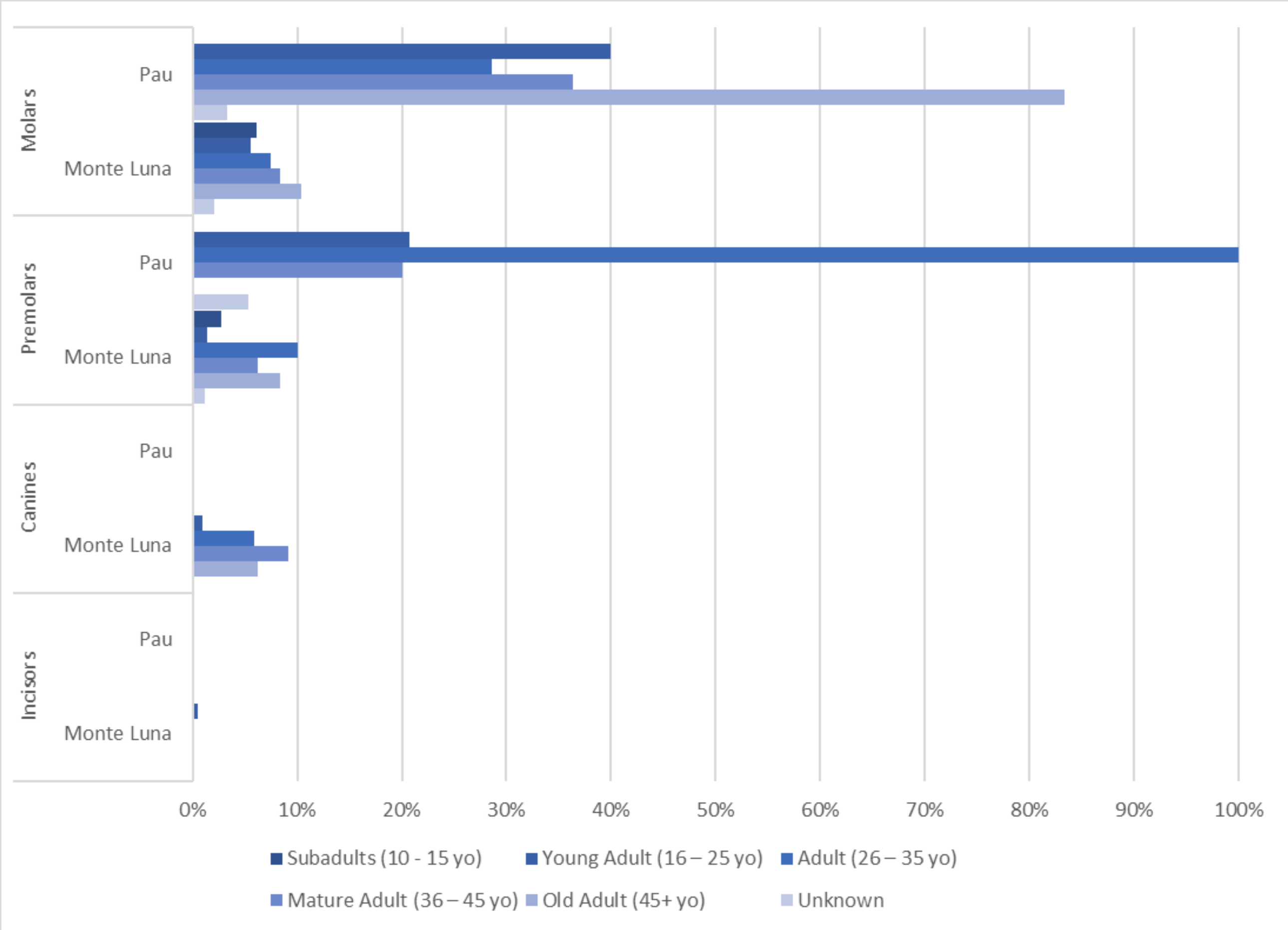

Figure 25 Pau and Monte Luna. Prevalence of caries based on tooth type and age.

5.7.2.1 Caries: Anterior vs Posterior

Caries lesions in the anterior dentition were rare in both samples (Table 29 and 30). Only one anterior canine from Pau exhibited caries (1.5%), while 11 incisors and canines were affected in the Monte Luna sample (11/743, 1.4%). The Pau sample showed a significantly higher frequency of caries in the posterior dentition (38/169, 22.4%) compared to Monte Luna (58/1212, 4.9%) (FET p-value <0.0001). Moreover, these differences were also significant within each age range, excluding the subadults (10-15 yo) (Table 30).

Table 30 Pau and Monte Luna. Prevalence of caries in the anterior and posterior dentition.

	Anterior Dentition			Posterior Dentition		
	Pau	Monte Luna	Site differences FET p-values	Pau	Monte Luna	Site differences FET p-values
Subadult (10 – 15 yo) (%)	0/13	0/16		3/69 (4.3)	0/42	
Young Adult (16 – 25 yo) (%)	1/32 (3.1)	4/610 (0.6)	0.2262	22/69 (31.8)	25/663 (3.7)	**<0.001***
Adult (26 – 35 yo) (%)	0/11	2/68 (2.9)		3/8 (42.8)	15/184 (8.1)	**0.0195***
Mature Adult (36 – 45 yo) (%)	0/5	2/19 (10.5)		5/16 (31.2)	7/92 (7.6)	**0.0160***
Old Adult (45+ yo) (%)	0/4	3/46 (6.5)		5/8 (62.5)	11/113 (4.7)	**<0.001***
Unknown	0/53	0/44		6/148	4/231	0.1978
Tot (%)	1/118 (1.5)	11/803 (1.4)	>0.9999	38/317 (22.4)	58/1325 (4.7)	**<0.001***

*Statistically significant p-value <0.05.

5.7.2.2 Caries: Tooth Type

The frequency of caries in each tooth type was also analysed (Table 29). There were no caries in any incisors in the Pau sample. The Monte Luna incisor sample had the most caries in the young adult group (16-25 yo), albeit at a very small frequency (0.5%, 2/389) (Figure 26). Only one canine of a young adult (1/43, 2.33%) was affected by caries in the Pau sample compared to 2.1% of the canines found at Monte Luna (7/327). There was a significantly higher proportion of premolars with caries in the Pau sample (12/129, 9.3%) compared to the Monte Luna sample (15/527, 2.8%) (FET p-value = 0.0024). The frequency of caries in premolars in the Pau sample was the highest in young adults (6/29, 20.6%) followed by mature adults (1/5, 20%). In the premolars found at Monte Luna, carious rates tended to be lower in the younger age groups and higher in the older age groups (Figure 26). There was a significantly higher proportion of caries in premolars of young adults in Pau compared to Monte Luna (FET p-value<0.0001). Similarly, there was a significantly higher proportion of molars with caries at Pau (32/190, 16.8%) when compared with Monte Luna (47/914, 5.1%) (FET p-value <0.0001). Caries in molars from Pau, were evident in all age groups with the old adults having the highest frequency (5/6, 83.3%). Although 40% of young adult molars were affected by caries too, this could be influenced by the small sample size (Figure 26). In molars from Monte Luna, carious rates steadily increased from the younger to the older age groups, reaching a maximum of 10.3% in old adults (8/77) (Figure 26). In most age groups, Pau molars showed a higher prevalence of caries compared to the Monte Luna samples (Table 29).

5.7.2.3 Caries: Severity

Grade 1, 2, and 3 crown caries were evident in teeth from both localities (Table 31). While only a small percentage of Grade 2 crown caries were observed in both samples, there was a significantly higher frequency of affected teeth in the Pau sample. The rates of Grade 1 and 3 severities of caries were very similar between the two samples. There was a general tendency for Grade 1 caries to decrease with age in both samples as would be expected. However, old adults in Monte Luna showed a similar rate of Grade 1 caries as young adults, although it has to be cautioned that the sample size is small. The rate of Grade 3 caries increased with age at Pau, however, there was no consistent pattern with increased age at Monte Luna (Table 31).

Table 31 Pau and Monte Luna. Frequency of the severity of caries (grade 1, 2, 3) for crown lesions and per tooth type and age category.

	Grade 1 (%)[1]			Grade 2 (%)[1]			Grade 3 (%)[1]		
	Pau	Monte Luna	FET p-values	Pau	Monte Luna	FET p-values	Pau	Monte Luna	FET p-values
Subadult (10 – 15 yo)	2/3 (66.6)	0/0		0/3	0/0		1/3 (33.3)	0/0	
Young Adult (16 – 25 yo)	16/23 (69.5)	18/29 (62.0)	0.7698	1/23 (4.3)	0/29		6/23 (26.0)	10/29 (34.4)	0.5600
Adult (26 – 35 yo)	3/3 (100)	9/17 (52.9)	0.2421	0/3	0/17		0/3	7/17 (41.1)	0.5211
Mature Adult (36 – 45 yo)	1/5 (20.0)	4/9 (44.4)	0.5804	1/5 (20.0)	0/9		3/5 (60.0)	4/9 (44.4)	>0.9999
Old Adult (45+ yo)	0/5	9/14 (64.2)	**0.0325***	2/5 (40.0)	2/14 (14.2)	0.2722	3/5 (60.0)	3/14 (21.4)	0.2621
Unknown	2/6	0/4		0/6	0/4		2/6	3/4	0.5238
Tot (%)[2]	24/45 (53.3)	40/73 (54.7)	0.2840	4/45 (8.8)	2/73 (2.7)	0.2000	15/45 (33.3)	27/73 (36.9)	>0.9999

[1]: Percentage is based on the total amount of type of affected teeth for each grade of severity based on the total amount of affected teeth in each age ranges.
[2] Percentage is based on the total amount of type of affected teeth for each tooth type based on the total amount of affected teeth in the sample.

Table 32 Pau and Monte Luna. Frequency of the severity of caries (grade 1, 2, 3) for maxillary and mandibular molars.

Severity grade	Maxillary M1, M2, M3			Mandibulary M1, M2, M3			Maxillary and Mandibular M1, M2, M3		
	Pau (N = 14)	Monte Luna (N = 22)	FET p-values	Pau (N = 17)	Monte Luna (N = 25)	FET p-values	Pau (N = 31)	Monte Luna (N = 47)	FET p-values
1(%)	9 (64.2)	14 (63.6)	>0.9999	8 (47.0)	24 (96.0)	**0.0004***	17 (54.8)	38 (80.8)	**0.0217***
2(%)	2 (14.2)	0		2 (11.4)	0		4 (12.9)	0	**0.0221***
3(%)	3 (21.4)	8 (36.3)	0.4672	7 (41.1)	1 (4.0)	**0.0043***	10 (32.2)	9 (19.1)	0.2818

*Statistically significant p-value <0.05.

The total number of maxillary and mandibular molars affected by Grade 1 and 2 caries was significantly lower in Pau compared to Monte Luna. While the frequency of Grade 1 and Grade 3 caries in maxillary teeth from both Pau and Monte Luna were similar (Table 32), the mandibular molars showed a different pattern. At Monte Luna there was a significantly higher frequency of Grade 1 caries (96.0%) than at Pau (47.1%) (FET p-value = 0.004). In contrast, the mandibular molars from Pau showed a significantly higher frequency of Grade 3 caries (41.17%) compared to Monte Luna (4.0%) (FET p-value = 0.0043) (Table 20). Additionally, samples from Pau showed a small frequency of Grade 2 caries in both the maxillary (14.29%) and mandibular molars (12.90%), with none present in Monte Luna.

5.8 SUMMARY OF RESULTS

5.8.1 Pau

At Pau, 10.32% of teeth were affected by caries, the majority of which were Grade 1 (53.33%) and Grade 3 affected 33.33% of teeth. Caries were most common in the posterior dentition, especially the molars (16.84%), and was highly age progressive, with the highest frequency of 41.67% recorded for old adults (45 + yo).

5.8.2 Monte Luna

At Monte Luna, caries was detected in 3.52% of teeth. A total of 54.79% were categorised as Grade 1, followed by 36.99% as Grade 3. Caries was most common in the posterior dentition, specifically in molars (5.32%), and increased with age. In the small sample available with sex determination, females had 4.6% of their teeth affected by caries with the age-progression reaching the highest frequency of 20.83% in older females. In contrast, males showed no caries. Only 1.9% of tooth positions had periapical lesions, with a higher proportion observed in males (6.3%) than in females (1.8%). Periapical lesions were most common in old adults (11.3%), with old males having a higher frequency (18.5%) compared to old females (7.1%). Antemortem tooth loss was recorded in 8.2% of the sample. Old adults showed a higher proportion compared to other age groups (58.0%) with old females more frequently affected (57.1%) than old males (37.0%).

5.8.3 Pau and Monte Luna

There was a higher frequency of caries in permanent teeth at Pau (10.3%) compared to the Monte Luna sample (3.5%). In both locations, the rate of caries increased with age and was most commonly found on molars. At Monte Luna, mandibular molars tended to have higher levels of Grade 1 (96.0%, 24/25) and a lower rate of Grade 3 crown lesions (4.0%, 1/25) compared to maxillary molars (63.6%, 14/22 and 36.3%, 8/22, respectively). While Pau sample Grade 1 majority resulted in maxillary molars (64.8%, 9/14) and a lower Grade 3 lesions (21.4%, 3/14) compared to mandibular molars (47.0%, and 41.2%). The frequency of Grade 1 was significantly higher between Pau and Monte Luna (FET p-value = 0.0217) (Table 32).

5.9 DISCUSSION

5.9.1 Sardinian dental health

There are not many studies on Sardinian dental health (Angelini et al., 2014; Casula et al., 2017; Murgia et al., 2021) and many are part of broader studies in which the Sardinian data can be easily overlooked (Jacobson et al., 2020). The present study introduces new data from chronologically separated samples providing an insight into changes in oral health over time on the island. The dental samples from the site of Pau represent a period when permanent settlements were being established following large-scale colonisation by Neolithic groups from the mainland. In contrast, the sample from Monte Luna represent the Punic Era, a time in which urban settlements had been established by new populations from Africa and the east and west Mediterranean. The dental information is considered in light of genetic studies which have shown genetic uniformity among populations based on autosomal and uniparental markers (Chiang et al., 2018). This is characteristic of the long period of isolation of the island followed by a period of intermixture of populations reflecting the Phoenicians and Punic Era (Marcus et al., 2020).

The focus on the interpretation of oral health to better understand prehistoric lifeways has highlighted that cariogenesis is a nuanced and multifactorial process (Marklein et al., 2019). This has prompted a reassessment of the biocultural and environmental contexts of the groups to better understand the variation in the frequency of caries. This includes factors such as demography, culture, behaviour, and food consumption and their effects on oral health (Marklein et al., 2019).

The Neolithic in Sardinia was a period of cultural and technological development. Cultivated plants and new wild fruits were introduced (Ucchesu et al., 2017). Analyses of pottery residues from three Sardinian Middle Neolithic B sites showed that the diet was based primarily on agriculture and animal husbandry (Fanti et al., 2018). Neolithic Sardinians raised sheep, goats, pigs, and cattle, and also grew crops such as wheat, barley, and legumes. This was supplemented by fishing and collecting of wild fruits, nuts, and molluscs. Thus, the diet was rich in animal protein and fat sufficient for maintaining good health. Furthermore, food processing involved mainly simmering and boiling rather than frying (Fanti et al., 2018). This, in conjunction with living in small, permanent settlements, suggests Neolithic Sardinians had a relatively healthy lifestyle. In contrast, during the Punic Era only cereals were allowed to be cultivated locally owing to the importance of Sardinian grain to supply the main city of Carthage (Pesce, 1961; Moscati, 1985; Van Dommelen, 1998; Bartoloni, 2017). However, there is evidence of a varied diet including fish and seafood, sheep, goats, pigs, legumes, fruits, vegetables, and various cereals although barley, a staple grain in the Mediterranean region, dominated. The ceramic findings in Sardinian Punic sites are consistent with the processing of cereals and making bread (Hayne, 2019) as well as meat and fish products, oil, and wine (Ramon Torres, 1995; Sanna, 2019).

Interestingly, the limited dental health profiles calculated from the Pau and Monte Luna samples show some similarities and some differences. The two communities were separated by fours thousands of years, a spatial distance of 50 km and subsisted on different types of food. As expected, caries was highly age-progressive and within the Monte Luna sample this feature of dental health is further evidenced through as the rates of antemortem tooth loss and periapical lesions. There was a significantly higher frequency of caries at Pau. In the Neolithic, teeth were more exposed to abrasive foods such as nuts and grains (Fanti et al., 2018). Teeth were also used to handle lithic tools potentially further damaging the teeth (Klinger et al., 2008) making them vulnerable to disease. At Monte Luna, the lower caries rates, despite potentially more exposure to processed carbohydrates, may suggest other factors did not promote caries such as good oral hygiene and lower fertility rates (and concomitant exposure of hormonal changes that can affect the dental health of women).

The similarity of the oral health profiles at Pau and Monte Luna in the age progression and the increase in severity with age, as expected, may suggest the samples are good a representation. It may also be attributed to the island's abundance of natural resources, which would have provided a stable and nutritious diet for the population through time. Furthermore, the genetic profiles of people in Sardinia from the Middle Neolithic to the present are similar (Marcus et al., 2020) further supporting the hypothesis that, despite Punic foreign domination and cultural fusion, the indigenous Sardinians in minor sites maintained their general lifeways as shown by the stability in oral health profiles over time.

6 HEALTH AS AN INDICATOR OF STRESS

6.1 INTRODUCTION

The social and economic framework within which a community exists has a direct bearing on the health and stress experienced by people. Stress is a physiological response to a perceived threat or danger that can have a negative impact on physical health. Stress can have a physical and emotional dimension and does not necessarily have an immediate effect on health (Ashmore et al., 1982; Goodman et al., 1988; Reitsema, and McIlvaine, 2014). When a stressful event occurs during childhood, it can leave a marker significant enough to be impressed on the skeleton. These markers are useful to make inferences about the health and lifestyle of past populations and can be used as a proxy for estimating aspects of health (Goodman et al., 1988; Goodman and Armelagos, 1989; Reitsema, and McIlvaine, 2014). The analysis of osteological markers in the context of the population, can be used to suggest the origin of stress, such as economic and political instability, resource scarcity, and environmental degradation. The analysis of stress experienced by individuals informs on the biological responses at a community level (Buikstra, 1977; Armelagos et al., 1982; Goodman et al., 1984; Goodman and Rose, 1990; Temple and Goodman, 2014). The present study focused on the analysis of stature and enamel hypoplasia (EH).

Throughout life, the human body experiences periods of fast and slow growth correlated to genetic, social, and environmental factors (Bogin and Smith, 2000; Kuzawa and Bragg, 2012; Gage et al., 2012). Each stage of growth is defined by a particular pattern of dental development, changes related to feeding methods, and maturation of the reproductive system and sexual behaviour (Bogin, 2007). During the life cycle of an individual, a synergetic relationship between nutrition, disease, immune function, environmental, and individual factors influence growth (Stinson, 2012). Typically, the fastest periods of growth take place during the prenatal period and infancy, albeit highly dependent on nutrition (Kuzawa and Bragg, 2012) and maternal health (Bogin, 2007). The mother provides nourishment and antibodies to some diseases through the placenta in the prenatal stage, both of which is continued through breastfeeding in infants (Harding and Johnston, 1995; Bogin, 1999; Barker, 2012). As an infant develops into a young child, the reliance on breastmilk is reduced and new foods are introduced, and a child may experience malnutrition as they adjust to this new diet. The new diet and the acquisition of motor skills may expose the child to a wider range of infectious disease from their environment. If growth is significantly affected, these factors may leave osteological markers on the human skeleton (Bogin, 2007; Kuzawa and Bragg, 2012).

During childhood, growth typically slows but speeds up again during puberty under the influence of hormones; good nutrition at this time is also important to growth (Bogin, 2015). These two phases, childhood and adolescence, are the least influenced by environmental factors and, consequently, it is unusual to see older children and adolescents in prehistoric burial sites. During these two developmental periods, nutrition will affect growth and, thus, the attained stature of the adult. Shorter statured adults may have experienced periods of retarded growth during childhood and puberty (Allen, 1994; Kuzawa and Bragg, 2012). However, these periods are typically followed by 'catch-up growth' which is the increase in growth following a period of retardation when the cause is no longer present (Prader et al., 1963; Wit and Boersma, 2002). Catch-up growth does not always occur as it relies on adequate nutrition (Pando et al., 2010).

From the moment of conception there is a constant interaction between the foetus, the placenta, and the mother that can influence the health of the child well into adulthood (Hodson, 2017). The analysis of subadult skeletal remains can not only provide information on the nutritional status and the health of the individual during childhood and early adulthood, it can inform about the mother's nutrition and health, her role in the family, and provide insight into the general health of the community. A challenge in using physiological stress markers to measure health in past populations is the difficulty in interpreting skeletal indicators of stress in the absence of contextual information (Piperata et al., 2014; Tanner et al., 2014). For example, the interpretation of these markers is complicated by the fact that some stress markers can be caused by a number of factors, such as nutritional deficiencies, infectious disease, and environmental stress. Thus, it is important for bioarchaeologists to consider the broader economic, cultural, and environmental context in which the skeletal remains were deposited (Steckel and Rose, 2002; Wilson, 2014; Newman et al., 2019; Hodson and Gowland, 2020). According to the bioarchaeological approach, stature, and enamel hypoplasia (EH) are phenomena shaped by biological and cultural elements (Vercellotti et al., 2014; Wilson, 2014). The analysis of stature and EH biomarkers can provide insight into the health of the people of Pau and Monte Luna during the Neolithic and Punic eras in Sardinia. Furthermore, by studying the sex-specificity of these biomarkers a better understanding of the environmental, cultural, and temporal factors that shaped the health of the population can be gained. The combination of data on health, time and place, culture, and environmental factors all contribute to a life course perspective analysis of the respective community (DeWitte, 2014; Wilson, 2014; Reitsema and McIlvaine, 2014).

6.2 SEXUAL DIMORPHISM

Sex-specific patterns of physiological markers of skeletal stress have been investigated in association with socioeconomics, labour, and individual variability and susceptibility (DeWitte, 2014). Generally, females have a stronger immune system than males and are considered immune-privileged (Lonzano et al., 2012; Giefing- Kroll et al., 2015). This is evident as early as in utero, with the male foetus being more susceptible to prenatal stress than the female (Stinson, 1985; Lamp and Jeanty, 2003). Males are also more vulnerable to environmental stress (i.e., socioeconomic, altitude-related, disease during developmental stages (Stinson, 1985)). Malnutrition and environmental conditions can determine individuals with poorer health are less able to cope with environmental stressors, increasing their vulnerability to disease, which then further weakens their bodies. This can lead to a range of negative outcomes, including physical stunting, decreased cognitive development, and increased risk of mortality. Socioeconomic inequalities can further amplify the effects of malnutrition, environmental conditions, and stress, as those with fewer resources are more likely to suffer from poor nutrition and inadequate housing, and to be exposed to more hazardous environmental conditions. By measuring individual variation in response to stress and body measurements, it is possible to identify those at greatest risk of suffering from malnutrition and its associated health effects.

6.3 STATURE

Stature is a variable useful to gain information on both past and present populations (Larsen, 2002; Formicola and Holt, 2007). This biometric variable has high genetic predictability (80 – 90%) (Sanna et al., 2008; Lettre, 2009; McEvoy and Visscher, 2009; Zoledziewska et al., 2015) but environmental and socio-economic factors also influence the final stature of adults (Steckel and Rose, 2002; Li et al., 2004; MacGregor et al., 2006; Perola et al., 2007; Danubio and Sanna 2008; Moore and Ross, 2013). Phenotypic or developmental plasticity can vary in response to health (Steckel and Rose, 2002; Pietrusewsky and Tsang, 2003; Maat, 2005; Cohen and Crane-Kramer, 2007), social status (Peck and Lundberg, 1995; Bielicki e Szklarska, 1999), nutrition (Steckel, 1995; Larsen,1997), and biological sex (Smith and Horowitz, 1984; Ruff, 2002; Gustafsson et al., 2007). Furthermore, variations in stature are influenced by the nature of subsistence strategies, such as pastoralism and foraging, climate, and political changes (Bogin and Keep, 1999; Malina et al.,2010; Ulijaszek and Komlos, 2010 (Frayer, 1984; Ruff, 1994), The accuracy and reliability of estimating stature in past populations are affected by several factors such as the method used, the sample size, and the quality of the data. The accuracy of estimates has improved over time due to the development of new methods and availability of larger samples (Feldesman and Lundy, 1988; Sciulli et al., 1990; Formicola and Franceschi, 1996; Sciulli and Hetland, 2007; Raxter et al., 2008; Vercellotti et al., 2009; Auerbach and Ruff, 2010; Maijanen and Niskanen, 2010). The main approaches to estimating stature use either anatomical or mathematical methods. Based on Dwight's methodology (1894), anatomical methods position all skeletal elements accurately on an osteometric table in their *in vivo* position. However, this method is often impractical and sometimes difficult to use due to the incomplete preservation of a skeleton. Another anatomical method combines measurements of various parts of the skeleton such as the femur, tibia, and humerus to estimate stature including a correction factor (Fully, 1956; Fully and Pineau, 1960; Raxter et al., 2006, 2007). This method is highly reliable and yields good results (Sierp and Henneberg, 2016), but it is not applicable to skeletal remains with incomplete preservation. As an alternative, mathematical methods based on measurements of the long bones (Pearson, 1989; Trotter and Gleser, 1952, 1958, 1970; Sjovold, 1990; Ruff, 1997; Ruff et al., 2012), and tarsals (Himes et al., 1977; Musgrave and Harneja, 1978; Meadowse Jantz, 1992; De Groote, 2011) to develop regression equations were developed. This method is population-specific and less reliable if applied to a population with different ancestry and environment (Boccone et al., 2010; Rosing et al., 2007). A third approach is a combination of both the anatomical and mathematical methods. In this method, stature is measured in a contemporary population similar to the one under examination, based on the idea that the size and shape of the bones are related to the size and shape of the living person. Then the regression equations are used to calculate the estimated stature of the individual based on the long bones of the human remains (Ruff et al., 2012), producing more reliable data for individuals with incomplete skeletons (Raxter et al., 2008; Vercellotti et al., 2009; Auerbach, 2011).

6.4 ENAMEL HYPOPLASIA

Enamel hypoplasia (EH) is a marker which provides evidence of a disturbance of growth in the dentition. Tooth development is a complex process involving interactions between genetic and environmental factors. As teeth form, they provide a permanent record of growth and development clearly identifying any disruptions that may have occurred (Cucina and Işcan, 1997; Goodman and Rose, 1990). These disruptions provide an indelible and chronological record of stress during crown formation. These abnormalities occur during the sensitive time in which the formation of the tooth, specifically the crown, occurs in childhood.

Crown formation occurs via a lamellar deposition of the enamel (Hillson, 1996, 2005). Initially, cuspal enamel is deposited which is then mineralised to format lateral enamel. If during this process a stressor causes the completion of an increment to be disturbed, the following increment will be formed leaving the previous one shorter and incomplete. This record is preserved in the form of enamel hypoplasia, which is evidence of developmental disruptions in the form of raised or depressed areas of enamel. This is called a hypoplastic groove and has been studied both macroscopically (Goodman and Rose, 1990; Hillson, 2005; Temple, 2014, 2016, 2018, 2020) and microscopically (Humphrey, and Hillson, 2010; Temple, Nakatsukasa, and McGroarty, 2012; Bocaege and Hillson, 2016; Cares Henriquez and Oxenham, 2017, 2018, 2020), with the latter being considered more precise regarding the timing of a disruption and the intervals between episodes (Cares Henriquez et al., 2022, in press). The aetiology of hypoplastic grooves is multifactorial and generally attributable to nutritional deficiencies, disease, physiological stress, and/or trauma (Hillson, 1996;

Belcastro et al., 2004). Accordingly, populations with a high degree of malnutrition and disease generally suffer from high rates of enamel hypoplasia (Goodman and Rose, 1990; Temple, 2020; Folayan, 2020).

Traditionally, bioarchaeology has focused on reporting the type and timing of enamel defects (Brothwell, 1981; Fédération Dentaire International, 1982, 1992) and the sex-linked specificity within and between populations, ultimately aimed at creating an index of systemic stress. This macroscopic approach is reliant on the observer's skills and experience, and this individual variability therefore limits comparisons between studies. To address these issues, bioarchaeologists have established a microscopic approach to quantify the defects in terms of chronology, duration, and intervals of EH (Guatelli-Steinberg et al., 2004; King et al., 2005; Reid and Dean, 2000; Temple et al., 2012) through the application of tools such as casting, image processing, and statistical analysis. These automated tools reduce observer errors and deliver more reliable and comparable results. However, this type of analysis is tied to sophisticated machinery such as a scanning electron microscope (SEM), which is not always accessible and dependent on the appropriate permissions.

One focus of this research was to examine how hypoplastic defects relate to chronological age. Tooth development occurs in a predictable sequence with the calcification and formation of specific teeth occurring at specific times (Hillson, 2005; Bogin, 2007). The formation of teeth involves the mineralisation of dental tissues with enamel forming in layers. Hypoplastic lines are related to disruptions in this process (Goodman and Rose, 1990; Reid and Dean, 2000; Hillson, 2005). Measurement of the distance between a hypoplastic line and the cemento-enamel junction (CEJ) in relation to the dental developmental stage allows an estimate of the chronological age at which these disruptions occurred to be made (Goodman and Rose, 1990; Reid and Dean, 2000; Hillson, 2005).

6.5 MATERIALS

6.5.1 Su Forru de is Sinzurreddus (Pau)

There were no complete long bones available for study from this site due to the high level of fragmentation of the human remains. The dental collection consisted of 565, isolated deciduous and permanent teeth.

6.5.2 Monte Luna Necropolis

The human remains recovered from the 70 tombs at Monte Luna were analysed to determine biological sex, stature, and presence of EH. The remains of 32 individuals (20 females and 12 males) were analysed and used as a reference to other single, isolated elements (see section point analysis below) namely 31 clavicles, 81 humerii, 43 radii, 27 ulnae, 73 femora, 34 tibiae, 99 patellae, and 52 first metatarsals. The dental collection consisted of 2229 teeth.

6.6 METHODS

6.6.1 Sex estimation

Sex was assessed via analysis of pelvic morphology, considered to be the most reliable method, followed by the morphology of the cranium and mandible (Buikstra and Ubelaker, 1994; Gülekon and Turgut, 2003; Bruzek, 2002; Murai et al., 2005;). When it was not possible to establish an anatomical relationship between elements, or when the above elements were missing, discriminant morphometric features such as indices of robusticity and specific measurements of bones were analysed instead (Pearson, 1917, 1919; Thieme, 1957; Black, 1978; Stewart, 1979; Stewart and McCormick, 1983; Dwight, 1984; Mallegni and Rubini, 1994; Canci and Minozzi, 2005). Since these measurements and bone indices are strongly population-specific, a section point analysis was applied using the average of the of the average male and female measurements of the humerii and femoral maximum lengths derived from skeletons with at least 75% preservation). Measurements of these long bones of unknown sex that were more than 0.5cm above the section point were classed as male, whereas those 0.5cm below were deemed to be female, with a buffer of 1cm either side of the section point (indeterminate sex). An index of robusticity (Mallegni and Rubini, 1994) was then applied and used as additional parameter to verify the results of the section point analysis.

6.6.2 Stature

Long bones from individuals older than 15 yo with fused epiphyses were measured using an osteometric board, tape measure, and calipers. For each element, measurements were taken following the methods of Martin and Saller (1957), Brauer (1988), Murail et al., (2005), and De Groote and Humphrey (2011) (Tables Appendix B).

Since the remains were from commingled and multiple burials, were mostly incomplete, and rarely in anatomical position or articulation, stature estimation was mostly performed on single elements. While regression equations for lower limb bone stature tend to have smaller standard error values than those for upper limbs (Sjøvold, 1990; Formicola and Franceschi, 1996; Ruff et al., 2012), this study presents stature for all available long bone lengths using a range of equations before assessing which results are the most appropriate to use.

Stature was calculated using a range of published regression equations based on predominantly European populations (Giannecchini and Moggi-Cecchi, 2008; Ruff et al., 2012) as follows: Pearson (PEA) (1899), Trotter and Gleser for European Afro-American (TGW e TGA) (Trotter e Gleser 1952; 1977), Sjøvold for European and other “combined” samples (SJO1 e SJO2) (1990), and Ruff et al., (RUFF) (2012). Pearson, Sjøvold, and Ruff’s equations are based on European populations, however, the European formulae of Trotter and Gleser are most commonly applied to European bones (Giannecchini e Moggi-Cecchi, 2008). The Afro-American method is more accurate when applied to populations from Italian prehistory (Formicola, 1983), and also to populations from central Italy ranging from the Neolithic period to the Middle Ages (Giannecchini e Moggi-Cecchi, 2008). When the same bones from both the left and right side of an individual were present, stature was calculated using both bones. In order to assess which regression equation was the most suitable to use on the skeletal samples available, a comparison was performed using Welch's t-test. In addition, since the skeletons were mostly incomplete, the mean differences in stature estimation using the humerus and femur in individuals of known sex was applied in order to validate the bone with the least difference within the same sex (Malher, 2009). Following this, sexual body stature dimorphism was verified in order to understand possible disparities in growth between sexes (Frayer et al., 1985; Stini, 1985; German and Hochberg, 2020).

6.6.3 Enamel Hypoplasia

The traditional macroscopic approach was employed to detect enamel hypoplastic defects, such as transverse lines, grooves, or linear pits on the surface of a tooth (Hillson, 1996). They were recorded following the grading system of "0": no defect; "1": one or two lines; "2": two or more lines (Brothwell, 1981; Fédération Dentaire International, 1982, 1992). The distance of an enamel hypoplasia from the CEJ was measured with callipers and recorded in millimetres. These measurements were used to estimate the age of the individual at the time of formation using Goodman and Rose's (1990) regression equations. If multiple lines were present, they were considered as the interval of occurrence between the younger and the oldest linear occurrence. Wear was estimated using Lovejoy's standard (1984), and only teeth with a crown preserved at a minimum of 50% were included in EH analyses.

6.7 RESULTS

6.7.1 Su Forru de is Sinzurreddus (Pau)

No estimations of stature were possible for this sample.

6.7.1.1 Enamel Hypoplasia (EH)

The permanent teeth showed 4.1% of the total sample (18/277) with one or more EH. The number of lesions by tooth type are detailed in Table 1 (Appendix D). Hypoplastic defects were detected in 18 teeth, seven (38.8%) of which were in the form of lines and 11 (61.1%) displayed pitted enamel. Only 33.3% (six teeth, M^3 was excluded) of the sample had linear EH and could be analysised for age of occurrence; other EH evidence was in the form of pits (Table 33). The earliest appearance of EH was found on the incisors aged to between 0.9-3.7 years, followed by canines between 3.6-4.8 years, while the latest episodes were detected in the molars occurring between 5.8-7.1 years. There is no correlation between earlier appearance and age-at-death but it is noteworthy that all individuals with EH, either in the form of pits and lines, died as young adults (Table 33).

Table 33 Pau. EH type of occurrence estimates.

Tooth	N Teeth (%)[1]	N Hypoplastic lines (%)[1]	Interval	5	4	3	2	1	Age-at-death
I^2	1 (4.7)	5 (27.7)	0.90 – 3.70	0.90	1.73	2.59	3.19	3.70	Young Adult (16 – 25yo)
C^1	1 (6.6)	4 (22.2)	3.60 – 4.80			3.57	4.13	4.80	Young Adult (16 – 25yo)
M^1	1 (12.5)	2 (11.1)	2.40 – 3.10			2.40	2.60	3.10	Young Adult (16 – 25yo)
M^2	1 (14.2)	2 (11.1)	6.40 – 7.10				6.37	7.10	Young Adult (16 – 25yo)
P_4	1 (5.0)	2 (11.1)	2.80 – 3.50				2.80	3.50	Young Adult (16 – 25yo)
M_2	1 (9.5)	3 (16.6)	5.80 – 6.40				5.80	6.40	Young Adult (16 – 25yo)
Tot	6 (33.3)	18							

[1]Percentage based between A/O.

6.7.2 Monte Luna Necropolis

6.7.2.1 Sex estimation

Due to the high level of fragmentation, the majority of long bones were isolated bones, while among the nine known individuals it was not always possible to measure the maximum length. The maximum length of 24 of the 81 humerii and 15 of the 73 femora was measured. The association with either a skull or pelvis allowed an estimated sex of five males and nine females (Appendix A). Section point analysis (Table 34) of the maximum length of the long bones from the sexed individuals was then used to estimate the sex of isolated bones, resulting in the further identification of nine males and 11 females.

Table 34 Monte Luna. Section Points Analysis from humerii and femora.

	Section Point Analysis	
	Humerus maximum length (mm)	Femoral maximum length (mm)
Section point*	29.8	42.7
Male	>30.4	>43.2
Indeterminate sex	29.4 – 30.4	42.2 – 43.2
Female	<29.3	<42.2

*Average of male and female average of individuals with a sex estimate from the skull or pelvis

6.7.2.2 Stature

Stature estimates were calculated from the humerii and femora using a range of regression equations (PEA, TGW, TGA, SJO1, SJO2, RUFF), and the results were variable, not only for average stature, but also the minimum and maximum range (Table 35 and 36, Figure 27 and 28).

The range of the estimates of the average male stature based on the humerus (Table 35) varied from 161.1 cm using the RUFF method up to 168.5 cm using the TGW method. The female average statures varied from 149.5 cm (PEA method) to 153.3 cm (TGW method) (Table 35). In all of the methods used, the stature of males was significantly taller compared to the stature of females ($P<0.0001$).

Table 35 Monte Luna. Stature (cm) assessment based on maximum humerus length.

	Humerus							
	Male (N = 9)				Female (N = 11)			
	Min	Mean*	Max	SD	Min	Mean*	Max	SD
PEA	157.5	161.1	165.9	2.556	142.5	149.5	164.0	5.875
TGW	164.8	168.5	173.2	2.554	145.2	153.3	170.9	7.054
TGA	161.9	165.5	170.2	2.545	144.6	152.1	168.2	6.465
SJO1	157.5	163.4	171.2	4.189	138.6	149.8	174.5	9.948
SJO2	157.6	163.4	171.0	4.082	138.9	150.1	174.2	9.738
RUFF	156.5	161.1	167.3	3.407	141.4	150.4	169.9	7.808

* Welch's Test was used to compare the means for males and females for each method and was found to be significantly different ($P <0.05$).

Table 36 Monte Luna. Femur. Stature (cm) assessment.

	Femur							
	Male (N = 9)				Female (N = 7)			
	Min	Mean*	Max	SD	Min	Mean*	Max	SD
PEA	164.4	166.6	170.0	2.082	145.6	151.9	155.5	3.282
TGW	168.1	170.8	175.0	2.568	146.5	154.4	159.0	4.076
TGA	165.0	167.5	171.3	2.324	145.0	152.3	156.7	3.763
SJO1	166.2	169.3	174.1	2.912	148.3	155.9	161.7	4.568
SJO2	165.6	168.8	173.8	3.000	147.2	154.9	161.0	4.710
RUFF	162.9	166.2	171.2	3.065	144.1	152.1	158.2	4.813

* Welch's Test was used to compare the means for males and females for each method and was found to be significantly different ($P < 0.05$).

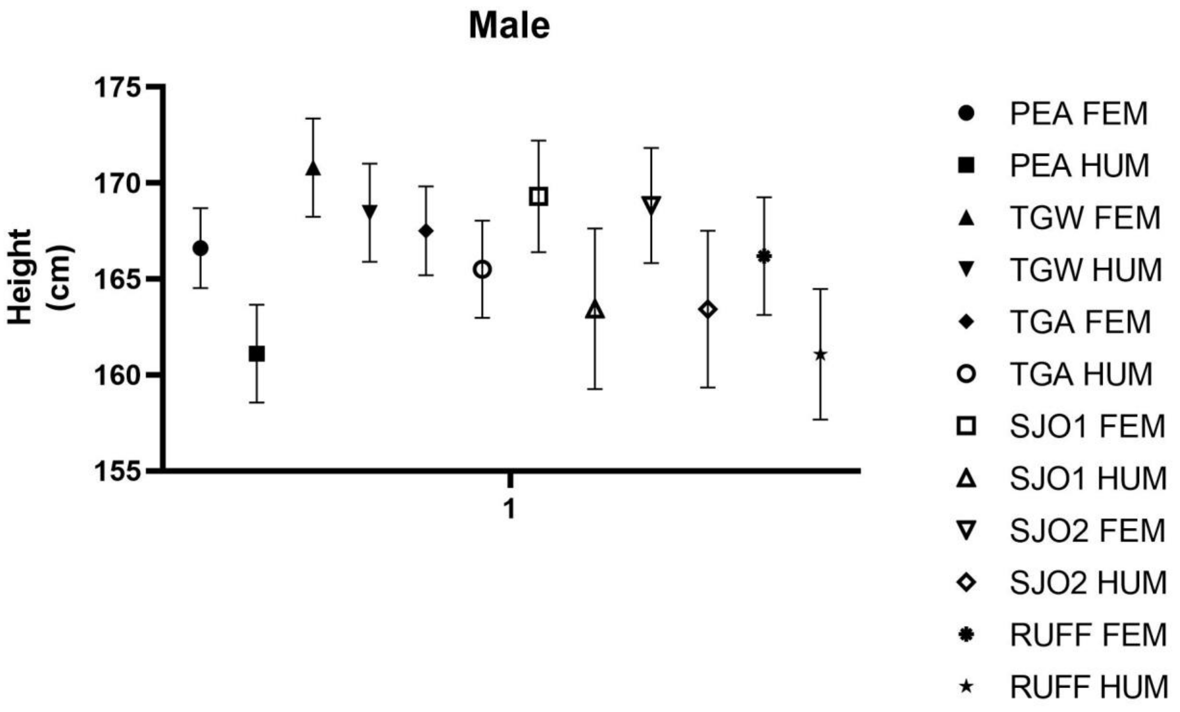

Figure 26 Monte Luna. Male stature: mean and confidence intervals at 95% for the different regression equations.

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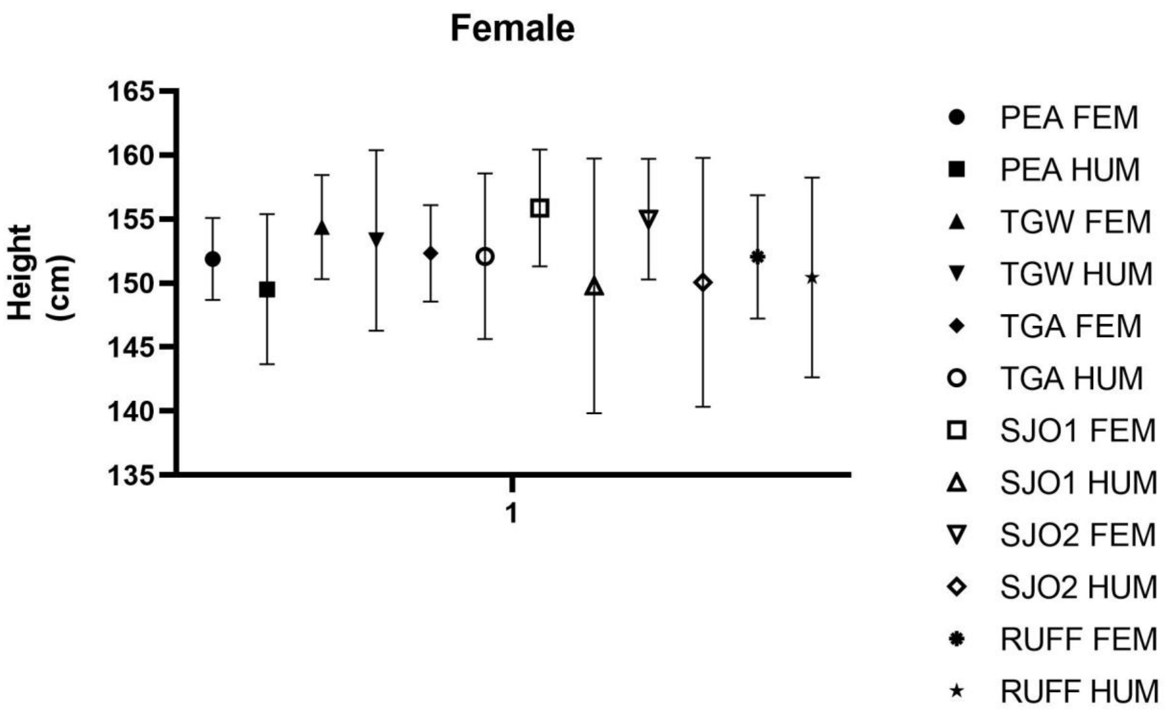

Figure 27 Monte Luna. Female stature: mean and confidence intervals at 95% for the different regression equations.

The method that provided stature estimates with the least difference between results calculated from the femur and from the humerus was considered to have body proportions most similar to the reference population. Stature estimates from the humerus and femur using the TGW and TGA methods were most similar (least difference) in both males and females (Table 35 and 36) and, furthermore, were not significantly different between males and females. The p-value of 0.0688 for TGW was marginally non-significant in the males, and the p-value for TGA was 0.1005 (*i.e.* most similar) (Table 37). In females, none of the stature estimates derived the femur and humerus was significantly different for any of the methods used. The TGA method had the highest p-value (0.9340; *i.e.* most similar) (Table 38).

Table 37 Monte Luna. Males' stature estimation from humerus and femur in comparison within same method.

	PEA Hum	TGW Hum	TGA Hum	SJO1 Hum	SJO2 Hum	RUFF Hum
PEA Fem	**0.0001**					
TGW Fem		0.0688				
TGA Fem			0.1005			
SJO1 Fem				**0.0038**		
SJO2 Fem					**0.0061**	
RUFF Fem						**0.0041**

*Significantly different (P <0.05)

Table 38Monte Luna. Females' stature estimation from humerii and femora in comparison within same method.

	PEA Hum	TGW Hum	TGA Hum	SJO1 Hum	SJO2 Hum	RUFF Hum
PEA Fem	0.3740					
TGW Fem		0.7403				
TGA Fem			0.9340			
SJO1 Fem				0.1777		
SJO2 Fem					0.2604	
RUFF Fem						0.6520

To further ensure the TGA method was the most appropriate, the stature estimates from the few individuals with both a humerus and a femur were compared using all methods.

Following that, Malher's (2021) method was applied and, in the three of the four individuals where this was possible, the TGA estimates showed the smallest difference (Table 39).

Table 39 Monte Luna. Malher's mean stature (cm) differences comparison method.

	Male						Female								
	T63_INDA			T7_INDA			T59_INDA			T59_INDB			T7_INDB		
	Hum	Fem	Difference	Hum	Fem	Difference	Hum	Fem	Difference	Hum	Fem	Difference	Hum	Fem	Difference
PEA	160.1	166.1	-6.02	157.5	164.4	-6.94	148.7	151.6	-2.9	145.3	148.5	-3.22	150.5	152.9	-2.47
TGW	167.4	171.1	-3.69	164.8	168.2	-3.44	152.2	154.4	-2.19	148.0	150.2	-2.16	158.8	155.9	2.91
TGA	164.5	167.8	**-3.3***	161.9	165.2	**-3.31***	151.1	152.1	**-1.03***	147.2	148.5	**-1.23***	153.1	153.7	**-0.62***
SJO1	161.7	168.6	-6.84	157.5	166.2	-8.75	148.2	156.5	-8.25	142.3	152.3	-9.98	151.3	152.3	-0.96
SJO2	161.8	168.0	-6.32	157.6	165.6	-8.03	148.6	155.6	-7.03	142.8	151.3	-8.46	151.6	151.3	**0.31**
RUFF	159.8	165.4	-5.62	156.5	162.9	-6.47	149.2	152.7	-3.47	144.6	148.3	-3.69	151.6	148.3	3.36

*The least difference results from the TGA regression equation.

Therefore, the TGA method was selected as the most appropriate for the samples. The equations based on the femur were the most accurate (with the lowest standard error), resulting in an average male stature at Monte Luna of 167.5 cm and an average female stature of 152.3 cm (Table 39). There was a wider range (11.7 cm) of stature in females compared to males (6.2 cm).

Table 40 Monte Luna. Stature (cm) estimates (TGA) (femur).

	Male	Female
Average stature	167.51	152.33
N	9	7
Minimum stature	165.0	145.0
Maximum stature	171.3	156.7
Range (max – min)	6.3	11.7
Standard deviation	2.324	3.763

6.7.2.3 Enamel Hypoplasia (EH)

In the sample of permanent (subadult and adult) teeth, 6.0% (133/2229) showed evidence of hypoplasia. The 133 lesions were divided by tooth type for both the maxilla and mandible (Appendix D).

Each tooth type was clustered to highlight the interval of occurrence from the age of the first defect to the age of the last defect (Tables 40-43). This showed that the few M^1 with evidence of EH were the teeth with the earliest appearance, between 1.9yo-2.9yo, followed by incisors with linear lesions likely to develop between 2.8yo and 3.5yo. The occurrences on both canines and premolars were allocated to later developmental stages between 4.3yo- 5yo. The estimation of the age of occurrence of EH in subadults was the same.

Table 41 Monte Luna. Incisors' EH estimation.

Tooth	N Teeth (%)[1]	N Hypoplastic lines (%)[1]	5	4	3	2	1
				2.7	3.1	3.6	4
					4	3.5	4
			1.8	2.7	3.1	3.6	4
					2.2	3.5	4
					3.1	3.6	4
					2.2	2.7	3.1
I^1	13 (56.5)	40 (60.6)			1.3	2.7	3.1
						2.7	3.1
					2.2	2.7	3.3
						2.7	3.4
				1.3	2.2	3.1	3.6
					2.6	3.4	3.6
						3.2	3.6
						3.3	3.9
I^2	3 (13.0)	7 (10.6)				3.3	3.9
					2.9	3.7	4.1
I_1	1 (4.3)	2 (3.0)				2.6	3.1
						2.3	3.2
						2.3	3.2
						2.7	3.4
I_2	6 (26.0)	17 (25.7)	1.9	2.3	2.7	3.2	3.6
					2.7	3.2	3.6
					3.1	3.4	3.6
Tot	23	66					

[1]Percentage based between A/O (Number Affected/ Number Observed)

Table 42 Monte Luna. Canines' EH estimation.

Tooth	N Teeth (%)[1]	N Hypoplastic lines (%)[1]	5	4	3	2	1
							3.6
							4.1
						3.5	4.4
							4.6
C^1	25 (40.3)	68 (68.0)		2.9	3.5	4.1	4.8
				2.9	3.5	4.1	4.8
						3.8	4.8
				2.9	3.5	4.4	4.8
			2.3	2.9	3.8	4.1	4.8
							4.8

						3.5	4.8
					4.1	4.8	4.8
					3.2	4.4	5.1
					4	4.4	5.1
					4.1	4.8	5.1
					3.5	4.2	5.3
					4.1	5.1	5.4
						4.8	5.4
				2.9	3.5	4.8	5.4
			3.2	3.8	4.1	4.4	5.4
				2.3	3.2	4.1	5.4
					3.8	4.4	5.4
						4.8	5.4
					3.8	4.7	5.7
						4.1	5
						4.1	5
						4.1	5
							4.1
						3	4.1
							4.1
					2.7	5	4.1
							4.1
						3.6	4.4
						3.9	4.7
							4.7
						4.3	4.7
						3.7	4.7
							4.9
					3	4.1	5.2
	37 (59.6)	90 (56.9)		3	3.6	4.7	5.3
					3.5	4.4	5.3
C_1						3.9	5.3
					4.1	4.7	5.3
						3.9	5.3
					3.9	4.7	5.3
						4.1	5.3
						5.3	5.6
					4.4	5	5.6
					3.6	4.4	5.6
					4.1	5.2	5.6
					3.6	4.4	5.6
						5.3	5.6
					3.6	4.7	5.8
					4.1	5.3	5.9
						5.3	5.9
			3	4.1	4.7	5.3	5.9
					4.4	5.3	5.9
			3.6	4.1	4.7	5.3	5.9
			2.4	3.6	4.7	5.3	5.9
					4.7	5.3	5.9
Tot	62	158					

[1]Percentage based between A/O.

Table 43 Monte Luna. Premolars' EH estimation.

Tooth	N Teeth (%)[1]	N Hypoplastic lines (%)[1]	5	4	3	2	1
P^3	5 (16.6)	8 (15.0)				4.4	5
						4.8	5
						4.5	5
						5	5.5
				3.3	4.3	5	5.5
P^4	4 (13.3)	10 (18.8)				4.6	5.3
					4.4	4.6	5.4
						4.1	5.6
					5.1	5.3	5.8
P_3	11 (36.6)	18 (33.9)				4.6	5
							4.6
							4.7
							4.7
						3.3	4.7
					3.4	4.4	4.7
							4.7
						5	5.4
						4.7	5.4
					4.1	4.7	5.4
				3.4	4.1	4.7	5.4
P_4	10 (33.3)	17 (32.0)				4.6	5
							5
							3.8
						4.1	4.7
							4.7
						4.4	5.2
							5.4
					4.7	5	5.4
					4.1	4.7	5.4
					3.8	4.7	5.4
Tot	30	53					

[1]Percentage based between A/O.

Table 44 Monte Luna. Molars' EH estimation.

Tooth	N Teeth (%)[1]	N Hypoplastic lines (%)[1]	3	2	1
					3
					1.7
M^1	5 (45.4)	6 (46.1)		2.2	2.6
			1.7	2.2	3.1
				1.7	3.1
M_1	2 (18.1)	2 (15.3)			1.3
				2.4	2.8
					5.8
M_2	4 (36.3)	5 (38.4)			6.1
					6.1
				5.4	6.5
Tot	11	13			

[1]Percentage based between A/O.

The frequency of the defects was non-significantly higher in males (11.5%) compared to females (7.8%) (Table 45). In both sexes the mandibular canines were most frequently affected (Table 46).

Table 45 Monte Luna. Male and Female's frequency of EH based on tooth count.

Tooth	Male (%)[1]	Female (%)[1]
Tot (%)[1]	11/96 (11.5)	19/244 (7.8)

[1]Percentage is between male and female estimation on total observed teeth for each sex.

The analysis of 16 individuals (12 females and 4 males) showed that the periods when most defects occurred was between 1.9yo-2.9yo, and between 4.3yo-6yo (Table 46). There was no marked difference in the age of occurrence between males and females in the 16 individuals. Four of the females affected by hypoplasia died as young adults, one as an adult, and the remaining three as mature adults. Of the four males with EH, one was a young adult, two were adults, and one was a mature adult. Although the data are limited, females with EH were probably more susceptible to die as a young adults compared to males (Table 46).

Table 46 Monte Luna. Individuals with multiple hypoplastic lesions.

Individual	Tooth	5	4	3	2	1	Interval	N Hypoplastic lines/Affected teeth	Age-at-death
Females									
28.2	P^4				1.9	4.1	1.9 – 4.1	3/2	Young Adult (16 – 25yo)
R1.1	I_1				2.6	3.1	2.6 – 4.7	6/3	Young Adult (16 – 25yo)
	C_1				4.3	4.7			
	P_4				4.1	4.7			
Enkytrismos	I^1			2.6	3.4	3.6	2.6 – 5.9	9/3	Adult (26 – 35yo)
	C^1			4	4.4	5.1			
	C_1			4.7	5.3	5.9			
16	C^1		2.9	3.5	4.8	5.4	2.9 – 5.4	4/1	Young Adult (16 – 25yo)
27.2	C_1	3.5	4.1	4.7	5.3	5.9	3.5 – 5.9	7/2	Young Adult (16 – 25yo)
	P_4				4.7	5.4			
	M^1					3			
97	C_1				4.1	5	4.1 – 5	2/1	Young Adult (16 – 25yo)
0	C_1				4.1	5.3	4.1 – 5.3	2/1	Young Adult (16 – 25yo)
116	P_4			4.1	4.7	5.4	4.1 – 5.4	3/1	Adult (26 – 35yo)
PV.2	C_1			4.1	5.3	5.9	4.1 – 5.9	2/2	Young Adult (16 – 25yo)
4	P_4					5.4	5.4	1/1	Mature Adult (36 – 45yo)
25	C_1				5.6	5.3	5.3 – 5.6	2/1	Mature Adult (36 – 45yo)
R1.2	M_2					6.1	6.1	2/2	Young Adult (16 – 25yo)
						6.1			
Males									
63A	C^1	2.3	2.9	3.8	4.1	4.8	2.3 – 5.8	20/6	Mature Adult (36 – 45yo)
				4.1	4.8	5.1			
	P^4			5.1	5.3	5.8			
	P^3		3.4	4.1	4.7	5.4			
	P^4			3.8	4.7	5.4			
	M^1				2.4	2.8			
7A	I^1			3.1	3.6	4	3.1 – 4.0	3/1	Young Adult (16 – 25yo)
48	C^1				4.1	5	4.1 – 5.0	2/1	Adult (26 – 35yo)
PV.1	I^1			3.1	3.6	4	4.1 – 5.6	4/2	Adult (26 – 35yo)
	C^1				3.9	5.3			

	C_1		3.6	4.4	5.6

In the sample of teeth of known sex, there was no significant difference when teeth with EH were compared with teeth without EH (p-value=0.0506). Half (6/12) of the male sample with no EH were aged as old adults, while of the nine females without EH (9/24), six were young adults. No correlation between an earlier age of occurrence of EH and a younger age-at-death in either sex was detected.

The teeth from three subadults in the sample (Table 47) show that latest appearance of EH is associated with the earliest age-at-death.

Table 47 Monte Luna. Subadult individuals (permanent teeth) with hypoplastic lesions.

Individual	Tooth	5	4	3	2	1	Interval	N Hypoplastic lines/Affected teeth	Age-at-death
27.1	C^1			3.5	4.8	5.4	2.2 – 5.4	21/6	Subadult (10 – 15)
	P^3		3.8	4.3	5	5.4			
	M^1			2.2	2.6	2.8			
	C_1	3.6	4.1	4.7	5.3	5.9			
	P_3				4.7	5.4			
	M_1					4.4			
DDJ1_ST4	P_3				4.6	5	4.6 – 5	2/1	Subadult (0 – 9)
DDJ1_ST5	P_4			4.1	4.7	5.2	4.1 – 5.2	3/1	Subadult (0 – 9)

6.7.2.4 *Stature and EH*

The individuals that were analysed for both stature and hypoplastic lesions showed that both males and females with EH have a stature either close to the average or just below the average (Table 48).

Table 48 Monte Luna. Stature (cm) and EH estimation for known sex individuals.

Individual	5	4	3	2	1	Interval	TGA Hum	TGA Fem	Sex
16		2.9	3.5	4.8	5.4	2.9 – 5.4		151.5	Female
25				5.6	5.3	5.3 – 5.6		152.5	Female
			5.1	5.3	5.8				
63°		3.4	4.1	4.7	5.4	2.3 – 5.3	164.5	167.8	Male
			3.8	4.7	5.4				
				2.4	2.8				
7°			3.1	3.6	4	3.1 – 4.0	161.9	165.2	Male

[1]TGA Male estimate for the sample: Humerus 161.88<165.51>170.23; Femur 165.04<167.51>171.34
[2] TGA Female estimate for the sample: Humerus 144.60<152.09>168.16; Femur 145.03<152.33>156.66

Individuals of known sex without EH had a stature either equal to or higher than the average (Table 49).

Table 49 Monte Luna. Stature estimation for known sex individuals with no EH.

Individual	TGA Hum	TGA Fem	Sex	Age-at-death
26	155.8	155.6	Female	Young Adult (16 – 25yo)
59°	151.5	152.5	Female	Mature Adult (36 – 45yo)
59B	150	150	Female	Mature Adult (36 – 45yo)
81	161.3		Female	Adult (26 – 35yo)
85	165.9		Male	Old Adult (+45)

[1]TGA Male estimate for the sample: Humerus 161.88<165.51>170.23; Femur 165.04<167.51>171.34
[2] TGA Female estimate for the sample: Humerus 144.60<152.09>168.16; Femur 145.03<152.33>156.66

6.8 RESULTS SUMMARY

6.8.1 Sex estimation

Analysing the maximum length of both the humerus and femur with Malher's method (2009) and section point analysis allowed the identification of a further nine males and 11 females.

6.8.2 Stature

The TGA regression equation was shown to be the most reliable for the Monte Luna population. Using the femoral lengths, the average male stature was 167.5cm with a range of 165.0-171.3cm (6.3cm), while the average female stature was 152.3cm with a range of 145.0-156.7cm (11.6cm).

6.8.3 Linear Enamel Hypoplasia (EH)

6.8.3.1 Su Forru de is Sinzurreddus

Pau permanent teeth affected by EH (4.1%) had the majority (61.1%) with evidence of pits and 33.3% affected by hypoplastic lines, all in the young adult population (16-25yo). The earliest appearance of defects occurred between 0.90yo-3.10yo, followed by between 3.60-4.80yo, and a final interval between 5.80-7.10yo.

6.8.3.2 Monte Luna Necropolis

At Monte Luna, 6.0% (133/2207) of the permanent teeth were affected by hypoplastic defects. The highest level of occurrence was found on lower canines (27.8%, 37/133), followed by upper canines, and upper incisors. The earliest appearance of defects was between 1.95yo-2.95yo; followed by another interval between 2.85yo-3.59yo, and a third one between 4.3yo-5yo. Males were more affected by hypoplastic defects than females (11.5% and 7.8%, respectively).

6.9 DISCUSSION

Childhood stress in Sardinian populations from the past is not well documented, as archaeological and historical records do not typically provide this information. However, studies on the effects of stress on skeletal growth in other past populations have generated insights into the impact of stress during childhood (Goodman and Armelagos, 1988; Goodman and Armelagos, 2010; Humphrey and King, 2010). These studies suggest that stress during childhood can lead to changes in skeletal and dental development. This includes changes in bone size, shape, and structure, which may reflect the impact of environmental stressors such as disease, food insecurity, as well as social stressors.

Childhood health and disease profiles of past populations are mostly based on analyses of stature and enamel hypoplasia since both are sensitive to external factors such as the environment, socioeconomic status, disease, and nutrition (Hillson, 1996; Belcastro et al., 2004; Sanna et al., 2008; Lettre, 2009; McEvoy and Visscher, 2009). The studies on growth, growth disruption, and stature have highlighted the importance of early detection and identification of growth abnormalities through the synergistic interactions between environmental constraints, biology, cultural buffering systems, and psychological disruptions (Goodman et al., 1988; Temple and Goodman, 2014). Research has demonstrated that there are sexually dimorphic differences in the appearance of hypoplastic lines, and growth and stature. This difference is important as it facilitates the identification of risk factors contributing to morbidity and mortality (DeWitte and Wood, 2008; DeWitte, 2010; Temple, 2014).

Information on the morbidity and mortality of a population can assist with the correlation of childhood stress and the frailty of an individual of interest (DeWitte, 2010; Temple, 2014). The differences in life expectancies, age-at-death, enamel hypoplasia, and stature of individuals can be used to distinguish the three potential childhood states: frail children, indicating the weaker or more vulnerable condition; medium frail children; and strong children, meaning a robust or healthy state (Domett, 2001).

Frail children are those who have a weakened physical condition due to a range of factors such as age, poor nutrition, chronic illnesses, or genetic disorders. This makes them more susceptible to external factors and may trigger acute responses thereby lowering life expectancy. Skeletal remains with an early occurrence of EH, or no evidence of EH but an early, premature death could be classified as belonging to this category.

Medium frail children are those who are not as weak as the frailest children, but still require extra attention to maintain their health. They show some resilience when suffering through traumatic events by overcoming episodes of stress. However, this generally leaves lasting physical marks on the skeletal remains. The severity of these marks is highly dependent on the individual's health status, and the ability to cope with the events of stress. However, the general assumption is that individuals with severe rates of enamel hypoplasia will die as subadults. Individuals with moderate levels may die as adults with either a short or tall stature, depending on whether they were able to go through a period of catch-up growth.

Strong children are those who are generally healthy, with no major medical conditions or chronic illnesses. They are expected to have a high level of immunity and ability to respond to external factors. There would be minimum evidence of stress on their skeletal remains, resulting in adult populations with a low or absent level of enamel hypoplasia, tall stature, and not dying young.

6.9.1 Sardinia Stature Overview

Results on stature changes through time in Sardinia are widely divergent as they were based on different ethnic groups, or the disparities in the living conditions of early settlers (Pes et al., 2017). Studies of long bones from the Early Neolithic (3900-3000 BC) (Floris, 1983; Martella et al., 2016; Danubio et al., 2017) show that the average stature for Sardinians was 161.7 cm for males and 150.1 cm for females. Stature in the Late Neolithic (3300-2500 BC) was reported as slightly higher with

162.8 cm for males and 151.7 cm for females (Floris, 1983; Martella et al., 2016; Danubio et al., 2017). Between the Eneolithic and Bronze Age (2800-2400 BC) the average stature increased again to 165.2 cm for males and 152.2 cm for females (Floris, 1983; Martella et al., 2016; Danubio et al., 2017), which is consistent with the stature of other coeval populations in Europe (Formicola and Giannecchini, 1999; Hermanussen, 2003) (Figure 29 and 30). However, other studies based on coeval remains reported a different stature range for males (156.2-168.7 cm) and females (106.7-154.8 cm) (Germanà, 1995). This information is consistent with literature for male population, but need careful consideration, and further investigation, when assessing female population, which are estimated very short based on other studies (Danubio et al., 2017). As is evident for Mediterranean populations, the average stature of Sardinians saw a new phase of decrease during the Punic and Roman Era (480 BC-476 BCE) to 163.5 cm for males and 152.2 cm for females (Martella et al., 2016; Danubio et al., 2017).

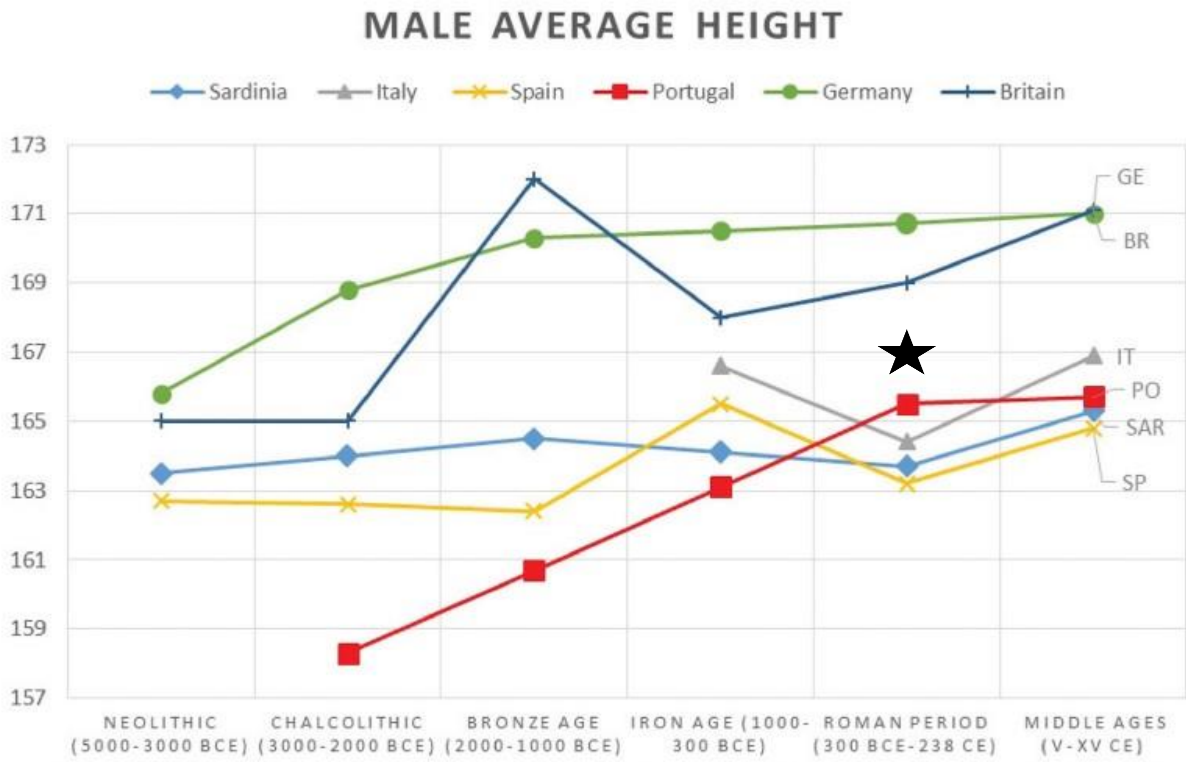

Figure 28 Summary of Sardinia's male population stature from the Neolithic to the Middle Ages in comparison with other Europeans countries. Adapted from Danubio et al., 2017. The black star indicates the average male stature from Monte Luna.

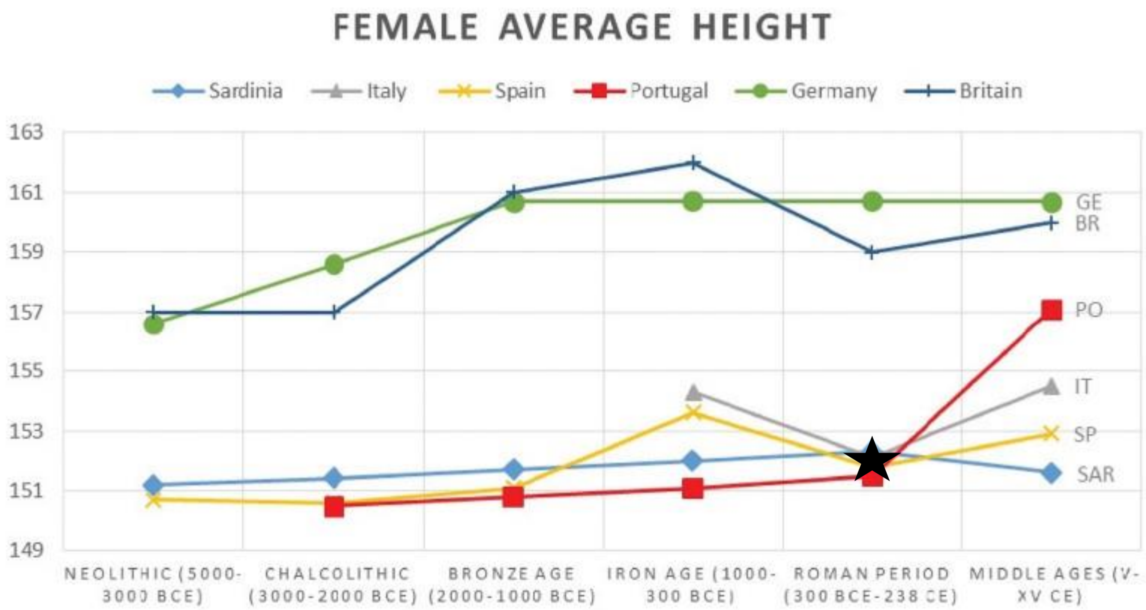

Figure 29 Summary of Sardinia's female population stature from the Neolithic to the Middle Ages in comparison with other Europeans countries. Adapted from Danubio et al., 2017. The black star indicates the average male stature from Monte Luna.

In the present study, the application of multiple methodologies to estimate stature showed that Trotter and Gleser's method for African people (TGA) (1952, 1977) was most suitable to estimate the stature of both males and females in the Monte Luna sample. In accordance with previous studies (Floris, 1983; Martella et al., 2016; Danubio et al., 2017), a statistical difference in mean stature between males and females ($p<0.0001$) was found at Monte Luna which was expected due to sexual dimorphism (Wells, 2007). The average stature for both sexes in the Punic/Roman Era is consistent with the mean stature reported in previous studies for females (Danubio et al., 2017; Martella et al., 2018), while males in the Monte Luna sample had a slightly taller stature (167.5 cm) than previously reported (164.5 cm) (Danubio et al., 2017) (Figure 29 and 30).

The changes in average Sardinian stature have been explained to be a result of the transition to agriculture, changes in diet and food consumption, and the coexistence of different ethnic groups. However, there were substantial disparities in the living conditions of early settlers (Morelli, et al., 2010; Pes et al., 2016) and Sanna et al., (1993), pointed out that limb length instead of trunk length increased due to environmental and/or nutritional factors (Brown, 1983; Sanna and Soro, 2000; Bogin, 2013). Since the leg length increases mostly prior to puberty, short leg lengths may just be the result of prepubertal malnutrition (Leitch, 2001). Other possible reasons could be the spread of diseases and infections such as malaria (Tognotti, 2009) and helminth infections (Palmas et al., 2003), which could have affected pregnant women and children during developmental stages (Pes et al., 2017). Genetic diseases, such as beta-thalassemia, could also be considered to be a possible cause of stature variation. Beta-thalassemia is particularly common in modern Sardinia, where the frequency of carriers of the mutated gene is estimated to be one in 8-10 people (Cao et al., 1978). The correlation between beta-thalassemia, reduced growth velocity, and short stature has been demonstrated in several studies conducted in modern Sardinia and other parts of the world (Raiola et al., 2003; Karimi et al., 2004; Pes et al., 2017; Arab-Zozani et al., 2021). Therefore, the consistent shorter average stature of Sardinians compared to other European populations reported previously and in the present study could be due to the high incidence of beta-thalassemia in Sardinia. Further investigation of possible skeletal markers of thalassemia will be conducted in future studies of the Monte Luna skeletal sample.

6.9.2 Enamel Hypoplasia Overview

Data on the occurrence of enamel hypoplasia in past populations of Sardinia are only preliminary. Studies on the defects are included in Bachelor and Master theses, but the data sets are too small to be published and, more importantly, the studies are not directly comparable due to the application of different methodologies. Hypoplastic defects were analysed only macroscopically in the current study. Although fundamental conclusions cannot be drawn based on the data, it does add to the discussion on the health of the people of Pau and Monte Luna.

The earliest appearance of hypoplastic lines at Pau and Monte Luna occurred between 0.90yo-3.10yo and between 1.95yo-2.95yo, respectively. Furthermore, at Monte Luna hypoplastic lesions corresponded with a shorter stature in both males and females, and females were more affected by EH than males.

6.9.3 Sardinia Growth from Middle Neolithic to Punic Era

The nuances in studying stature are numerous, in terms of methodology, differences across the millennia, and between sexes of the same population (Martella et al., 2016). In the present study, published data on stature during the Neolithic were used as Pau's remains were poorly preserved and did not yield data suitable for comparative studies. Similarly, the Monte Luna sample size was very small and only limited comparisons were possible.

During the Early Pleistocene, Sardinia was connected to the Italian continent (Sondaar, 1977), which possibly led to large-scale immigration to the island prior to the last glaciation (Calò et al., 2008).

The archaeological evidence of obsidian relics found outside the island suggests that the Neolithic Sardinians were involved in extensive trade activities (Alciati, 1978; Luglié, 2019). This movement of people and their genes is important to consider when interpreting the variability in stature of the ancient skeletal remains from the Early Neolithic to the Middle Ages (Floris, 1983; Martella et al., 2016; Danubio et al., 2017).

Nutrition has to be considered as a possible cause of the observed variation in stature, as diet strongly influences growth during childhood. An inadequate food supply could lead to delayed growth and short stature in adulthood (Bogin and Smith, 2020). Variation of stature in Sardinia across time was influenced by both differences in food and behaviour based on archaeological data. During the Neolithic, the introduction of agriculture probably separated people in that some had more access to dairy and meat, while others had to rely more on plant-based food, as suggested by food residues found in Middle Neolithic pottery (Fanti et al., 2018). The subsequent increase in stature during the Bronze Age, could be explained by the reported high intake of milk and meat from cows, deer, pigs, and sheep (Pes et al., 2017). In the Punic Era, the transition to agriculture is complete and Sardinia is a supplier of grain to the main city of Carthage (Pesce, 1961; Moscati, 1985; Van Dommelen, 1998; Bartoloni, 2017). Archaeological findings show a diet based on mostly cereals, legumes, fruits, seafood, as well as domesticated animals such as sheep, goats, and pigs (Ramon Torres, 1995; Sanna, 2019). There were probably societal differences in access to food, possibly causing childhood stress and decreased stature in some people.

Furthermore, infectious diseases such as malaria are reported to slow growth, affecting a person's genetic potential for stature, as seen in populations in contemporary under-developed countries (Pes et al., 2017). Malaria was endemic to Sardinia from prehistoric times up until 1950 when it was eradicated (Brown, 1984). The disease was considered critical in shaping population genetics, the economy, and culture throughout history (Brown, 1981; Tognotti, 2008). In fact, the primary malarial vector, *Anopheles labranchiae*, was indigenous to the island and existed well before human habitation (Trapido, 1951; Aitken, 1953). The Carthaginians probably imported malaria when they brought new populations (900-300 BC) from North Africa to the island to help cultivate the fertile plains (Tognotti, 2008). The Trexenta, the area in which Monte Luna is located, is famous for its fertile plains but also characterised by multiple swamps. The ecological and epidemiological conditions favoured the spread of mosquitoes and hence malaria, possibly affecting stature in the Sardinian population.

Moreover, genetics has a significant role in influencing human stature (Allen et al., 2010; Wood et al., 2014). The Sardinian population is highly affected by beta-thalassemia, a genetic adaptation to malaria (Cao et al., 1978), which is associated with short stature (Brown, 1983; Tognotti, 2009). The condition causes a delayed onset of puberty due to an insufficient production of sex hormones (hypogonadism) leading to stunted growth and development. As a result, individuals affected by beta-thalassemia may not reach their full potential adult stature (Pes et al., 2017). People with severe beta-thalassemia major, the homozygous state, did not survive until the development of advanced treatments in modern times (Cao, 2004), while people with minor, heterozygous forms of thalassemia, resulting shorter stature may have survived (Pes et al., 2017).

Interpreting the health and frailty of Sardinian children and adults represents a challenge due to issues outlined in the osteological paradox (Wood et al., 2010) such as selective mortality, hidden heterogeneity in frailty, and demographic nonstationarity. Although there was a reasonably good representation of subadult remains in both samples (with the exception of the very young in the Monte Luna sample) (Chapter three), the prevalence of enamel hypoplasia was low, suggesting many subadults died from acute conditions before skeletal changes could occur. The subadults of Pau had a higher frequency of enamel hypoplasia (31.4%) than the Monte Luna sample (11.47%). However, this is still the second highest frequency in the studied populations, leading to the hypothesis that these communities had a high proportion of frail children in both the Middle Neolithic and Punic Era

(Wood et al., 1992; Domett, 2001). The young adults in Pau and Monte Luna showed high levels of hypoplasia which, in Monte Luna, is also associated with a slightly shorter stature than the mean average for both sexes. This may suggest the presence of some 'medium frail' children who survived a number of stress events, and reached adulthood albeit with a slightly reduced stature. Lower average statures of European populations (Danubio et al., 2017; Pes et al., 2017; Martella et al., 2018) could suggest that they experienced episodes of malnutrition or illness which affected their growth. Therefore, the slightly taller stature of males in Monte Luna compared to previous reports (Danubio et al., 2017; Martella et al., 2018) in conjunction with the EH data indicates that environmental stressors have the least effect on male growth. While the stature of women is consistent with the stature reported in other studies (Danubio et al., 2017; Martella et al., 2018), it suggests that some females were unable to reach their genetic potential. Catch-up growth may compensate for any loss suffered during events of stress if adequate nutrition is provided, however, chronic stress can result in shorter stature (Stinson, 1985). Females are considered to be environmentally buffered (Kuh et al., 1991) and possibly less affected by stress (Brundtand et al., 1980). The majority of females with EH in Monte Luna had a shorter than average stature possibly due to limited access to food, less care when ill, or a genetic predisposition to beta-thalassemia (the gene of which is located on the X chromosome). Further studies using isotope analysis, DNA, and x-rays to verify the anaemic condition of the bones will be carried out.

6.9.4 Limitations and bias

The study of stature and EH suffers the following limitations:

- The methods used were developed based on different populations.
- The results of the present study cannot be compared with other studies on Sardinian samples due to the absence of mean and/or standard deviation values in these studies.

These limitations and biases were addressed by applying a multi methodological approach to estimate sex, and stature. Hypoplastic defects, which were only studied macroscopically, are presented as a general indicator of stress.

7 AN UNUSUAL CASE OF PRONE POSITION IN THE PUNIC/ROMAN NECROPOLIS OF MONTE LUNA IN SARDINIA (ITALY): A MULTI-DISCIPLINARY INTERPRETATION OF TOMB 27[2]

7.1 INTRODUCTION

In the last few decades, the highly detailed analysis of human skeletal remains, and the individuals they represent has seen a significant surge of interest (Buikstra and Beck, 2006). The creation of individual osteobiographies of past people has provided a nuanced understanding of individual lives, as well as adding data to the population perspective potentially allowing larger social phenomena to be examined (Binford, 1971; Domett et al, 2016). Key to the understanding of past people's lives based on their biological evidence, is the consideration of the context in which they lived, their social and physical environment, and died - a truly bioarchaeological approach (Gowland and Knüsel, 2006).

A re-examination of an old photograph of Tomb 27 (Figure 30), excavated from the Punic/Roman Necropolis of Monte Luna (Senorbì) in Sardinia, stimulated the present study. The photograph shows the individual in a prone deposition and surrounded by grave goods. An individual buried in a prone position is often considered deviant (Murphy, 2008, pp 12 - 17) if it is different than the norm for the period and/or populations on which the examination is focused. It has been widely observed that, regardless of culture, period and geographical area, humans tend to bury some individuals in their

[2] *This chapter is written as a standalone journal article, published by the Journal of Archaeological Science: Reports 48 (2023) 103846, doi: https://doi.org/10.1016/j.jasrep.2023.103846. As such, there will be some repetition from previous sections particularly in regard to context and materials.*

society in particular ways, differentiating them in death from others. These usually reflect specific circumstances such as an individual guilty of criminal behaviour, women who died during childbirth, and people affected by dangerous and inexplicable diseases or disabilities (Tsaliki, 2008). While each case reflects specific social and religious beliefs, they can generally be interpreted as an apotropaic way to prevent the person's return from the world of the dead, ensuring their permanent exile from the living community. There are testimonies from the Roman age to Medieval times, both in Italy and in Sardinia (Piga et al., 2015; Quercia and Cazzulo, 2016), that provide a basis for understanding the case presented here, however, there are some aspects that differ from the common profile of such deviant burials. The aim is to examine all the available archival evidence, the current literature, alongside a detailed archaeological analysis of the region, the time period and grave goods, and the biological data from the skeletal remains themselves. All aspects may have relevance to the interpretation of the symbolic behaviour useful to reconstruct a story of a single individual to understand the ideology of the community that buried them.

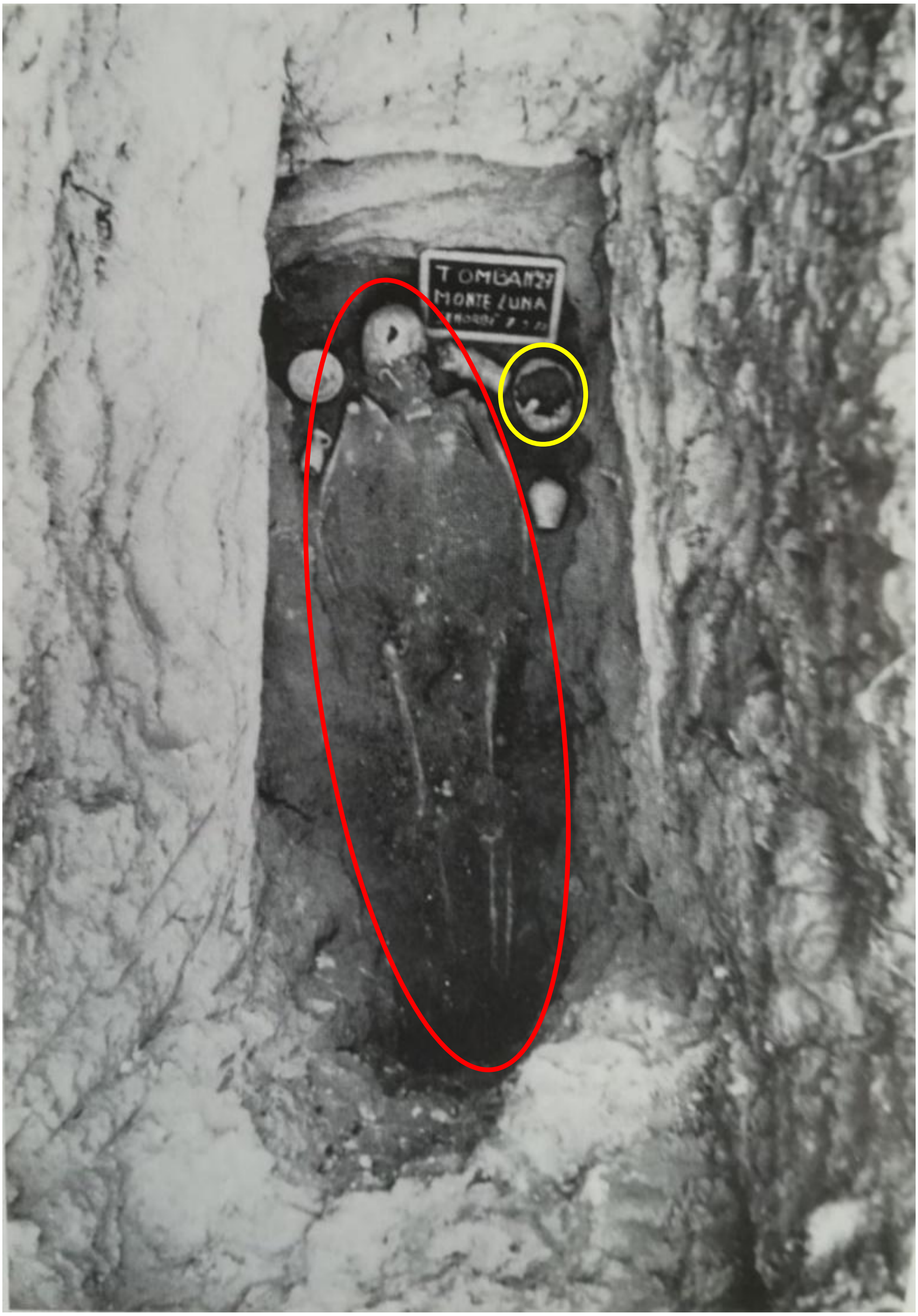

Figure 30 Tomb 27 (Costa, 1980, tab. XCIII). First layer of excavation exhibiting a prone deposition (red oval); in the right corner, representing a lower layer, is the cranium (yellow oval).

7.2 ARCHAEOLOGICAL CONTEXT

7.2.1 Geographic and historical background

The site of Monte Luna is in the central-southern part of Sardinia, near the town of Senorbì, which is 30 km north from Cagliari (Figure 31). The necropolis is thought to be linked to the urban settlement of Santu Teru, a Punic-Roman town active from the 6th century BC until mediaeval times, probably as a direct emanation of the city of Cagliari (KRLY in Punic language and Caralis/Carales or Karalis/Karales during the Roman phase). During the Punic phase KRLY was possibly in charge of the entire area where Santu Teru is located. In fact, this settlement is linked to an agricultural economy managed by the city of KRLY under the direction of the main Punic centre of the Western Mediterranean, Carthage. The town of Santu Teru was possibly one of the main urban settlements linked to the management of cereal production, probably wheat, for the Punic city of KRLY and it demonstrated a high level of wealth, as suggested by the majestic funerary artefacts found in the Monte Luna necropolis active from the end of the 6th century BC to the Roman Republican age (Todde, 2020). More is known about the settlement of Santu Teru during the Republican and Imperial ages, attested by an inscription (Forci, 2011) which states that the city was active during the first Imperial age. Information regarding the Imperial age phases is disjointed and incomplete. However, Santu Teru seems to have survived beyond the end of the Roman Empire dated to the 6th century AD as is evidenced by some Late Antique and mediaeval pottery (7th - 8th c. AD) found near the site of the so-called acropolis. The acropolis was a place where some scholars had hypothesised the existence of the mediaeval village attested by the agiotoponym of Santu Teru, which is linked to a church related to the worship of Saint Theodorus that gives name to the whole area (Costa and Usai 1990).

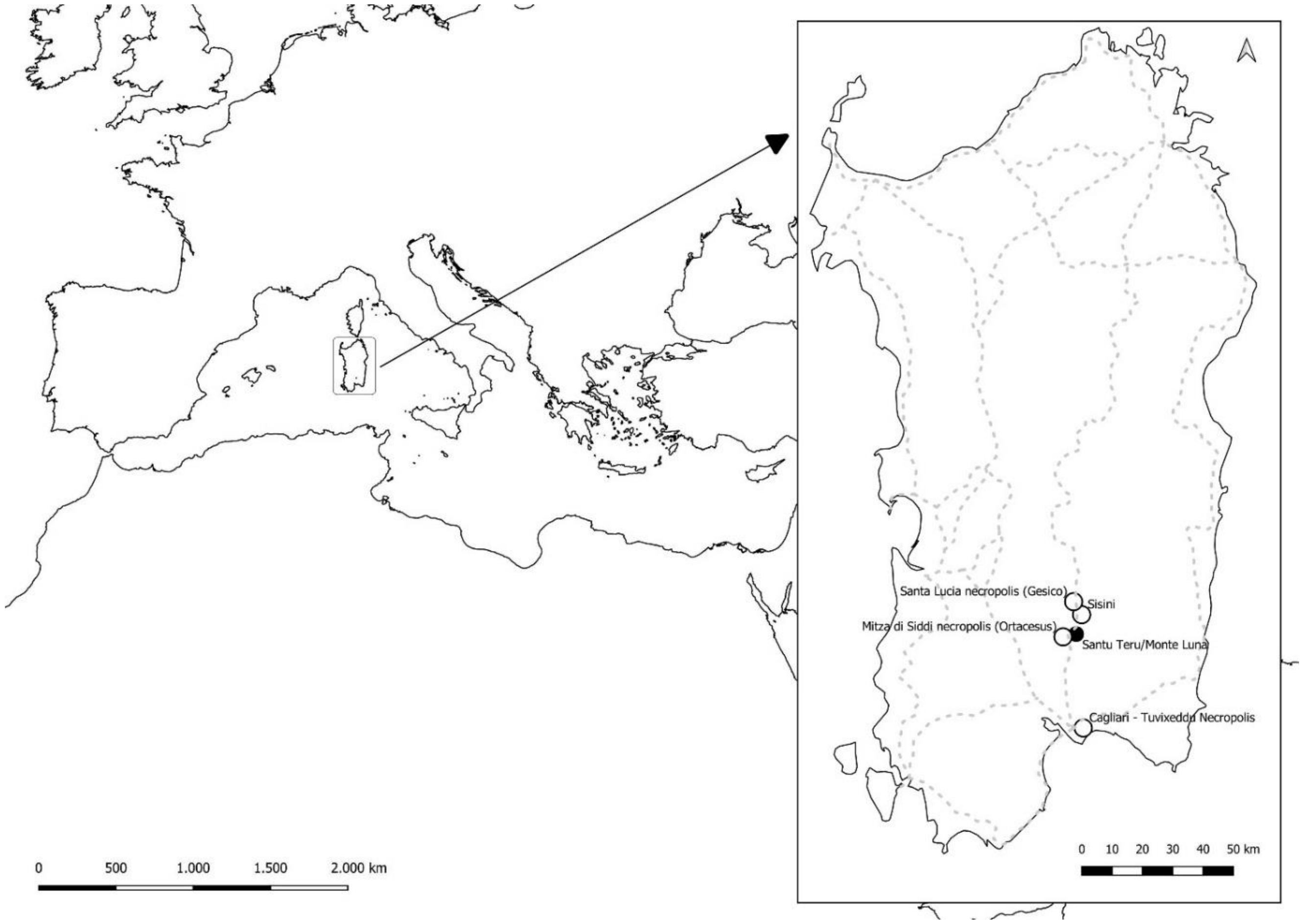

Figure 31 General map of South-East Sardinia (Italy) with the archaeological area of Monte Luna (Senorbì) and other main sites mentioned in the present paper. (Map: D. D'Orlando)

7.2.2 The necropolis of Monte Luna

The necropolis of Monte Luna (Figure 32) was investigated archaeologically during the late 1970s to the early 1980s by Antonio Maria Costa as Ispettore onorario (Honorary Inspector) for the local Soprintendenza ai Beni Culturali (Superintendent for Cultural Heritage). Only a portion of the necropolis was excavated but at least 120 tombs were partially documented, though there is a significant lack of contextual information recorded (Costa, 1980; 1983a; 1983b; 1983c; Costa and Usai 1990).

Figure 32 Aerial photography of Monte Luna at present. Red arrow indicates Tomb 27 (Aerial photo and planimetry: R. Paba)

During the investigation, Costa describes two different funerary areas. The first, Monte Luna, active from the 6th - 2nd century BC, located immediately in front of the hill of Santu Teru, with its wealthy tombs and the second, the *necropoli romana* (Costa and Usai, 1990), a few metres north-west from Monte Luna, which was active from the 2nd - 1st century BC until the 4th - 6th century AD. The original funerary area of Monte Luna is composed of chamber tombs with an access pit similar to the ones used in the necropolis of Tuvixeddu in Cagliari, pit-tombs, like Tomb 27, along with other types such as cist tombs and *enchytrismoi* (jar burials) (Costa, 1983c). Some of the tombs, such as Tomb 87, also known as the *tomba principesca*, suggests a number of the inhabitants of Santu Teru were wealthy as they were buried with funerary goods including masterpieces of Magna Graecia jewellery (Usai, 1981; Pisano, 1996). As to the rituals, there is evidence for both inhumation and cremation, but the former is the more common rite (Costa, 1983c). The *necropoli romana* instead is little known and only 10 tombs were excavated. This funerary area is composed of simple rectangular graves and cist tombs and were probably in use after the necropolis of Monte Luna.

7.2.3 The archaeological framework of the Tomb 27

Tomb 27 is a pit-tomb (Figure 33) carved into the stone of the hill of Monte Luna. The funerary artefacts found in this tomb include a pitcher, a balsamarium (ointment jar) of Punic-era production, and a jug and cup of Punic Black gloss-ware, providing evidence of the chronology of the deposition. Two coins and some glass beads that were part of a necklace were also found (Figure 34).

Figure 33 Tomb 27 grave goods. (D. D'Orlando). Licensed by MIC – Soprintendenza Archeologia, delle arti e paesaggio per la città metropolitana di Cagliari e le province di Oristano e Sud Sardegna; reproduction is prohibited.

The pitcher may be an example of the last evolution of the Cintas 61 type vase, which dates to the 3rd-2nd century BC. One has clear similarities with some of the vessels from the necropolis of Tuvixeddu (Bartoloni, 2000, pp. 91) and could be considered to suggest a direct commercial, and perhaps cultural, connection between Cagliari and Santu Teru. The coins, one of Sardo-Punic era and one Roman emission overstruck on an earlier Sardo-Punic coin, are of particular interest (Hersch, 1953). The latter helps to date the context to between the last decade of the 3rd century BC and the beginning of the 2nd. Even more precise, from a chronological point of view, is the Punic Black gloss pottery cup, identified as a Lamboglia 28F/Morel 2648 form, dated from the end of the 3rd until the 2nd century BC (Morel, 1981, pp. 200-201). The funerary artefacts of Tomb 27 all confirm that the burial context dates from at least the last decades of the 3rd century BC but, given the presence of the other artefacts, a more precise chronology into the early 2nd century BC, perhaps from the very first decades, is suggested.

7.3 ANTHROPOLOGICAL SETTING

The necropolis of Monte Luna contained 120 tombs, but human remains were recovered from only 70 tombs. The majority of these 70 tombs were also re-used, containing between two to 12 adults within one tomb. When subadults and young children are present in a tomb, there is only ever a maximum of two individuals (subadult included) within that tomb. Tomb 27 is located near two analogous tombs, Tomb 25 and 28, that each, like Tomb 27, contain two individuals, one adult female and one subadult. In addition, the individuals within Tomb 28 also have the same non - metric traits and presence of grave goods as Tomb 27. It is possible that within the necropolis, burials were located based on familial lineage. Whether the people in each tomb are family, will hopefully be confirmed through DNA analysis in further studies.

Due to poor preservation and comingling of the human remains within tombs, the recording of each tomb is undertaken in a systematic manner as follows: each element is sorted by anatomical region and side, and, where possible, upper limb bones (humerus, radius and ulna) are matched to an individual, as are lower limb bones (ilium, femur, tibia, fibula); for each bone, morphology is described and measurements are take; then, following standard methods, age-at-death and sex are estimated, and pathology and trauma are described (Buikstra and Ubelaker, 1994; White and Folkens, 2005; Schaefer, et al., 2009).

The minimum number of individuals (MNI), based on the same repeated element within tombs, in the 70 tombs studied has been calculated at 226 adults over 15 years (Brothwell, 1981; Lovejoy, 1985) and 59 subadults between 1-15 years (Schaefer, et al., 2009). No subadults less than 1 year have been found, which suggests the possible presence of a *tophet*, a designated funerary area for unborn and newborn perinates, that was common in Phoenician and Punic times (Xella, 2013).

7.3.1 Human remains from the Tomb 27

Given that the excavation diary was missing, the analysis of the 1977 excavation photograph (Figure 35) was essential in understanding the deposition of Tomb 27. In fact, from the image, it is possible to observe a deep grave (2.10 x 0.8 m), showing two distinct excavation levels. It shows the prone deposition of one articulated skeleton which occupies the entire space of the tomb located in the upper layer, and the location of another deeper deposition, a non-articulated skeleton in the upper right corner. Based on the articulated nature of the prone skeleton (ML_T27.2), it is evident that this individual was the second deposition. The cranium located in the upper right corner of the pit (Figure 1) was the first deposition (ML_T27.1), that was disturbed by the burial of ML_27.2; the postcranial remains of ML_T27.1 were found at a deeper level. Seventy-five per cent of the skeletal remains were recovered for both individuals.

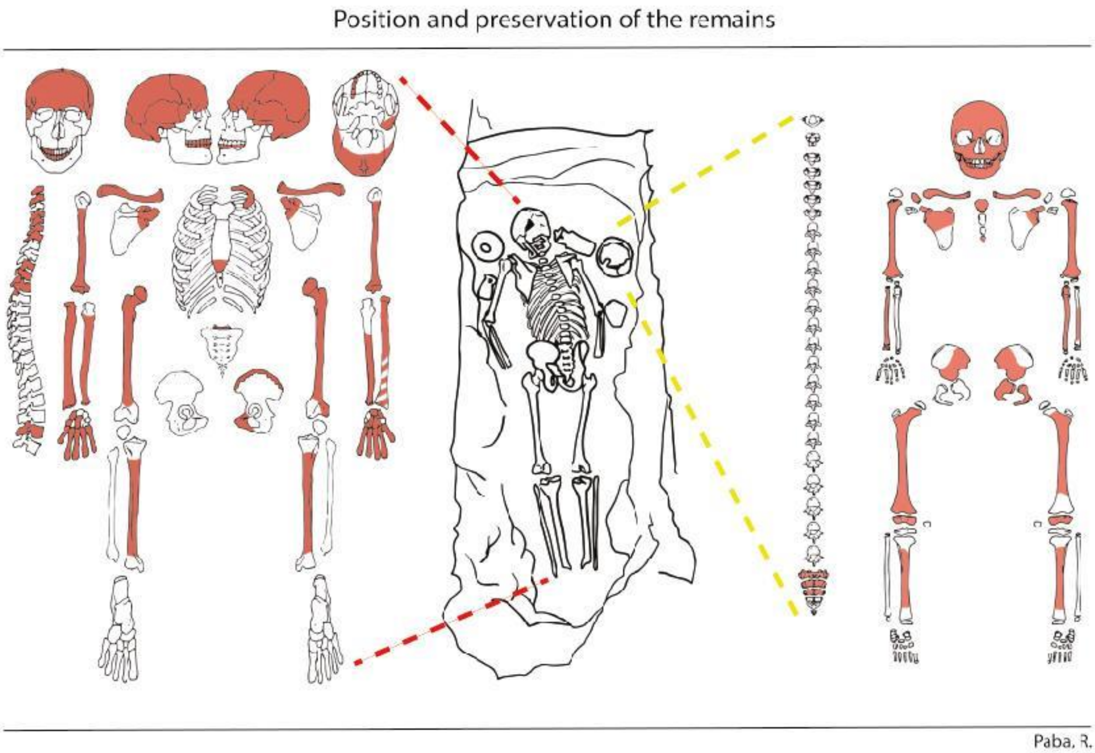

Figure 34 Graphic representation of position and conservation of the human remains from Tomb 27. The yellow lines indicate the cranium around which was found the postcranial remains of T27.1. The preserved remains are indicated in the skeleton schema to the right. . The red lines indicate the location of T27.2, found in the prone position, and represented by the preserved remains shaded in the skeletal diagram to the left. (Paba, R.).

The former deposition (ML_T27.1) was estimated to be aged 15 years +/- 3 years based on tooth eruption and epiphyseal fusion. All second permanent molars were erupted, while the crowns of the third permanent molars were only half formed and unerupted. In addition, non-fusion is recorded at the proximal and distal epiphyses of both humeri, the right radius and the left ulna; the acromion process is partially fused, and the coracoid is unfused in the right scapula; the three bones of the pelvis are unfused; the unfused distal epiphysis of the right femur is also present (Schaefer, et al., 2009). Sex was estimated through pelvic and cranial morphology (Schaefer, et al., 2009), but given the very young age, skeletal sexual dimorphism may not yet be fully developed, and this estimation awaits further study, such as through enamel peptide analysis (Stewart et al., 2017).

The prone deposition (ML_T27.2) was estimated to be a young adult female, based on pelvic and cranial morphology (Buikstra and Ubelaker, 1994), aged between 18-22 years (Schaefer, et al., 2009). Age-at-death was estimated using a multifactorial approach including dental eruption, dental wear, and epiphyseal fusion. The femoral head femur and iliac crest were partially fused. Stature and weight were estimated respectively as 153.0 cm and 49.2 kg (median on a CI of 95% (Manouvrier, 1893; Pearson, 1899; Ruff, 2012). The stature and weight calculations used here are based on generic European populations, as there are no formulae based on Italians, nor Sardinians. The mean stature of the people buried in the Necropolis of Monte Luna, based on measurements of 32 adult long bones is 157.27 cm for women and 160.62 cm for men.

7.3.2 Genetics factors

The cranial vaults of T27.1 and T27.2 both have a retained metopic suture and Wormian bones at the intersection of the lambdoidal and sagittal sutures (Figure 36). These traits are not common in the necropolis. In other calvaria with ossicles they are located in other places, such along the sagittal suture, and not associated with metopism. These 'primary' discrete traits (Buikstra and Ubelaker,

1994) in both individuals and in the aforementioned Tombs 25 and 28, suggest that there are family areas within the necropolis.

Figure 35 Evidence of metopism (Red arrows) and Wormian bones (Red circles) in T27.1 and T27.2 calvarium (Paba, R.).

The metopic suture usually closes by 2 years of age, though it can close later in childhood (Coppa, and Rubini, 1996) or adulthood (Zdilla et al., 2018). While some individuals with metopic sutures have been reported to have larger transverse, cranial dimensions suggesting this feature may be related to morphogenesis (Bolk, 1917; Schultz, 1929), this is not the case in T27 and T28 crania. Further support to a more genetic aetiology is the persistence of the metopic suture into adulthood, which can be hereditary and is more common in some ethnic groups than others (Berry and Berry, 1967). There are some external factors, such as frontal sinus abnormalities, or pathological conditions, such as hydrocephaly, that may also cause it to persist (Zdilla et al., 2018) but the above conditions are excluded in T27. In this case, according to the studies of Torgensen (1951) and Sjovold (1984), metopism is considered to be a hereditary trait.

Lambdoidal Wormian bones are the result of extra ossification centres, but their aetiology is not fully understood (Bellary et al., 2013). In some cases, they are a normal anatomical variation, associated with mechanical stress and the environment (Sanchez-Lara, 2007). For example, in some populations sleeping in a supine position places pressure on the occipital area that can lead to expansion of the occipital suture and brachycephaly (Sanchez-Lara, 2007). This can be excluded in the case of T27.1 and T27.2 because their skulls are not brachycephalic. In other cases, Wormian bones may be related to specific pathology, such as hydrocephaly or craniosynostosis, but these conditions are usually associated with numerous, more than 10, and large, Wormian bones and arranged in a mosaic pattern and size larger than 6 mm by 4 mm (Bellary et al., 2013). Other factors suggested to be correlated with the development of Wormian bones include epigenetic factors, cranial deformation, craniosynostosis, and premature suture closure, none of which are observed here. Other conditions, such as additive polygenic complex or osteogenesis imperfecta may have Wormian bones associated with them (Coppa and Rubini, 1996; Goto et al., 2004; Semler et al., 2010; Bellary et al., 2013). Wu et al., (2011) reported that geographic and ethnographic patterns in frequency suggest a possible genetic basis, with a low frequency in Europe populations.

The presence of both these variations in both these individuals and the absence of mechanical stress and cranial deformation, may suggest T27.1 and T27.2 were related to each other, but further evidence, such as DNA, would be required to be certain.

Interestingly, in the necropolis the same condition is present in Tomb 28, although the female adult (18-22 years old) has only a thin line of metopism, while the subadult (9+/-3 years old) has a complete opening through the frontal bone up to the coronal suture similar to both individuals in Tomb 27. The Tomb 28 individuals also have Wormian bones located in the lambdoidal suture, with the same shape and number of ossicles (2).

7.3.3 Trauma

Individual T27.2, the young adult female, presents with multiple traumatic lesions (Figures 37, 38, 39), suggesting the presence of both antemortem and perimortem trauma.

There is a healed fracture in the midshaft of the right clavicle (Figure 37). Healing has resulted in a thickened middle half of the clavicle. These types of fractures often occur in childhood and typically result from axial, longitudinal compressive forces (Nunn et al., 1989) commonly associated with a fall onto the shoulder or the outstretched hand, or from a direct blow to the humerus, either of which could be accidental or the result of intentional violence (Blount 1955; Thornton and Gyll 1999).

Figure 36 Evidence of healed trauma in the midshaft of the right clavicle of T27.2. Superior view (A) with focus on the healed trauma in red rectangle, and posterior view (B), red arrow points at the trauma. (Lai, G.).

Two traumatic injuries are evident on the cranium, possibly occurring peri or postmortem. One triangular-shaped lesion, measuring 41 x 19 mm, is located on the inferior aspect of the left occipital bone, just posterior to the lambdoidal suture (Figure 38) inferior to the hat brim line which is not consistent with an intentional blow (Kremer, 2009). Endocranially, there is an 'exfoliation' of a bone flake (Figure 38D/E) which is commonly seen with blunt force trauma as the force moves from the external aspect, inwards (Wedel and Galloway, 2004). There is also evidence of two short radiating fracture lines out from the medial aspect of the lesion usually associated with a moderate- or high-velocity impact on a common point (Kieser et al., 2014) (Figure 38B).

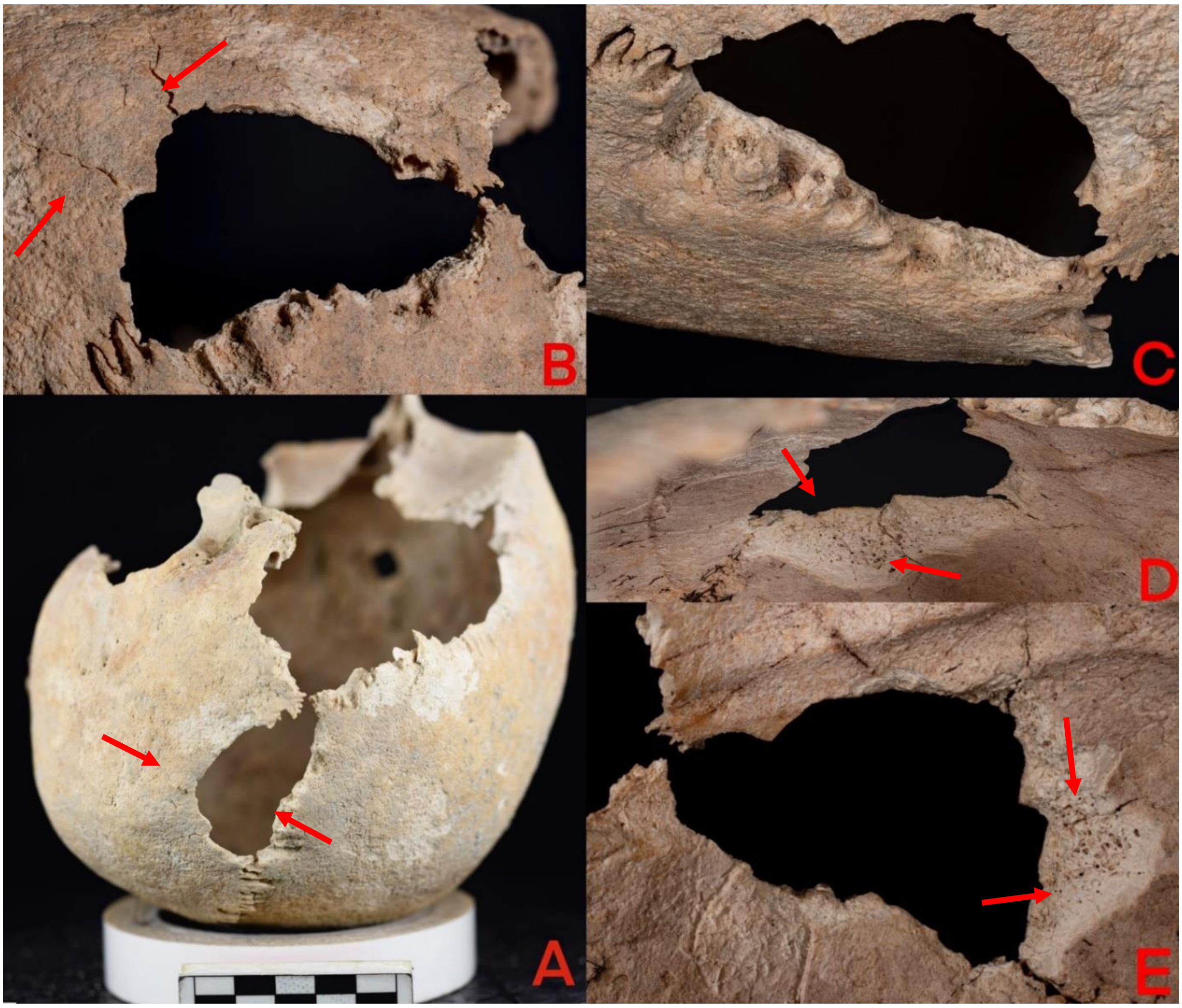

Figure 37 Evidence of trauma on the occipital bone adjacent to the left lambdoid suture (A) (Paba, R.). (B) ectocranial surface with radiating fractures (red arrows). (C) the lambdoid suture (ectocranial view, showing remodelling likely from partial suture closure with normal aging) indicating a disarticulation due to a diastatic fracture along the suture has occurred. (D) and (E) show flaking is evident on the endocranial surface. The flake was not found. (Lai, G.)

This traumatic lesion is possibly a short radiation fracture along the suture, leading to a possible diastatic lesion which caused the left lambdoid suture, at the point of trauma, to disarticulate (White et al., 2012, p.434). This suggestion is supported by the observation that most of the other sutures (coronal, sagittal, and right lambdoid) are slightly more fused than the left lambdoid (Buikstra and Ubelaker, 1994). In Figure 38C, it is possible to see where the disarticulation has occurred as there is a change in the surface of the suture to a rounded and pitted area possibly as a result of osteoclastic reaction within the first week of the trauma (Barbian et al., 2008) though could also be remodelling from normal suture closure with aging. Considering the location of the lesion, the radiating fractures, and the opening along the lambdoid suture, this is likely blunt force trauma either from an object or a fall onto this area of the head.

The second cranial lesion was located on the right side of the frontal bone showing a penetration from the outside inward (Figure 39). The shape (9.5 mm x 9.5 mm) of the lesion suggests a sharp force injury was inflicted using an object with a quadrangular section (Figure 39B). Intentional trephination is unlikely as there are no associated cut marks extending out from the lesion that would be consistent with the usual trephination practice in the Roman Era (Tullo, 2010; Giuffra and Fornaciari, 2017). There is a depression and exfoliation around the area of impact in the outer table due to the force of impact, and there is also bevelling of the inner table edges of the lesion (Figure 39G) (Barbian et al., 2008; Facchini et al., 2008; Amadasi et al., 2016); both are characteristic of penetrating injuries with a highly localised point of impact associated with considerable power (Wedel and Galloway, 2004). There is no evidence of bone remodelling (Figure 39), suggesting this incident occurred perimortem (Barbian et al., 2008). The shape of the lesion is similar to the cross section of ancient Roman nails. These nails are a common object in Roman settlements excavations in Sardinia (Figure 40).

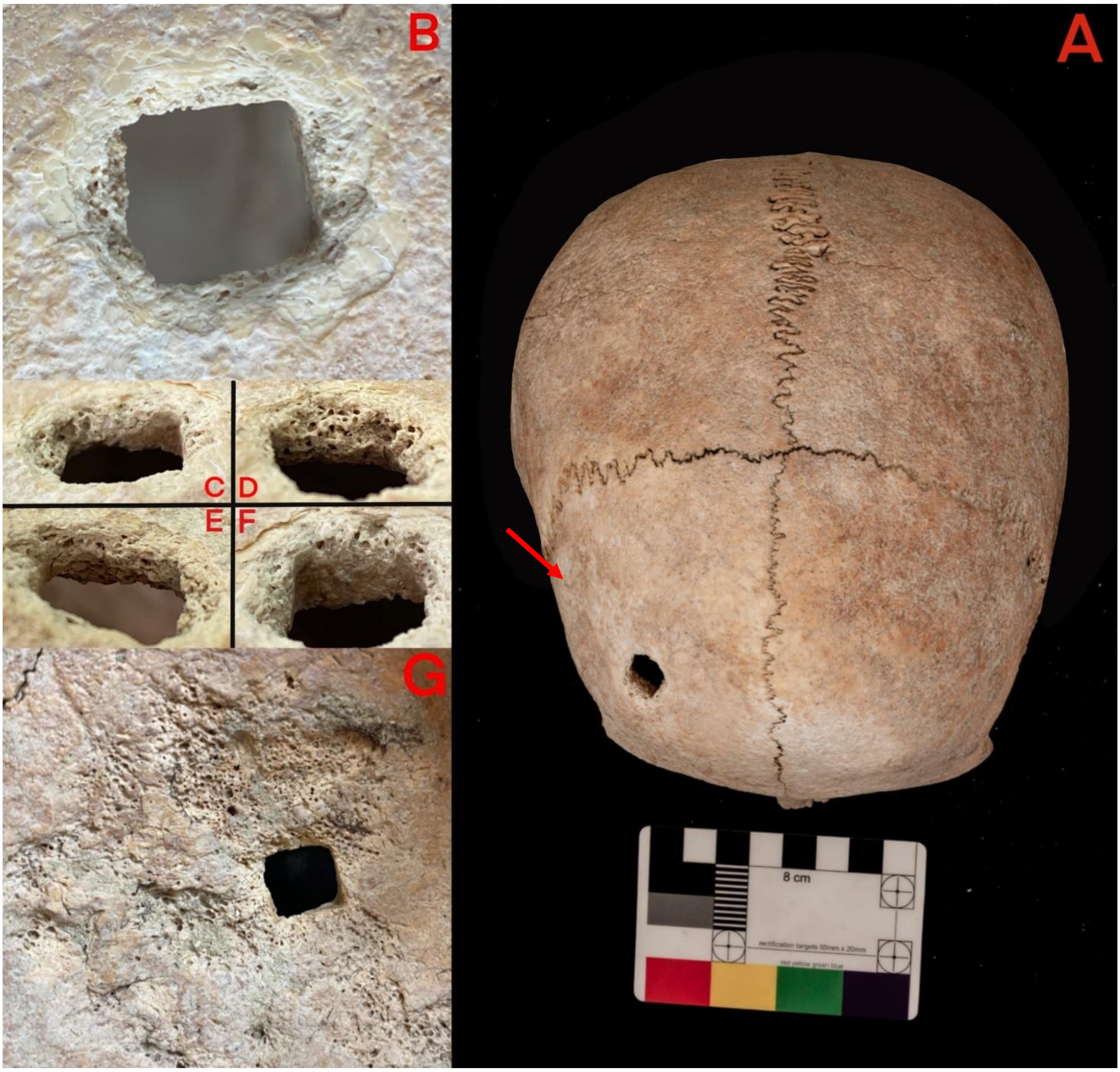

Figure 38 T27.2 skull. Evidence of frontal trauma is shown (A) (superior view) (Lai, G.). (B-G) Close up of the right frontal bone trauma. (B) ectocranial view of the trauma showing bone flaking. (C - F) close up of the internal edges of the trauma (ectocranial view). (C) is the posterior side, (D) is the right side, (E) is the inferior and (F) the left. These edges show exposed diploe due to the perimortem trauma. (G) Endocranial view indicating bevelling of the inner table. (Paba, R.).

7.4 Discussion

The skeletal remains of T27.2, a young woman buried in a tomb at the Monte Luna necropolis, are noteworthy not only because of their unusual prone position, but also for the presence of perimortem trauma. The necropolis, and the people buried within it, is of significant interest from a cultural perspective as it provides an insight into a critical period of transition from the Punic period to the Roman dominion for the city of *Santu Teru*.

7.4.1 The trauma and its cultural significance

T27.2 presents with multiple traumatic lesions, one healed fracture of the right clavicle and two cranial, possibly perimortem, lesions.

The cranial lesions are in the posterior aspect of the lambda suture in the occipital bone and on the right frontal bone. The occipital lesion (Figure 37) is typical of blunt force trauma most likely from a direct force such as from a fall, landing on the back of the head. Intentional cranial trauma is often associated with multiple traumatic lesions, often including facial trauma, and the lesions often occur on the left side (Guyomarc'h et al., 2010). T27.2 does have trauma on the left side and has another cranial trauma on the frontal bone, however this lesion does not fit the typical pattern of interpersonal violence-related trauma. In addition, the posterior fracture is within the 'hat brim line', suggesting the lesion is most consistent with an injury sustained from a fall (Kremer et al., 2009). It cannot be discounted, however, that the woman has fallen after being intentionally pushed.

The lesion on the right frontal bone, as discussed above, is quadrangular in shape and is typical of penetrating (sharp force) injuries (Wedel and Galloway, 2004; Amadasi et al., 2016; Facchini et al., 2008). The distinctive shape of this perimortem lesion is reminiscent of the square-shaped cross-section of nails commonly used in Roman times. Such nails can be directly compared to those found in the coeval and nearby site of Sisini (D'Orlando, 2019) (Figure 40). The Sisini nail has a cross-section of 7.5 mm x 7.5 mm, which is consistent with the measurement of the trauma (9.5 mm x 9.5 mm). The nail length is 103 mm and this helps to exclude the possibility that the nail exited at the occipital lesion, as the sagittal measurement from the frontal trauma to the occipital lesion is 160 mm

(Video representation in Appendix E). The significance of a potential nail being used around the time of death is more fully discussed below.

Roman ballista bolts have a similar quadrangular cross section and size (Pental et al., 2014; Rossi et al., 2015). However, there are no findings of Roman ballista bolts in the area, and they tended to be used only during warfare. There is no evidence for siege or warfare at this time period or for the region around Santu Teru. In addition, the gender of T27.2 also makes it unlikely that a ballista bolt caused this injury as women presence as been reported as abnormal and transgressive (Boatwright, 2011).

Figure 39 Nail from Sisini. (Lai, G.).

7.4.2 The burial archaeology

Tomb 27 is a pit-tomb carved in the stone of the hill of Monte Luna. The funerary artefacts include burial objects from a transition phase between Punic and Roman cultures that date back to the Mid-Republican period of the Sardinian timeline. Based on the contemporary presence of the overstruck coin and the Punic Black gloss pottery cup, Tomb 27 is dated into the 2nd century BC perhaps from the first decades of the 2nd century BC.

The funerary artefacts also suggest that there was a widespread shared culture in the rural landscape of Cagliari and its hinterland during the Punic-Roman ages. A locally made *balsamarium* (ointment jar) found in Tomb 27, is similar to a form commonly found in the Tuvixeddu necropolis (Bartoloni 2000, p. 91) and in the Santa Lucia funerary area (Gesico, SU) (Tronchetti 1996, pp. 999-1000) (Figure 34).

The entire funerary context of Tomb 27, including the placement of objects in the tomb, is more typical of a single deposition, rather than two interments. In the nearby necropolis of Mitza di Siddi, singular depositions such as Tomb 67 and 113 (with the same chronology as Tomb 27 of Monte Luna) (Cocco 2009, pp. 60-63; 80-83) contain a similar number of artefacts as Tomb 27, leading to the hypothesis that the prone individual, T27.2, may have been interred without any objects. As such, T27.2 may exhibit further evidence of deviancy (Shay, 1985). Therefore, there are multiple lines of evidence to support the case of Tomb 27 representing an unusual funerary rite: the prone position of the body, the perimortem cranial trauma, and the lack of artefacts.

Ethnographic sources suggest a wide range of reasons for the prone deposition of an individual including as punishment for a perceived fault. For example, the Merovingian King Pepin “asked to be buried face down for the sins of his father” (Taylor, 2008, cited in Gilchrist and Sloane, 2005, p. 154). But perhaps the most common explanation is related to *necrophobia*, mostly associated with a fear that the corpse could disturb the living (Tsaliki, 2008). These transcultural superstitions across the Mediterranean region were linked to witches, werewolves, vampires, and other mythical creatures (Quercia and Cazzulo, 2016).

Atypical burial rites have also been associated with contagious diseases and epidemics in antiquity (Tsaliki, and Taylor, in Murphy, 2008, pp. 18-32; 102-123). For example, *Pliny the Elder*, in *Naturalis Historia* (AD 77), describes a connection between a cross-eyed person and beliefs about an evil eye. This led to Romans' beliefs around other misunderstood diseases such as epilepsy, or so called *morbo sacro*, that was previously described by Hippocrates of Coos (5th century BC) in one of the first scientific treatises written on the topic (Hippocrates, *De Morbo Sacro*, 4). The disease was thought to include a powerful element of impurity both for the individual and for their community since they believed that epilepsy was contagious. For this reason, the treatment of the victims was mostly related to a purification rite dedicated to the divinity responsible for the sickness. *Pliny the Elder* wrote in the 1st century AD, that if a person died from an epileptic seizure it was suggested to nail the part of the body in which the trauma began to prevent the diffusion of the disease, miasma, into the community (Pliny the Elder, *Naturalis Historia*, 28 17, 63) and requires purification.

This raises the possibility that the frontal bone lesion in T27.2 was created by a ritual nail, though a nail was not left in this tomb. Elsewhere in the Mediterranean, sacred nails are usually left in the tomb, as attested in religious contexts. Sacred nails are usually marked with sacred symbols indicated as *charakteres*, letters and signs inscribed on a magic object, which are common in Graeco-Egyptian, Judeo-Christian, and other religious practices (Bevilacqua 2001). Such sacred objects were associated with auspicious and apotropaic functions. Nails were a powerful symbol in ancient times usually associated with the concept of *defigere*, meaning to fix down or fasten something. In a religious context, these objects are linked to specific rituals. The ritual of the *clavum figendi* (to nail) was used to celebrate recurring or official events, such as the foundation of a temple or the beginning of a new year. They are linked as well to the *tabulae defixionum*, curse tablets (usually made of lead), which were pierced by nails and hidden in places near to the underworld such as necropolises or wet places as the water was a useful medium to link the living and the dead (Dungworth, 1998). The practice described by Pliny is clearly linked to the power attributed to nails, which could prevent or avoid a particular occurrence (Bevilacqua, 2001, p. 133). The use of a ritual nail on a person usually occurred after death. Such is the nature of perimortem injuries, that it is impossible to determine whether the perimortem frontal lesion in T27.2 occurred just before or after death.

One such hypothetical explanation for T27.2 may be that they were suffered a series of epileptic seizures that could have first resulted in the clavicle fracture. A subsequent seizure may have led to the blunt force trauma to the occipital bone, perhaps occurring as the woman fell or knocked their head against something hard. In fact, as presented in contemporary clinic literature, people affected by epilepsy are three times more likely to injure themselves during seizures and among the most common types of injury (that might be seen on a skeleton) are head injuries, fractures, and dislocations (Nguyen et al., 2009; 2013; Camfield et. al., 2015). The blunt force trauma after an epileptic seizure may have been the cause of death and the sharp force trauma was inflicted around this time to prevent the miasma associated with the epilepsy spreading to the community. The woman was then buried in the prone position, further symbolising her aberrant life and/or death.

There are, of course, other possible explanations for this collection of archaeological and biological evidence. For example, prone burials are sometimes carried out on people who have committed particularly harsh crimes (Tsaliki, and Taylor, in Murphy, 2008, pp. 18-32; 102-123). However, if this was the case it is unlikely that such a person would be buried in another person's grave, possibly a relative's grave, and within the community necropolis. Another interpretation could be considering the clavicle fracture unrelated to a seizure and the occipital trauma as cause of a seizure which led to the unusual nailing to release pressure in the cranial vault.

7.4.3 Conclusion: Tomb 27 and its wider significance

The bioarchaeological analysis of a single tomb in the Monte Luna necropolis, Tomb 27, has detailed some striking possibilities around life and death and the cultural perception of these during a period of significant cultural change from Punic to Roman times. While it is clear that T27.2, a young woman, suffered perimortem cranial injuries, the sequence of events and cause of these injuries is not conclusive but give clues and raise the possibility of a significant perimortem funerary rite associated with disease, a nail, and prone burial. This highlights the potential superstitious nature around death most similar to Roman Era culture, suggesting that Roman cultural practices had already been put in place at this early stage of the transition from Punic to Roman culture. Such analyses can focus on the nuances of life in the past, closer to the day-to-day realities of people in past communities in contrast to the larger scale histories of empires and battles.

8 HUMAN REMAINS IN THE CULTURAL SPACE: THE STUDY OF PAST BEHAVIOUR USING GIS AND AERIAL PHOTOGRAMMETRY

8.1 INTRODUCTION

The interactions between humans and nature affect the biological, social, and spatial perspectives of populations (Seymour, 2016). Nature influences humans in their biology and behaviour via the landscape, climate, availability of raw materials, and wildlife. The landscape in particular shapes the characteristics and behaviour of populations. Therefore, the science of geography does not merely describe a landscape as the sum of places, resources, and people but integrates this with social, economic, and historical information (Dardel, 1986). As such, a landscape can be viewed as a territory inhabited and modified by a population through resource extraction based on local knowledge, economic practices, and use of tools which reflect this mutual relationship (Claval, 2004). Cultural symbols embedded in the landscape further inform on the relationship between a local population and nature. They symbolise the human-nature relationship, the continued presence of humans in the landscape and transform it into a humanised space (Turco, 2002).

Since at least the 1700s, cultural materials have been of interest to people studying history (Turner, 1972; Kopitoff, 1986). They are the result of technological processes and social relationships within a population and can be used to deduce aspects of people's behaviour, perspectives, and ideas about the world. There is a reciprocal link between people and their cultural materials: people make and use tools and, in turn, tools determine, influence, and transform individuals and their social relationships. Cultural material analysis is used to study a variety of artefacts such as tools, pottery, artwork, and architecture in order to gain an understanding of the people who created and used them. Cultural material analysis is used by archaeologists to understand how ancient people lived based on two complementing approaches. First, the actual materials used to create cultural artefacts are examined to learn about the types of materials employed, whether they were transported from different places, their availability, and the technological requirements to make them. This includes the study of the morphology of the land and location of materials as this comprises an essential part of the archaeological record. Secondly, cultural materials are examined with a view to understand their usage and implications for cultural identity and societal structure and lifeways (Warnier, 2005). Cultural materials are highly relevant with regards to the formation of group identity (Handler, 2010).

The re-creation of ancient landscapes is greatly assisted by new technological developments. GIS-techniques have substituted manual cartographic recording resulting in a faster and more precise representation of the landscape, which is also more cost-effective. Photogrammetry, and specifically aerial photogrammetry, is used to create 3D models of both cultural objects and the landscape. Simulated 3D models allow users to interact with digitally re-created objects and environments, creating a more immersive experience than can be gained from traditional media. The application of aerial photogrammetry and GIS mapping to produce 3D models of past landscapes has increased over the last decade, greatly assisting archaeological excavations (Hodder, 2020). These technologies have also facilitated the use of spatial data analysis in archaeology (Gillings and Goodrick, 1996; Frischer, 2008) which produces a more accurate overview of the location of cultural materials in a landscape than can result from field excavations only (Wilhelmson and Dell'Unto, 2015). Spatial data analysis aids the reconstruction of architectural spaces, which allows them to be analysed (Landeschi, 2016), and assess their eventual decay (Campanaro et al., 2015). It also allows an analyse of single findings in minute detail and to then extend the results to the georeferenced space (Landeschi, 2018). This, in turn, produces more powerful models than traditional methods and provides information about patterns in complex, dynamic environments. These results are suitable for a wide range of purposes such as research, teaching, museum displays, and community engagement.

The ‘tripartite’ approach in bioarchaeology views humans and their remains holistically as simultaneously biological, representational, and material (Soafer, 2006). This approach treats the skeleton not just as a physical object, but also as a representation of an individual's social and cultural identity. This fosters a better understanding of the connection between the individual's life experience and the context of their burial, allowing to build a more accurate picture of the life and times of a specific population. In addition, a bioarchaeological approach considers the plasticity of the skeleton in its various states, and how it can represent and reflect the actions of the individual, society, or environment (Cohen and Armelagos, 1984; Larsen, 1997; Buikstra and Beck, 2009). Through this approach, a deeper understanding of people’s lifestyle, diets, economic status, health, biological background, and their cultural and social identities is gained. Bioarchaeology can also provide insights into how people interacted with their environment, how they adapted to changes, and how they responded to external influences. In this regard, the dispersal analysis of the remains is carried out to unwind all the information required from the environment and the space in which the people lived. The analysis of human remains *in situ* provides spatial-temporal information regarding human behaviour including sedentism, territoriality, inclusive vs. exclusive relations, mobility, migration, and health patterns associated with hunter-gatherer and agricultural lifeways (Cohen and Armelagos, 1984; Goodman, 1993; Larsen, 1997; Pete, 2008). Burials can be interpreted as social mechanisms for the maintenance and renewal of social structure (Childe, 1944, 1946). In general, social actions help to sustain the social system (Radcliffe-Brown, 1952). Examples include participation in civic engagement, volunteering in the community, advocating for social justice issues, and supporting local businesses. These actions help to create a sense of solidarity within the community and ensure that the system remains strong and resilient, even if only performed to meet social expectations and norms or to gain recognition from peers and the wider community (Radcliffe-Brown, 1952). In this regard, the understanding of burial ways could enhance the interpretation of the social sphere, either symbolic, or material.

The analysis of human remains and the relationships between humans, nature, and cultural materials using the new technologies mentioned before, results in a better understanding of past lifeways, mortuary patterns, and the processes involved in the creation of a humanised space (Turco, 2002). The human remains are central and are contextualised within the geographic and material cultural sphere (grave goods). The mapping of human remains *in situ* produces an overview of the distribution of the remains in terms of sex, age-at-death, health, trauma, number of individuals in a tomb, and the type of burial rite. Following that, the biological data are cross-referenced with the archaeological data in terms of stratigraphy, grave goods, and typology of tomb structure. This allows the identification of patterns and trends in the behaviour of people within a particular culture, as well as to gain an insight into the motivations for actions and to determine whether they were driven by conscious or unconscious factors. Additionally, potential causes or specific intent behind certain behaviours can be studied.

Visual representation is a powerful tool for understanding and communicating archaeological concepts. Archaeologists can use it to present complex ideas in a way that is both easy to comprehend and visually stimulating. Visual representation can also be used to infer activities and behavioural patterns that may not be obvious when looking at isolated data sets such as artefact distributions, site layouts, and regional trends. Furthermore, it creates interactive models or simulations, which can help to explain and explore archaeological theories and hypotheses (Erickson and Thompson, 2017). The use of 3D imaging and GIS mapping to interpret the behaviour and culture of past populations is an on-going process (Leusen, 1993; Chandler, 1998; Macchi Jànica, 2009). The data set produced can constitute a digital open-source output placing all available information on the bioarchaeology of Monte Luna in context to facilitate an improved understanding of the social and biological processes that shaped it.

8.2 MATERIALS AND METHODS

8.2.1 What remains

The remains from Pau and Monte Luna were analysed to reconstruct the life history of the individuals, their physical health, diet, mobility, and migration patterns, as well as their cultural practices. The analysis of the remains includes the macroscopic and microscopic examination of the skeletal elements. Furthermore, the analysis of the burial context, grave goods and mortuary practices is used to infer the cultural behaviour of the individuals. Using GIS and aerial photogrammetry will assist to integrate all data on the human remains, their environment, and inferred behaviour in accordance with the life course theory (Gowland, 2016). The connection between lives and social/historic contexts are drawn through a close consideration of archaeological, historical, and ethnographic sources (Buikstra and Beck, 2006).

The following data sets are presented for both burial sites:

- The minimum number of individuals (MNI), sex, and age-at-death are graphically presented to understand the demography and potential burial patterns (Hoppa Veupel, 2002; Sullivan, 2004)
- A list of pathologies is also referenced spatially. This refers to changes in the bone, and variations through stresses such as cribra orbitalia, and porotic hyperostosis, as well as traumatic lesions (Brothwell, 1981; Goodman and Rose, 1998; Schillaci and Stojanowski, 2002; Hillson, 2005; Mariotti, 2004, 2007; Ruff, 2012).
- The remains are put into context with the landscape, tomb type, and artefacts to reconstruct the social and cultural environment during the key transition periods in Sardinia represented by Pau and Monte Luna (Thomas, 1993; Richards, 1993; Tilley, 1994; Bender, 1997, 2002).

8.2.2 Su Forru de is Sinzurreddus (Pau)

The excavations in the *Monte Arci* area (Figure 41) have been ongoing since 2001, including the use of 3D and spatial analysis techniques by Lugliè. The aim of the survey was to place archaeological findings stratigraphically. The cave was mapped by means of GNSS (Global Navigation Satellite System) and GPS (Global Positioning System). Stonex and Leica cameras with an integrated reflector were employed. *ArcheoGIS* software was used to create a cartographic representation of the site including altitude, latitude, and longitude. A modified version was produced with the open-source software *QGis* for spatial analysis in the present study.

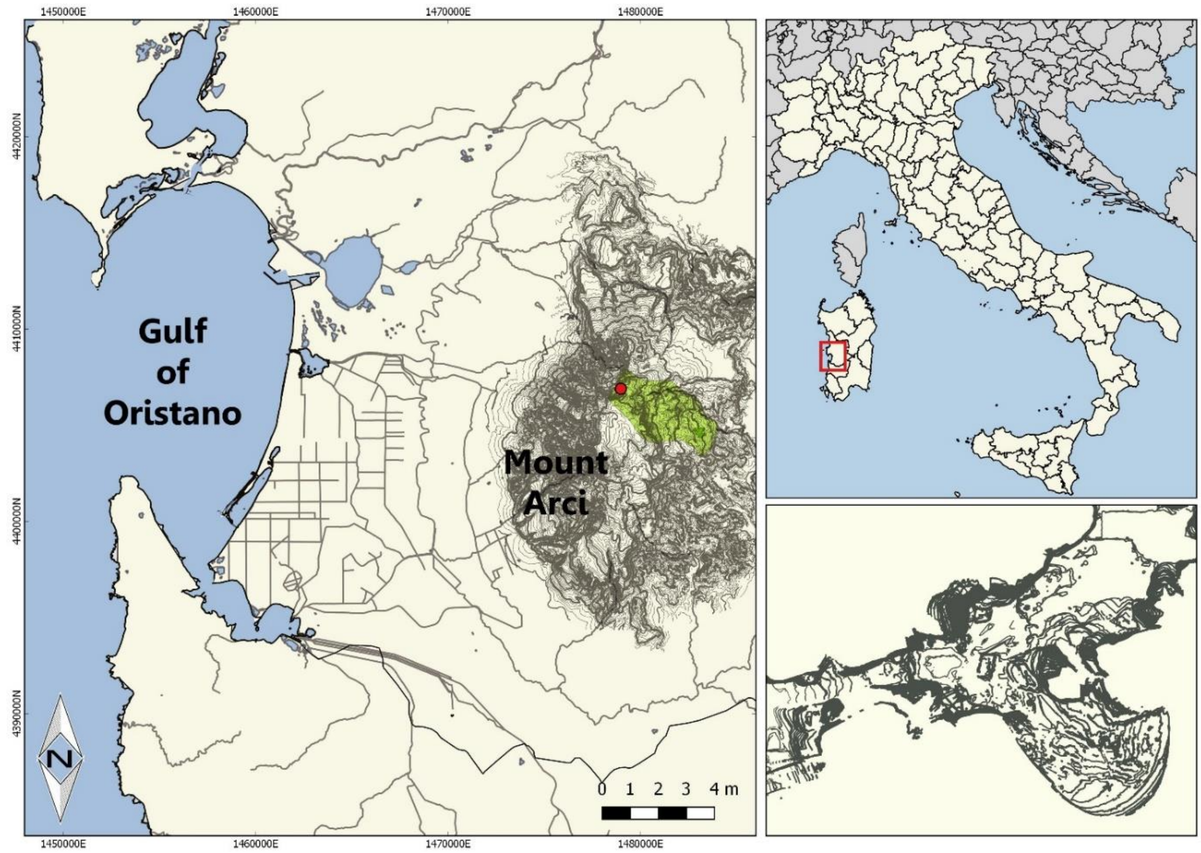

Figure 40 Pau. Geographical location and cartographic model of the cave. The red dot marks the position of Pau, while the green area indicates the site of Su Forru de is Sinzurreddus. The lower right-hand image represents the plan of the cave obtained using Stonex and Leica stations.

8.2.3 Monte Luna Necropolis

Three-dimensional data from the Monte Luna Necropolis were collected in January 2020 by the author. The area was mapped by aerial photogrammetry using a *DJI Mavic 2 Pro* drone equipped with a *Hasselblad L1D-20C* camera. A total of 138 photos were taken from the zenith at a constant altitude of 40 m (Figure 42) during the early hours on a day with optimal weather conditions (no wind and cloudless sky). The camera was set in manual mode with a constant focal length of 10.26, 200 ISO, and 1/640 shutter speed. The *Agisoft Metashape Professional* software was adopted for photo treatment to produce the following outputs: sparse cloud, dense cloud, 3D model, Digital Elevation Model (DEM with a resolution of 1.22cm/pixel) and Orthomosaic (resolution of 0.7cm/pixel).

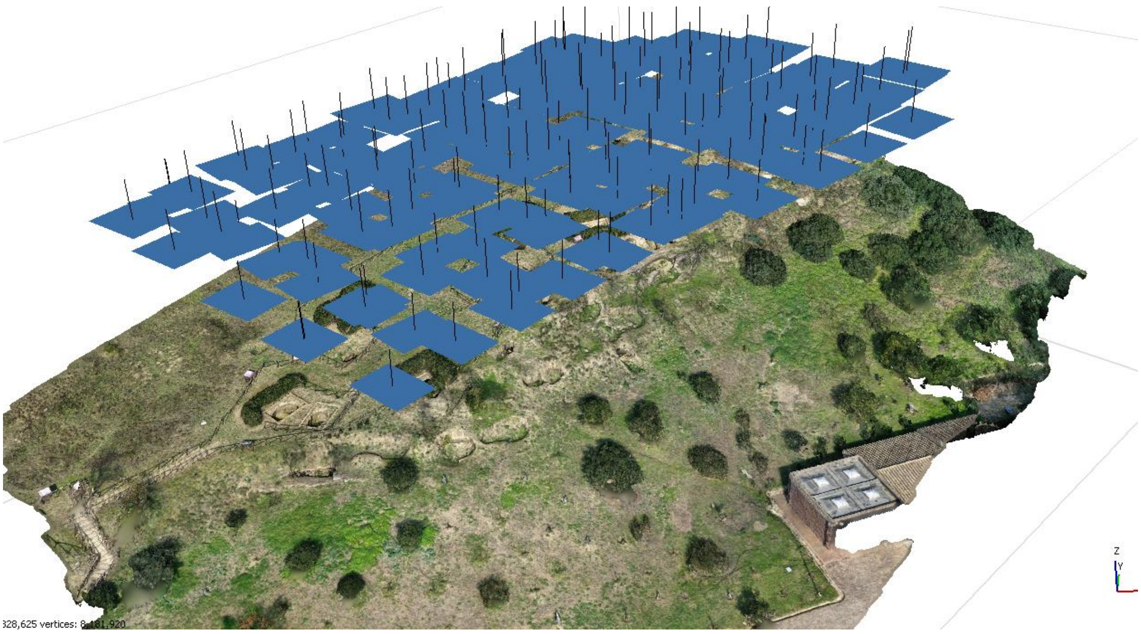

Figure 41 Monte Luna. 3D model of the area with the representation of single acquired images during the processing phase using Agisoft Metashape Professional.

DEM and Orthomosaic were imported into the open-source software QGis for spatial analysis. Vectorial reproduction of shapes and limits of the Monte Luna *necropolis* were obtained from a raster file (Figure 43).

Figure 42 Monte Luna. Raster file used to obtain shape and limits in the DEM and 3D model of the necropolis.

8.2.4 Artefacts

The grave goods found in tombs with the few preserved individuals (Appendix A) are listed in Table 49. The association between tomb, artefacts, and human remains is observed to understand past behaviour in terms of spatial dispersion between sexes/artefact, age correlation with type of tomb/artefact.

Table 50 Monte Luna. Tombs and grave goods.

Tomb	Artefact	Sex	Subadult	MNI	Tomb Type
T. 63	Iron ring eliptic shape	Female	1	2	Hypogeum Single Chamber
	Amphorae				
	Amphorae				
	Commercial amphorae (Bartoloni D7)				
T. 70	Amphorae	Male	1	2	Hypogeum Single Chamber
	Commercial amphorae				
	Amphorae				
	Iron knife				
T. 27	12 necklases vagues	Female	1	2	Pit and chamber

	Cylindrical pitcher				
	Conic pitcher				
	Pitcher				
	Little pot for oil				
	2 bronze coins				
	Cup				
T. 115/59	Lekytos	Female	0	2	Hypogeum Single Chamber
	Cup				
	Dish				
	Amphorae				
	Amphorae				
	Silver pendant				
	8 punic coins				
T. 7	Amphorae	Male	1	2	Hypogeum Single Chamber
	Amphorae				
	Oil lamp				
T. 81/16	Silver earring	Female	1	2	Hypogeum Single Chamber
T. 16/1	Gold ring with eliptic shape and Horus eye	Female	1	2	Hypogeum Single Chamber

8.3 RESULTS

8.3.1 Su Forru de is Sinzurreddus (Pau)

The digital reconstruction of a stratigraphic 3D volumetric model generated maps of frequency and density of the distribution of pottery, ornaments, obsidian, and faunal and human remains. The distribution of the 50,000 fragments of human bone and teeth more or less consistently followed the contours of the cave wall (Figure 44).

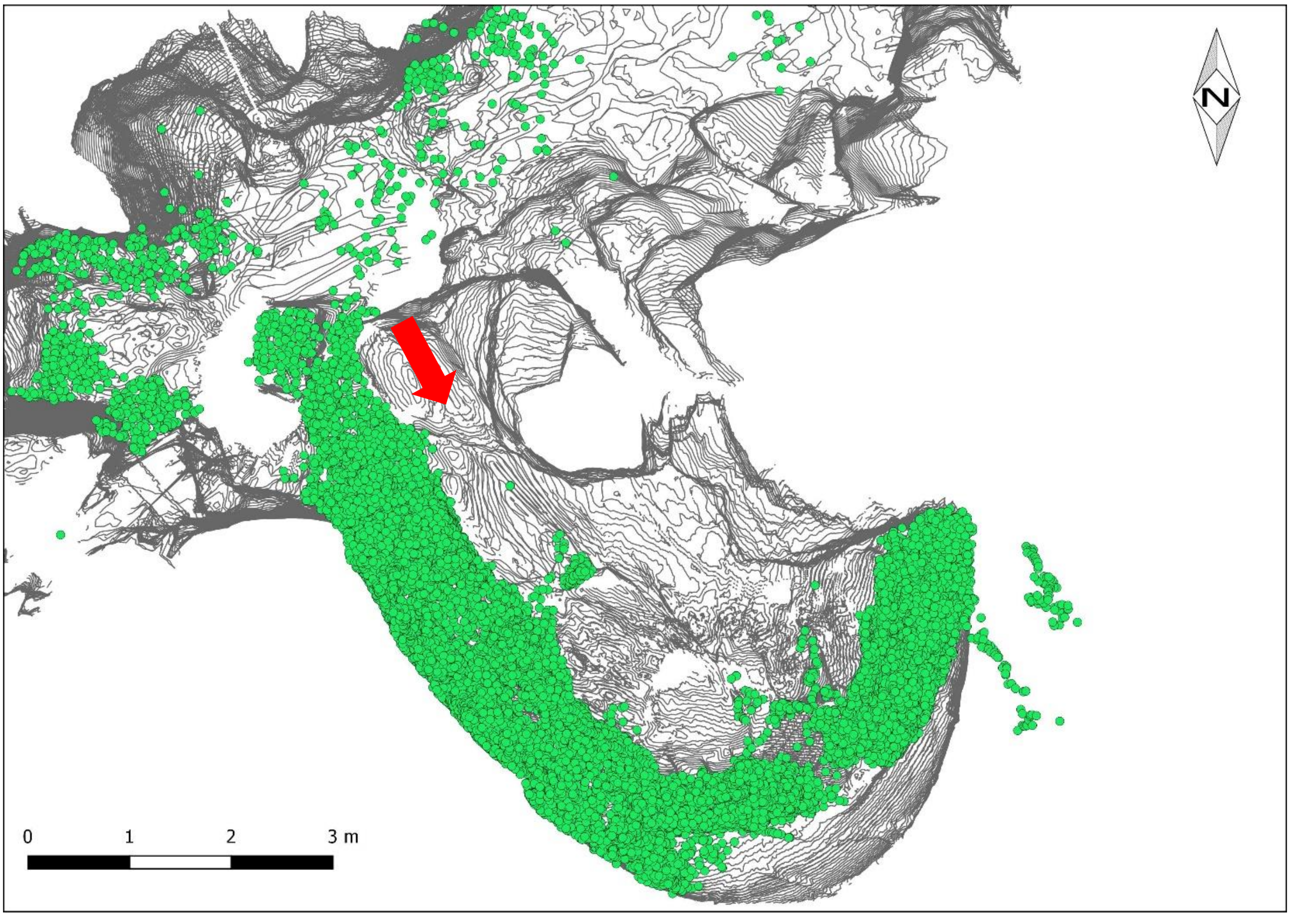

Figure 43 Pau. Mapping of all 50,000 faunal and human bone fragments. The cave is represented via its volumetric curves. The entrance is located to the north (red arrow).

The distribution of teeth, hand, and foot bones is shown in Figures 45 and 46.

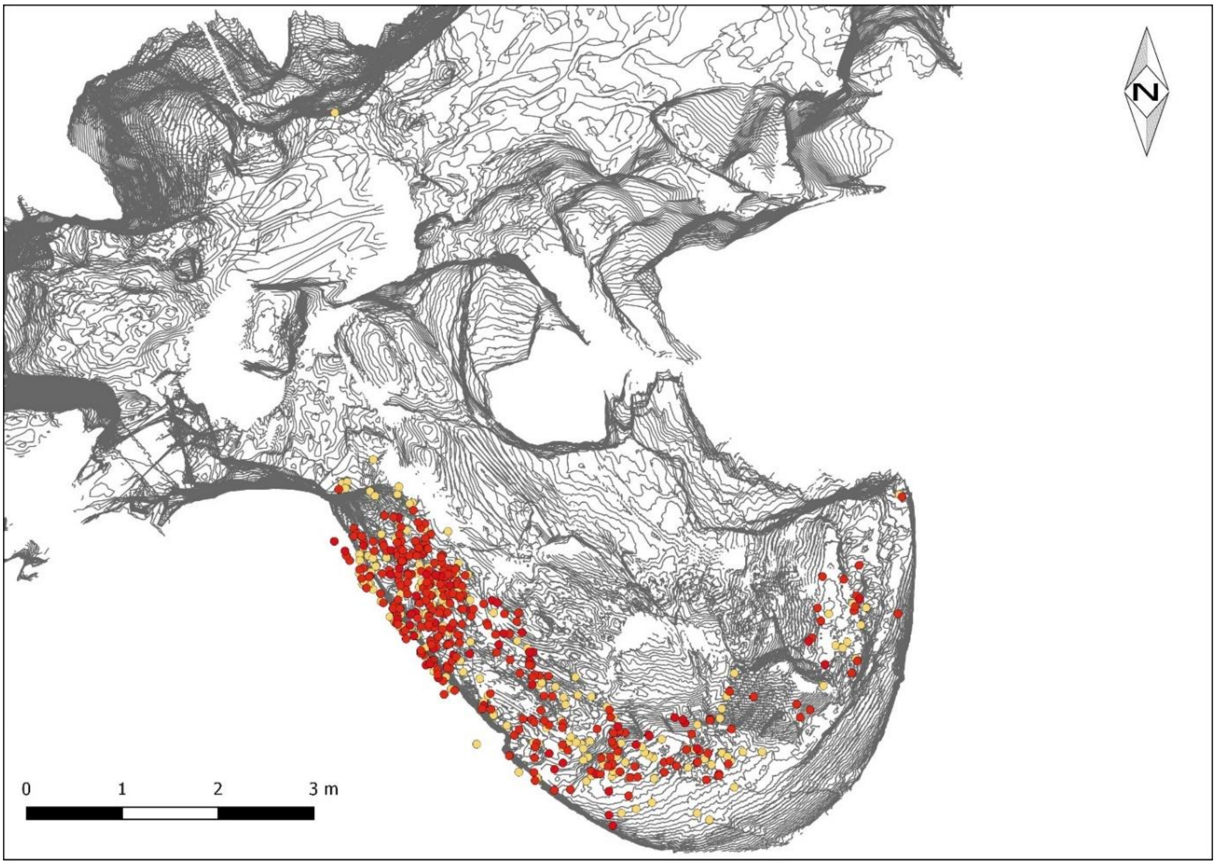

Figure 44 Pau. Mapping of all teeth (N=565). Red dots indicate thermally altered teeth (cremated), while yellow dots show the inhumated ones (unaffected by cremation).

The distribution of the remains is not separated according to funerary rite. Both cremated and non-cremated teeth were intermixed and distributed along the wall of the cave (Figure 45).

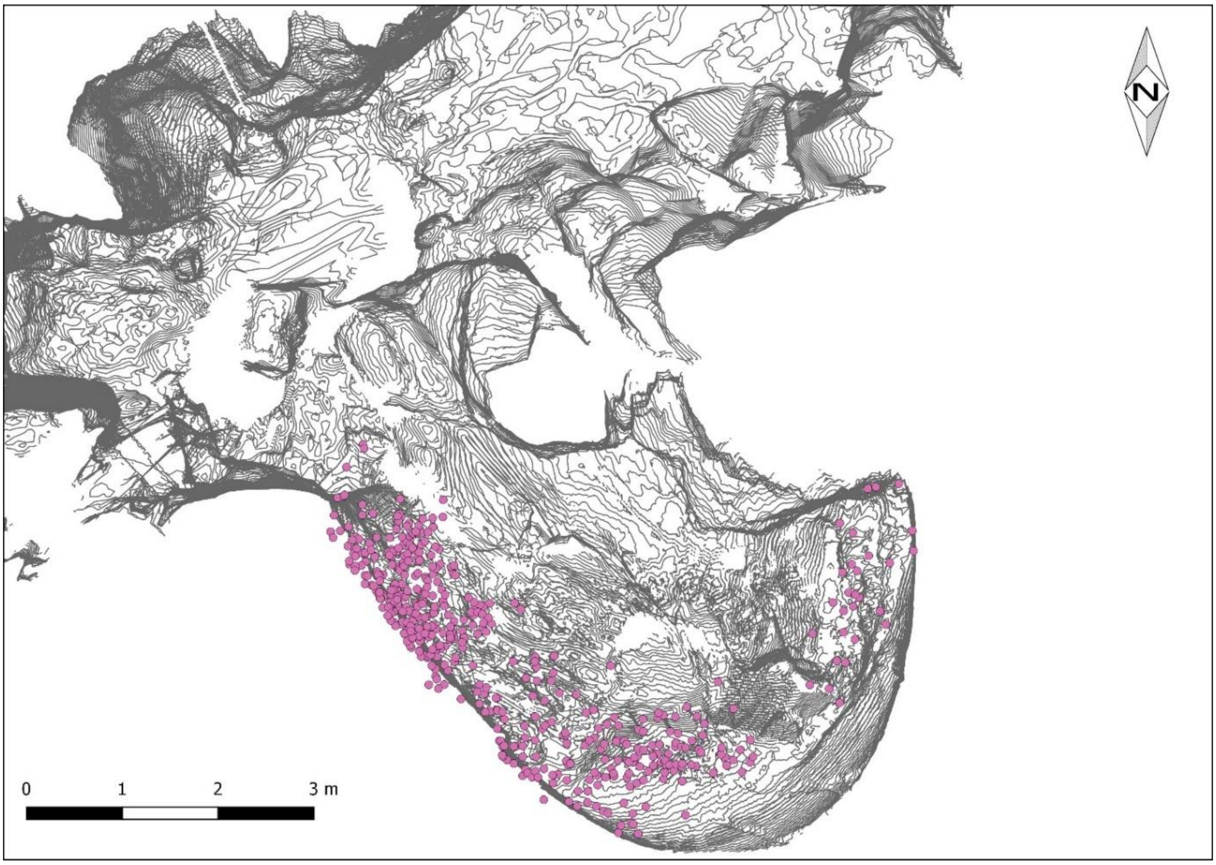

Figure 45 Pau. Mapping of all hand and feet bones (total of 500 bones).

Hand and foot bones were also distributed along the contour of the cave wall. There was no intentional separation of bones from different anatomical regions (Figure 47).

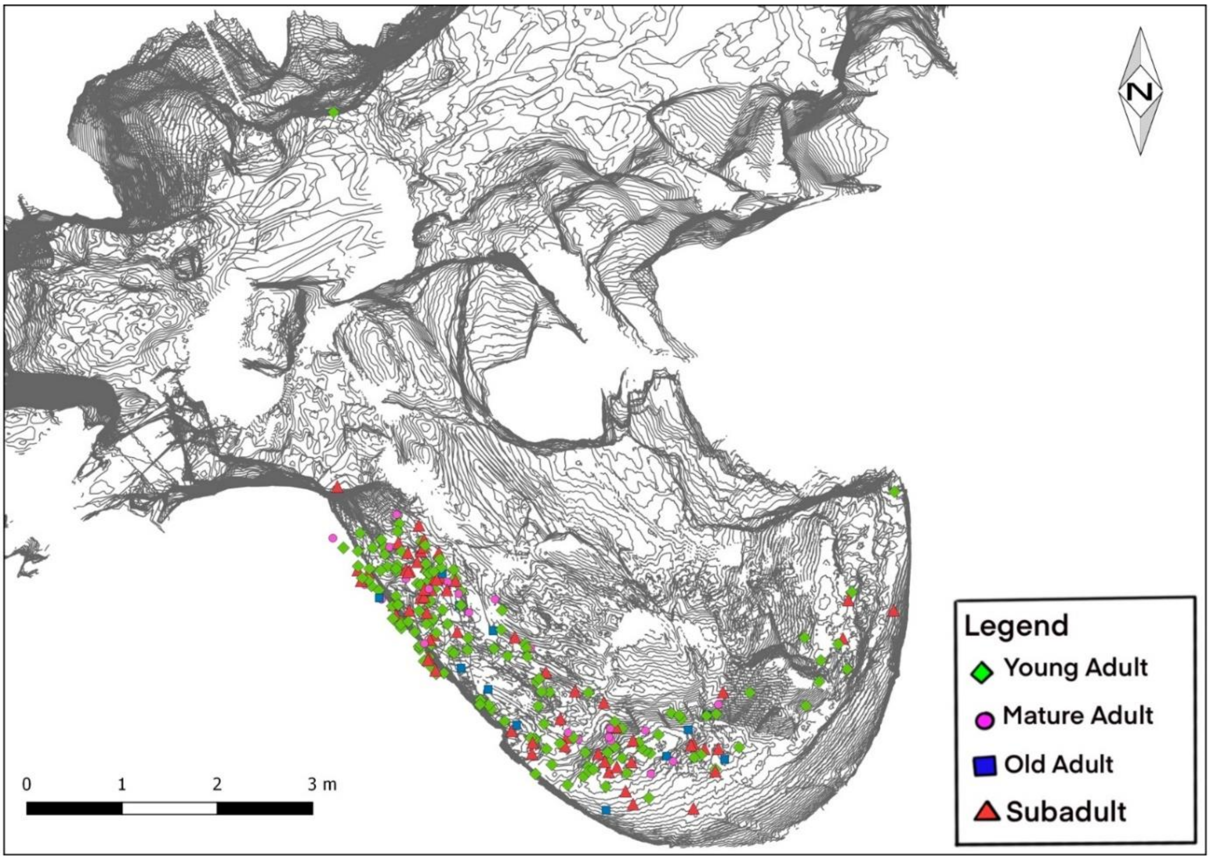

Figure 46 Pau. Mapping of teeth according to age ranges.

Generally, the distribution of teeth based on age did not reveal a depositional pattern. However, there were no mature and old adults buried in the eastern corner of the cave (Figure 44, 45, 46, 49).

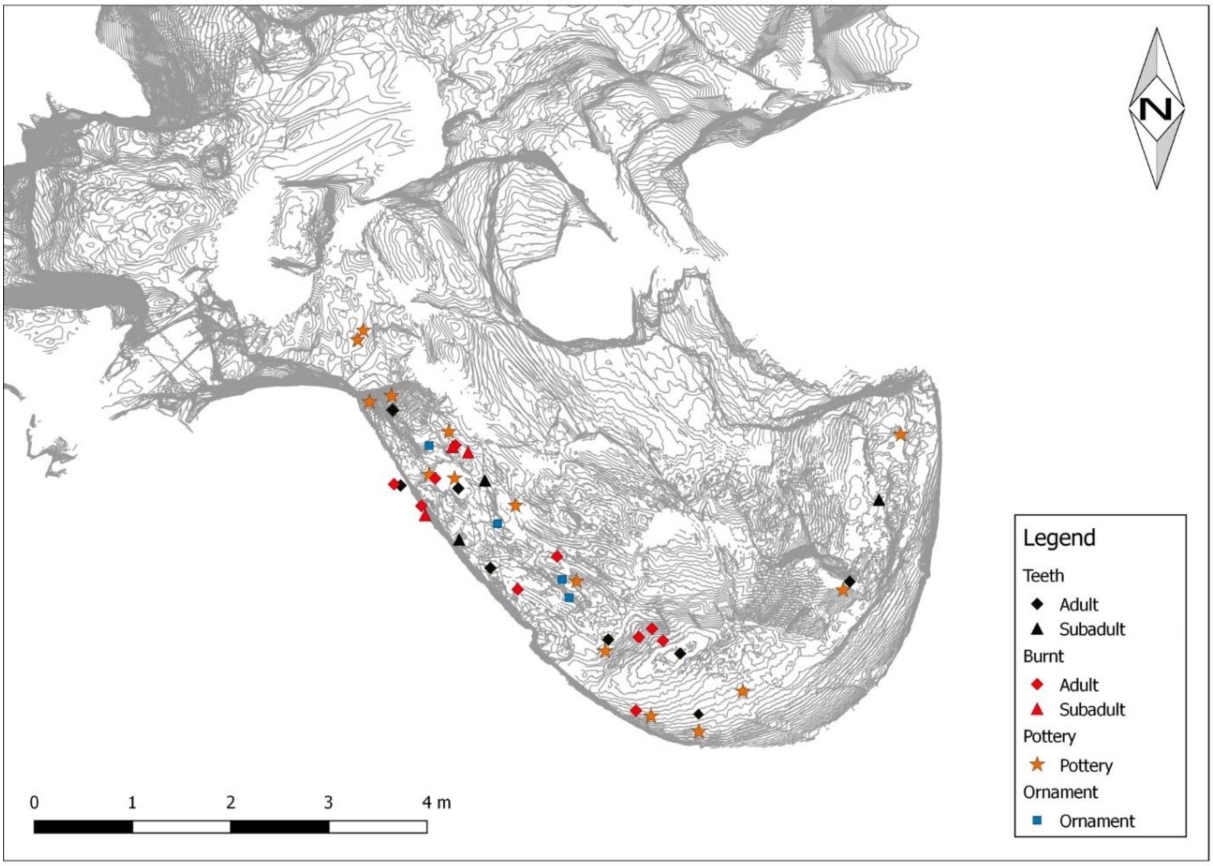

Figure 47 Pau. MNI of human remains (teeth), is associated with minimum count of pottery, and ornaments.

The calculation of MNI based on RI^1 and Rdi^1 on the one hand and based on pottery and the vague beads (Figure 48) on the other, suggests that the artefacts could have been funerary items due to their proximity to the teeth.

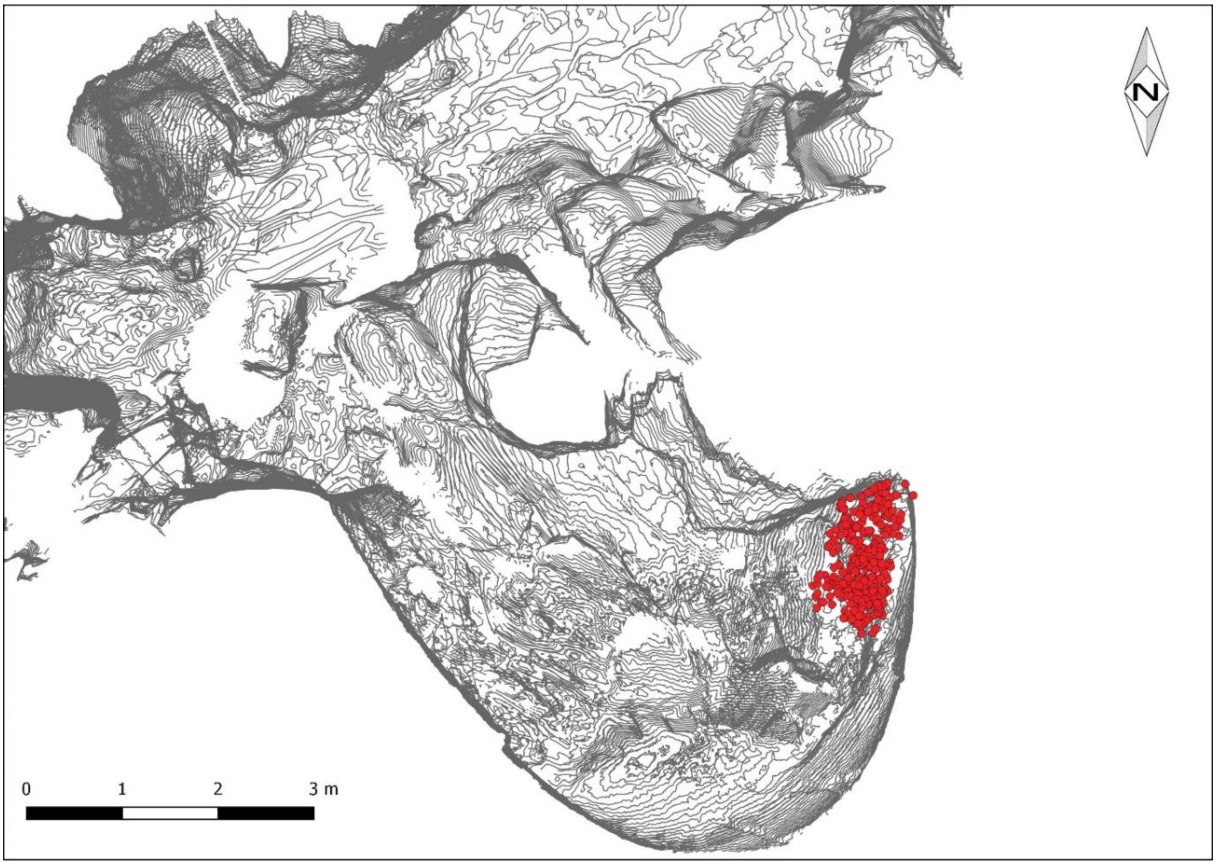

Figure 48 Pau. Location of the selected cremated remains to assess the cremation processes.

The distribution of a selected sample of cremations is shown in Figure 49. The analysis of the selected sample showed that the bones originated from different anatomical regions and belonged to people of different age groups. The data points are spread out evenly, showing that bones of a particular anatomical region and/or age group are not concentrated in a particular area. This is consistent with the idea that the sample is likely composed of individuals from a variety of and ages, indicating that the disposal of remains was unintentional and widespread.

8.3.2 Monte Luna Necropolis

The 3D reconstruction of the contemporary hill at Monte Luna is shown in Figure 50. At the end of the excavation, a small number of tombs were not backfilled so that they could be easily accessible.

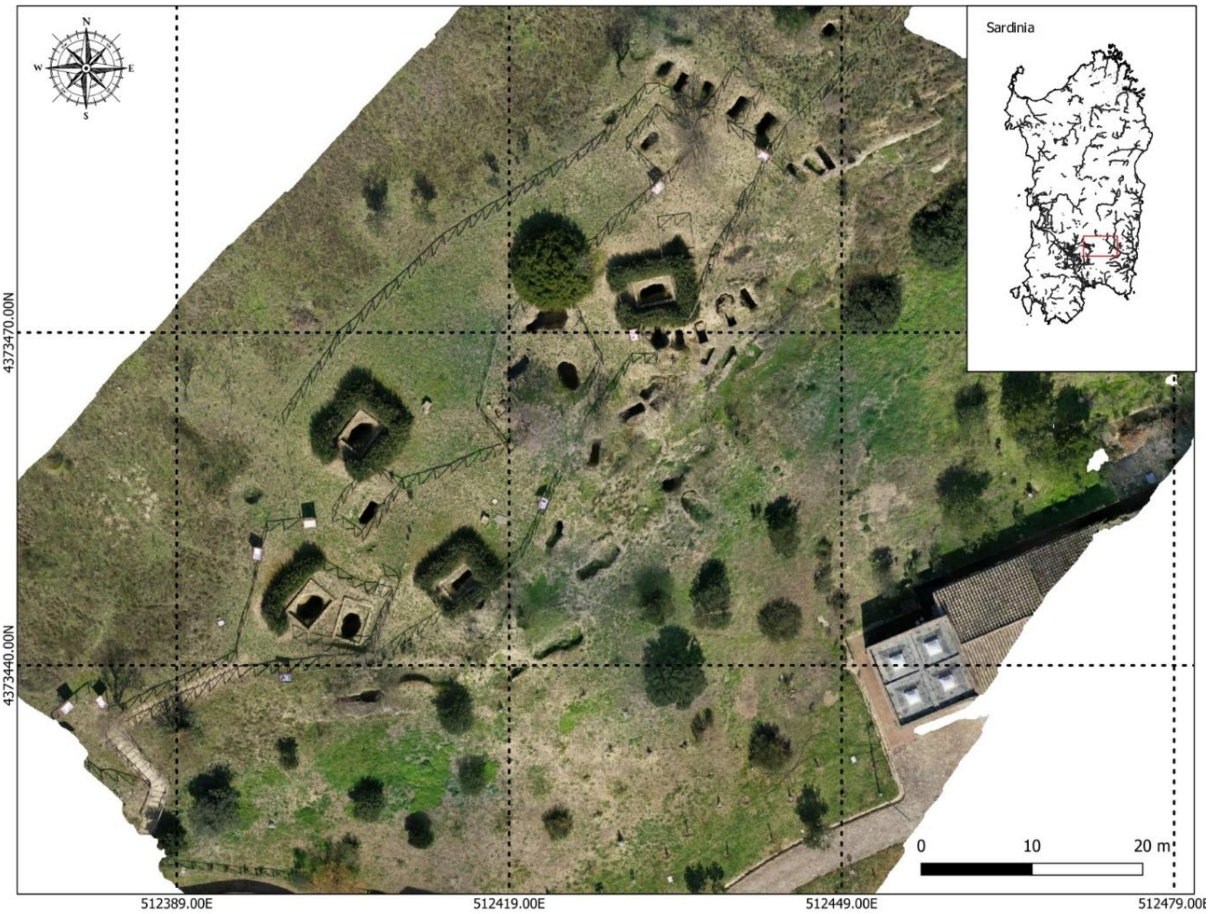

Figure 49 Monte Luna. DEM picture.

Figure 50 was used to create the topographical map showing the depth contours of Monte Luna (Figure 51).

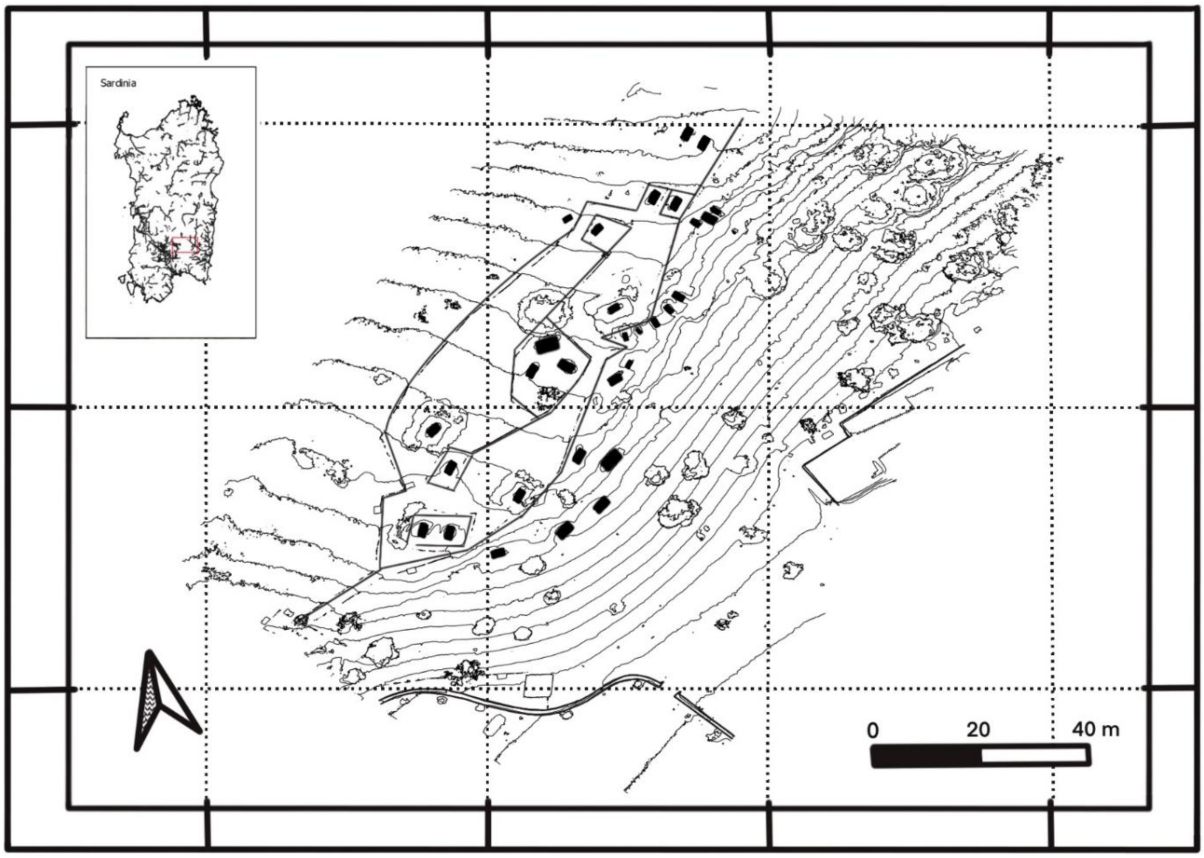

Figure 50 Monte Luna. Contour map of the hill. The tombs indicated by black rectangles have not been backfilled and remain open.

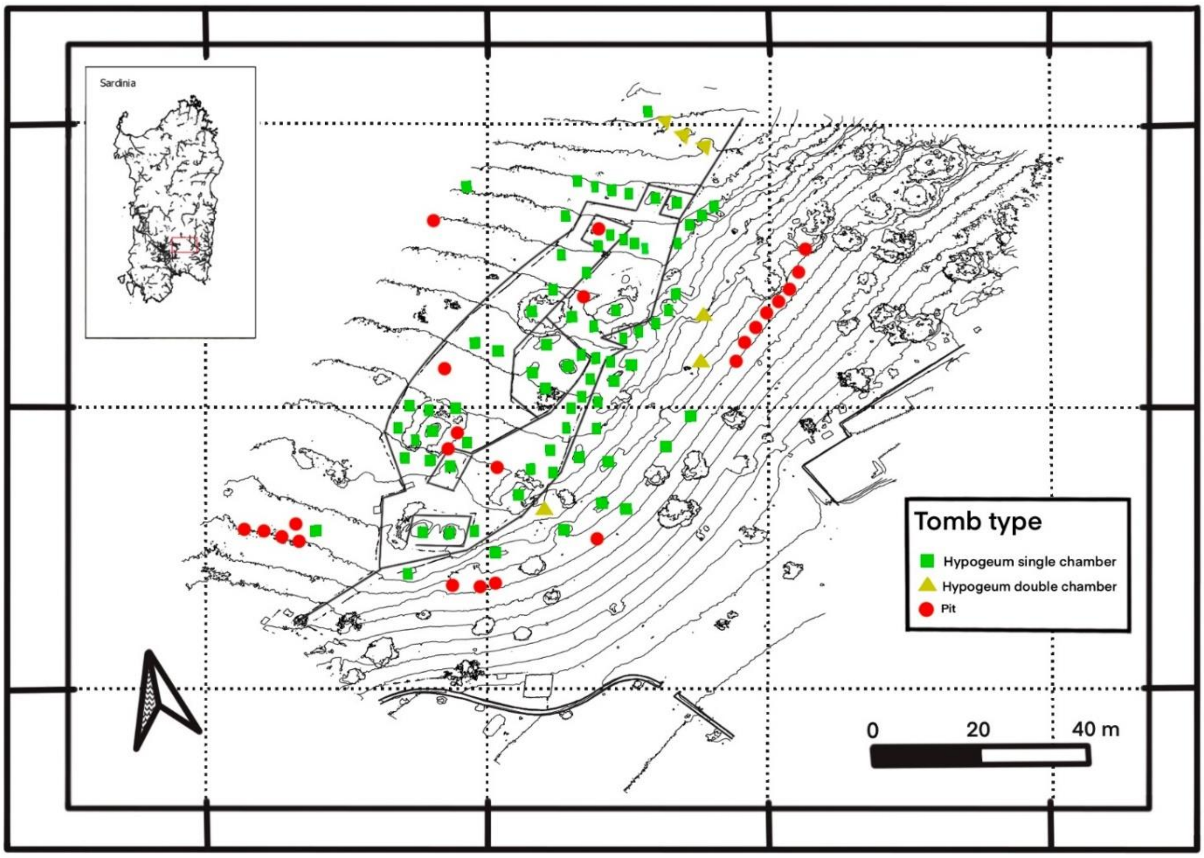

Figure 51 Monte Luna. Map of the distribution of the different tomb types.

The distribution of the different types of tombs is shown in Figure 52. The majority of the tombs are of the hypogeum single chamber type, followed by pits, and least abundant are hypogea with a double chamber.

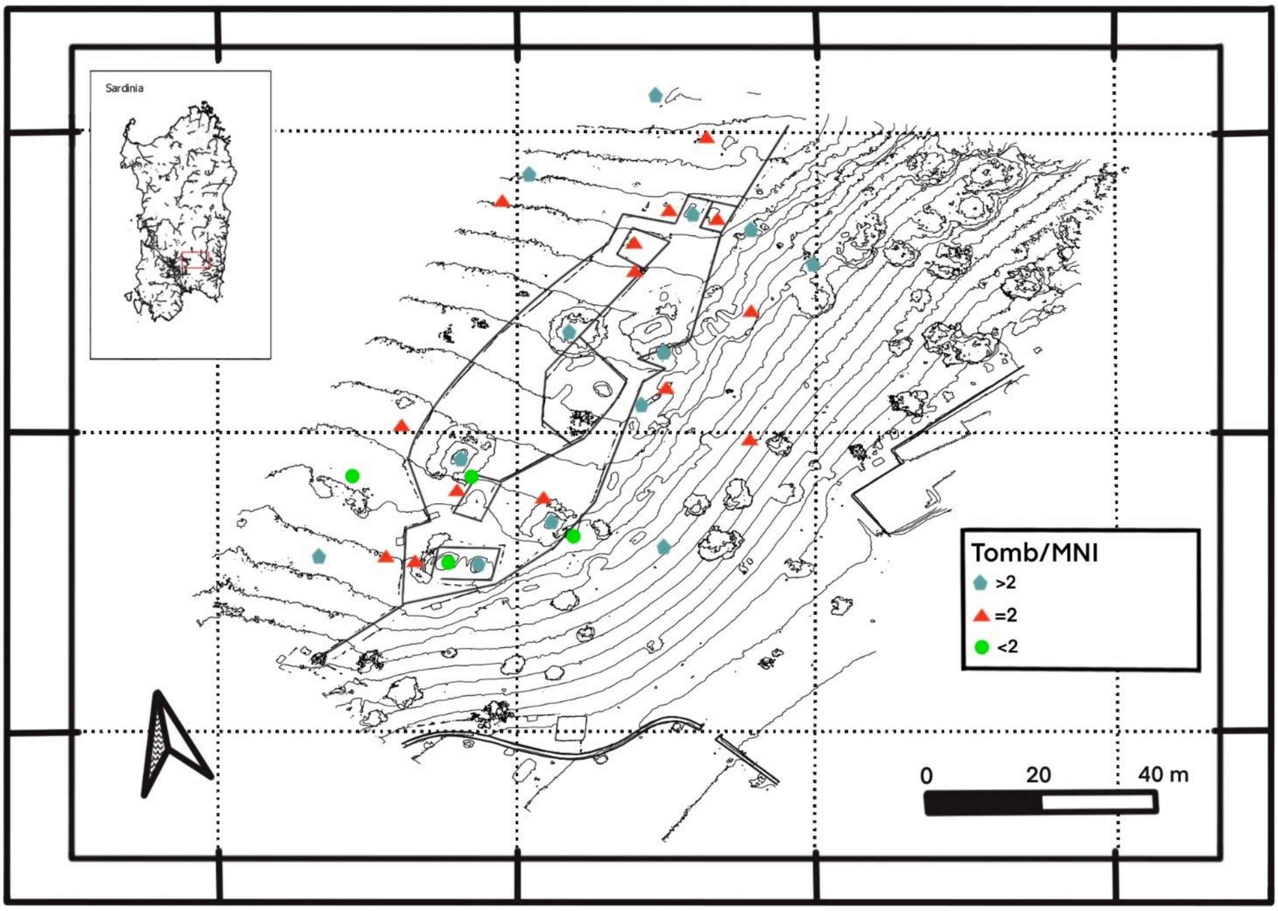

Figure 52 Monte Luna. MNI per tomb.

The bones and teeth found in a tomb were used to estimate the MNI per tomb and their approximate age and sex as described in previous chapters. The results were grouped into tombs with less than two individuals, two individuals, and more than two individuals. Single depositions are the least abundant and located at the bottom of the hill, while the upper area is populated by tombs with two or more individuals (Figure 53).

The tombs in the centre/upper area with a MNI of two individuals consistently contained an adult and a subadult. There are no signs that any of these tombs were re-used. Some of the tombs with more than two individuals were re-used, with seven containing three individuals, and five containing between four to twelve individuals. The tomb with the highest count was a *Domus De Janas,* a type of specific megalithic tomb carved in the rock from Nuragic times (Figure 53).

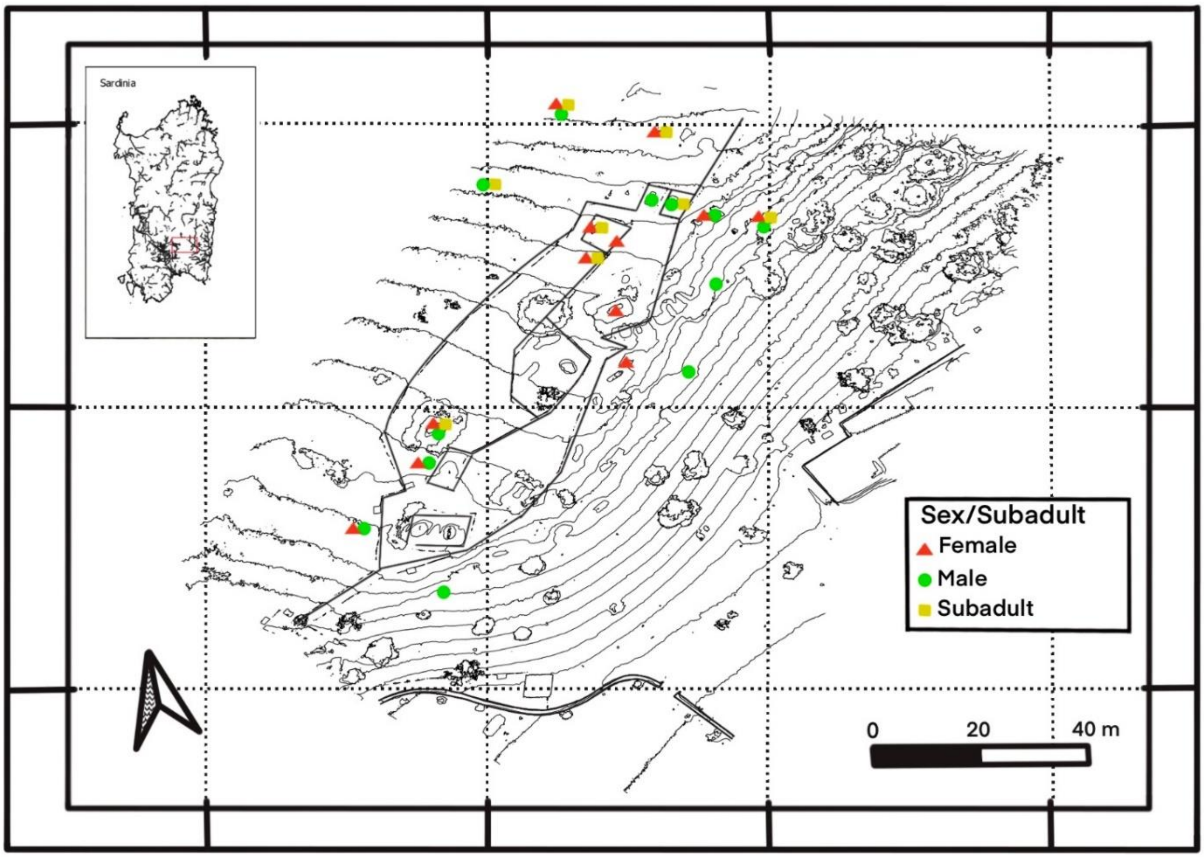

Figure 53 Monte Luna. Representation of the individuals with known sex per tomb.

The distribution of tombs with individuals of known sex estimations did not show a clear pattern, since both females and males were either buried alone or buried with subadults, across the site. Similarly, individuals of known sex are not associated with a preferred type of tomb. Subadults were always buried together with at least one adult (Figure 54).

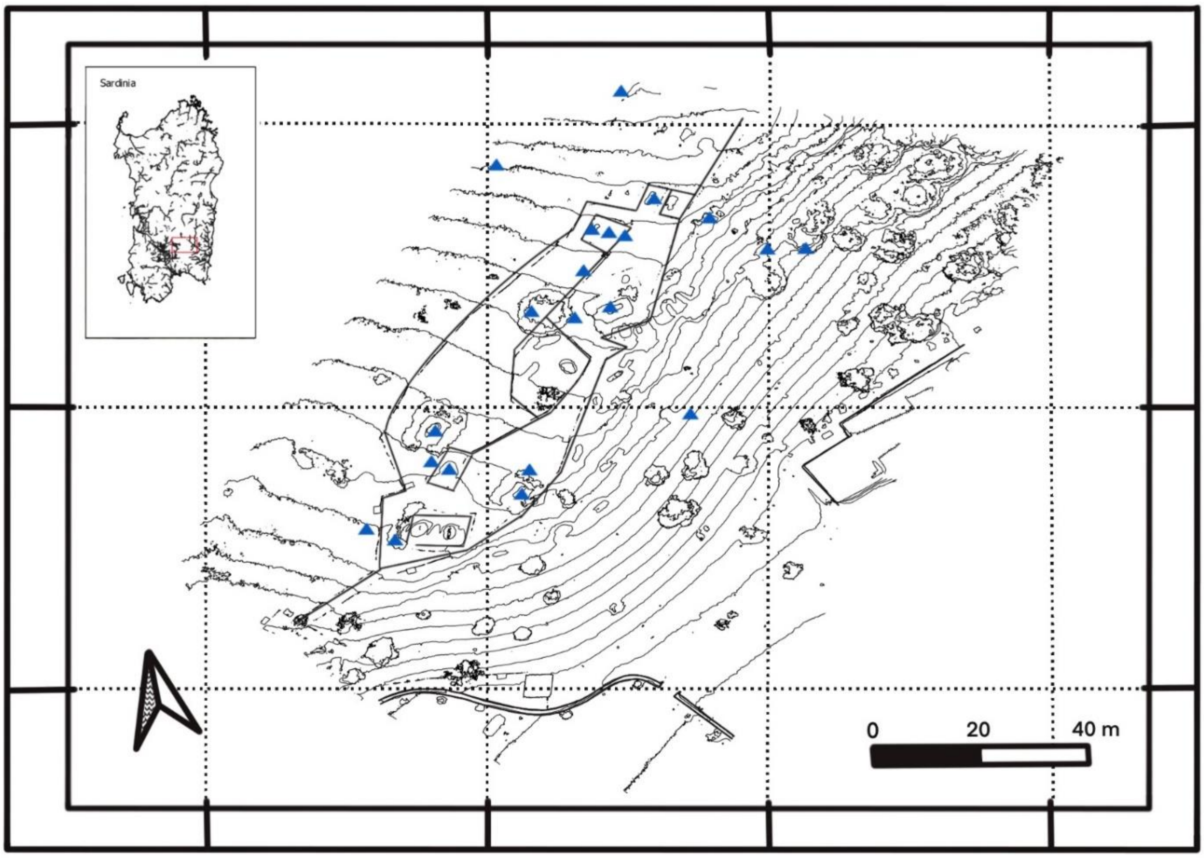

Figure 54 Monte Luna. Distribution of individuals with pathologies, environmental stress, and traumatic lesions.

The distribution of bones with evidence of pathologies, environmental stress, and traumatic lesions (Figure 55) suggests that frail or ill individuals were not separately buried in the necropolis following their passing. The detailed analysis of pathology, traumatic injuries, and evidence of cribra orbitalia and porotic hyperostosis (environmental stressors) are not included in the present work. They will be investigated in the near future.

The information available about the artefacts and their association with tombs provided a great deal of insight into locating the well-preserved individuals presented (Table 49).

8.4 DISCUSSION

Processual archaeology has greatly facilitated the interpretation of remains and the reconstruction of past lives. This has been achieved by developing a two-pronged research approach. First, to focus on the meaning of grave goods, burial practices, and the social and cultural context of the dead. Secondly, to explore how people in the past interacted with their environment, how they adapted to change, and how their lives were shaped by their social and economic circumstances. This type of archaeological interpretation has allowed us to better interpret life by the analysis of the dead and the diversity of past societies (Saxe, 1970). The burials, both the human remains and material culture, are assumed to reflect the socio-economic status, ethnic affiliation, and the behaviour either of the individual buried, or the people who buried them (Childe, 1944, 1946; Goodenough, 1965; Binford, 1971). However, post-processual archaeology argues that burials are not always a reflection of the customs of a population (D'Agostino, 1985; Shanks and Tilley, 1987; Tilley, 1999). Objects are not schematic related with socio-economic aspects of a society; the analysis of materiality needs to engage in the dialectic of people and things (Hodder, 1989). The integration of digital methods in the analysis of the burials provides new insights into the socio-economic status of individuals, and societal behaviour in Pau and Monte Luna. The methodology has shown to improve the interpretative framework to understand past populations (Landeschi, 2018). This has resulted in the development of new hypotheses, and answered questions related to the relationship between human activity, material culture, and landscape.

8.4.1 Su Forru de is Sinzurreddus (Pau)

Human remains were distributed along the wall of the cave with no intentional separation into designated areas for either inhumation or cremation. Based on archaeological findings, it has been suggested that the centre of the cave was a votive area. The spatial association of the individuals, pottery, and ornaments, as well as the type of cremation rite, are similar to coeval burials in other locations. For example, in *Ponte Ghiara di Fidenza*, a unique secondary burial of selected bones belonging to a cremated woman was associated with some remains of a dog and a single cylindrical calcite bead (Bernabò Brea et al., 2010). At the site of Gaione at least four graves showing evidence of cremation were found. Two of the individuals were identified as female and a series of small cylindrical steatite beads were recovered from the cremated bodies (Bernabò Brea et al., 2010). In the Northern Tyrrhenian region, further evidence of cremation of several individuals during the Middle Neolithic was recorded in the funerary cave of *Grotta della Matta* in the town of Orco Feligno, Savona (Liguria) (Delfino, 1981).

The spatial distribution of these burials, together with the cremation rites, and associated material culture have allowed to shed new light on the hypothesis on the seafaring during the Middle Neolithic. The obsidian production system at Monte Arci was integrated into complex exchange networks, resulting not only in trade but cultural and behavioural exchange between coeval populations in the Mediterranean basin.

8.4.2 Monte Luna Necropolis

The distribution of the remains, tomb type, and the archaeological findings at Monte Luna lends support to the hypothesis that there was dense human activity during the 5th – 4th century BC, as the majority of tombs were of the oldest hypogeum single chamber type (Costa, 1980; 1983). The distribution of males and females does not show a clear pattern, as both were either buried alone or with subadults. There was no evidence of foetal and infant burials, possibly indicating the presence of a local *tophet* specifically for these age ranges (Gurguis, 2010; Xella, 2013). Single burials were least abundant and always located at the bottom of the hill, with the higher areas containing tombs with two or more individuals. The high number of tombs with multiple burials meant the tombs were frequently re-opened to bury others, in some cases up to twelve individuals. This pattern is also found in other Punic cemeteries in Sardinia (*i.e.* tomb 277.278 and 274 di Monte Sirai, V-IV BC in Guirguis

2010, pp. 161-163). There is also evidence for moving previous burials to make space for new ones (*i.e.* tomb 10, in Ministero per i Beni Culturali e Ambiente (MIB), 1998, pp. 9-12). Monte Luna follows the pattern of re-used burials explained by Puddu (2019, p. 83). Typically, when re-using a tomb, the structure, burial orientations and positions, and grave goods were unaffected while the bones of the previous occupiers were moved to create space in the grave. Personal items, such as jewellery, *strigilii (*body scraper*)*, and ornaments could form part of the funerary assemblage in addition to the usual pots, making the assembled funerary items in each tomb unique.

The general pattern of distribution of tombs suggested that there were eventually areas for particular burials. The centre and upper area of the hill were made up of burials containing an adult and a subadult, suggesting that this could have been an area dedicated to families (Chapter seven). This is further supported by non-metric traits such as Wormian bones, and metopic sutures (Tomb 27, 28, and 25, Chapter Seven) common in the centre/upper area. The hypothesis that some remains belong to a familial lineage will be further investigated via DNA analyses if permission is granted.

The artefacts are mainly dated to between the 5^{th} – 4^{th} IV sec. BC, which is consistent with the type of burial. The presence of precious metal ornaments made of silver and gold, as well as pottery for personal use, suggests a high status of the settlement (Todde, 2020). The funerary sets associated with individuals indicate a preference for metals in the form of ornaments and coins, and pottery for personal use in female depositions, while practical objects such as shives and oil lamps are linked to male depositions. Also, commercial amphorae are present in depositions of both sexes.

The hypothesis of the presence of a *tophet*, and the existence of an area for family burials in the necropolis, requires further investigation.

8.4.2.1 Social engagement

The spatial analysis of the site of Monte Luna has proved very useful when integrated with the biology and archaeology of the necropolis. The integrated digital output will be donated to the *Sa Domu Nosta Museum* (MADN) in Senorbì to be used for further studies as well as public education.

8.4.3 Conclusions

The present study aimed to demonstrate that the application of digital methods can improve knowledge on the lifeways of past populations. Although no clear discernible behavioural patterns became evident, the results did point to possible new interpretations of the necropolis at Monte Luna.

9 DISCUSSION

This project has studied the lifeways of two Sardinian communities, Su Forru de is Sinzurreddus from Pau and the Monte Luna Necropolis from Senorbì, representing two different time periods. The Middle Neolithic (MN) and the Punic periods in Sardinia are several millennia apart and were characterised by different cultural and historical contexts. However, both periods were associated with a decisive moment of change. First, the introduction of agriculture in the MN led to a rapid transition from a nomadic to a sedentary way of life and, secondly, the settlement of new populations on the island in the Punic period saw the development of an urban-based economy that made Sardinia an important crossroads in commercial trade.

In the present study, human remains from Pau and Monte Luna were analysed in relation to the local natural and cultural environments, drawing comparisons and contextualising the results within a broader Sardinian bioarchaeological framework. Each objective, detailed in Chapter 1, is addressed below, summarising and integrating the results obtained from this study. Despite the temporal distance between the two communities, there were common cultural elements and health challenges for these populations. These results suggest that the lifespan of certain cultural elements may be longer than assumed.

9.1 Objective 1: Undertake an analysis of the demography, paleopathology, and metric variables of the skeletal remains at Pau and Monte Luna focusing on their specific archaeological, cultural, and environmental context to investigate the life histories of the people.

The integration of the archaeological and biological data allowed for a more comprehensive understanding of the lifestyles of the Pau and Monte Luna populations. This information was critical in providing a profile of the two settlements, which included their subsistence strategies, mobility, and the way they interacted with their local environment. The anthropological evaluation of Pau and Monte Luna revealed that the practices most used to bury the remains were both inhumation and cremation. In either case, the remains exhibited a significant level of fragmentation, resulting in an underrepresentation of the skeletal remains at both sites. Despite this, the morphological analysis revealed the minimal number of individuals (MNI), age ranges, pathology, environmental stressors, and female/male distribution (Monte Luna only).

9.1.1 Su Forru de is Sinzurreddus (Pau)

The Neolithic period saw the introduction of new technologies such as the use of polished stone tools and pottery, the domestication of animals, and the construction of permanent settlements. In particular, the Middle Neolithic (4900-4000 BC), with the introduction and intensification of obsidian artefacts, and transmarine interaction, played an important role leading to a shift from a hunter-gatherer lifestyle to a more sedentary one. This established an agro-pastoral system that lasted until recent times (Atzeni, 1987; Lugliè et al., 2008; Gibaja Bao et al., 2013; Tanda et al., 2014; Lugliè et al., 2019).

Sardinia is rich in raw materials, rivers, and natural barriers. The latter likely dictated the movement of people, delaying the establishment of farming communities on the island compared to the mainland Italy (Malone, 2003). The natural barriers present on the island such as mountains, rivers, and seas, have long played a role in isolating Sardinia from the rest of the Mediterranean. This has allowed the island to develop its own distinct demography, (Palmisano, 2021), health profiles, and culture and traditions. Although there is a paucity of data from other prehistoric sites in Sardinia, there was a general trend linked to the Neolithic Demographic Transition (NDT). People developed subsistence strategies and technologies to adapt to the land and climate leading to an increased population density by the Late Bronze Age (Atzeni, 1987; Campus et al., 2010; Lo Schiavo, 2013; Vanzetti et al., 2013; Giannitrapani, 2017; Palmisano, 2021).

The Middle Neolithic site of Pau was expected to show population growth, technological development prompted by new resources, as well as a lower density with high dispersion into the region and limited admixture with local populations (Cavalli-Sforza, 1993). The MNI of 18 adults and six subadults found at Pau is consistent with the hypothesis of a demic spread of agriculture and the use of most of the island's ecological niches by new communities (Tanda, 1995; Fenu et al., 1999; Martini et al., 2007) due to the NDT. Therefore, demographic data are based on the degree of conservation of the remains, and what has been found and recovered (Waldron, 1994). In prehistoric sites, the proportion of subadults is expected to be between 40-60%, with generally an even ratio of males to females, and high mortality rates in the "U" shaped population curve affecting infants and old people (Waldron, 1994). Twenty-five % of the population profile at Pau (6/24) constitutes all age groups of subadults ranging from foetuses, neonates, infants, and subadults. Due to the high level of fragmentation, no sex estimation could be carried out, and the population is best represented in the young adult age group (16-25 years), while the elderly category is the least represented at 2.6%. This figure was lower than expected likely due to poor preservation and, as such, is probably not representative of the living population at the time.

The analysis of oral health in the dental samples from Pau was limited to a general assessment of carious lesions. Since the isolated teeth had no association with either a mandible or maxilla, and could not be sexed, a more holistic understanding of dental health was not possible. Caries was strongly age-dependent with a higher prevalence in mandibular molars, which were mostly affected by Grade 3 lesions (Chapter five). The introduction of new abrasive foods such as nuts and grains, new processing methods, as well as the use of stone tools may have damaged the teeth, creating a favourable environment for bacteria leading to an increase in the frequency of caries lesions over the lifetime of individuals. However, according to the NDT model, the nuances of oral health were also affected by a possible increase in fertility, societal and sex-linked differences in tasks. Although the lack of information on biological sex in the Pau sample has limited the interpretation, the analysis of dental enamel hypoplasia (EH) defects was consistent with the effects of environmental stress as suggested by the oral health profiles, strengthening the assumptions referred to above. The evidence of early stress (0.90yo - 3.10yo) during this crucial moment in growth, when nutritional intake from maternal breast milk is known to improve health outcomes, such as fewer infections and better development of the newborn's immune system, could be framed in the NDT model as consequence of the assumed increase in fertility and pregnancy. Females may have experienced an increase in fertility with subsequent higher rates of pregnancies. However, if they were not able to access sufficient amounts of suitable foods to successfully produce nutrient-rich breast milk, this would have led to episodes of stress for infants.

The Pau population from the Middle Neolithic presents an interesting case study of the development of a new lifestyle, shaped by the introduction of agriculture and the subsequent NDT. The study of the dental health of the Pau population has shed light on the possible consequences of this transition, such as the emergence of caries and enamel hypoplasia. Although the analyses are limited by the poor preservation of the remains, it is possible to suggest a scenario in which changes in fertility, labour, and diet were fundamental in shaping the oral health of the Neolithic population of Pau.

9.1.2 Monte Luna Necropolis

In the 4th millennium BC, the anthropogenisation of the landscape began with the establishment of a large-scale agricultural and herding economy. This included the domestication of sheep, goats, cattle, pigs, and horses, and the cultivation of cereals and legumes. At this time is known irrigation systems and terracing were developed to make the land more suitable for agriculture in the mainland (Malone, 2003; Mercuri, 2013). The period was also characterised by differences in demography. In the main centres the population increased at least partly due to a system of wells and cisterns for collecting water. In contrast, in rural and extra-urban areas these systems were absent and population numbers were lower (Cespa, 2018). Accordingly, the acropolis of Santu Teru, located in a large fertile plain suitable for agriculture, was an important site in the Punic network in Sardinia and probably was a small to medium-sized extra-urban centre. This is based on archaeological evidence such as the remains discovered in Monte Luna.

The skeletal sample was used to calculate a MNI of 227 adults and 59 subadults, of which 16 individuals were partially complete, while the other remains were commingled and fragmented. The proportion of subadults was similar to Pau at 25.9% (59/227), however, there was no evidence of infants younger than 1 year (+/-3 months) of age. This missing section of the population could be due to the possible presence of a *tophet*, a designated burial site for unborn and newborn perinates, which was common in Phoenician and Punic times (Xella, 2013). However, no such *tophet* has been located in or close to the Monte Luna necropolis to date. Similar to the demography at Pau, the highest proportion of the Monte Luna skeletal sample is made up of the young age group (16-25 years) (53.9%), while the elderly age group is not well represented with only 7.5% (Chapter Three).

The new way of subsistence based on agricultural production of grains and cereals, led to an intensive use of the landscape and the establishment of a considerable number of smaller villages (Roppa and Madrigali, 2021). Both of these aspects can readily affect the health profile of a community, including oral health. Caries, periapical lesions (PL), and antemortem tooth loss (AMTL) are all strongly age-dependent, showing an increase with advancing age. The evidence of more severe? caries in the anterior dentition during the early years of life, possibly points to a dietary predominance of sugars and carbohydrates at of a young age. This was probably typical for the rural and ex-urban, and small and medium-sized towns that practised cereal farming and softer-textured food processing, as well as possibly poor oral hygiene. In the small sample for which biological sex could be estimated, only females were affected by dental caries. Over the whole female sample, the rate of caries was 4.6%, however, there was a particularly high rate in the older adult female age category (20.8%). In contrast, males had a higher rate of PL than females, while AMTL rates were similar in both sexes affecting mostly the mature and old adult categories. This suggests that females lost their teeth because of caries, while males lost their teeth as a consequence of PL. As such, this represents a differentiation in the dental pathology profile between males and females.

The dental health of males and females is affected differently by factors such as diet and pregnancy (Marklein et al., 2019). The status of women in Phoenician and Punic times was characterised by high mobility and inclusion into communities (Matisoo-Smith et al., 2018), leading to the hypothesis that women were part of the grain production chain and had easy access to food. Generally, as a consequence of a more sedentary lifestyle, the potential impact of cereal consumption, and softer-texture food processing, population health declined but this trend then stabilised. The oral health of females, due to their hormone profile, their differential salivary composition, and pregnancy Lukacs, 2008; Willis and Oxenham, 2013) showed a higher prevalence of carious lesions (4.6%) and AMTL (57.1%), which also increased with age. There was a lack of evidence of caries in males but a higher prevalence of periapical lesions. The latter may have been due to caries initially developing, followed by an infection, cracked or broken teeth, periodontal disease (gum disease), or other systemic disease which could occur in old age. In this regard, the prevalence of AMTL among females (57.1%), who also showed no evidence of periapical lesions, may suggest males were subjected to either less aggressive caries, or possible treatments to prevent the tooth loss.

EH in the Monte Luna sample showed an early onset between 1.95 and 2.95 years, there was a middle phase between 2.85 and 3.59 years, and a later phase between 4.3 and 5 years. Some of the earlier occurring EH defects were likely linked to environmental stress caused during weaning with cereals and processed grains becoming more important during the process. Among subadults, the late appearance of EH is associated with the earliest recorded age-at-death suggesting the presence of very frail children. A poor diet is not the only or main cause of growth disruption as the influence of genetics, sexual dimorphism, environmental and socio-economics factors need to be considered as well. For example, females with EH died as young adults more often than males, although there is no correlation between an earlier age of occurrence of EH and a younger age-at-death in either sex (Chapter Seven).

Long bone measurements and stature estimates in the Monte Luna sample provided further information on the health profile. The Sardinian stature profile has been highly variable over time, probably due to the isolation of the island and the early interregional contacts mentioned above (Floris, 1983; Martella et al., 2016; Danubio et al., 2017). The stature estimations presented here are consistent with the literature, with the transition to agriculture thought to be a major factor in the changes in stature seen in early settlers. This is because agriculture may have supplied a narrower diet, which led to a swift in nutrition and health that need to be understood in its variation of its effects around the world. Furthermore, the coexistence of different ethnic groups with different genetic potentials for stature likely contributed to the differences in height. Finally, disparities in living conditions likely had an impact on the changes in stature, as those with access to better nutrition and living conditions would likely have been taller than those in poorer conditions (Morelli, et al., 2010;

Pes et al., 2016). Males are, as expected, significantly taller than females but, interestingly, there is a considerably wider range of statures in females (Table 40 in Chapter 7).

Both males and females with EH were significantly shorter than those without EH. It can be assumed that, following the NDT, there was a reliable access to food and a subsequent increase in fertility. However, the dental pathology profile, EH, and stature analyses show that males and females displayed different levels of resilience and outcomes to these changes. Males appeared to be more resilient against childhood stress, perhaps as a result of being given better access to nutritious food. They also may have had preferential treatment, leading to an improved life expectancy. The prevalence of oral pathologies, EH defects, and short stature in some females suggest access to a different diet, a lower level of care when ill, or may represent a group of women who migrated to the community and had a genetic predisposition to either shorter stature or to develop certain diseases. However, this hypothesis is based on only a small sample.

9.2 OBJECTIVE 2: APPLY NEW TECHNOLOGIES SUCH AS SPECTROPHOTOMETRY, X-RAY FLUORESCENCE, AND FTIR-ATR TO STUDY BURIAL RITES AND PHYSICAL CHANGES IN THE CONTEXT OF BIOLOGICAL, SOCIAL, AND ENVIRONMENTAL INFLUENCES ON PEOPLE.

The thermal alteration of the skeletal remains from Pau were investigated through the application of spectrophotometry, X-Ray Fluorescence (XRF), and FTIR-ATR. It was crucial to include the contextual analysis of the remains, the environment, socio-economic, and cultural setting in these analyses. Since remains from archaeological excavation are usually poorly preserved and limited in quantity, destructive sampling must be kept to an absolute minimum. Advanced techniques have the advantage of providing detailed information on the remains without the need for physical destruction. Methods such as XRF and FTIR-ATR can be used to identify the source of materials and other variables that may be important to research. Furthermore, with regards to the regulations and restrictions on examining human remains in Italy, special care must be taken to ensure that all laws are followed. This includes obtaining permits from the authorities, ensuring that all procedures are performed ethically and responsibly, and respecting the religious and cultural beliefs of any community that may be affected by the research. It is also important to ensure that the research is conducted in a way that preserves the dignity of the remains and that all results are handled with the utmost respect. It is important to emphasise that human remains, similar to artefacts, are considered to be cultural heritage in Italy. Human remains from archaeological sites are of significant cultural value and fall under the responsibility of the *Minister of Cultural Heritage* (MIC, *Ministero della Cultura*). They are subject to D.Lgs. 22. January 2004, n. 42, "Code of Cultural Heritage and Landscapes", which includes specific clauses regarding their guardianship as they are both cultural and biological heritage.

Bioarchaeology has significantly advanced and refined methods and new technologies to improve on and maximise the information that can be obtained from human remains. New analytical technologies have made it possible to collect data even from bones in poor states of preservation and have added new angles of investigating remains previously unavailable Some of these new technologies were used in the present study.

Combining advanced with traditional techniques allows for a more comprehensive understanding of the biological and environmental conditions that affected the bones following the death of the person. The skeletal remains from Pau were analysed non-destructively using spectrophotometry, X-Ray Fluorescence (XRF), and Fourier-Transform Infra-Red Spectroscopy (FTIR). This was aimed at adding new data sets to either test existing hypotheses or to develop new ones regarding the causes of the changes observed in the human remains. The use of a multi-technique, analytical method has proved effective in providing information on the cremation rite and later deposition of burnt bones at Pau.

Cremations in the region usually date to the Punic Era and involve either a container such as an urn, or of a distinct burial (Moscati, 1985; Piga, 2010; Tronchetti, 2014; Piga, 2015; Bartoloni, 2017). The earliest cremations in Sardinia were found in the Middle Neolithic site of Pau. Generally, evidence of cremation in the Middle Neolithic in Northern Italy is scarce. The most important case is at Ponte Ghiara di Fidenza (4^{th} millennium BC), where a unique secondary deposition of selected bones belonging to a cremated woman was associated with some remains of a dog and a single cylindrical calcite bead (Bernabò Brea et al., 2010). Subsequently, at the site of Gaione (5600-4300 BC) were recorded at least four graves with evidence of cremation. Two of the graves were identified as that of a female and a rich series of ornaments (Bernabò Brea et al., 2010). In the Northern Tyrrhenian region, further evidence of cremation of several individuals during the MN was recorded in the funerary cave of *Grotta della Matta* in the town of Orco Feligno, Savona (Liguria) (Delfino, 1981) (Chapter Four).

The evidence from Pau suggests the presence of an interconnected network of trade and cultural exchange between populations in the Mediterranean basin during the Middle Neolithic period. The Monte Arci obsidian production system and its integration into trade networks linking Sardinia, Southern France, and the north of the Italian mainland, as well as the discovery of similar small beads among the cremated remains from these areas suggest that the populations were engaged in a sophisticated system of cultural and economic exchange (Lugliè et al., 2019). The similarity in the thermal pattern of cremations at Pau and the Emilia territory also supports this conclusion (Bernabò Brea et al., 2010). Furthermore, the evidence from Pau suggests that this interconnected trade and cultural exchange network was not limited to a specific region but extended across the Mediterranean basin. This network likely played an important role in the development of the Middle Neolithic period as it allowed for the spread of artefacts, technologies, and goods between different populations. This in turn allowed for the development of complex social and economic systems, which eventually had a significant impact on the development of the region.

9.3 OBJECTIVE 3: USE 3D MODELLING, GIS MAPPING, AND AERIAL PHOTOGRAMMETRY TO COMPREHEND THE LOCALITY IN WHICH PEOPLE LIVED, HOW THEY MODIFIED THE AREA, AND HOW THEY WERE MODIFIED BY IT.

Chapter one introduced Boas' (1911) concept of people as being influenced by their physical and cultural environment. This can shape the economic and social development of a community or region, influencing the way people live and interact. Environmental factors can also shape the development of an organism, influencing its growth and behaviour. Finally, the formation of social norms and values can be influenced by societal tiers such as family, peers, and cultural aspects. The analysis of artefacts is a key part of understanding the identity of past populations. Through their analysis, it is possible to gain insight into how people lived, how they worked, and how they interacted with one another. By studying the shape, size, and material of the artefacts, archaeologists can infer information about the technologies used and their economy. Additionally, the presence of certain types of artefacts, such as religious items, can help understand their spiritual and cultural beliefs. The analysis of burials and funerary rites, such as the placement of the remains, the orientation, and the type of burial, can be used to understand the identity, beliefs, and values of past populations (Puddu, 2018). Human signs can be interpreted as reflections of a pre-formed society, or as tools to create people perceptions (Puddu, 2018). This debate centres on the understanding of signs and their influence on people's actions. This information can be used to gain a better understanding of past social structures such as, *e.g.* gender roles. Ultimately, the identity of past populations is a complex and multifaceted concept. By analysing the physical remains and the environment, insight into the beliefs, values, and behaviour can be gained. The integration of digital methods facilitates a better comprehension of both behaviour and identity of past populations (Landeschi, 2018).

The dispersal analysis (Chapter eight) of the human remains at Pau and Monte Luna, and the associated burial practices and grave goods were integral in developing new hypotheses. The GIS mapping provided a spatial analysis of the remains. There was no spatial variability in the deposition of the remains at Pau as all individuals, irrespective of age, were either inhumed or cremated along the inner wall of the cave. Multiple depositions associated with archaeological artefacts, such as pottery and beads, may either signify a particular social or gender role or, alternatively, a certain level of status or respect within the community. The evidence of heat-induced changes in burials is as abundant as that for inhumation, corresponding with other coeval sites, and possibly indicating trans-maritime cultural exchange. The spatial analysis at Monte Luna potentially implied the presence of areas devoted to familial lineages and also to that of a *tophet*. The artefacts found in these areas and associated with the remains can be re-assessed to study family relationships, social structures, and religious practices. Additionally, ritual activities, such as animal sacrifices and offerings, can be analysed in terms on how these activities were related to the family lineage. The possible recovering of a *tophet* could be used to learn more about the religious practices and rituals associated with the death of the very young. Finally, the relationship between a *tophet* and other religious sites in the area could be explored to gain a better understanding of the religious beliefs of the ancient people of Monte Luna.

9.4 OBJECTIVE 4: PRODUCE A SYNTHESIS OF LIFE HISTORIES BOTH WITHIN AND BETWEEN PEOPLE OF THE NEOLITHIC AND PUNIC ERA. FURTHERMORE, THE ANALYSES WILL BE COMPILED SUITABLE FOR THE STUDY OF OTHER CULTURAL AND TEMPORAL ENVIRONMENTS ACROSS EUROPE, PARTICULARLY WHERE SKELETAL COLLECTIONS ARE POORLY PRESERVED AND/OR COMMINGLED.

The thesis aimed to provide significant new information on the people of Sardinia via the first comprehensive bioarchaeological study of human remains. This investigation into Sardinian populations has obtained information that can be useful for understanding their evolution and highlights how the human-nature dualism played a crucial role through time in the Mediterranean.

9.4.1 Connectivity and exchange: a summary

The geography and climate of Sardinia has been a major factor leading to the development of distinct cultures and populations. The island's rugged terrain, expansive coastline, and mild climate have also contributed to the island's distinct demographic changes, movement of people (Palmisano, 2021), and their health profiles. According to the Neolithic Demographic Transition (NDT), farming communities reached the island long after they had reached mainland Italy (Malone, 2003). The cultural break between the Mesolithic and Neolithic cultures in the region supports the hypothesis of a demic spread of agriculture, and the use of most of the island's ecological niches by new communities (Tanda, 1995; Fenu et al., 1999; Martini et al., 2007). The Neolithic period saw the introduction of new technologies such as the use of polished stone tools and pottery, the domestication of animals, and the construction of permanent settlements. This led to a shift from a hunter-gatherer lifestyle to a more sedentary one, which established an agro-pastoral system that lasted until recent times (Atzeni, 1987). In particular, the Middle Neolithic is characterised by the emergence of new social and religious practices, which were likely related to the development of maritime activities as evidenced by the exchange of obsidian tools, pottery, and the construction of new sedentary settlements. The changes in the stone industry due to the introduction and intensification of obsidian products saw an increase in the number of specialized artisans, suggesting that craft production was becoming increasingly important. The spread of obsidian throughout the region led to the establishment of trading networks and the exchange of goods and ideas between different sites such as northern Italy, Corsica, and France (Gibaja Bao et al., 2013; Tanda et al., 2014; Lugliè et al., 2019). Additionally, the increased production of pottery and other artefacts suggests that new concepts of material culture were emerging at this time. Furthermore, the ability to develop subsistence strategies and technologies to cope with the land and climate led to increased population density by the Late Bronze Age (Atzeni, 1987; Campus et al., 2010; Lo Schiavo, 2013; Vanzetti et al., 2013; Giannitrapani, 2017; Palmisano, 2021). The anthropogenisation of the landscape led to the introduction of new technologies and practices, resulting in an increase in the population in the fourth millennium BC. The domestication of animals allowed for the growth of pastoralism, which allowed for mobility and access to different resources that were not available before. The expansion of agricultural practices also allowed for an increase in trade and exchange of goods, leading to further population growth and the development of urban centres (Malone, 2003; Mercuri, 2013).

Evidence of maritime transport has been seen from the Middle Neolithic onwards, including in the Bronze and Iron Ages (Knapp and Demesticha, 2017; Martin, 2017; Lugliè et al., 2019), leading to easy access to the Phoenician maritime network based on the exchange of local products (Oggiano, 2000). The analysis of the amphorae provided information on the stability of the Phoenicians on the island and their relations with Carthage (Roppa and Madrigali, 2021). The materials used to make the amphorae were also used to produce the transportation amphorae to exchange local products to and from the main African city. As Carthage established its hegemony, Sardinia developed into multiple large urban settlements with elaborate architecture and burials (Tronchetti, 2014). The decrease in imports of amphorae suggests that the Punic period saw a shift away from commercial and trade-based activities towards more localised and subsistence-based activities. This change in lifestyle is evident in the archaeological record with the appearance of a large number of smaller sites that suggest an intensification of agricultural production to support local populations. These sites likely included small settlements, farms, and agricultural terraces. The shift away from trade-based activities also likely saw a decrease in the use of imported goods from abroad and a greater reliance on locally produced items (Roppa and Madrigali, 2021). Generally, this period was an important one in the development of human societies and cultures, as populations increased, and cities grew in size, and complexity enlarged through trade networks and the development of technologies (Cespa, 2018).

The regional diversity of the island, together with the features of the NDT model, may have influenced the population over time due to the raw materials available and the shape of the land. The availability of resources would have affected the development of different industries and economic activities, which in turn would have impacted the demographic makeup of the island. For example, the use of the sea as a source of food would have been highly beneficial to populations living along the coasts and in fishing villages, while those living in the mountainous regions may have relied more heavily on forestry and hunting. In addition, the shape of the land may have influenced the development of transportation networks, which would have impacted the flow of goods and people to and from the island. Finally, the island's climate and geography may have had a significant impact on agricultural production, which would have determined the type of crops that could be grown and the availability of food for the population. This agro-pastoral model lasted until recent times (Atzeni, 1987). Sardinia's economy was based on the transhumance of sheep, goats, and pigs until the 1970s (Le Lannou, 1979). Through a toponomastic study, agro-pastoral communities have been shown to establish a symbiotic relationship with the land through signs of a humanised geography (Murru Corriga, 1990) as in *Mont' 'e s'appettitu* (Bitti) «mount of hunger», *Nodos de massaja* (Bitti) «housewife's bumps»; *Abbas de zoza* (Bolotana) «Thursday water»; *Ischina 'e su re* (Dorgali) «King's back» (Pittau, 2011). The profile of the Sardinian population presented here is based on resilience and adaptation to the environment in a reciprocal relationship between the humanisation of the land and the subsequent learning of new practices (Maxia, 2003). The archaeological data from the ceramic remains of Pau have shown that the diet was based on the processing of milk and meat, as well as plant food (Fanti et al., 2018). Milk and meat probably came from goats and pigs, as Malone (2003) found when analysing finds and faunal remains in Sardinian sites consistent with the faunal remains collected at Pau. It is also known that the Punic diet was based on domesticated animals such as sheep, goats, and pigs, as well as cereals, legumes, fruits, and seafood (Ramon Torres, 1995; Sanna, 2019).

9.4.2 Understanding Pau and Monte Luna

The case studies from the Middle Neolithic and Punic eras in Sardinia have shown the need to address a number of key differences to mainland Italy:

- Late introduction of farming communities (Malone, 2003).
- Differential climate change (Pascucci et al., 2018; Palmisano, 2021).
- Regional environmental variability influenced the mutually inclusive relationships between humans and nature shaping culture, subsistence practices, and biology (Boas, 1911; Murru Corriga, 1990; Powell, 1991; Grauer, 1995; Larsen, 1997a/b; Maxia, 2003).

These features have played a crucial role in the complex and dynamic history of Sardinia. Despite the cultural components of the period based on different beliefs and practises, comparison of the case studies discussed so far reveals a relational understanding of Sardinia's identities through the following similarities:

- Rural settlements (Figure 2).
- Seafaring and maritime activities (Alciati, 1978; Oggiano, 2000; Luglié, 2019; Roppa and Madrigali, 2021).

- Intentional burning rites (Moscati, 1985; Piga, 2010; Tronchetti, 2014; Piga, 2015; Bartoloni, 2017; chapter three).
- Protein intake mainly from sheep, goats, and pigs (Ramon Torres, 1995; Malone, 2003; Sanna, 2019).
- Sedentarism and agro-pastoral systems (Atzeni, 1987; Malone, 2003; Lugliè, 2008; Tronchetti, 2014; Bartoloni, 2017; Roppa and Madrigali, 2021).
- Endemic malaria (Brown, 1981; Tognotti, 2008; Setzer, 2010; Viganò, 2010).

The interpretation of these factors must be contextualised by the above-mentioned information with the genetics and endemism of the island. The late arrival of farming communities is consistent with the genetic profile presented by Marcus et al., (2020), which was stable from the MN until the end of the Nuragic period (~900 BC). However, variation was noted with the arrival of different populations from all over the Mediterranean. The first to arrive were the Phoenicians, who came from the Levant (present-day Lebanon), followed by the Punics, who came from Carthage (present-day Tunisia). Then, during the Roman era, further new lineages continued to arrive. This influx of diverse populations has resulted in a unique genetic composition of the people of Sardinia, characterised by periods of long isolation and subsequent mixing (Chiang et al., 2018, Marcus et al., 2020). Although representing two temporally distinct cultural periods of Sardinia, both the people of Pau and Monte Luna have similar demographic profiles and oral health. This can be interpreted as demic diversity in the context of small rural centres that presumably had low-stress lifestyles in a geographically and historically isolated area, consumed local food, and engaged in economically oriented interactions with other coeval populations in the Mediterranean.

Malaria has been widely reported as endemic in Sardinia since prehistoric times up until 1950 (Brown, 1984), and the disease is considered crucial in shaping population genetics, economy, and culture throughout history (Brown, 1981; Tognotti, 2008). The appearance of transhumance is linked with the severity of malaria as people were moving to the mountains in summer and the valleys in winter (Brown, 1981; Tognotti, 2008). The primary malarial vector, *Anopheles labranchiae*, was indigenous to the island and existed before human settlement (Trapido, 1951; Aitken, 1953). Later, in Punic times, it was re-introduced by arrivals from North Africa (Tognotti, 2008). While the site of Pau is close to Monte Arci, Monte Luna is located in the fertile plain of Trexenta, which was characterised by numerous marshes until recent times. These ecological and epidemiological conditions were favourable to mosquitoes and facilitated the spread of the disease on the island, triggering behavioural responses by the Sardinians (Brown, 1981; Tognotti, 2008; Setzer, 2010). The malarial virus digests haemoglobin and reproduces within red blood cells releasing newly formed parasites (Wyler, 1983). Any condition that impairs the production and/or availability of haemoglobin to the malarial parasite will limit a person's ability to contract malaria. Among the many adaptive responses, thalassaemia and glucose-6-phosphate dehydrogenase (G6PD) have been shown to be present in the people of Sardinia (Brown, 1981; Cao et al., 1978; Carter and Mendis, 2002). It has been shown that this haematological disorder was endemic in the Roman period (Viganò, 2017), leading to the assumption that past populations were still adapting to the new situation at that time. As an adaptive response to malaria, thalassaemia major or minor, protects against malaria, but also causes other diseases such as iron deficiency and ovalocytosis, leading to further health implications (Carter and Mendis, 2002). In fact, thalassemia major produces the most severe skeletal changes and leads to death in early childhood if not treated with frequent blood transfusions (Cao, 2004). In contrast individuals with thalassemia minor do not need specific treatments and can control the condition by living a healthy lifestyle, thereby surviving longer and contributing to future generations (Tognotti and Montella, 2017; Pes et al., 2017). Iron deficiency is also highly influenced by dietary intake, leading to high mortality rates in childhood and stress in later years. In addition, the condition leads to delayed puberty due to insufficient production of sex hormones (hypogonadism), resulting in stunted growth and development. As a result, individuals affected by beta-thalassaemia may not reach their full potential for adult stature (Pes et al., 2017), which might explain the low mean statures calculated for a number of communities in Sardinia and in the present study at Monte Luna (Floris, 1983; Martella et al., 2016; Danubio et al., 2017).

A review of the literature and interpretation of the collected osteological data from Pau and Monte Luna presented here, suggest that environmental and social conditions were interrelated. Isolation, along with the environment, played a role in shaping the health profile of the Sardinians, which needs to be studied from a bioarchaeological perspective. In summary, this study is the first comprehensive work on two Sardinian populations and seeks to define the usefulness of a bioarchaeological approach to develop new data. The information gained by the associated study of oral health, stress markers, and height added an overview which encompasses together biological and cultural data throughout this two different Sardinian times, places, and customs. This thorough work has the benefit of being aligned with the most recent studies on Mediterranean and European population for comparison, allowing the understanding of new connections, and hypotheses.

9.5 CONCLUSIONS

A comprehensive bioarchaeological analysis of the people of Pau and Monte Luna was undertaken to provide data aligned with other studies on Mediterranean and European populations. The information on the environment and landscape here combined with data gained via traditional archaeological methods and specifically data via the study of poorly preserved remains using advanced analytical techniques have shown to be beneficial in understanding the past. The application of advanced techniques also provided a non-invasive approach aligning with the current legislation of cultural heritage. The specific theoretical and methodological frameworks used have allowed to place the human remains within an archaeological context, proving to be invaluable as a basis for future studies.

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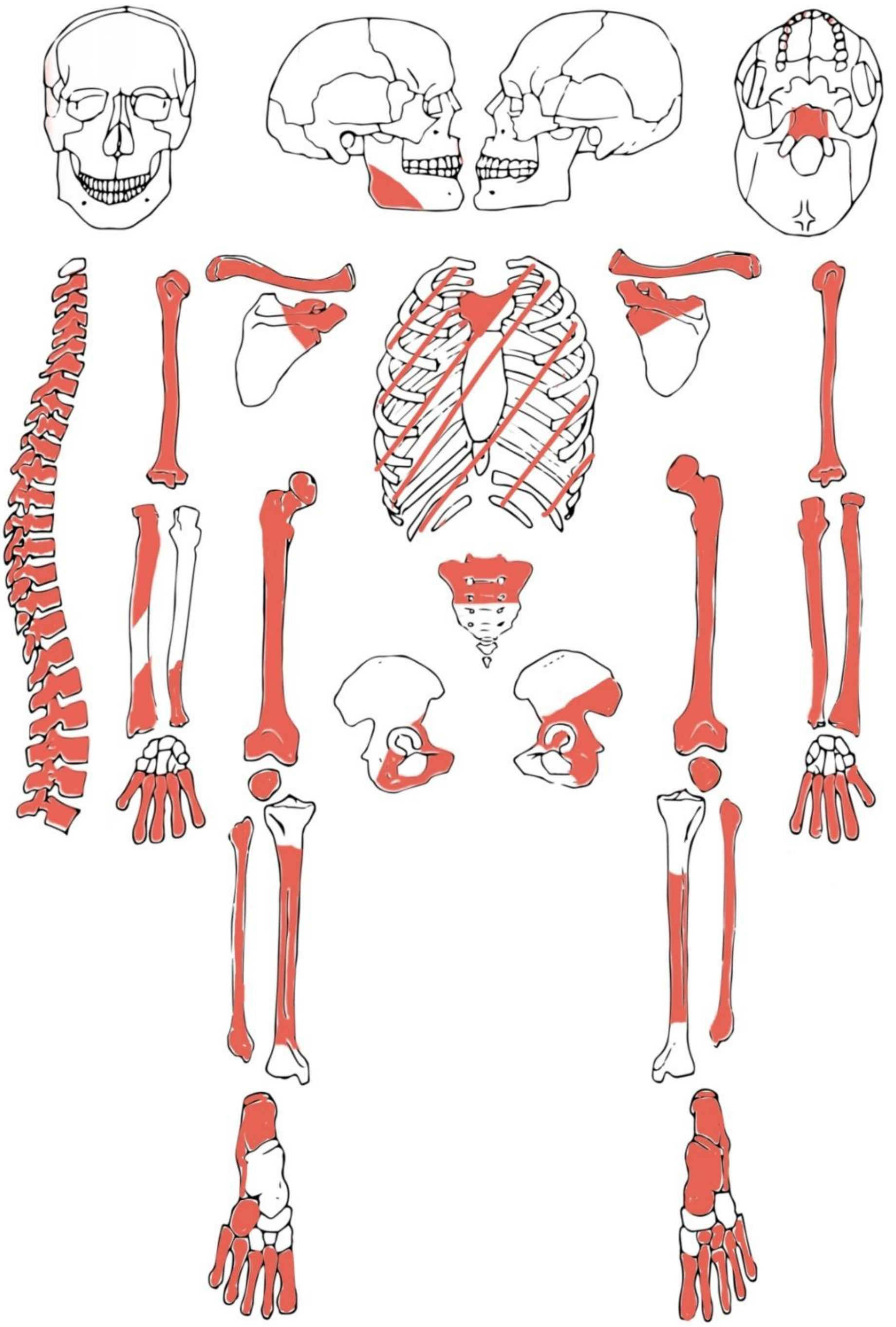

Figure 55 Monte Luna. Tomb 7A.

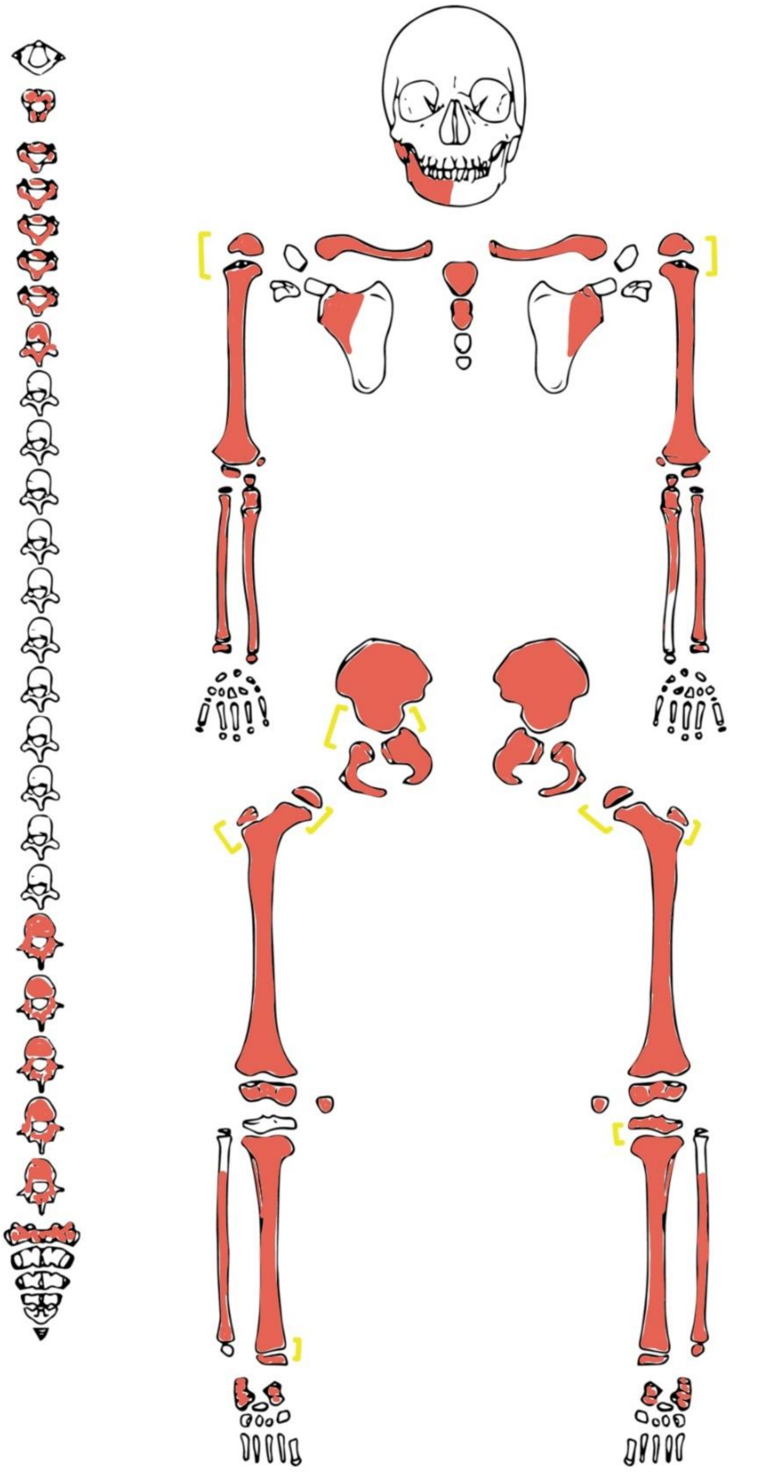

Figure 56 Monte Luna. Tomb 7B.

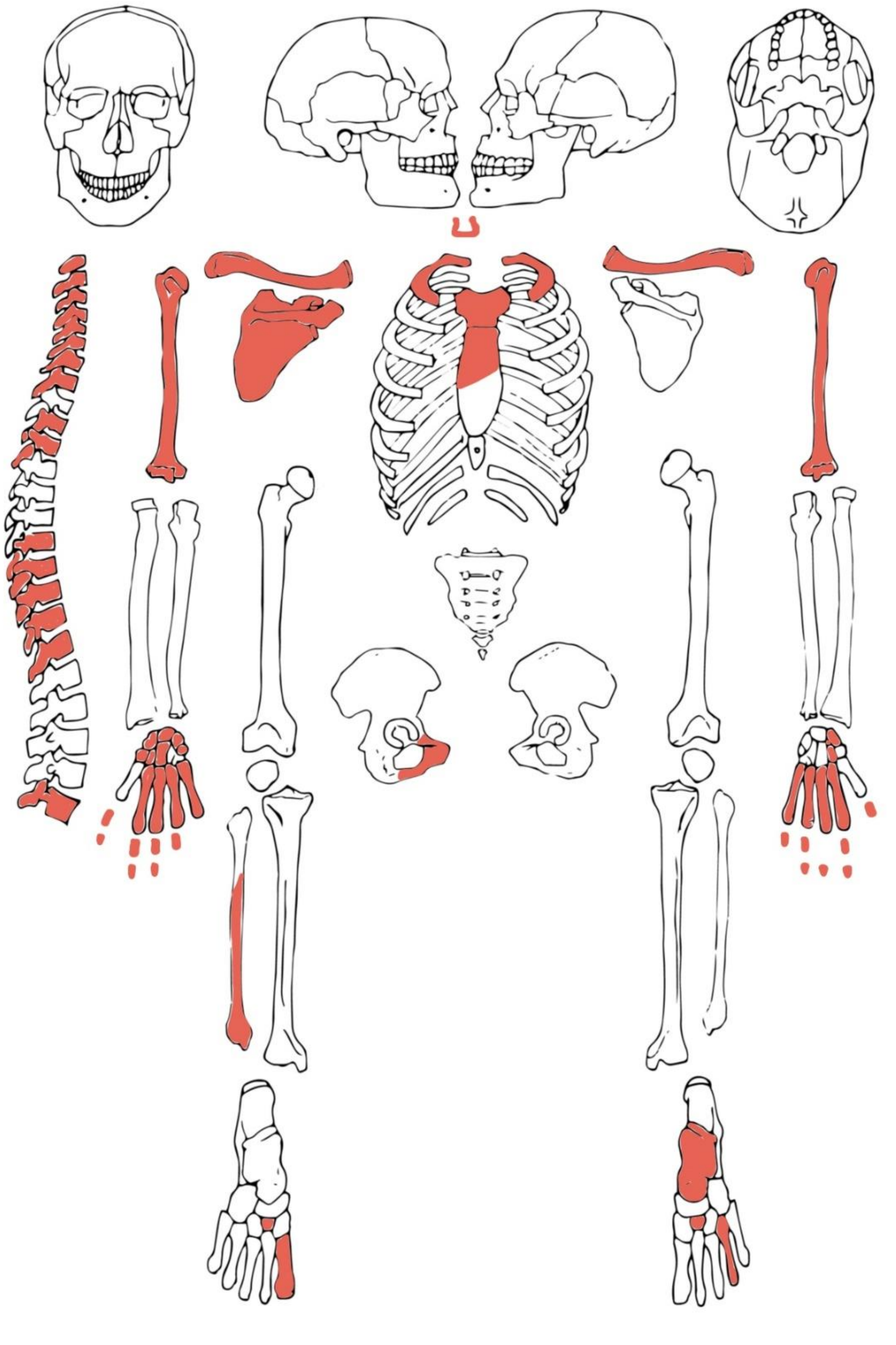

Figure 57 Monte Luna. Tomb 16.

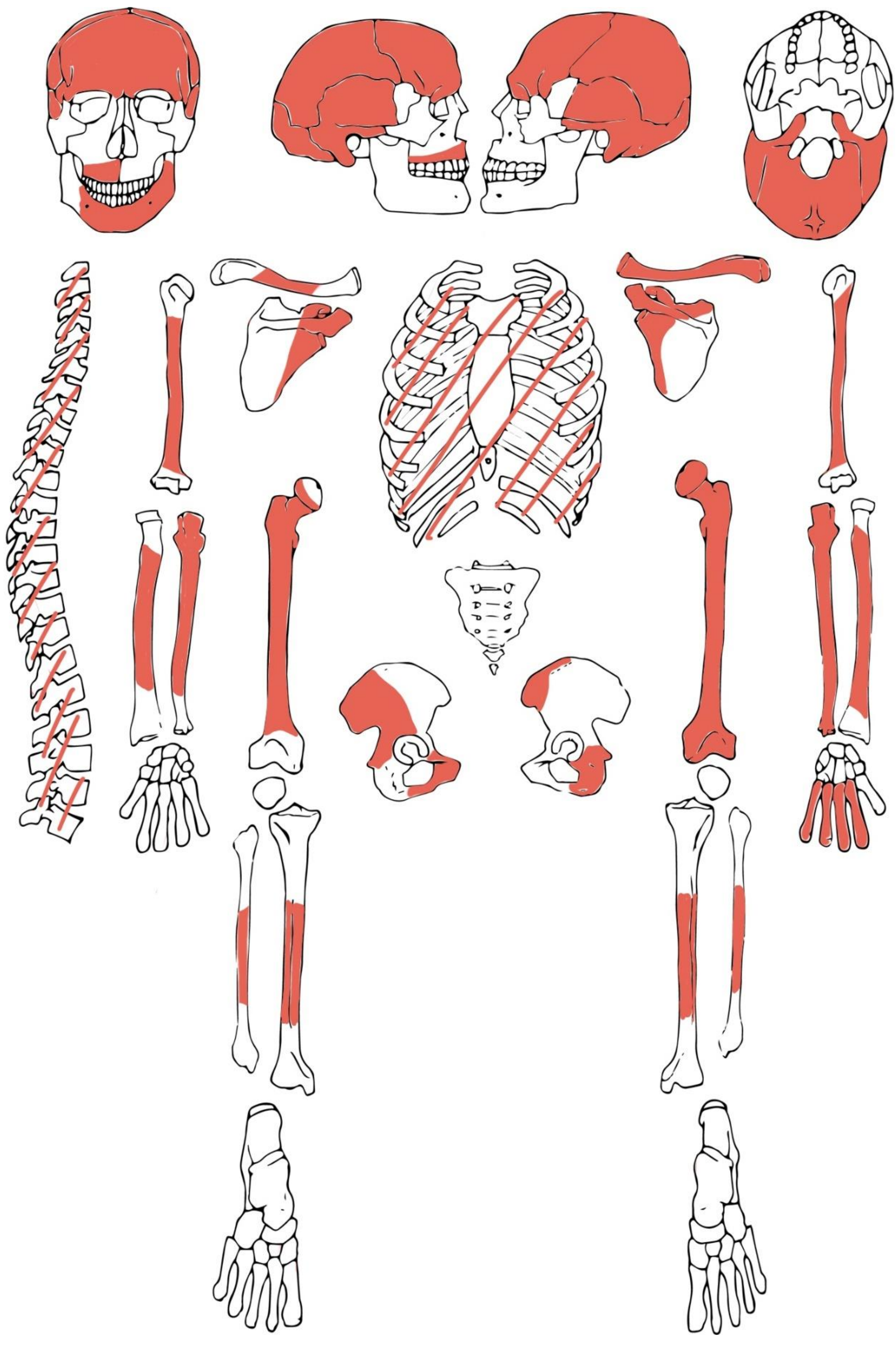

Figure 58 Monte Luna. Tomb 25.

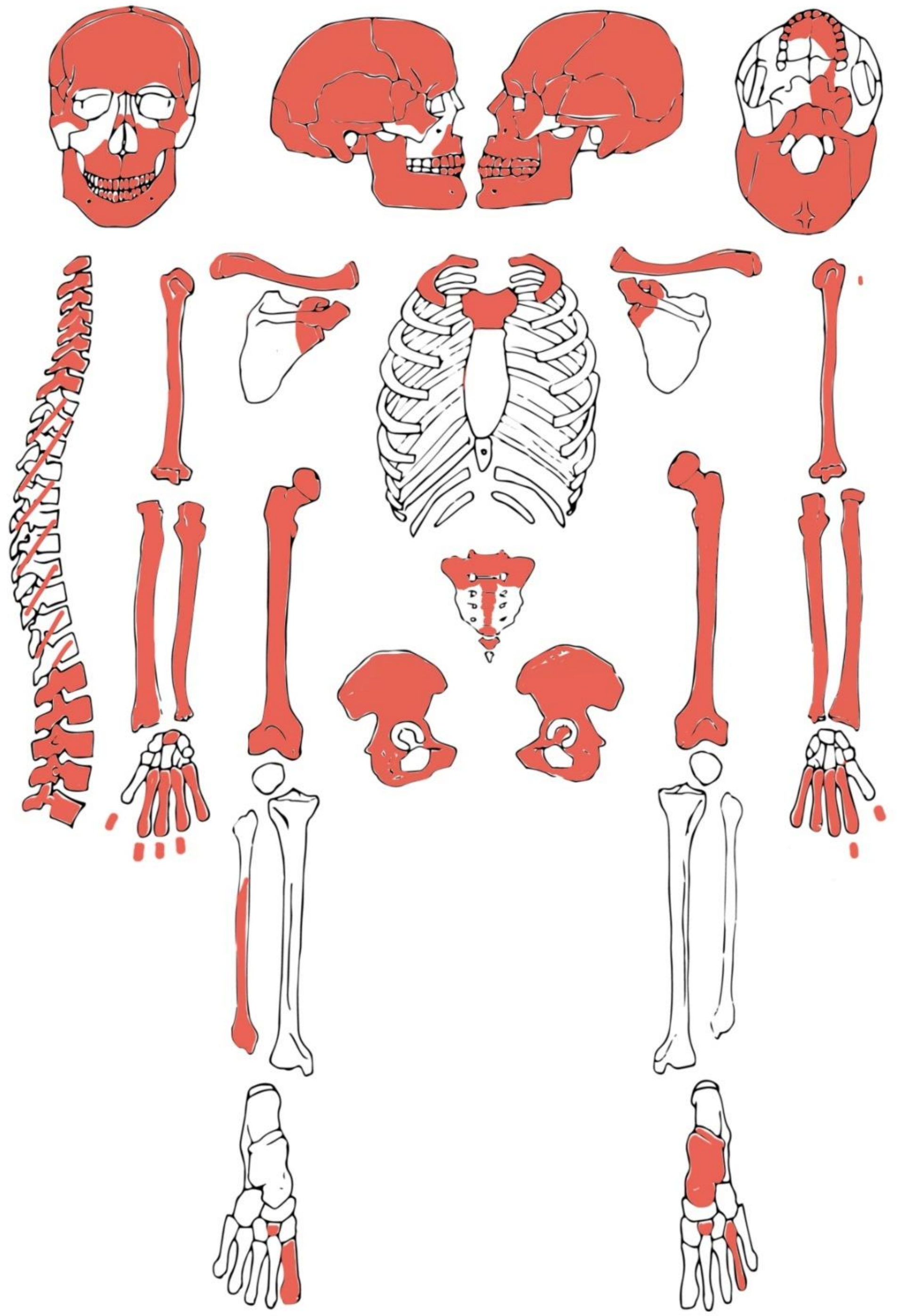

Figure 59 Monte Luna. Tomb 26.

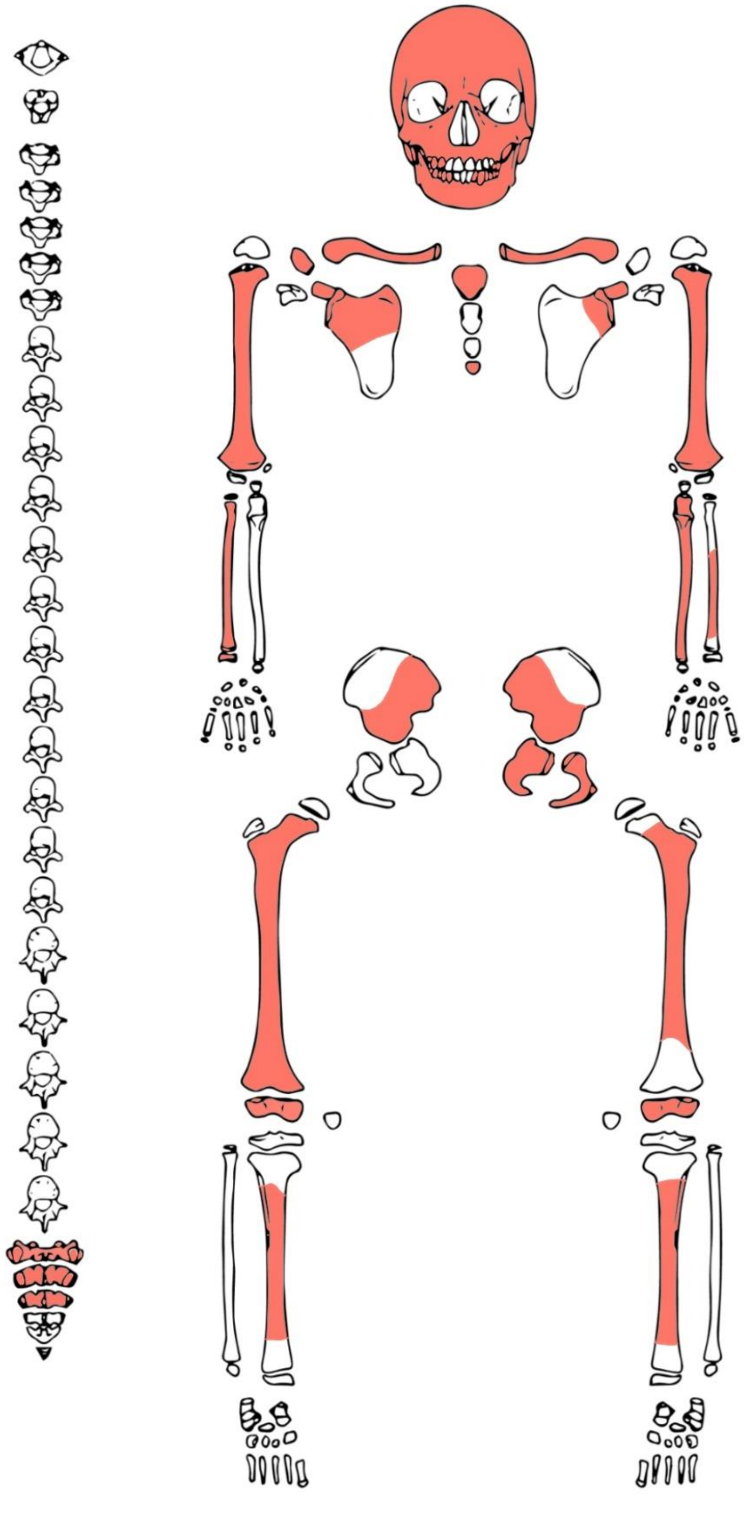

Figure 60 Monte Luna. Tomb 27.1.

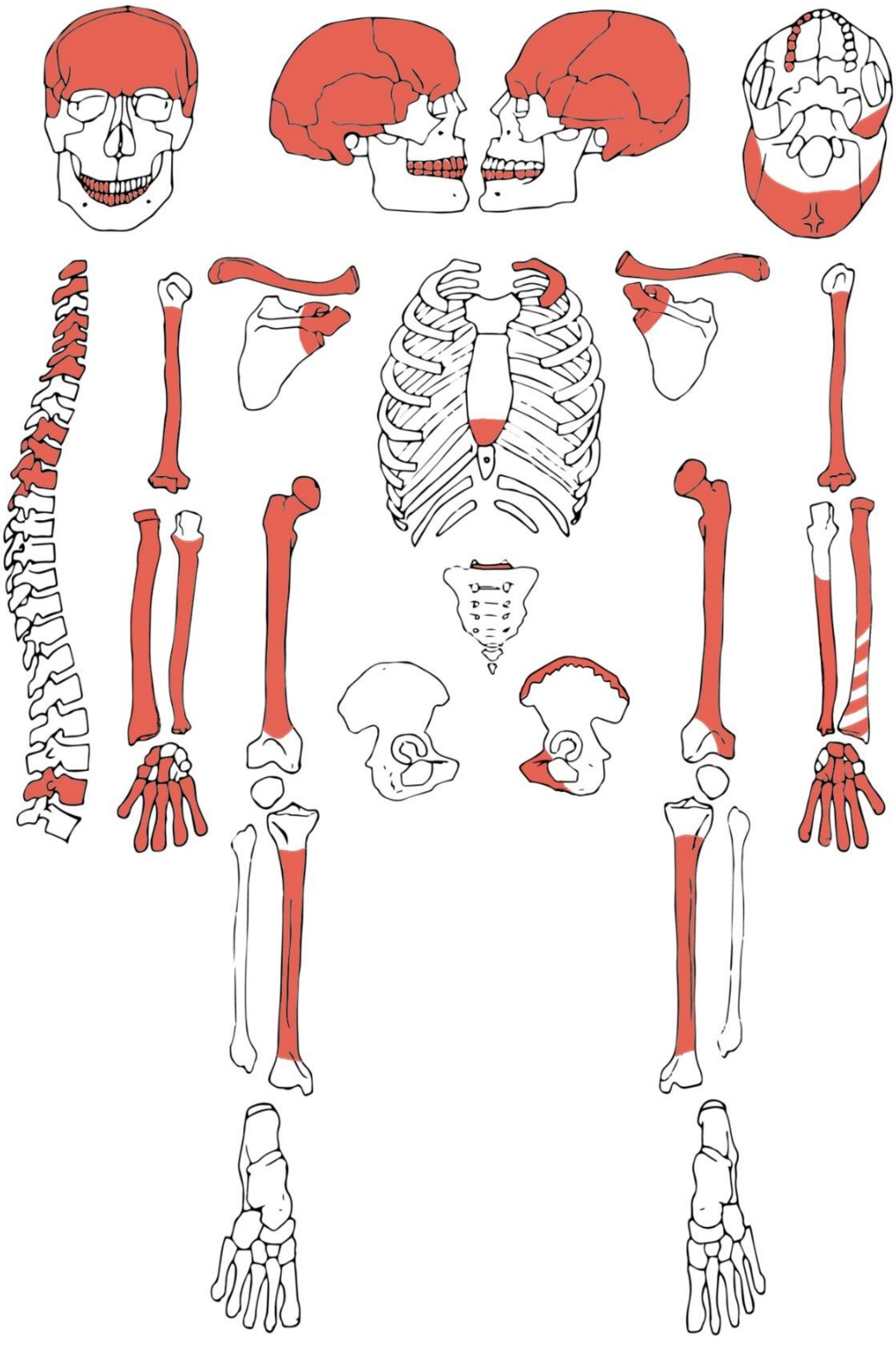

Figure 61 Monte Luna. Tomb 27.2.

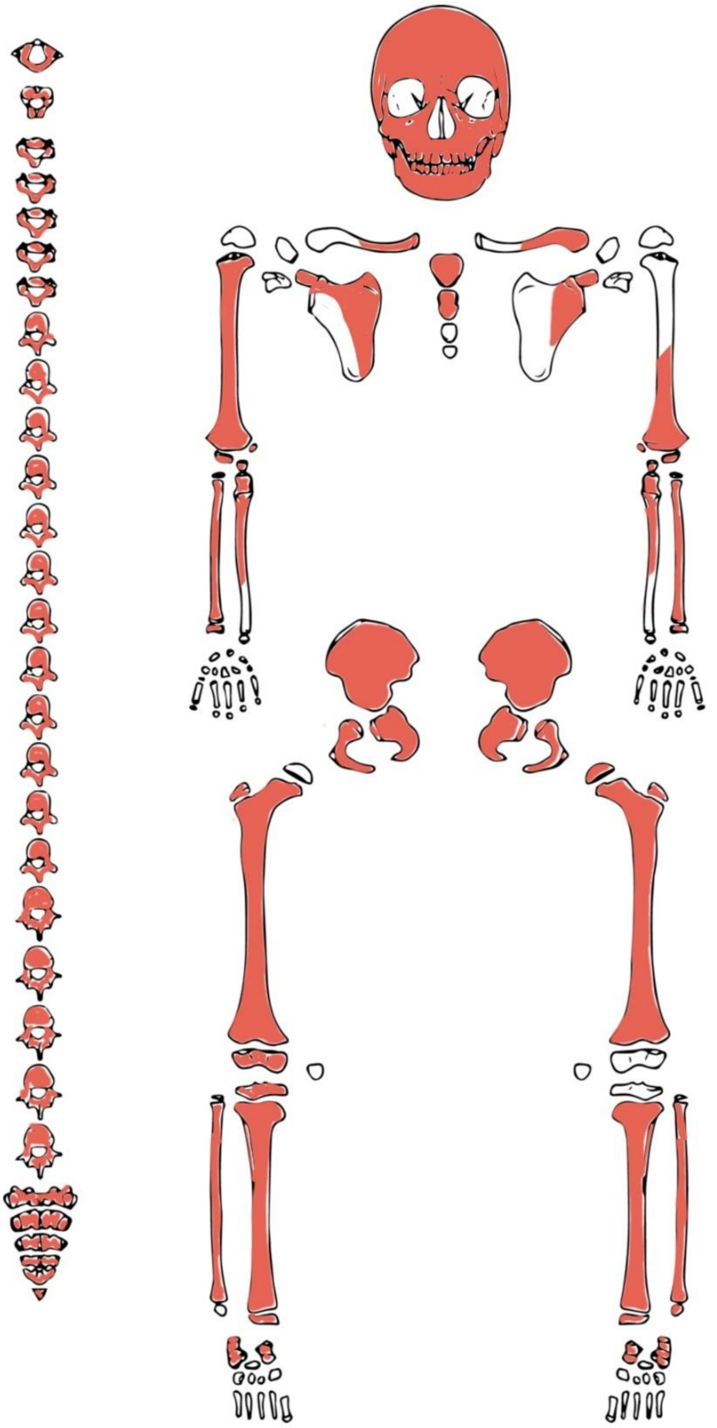

Figure 62 Monte Luna. Tomb 28.1.

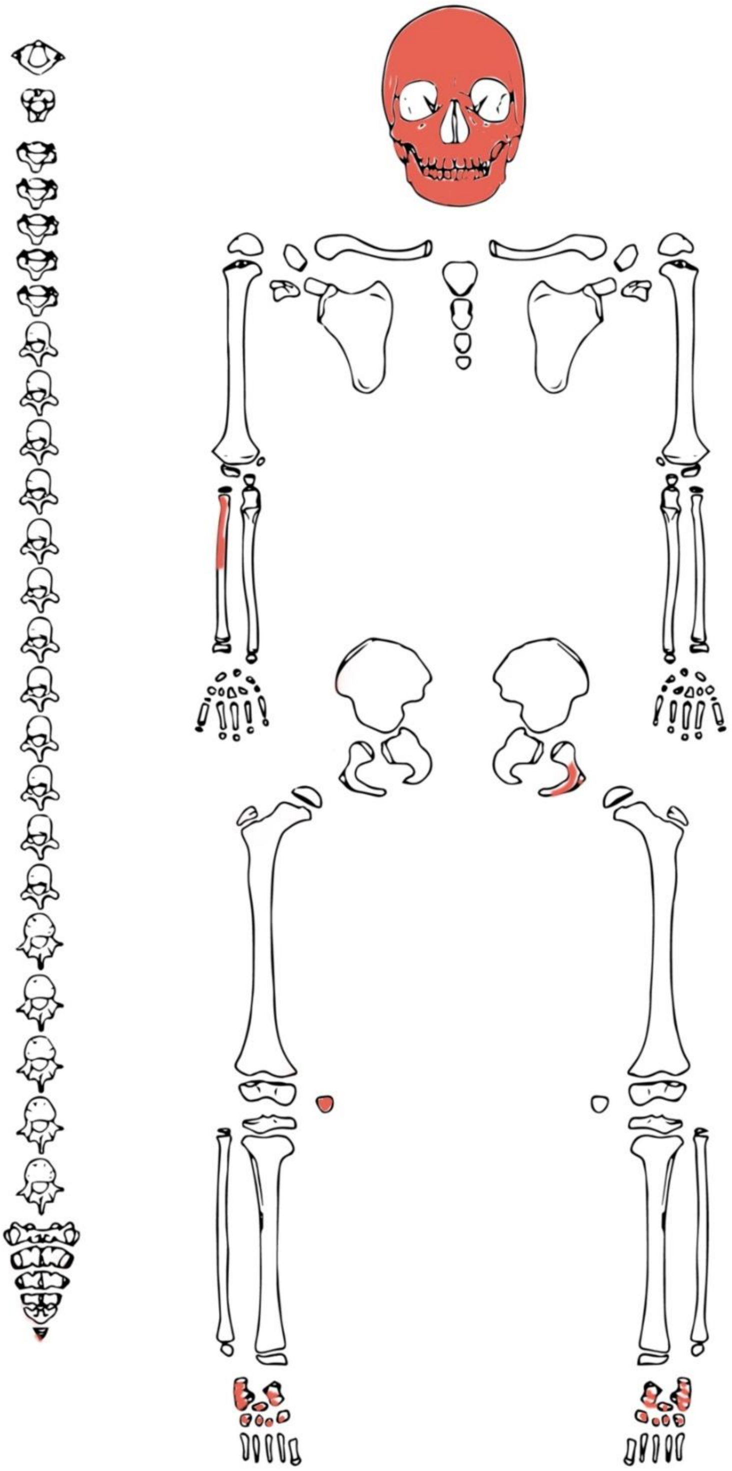

Figure 63 Monte Luna. Tomb 28.2.

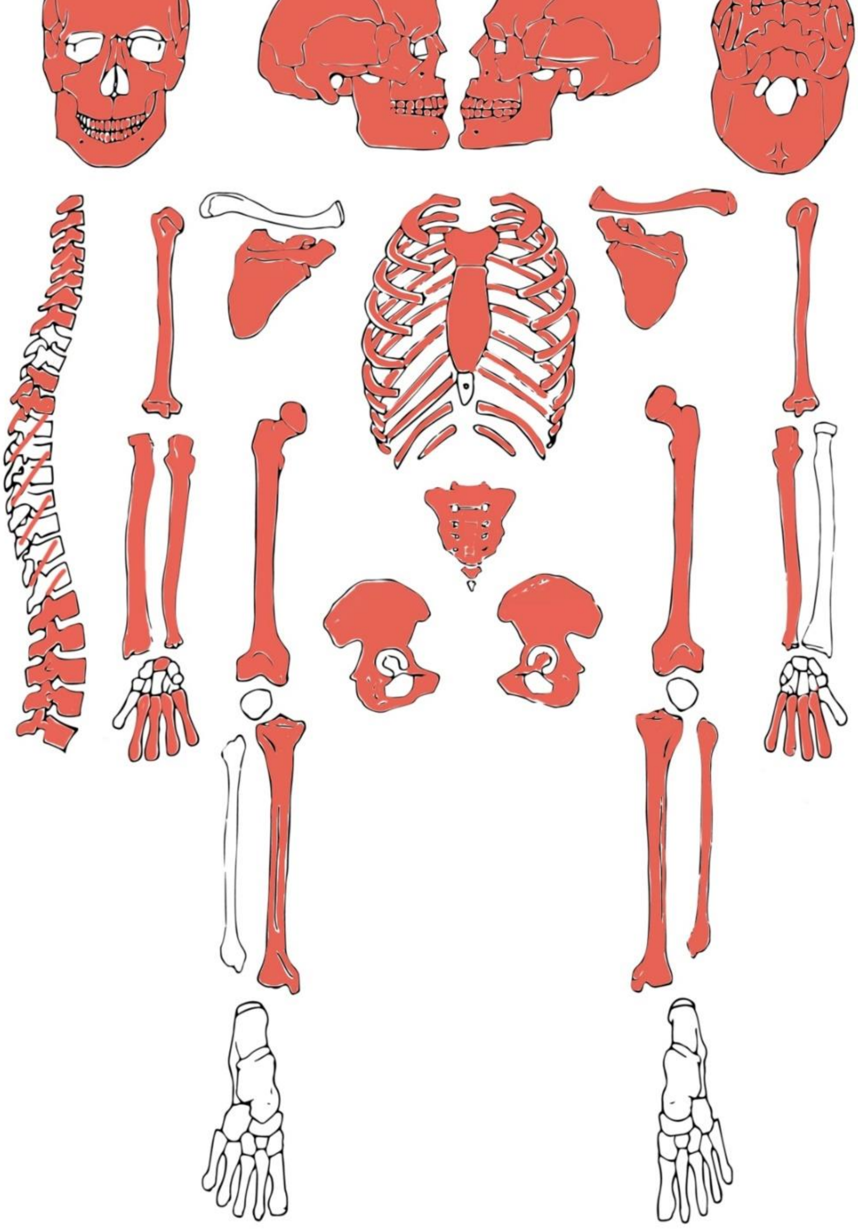

Figure 64 Monte Luna. Tomb 59A.

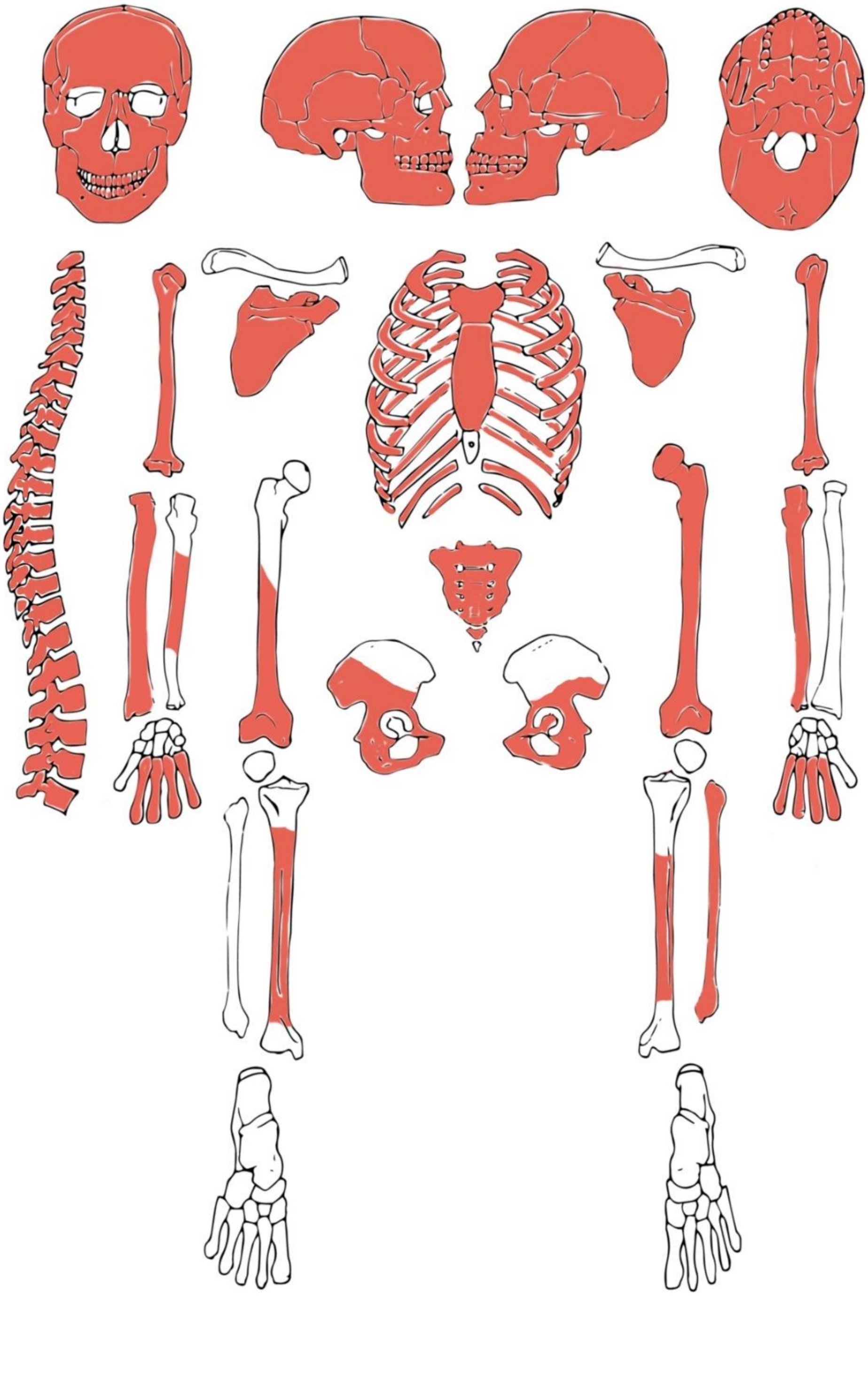

Figure 65 Monte Luna. Tomb 59B.

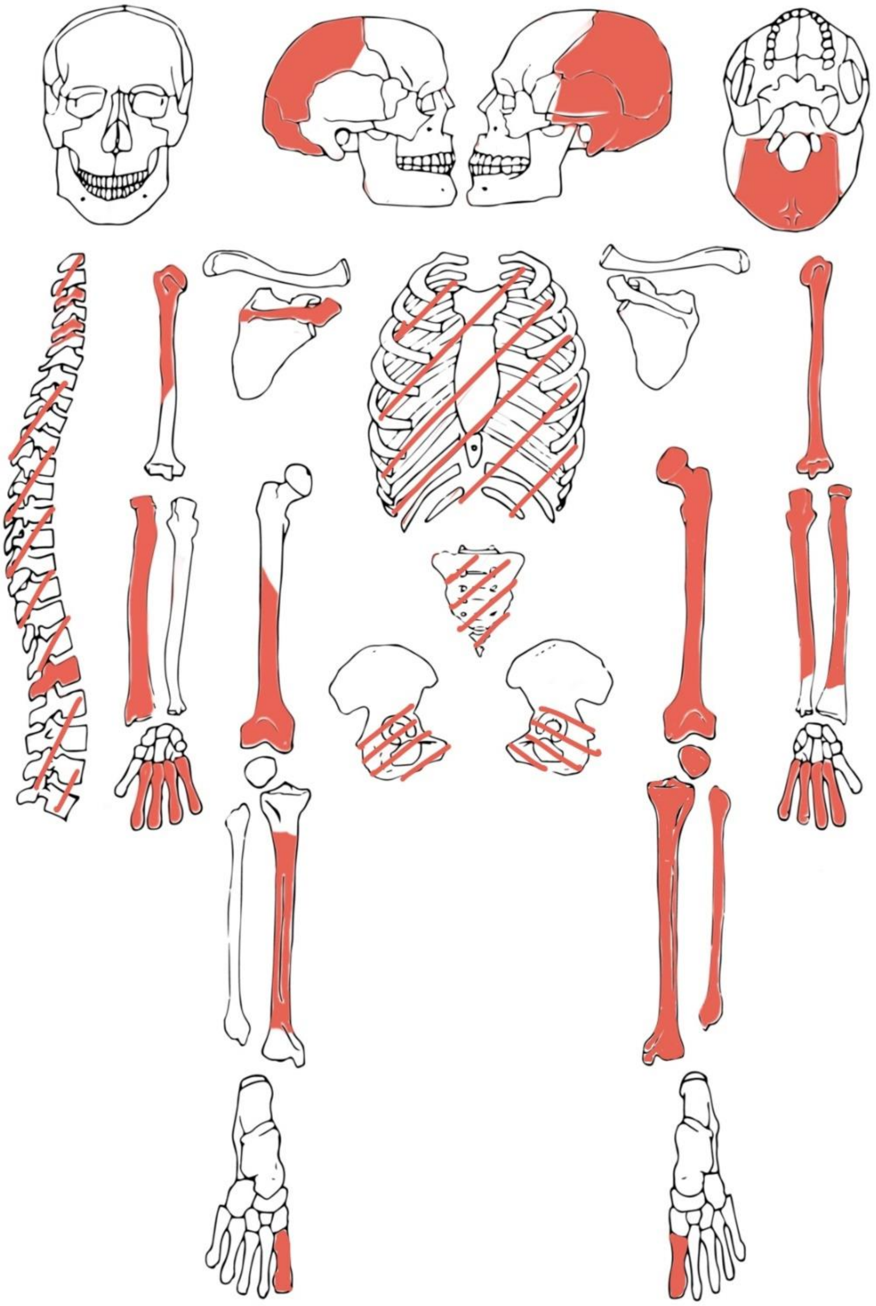

Figure 66 Monte Luna. Tomb 61.

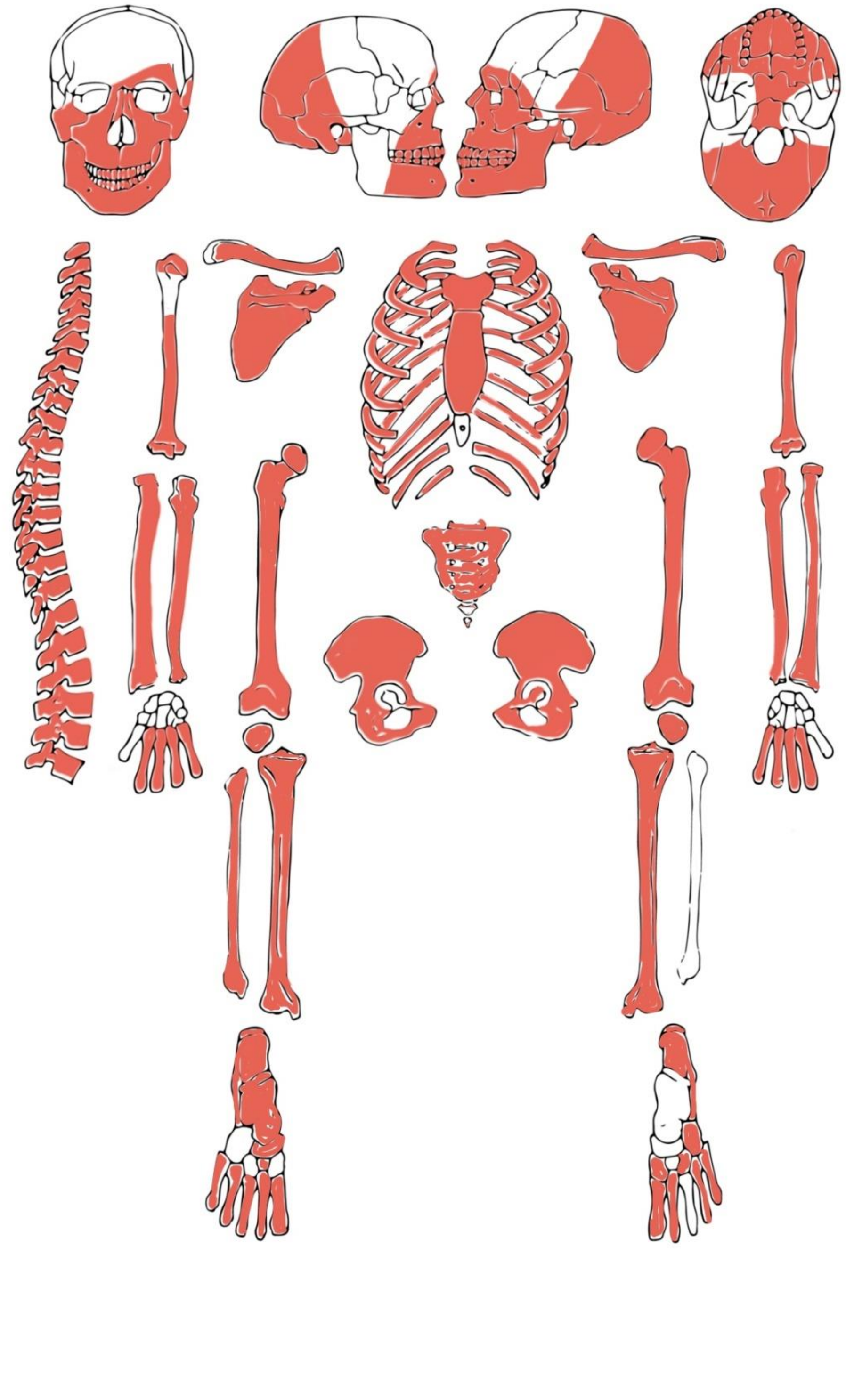

Figure 67 Monte Luna. Tomb 63.

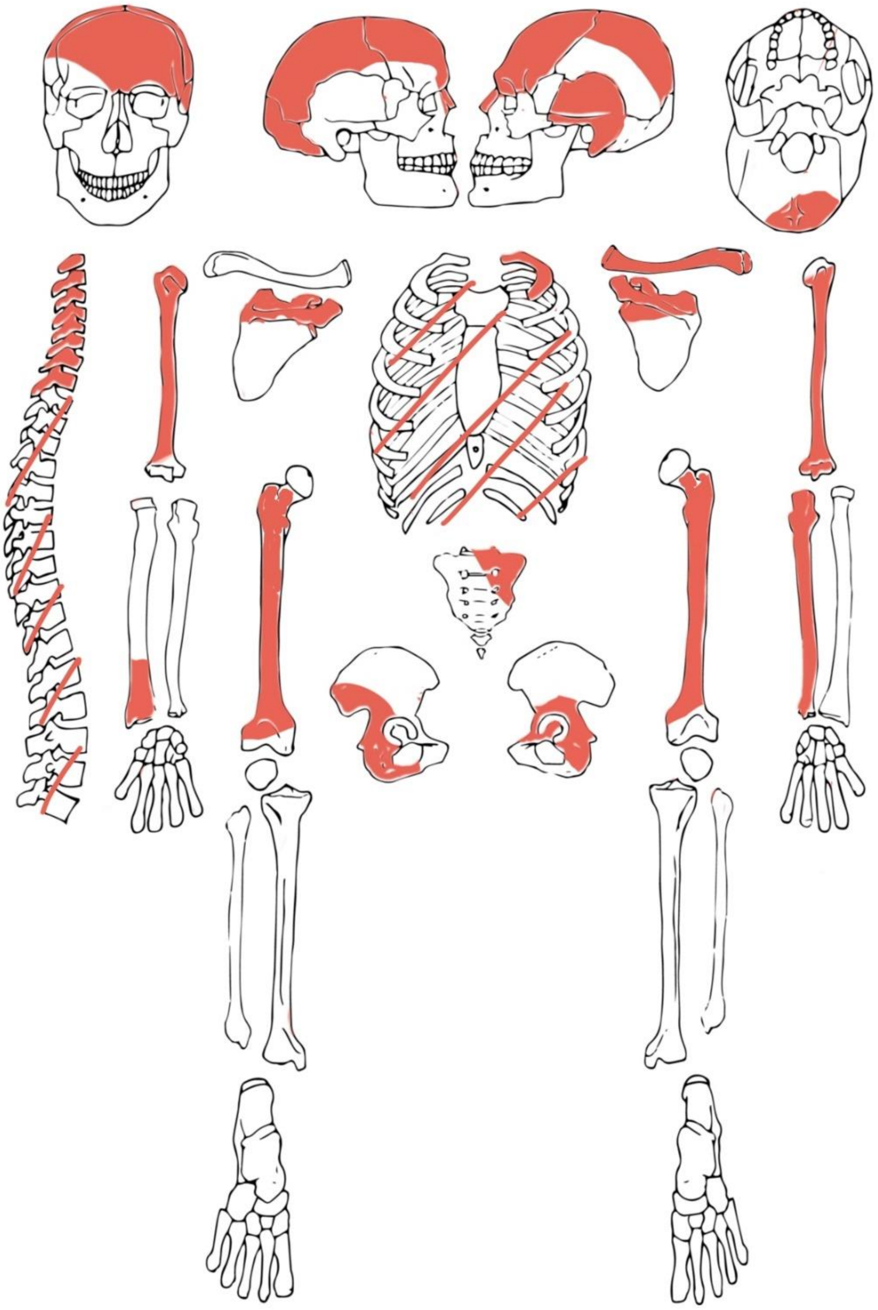

Figure 68 Monte Luna. Tomb 70.

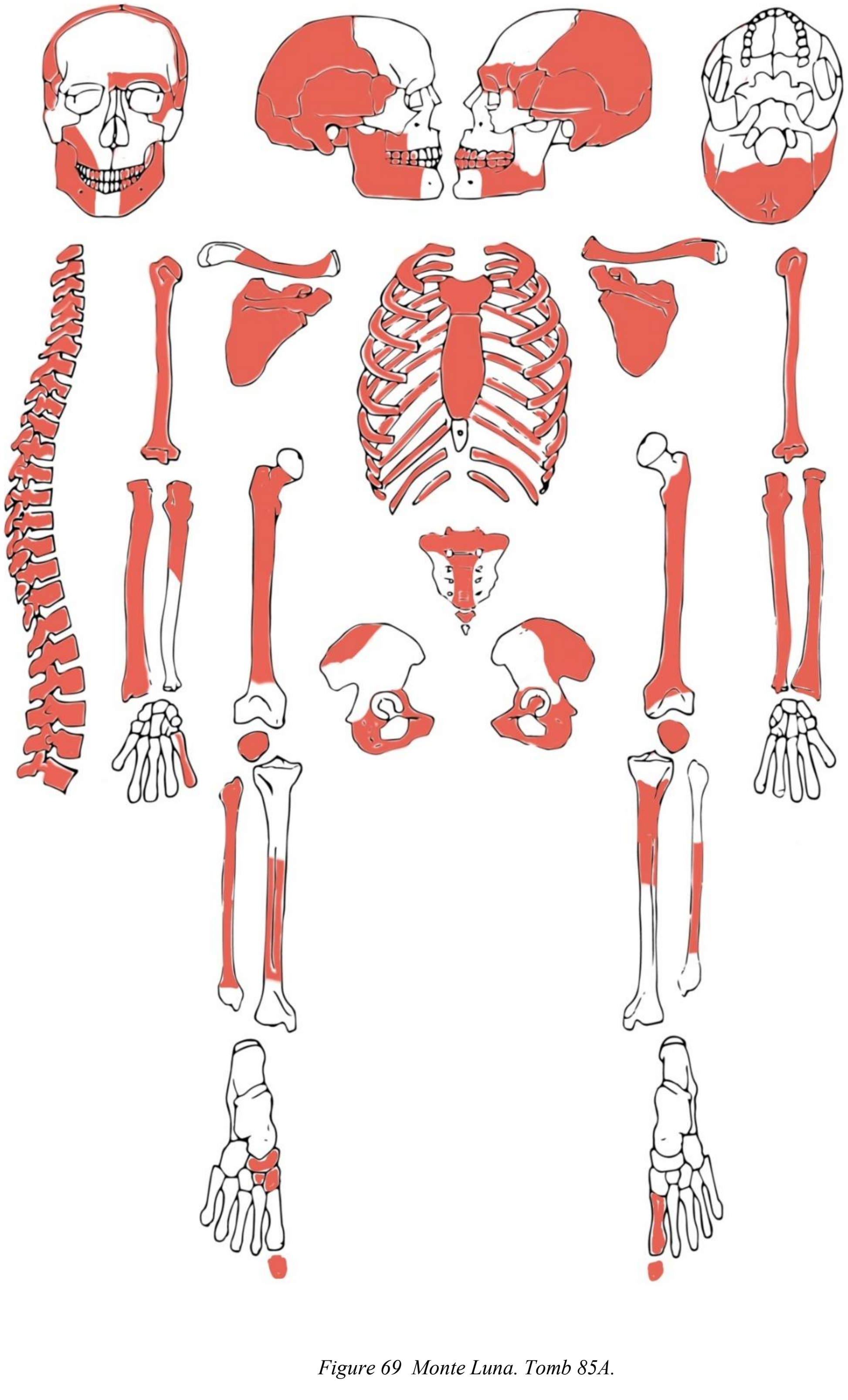

Figure 69 Monte Luna. Tomb 85A.

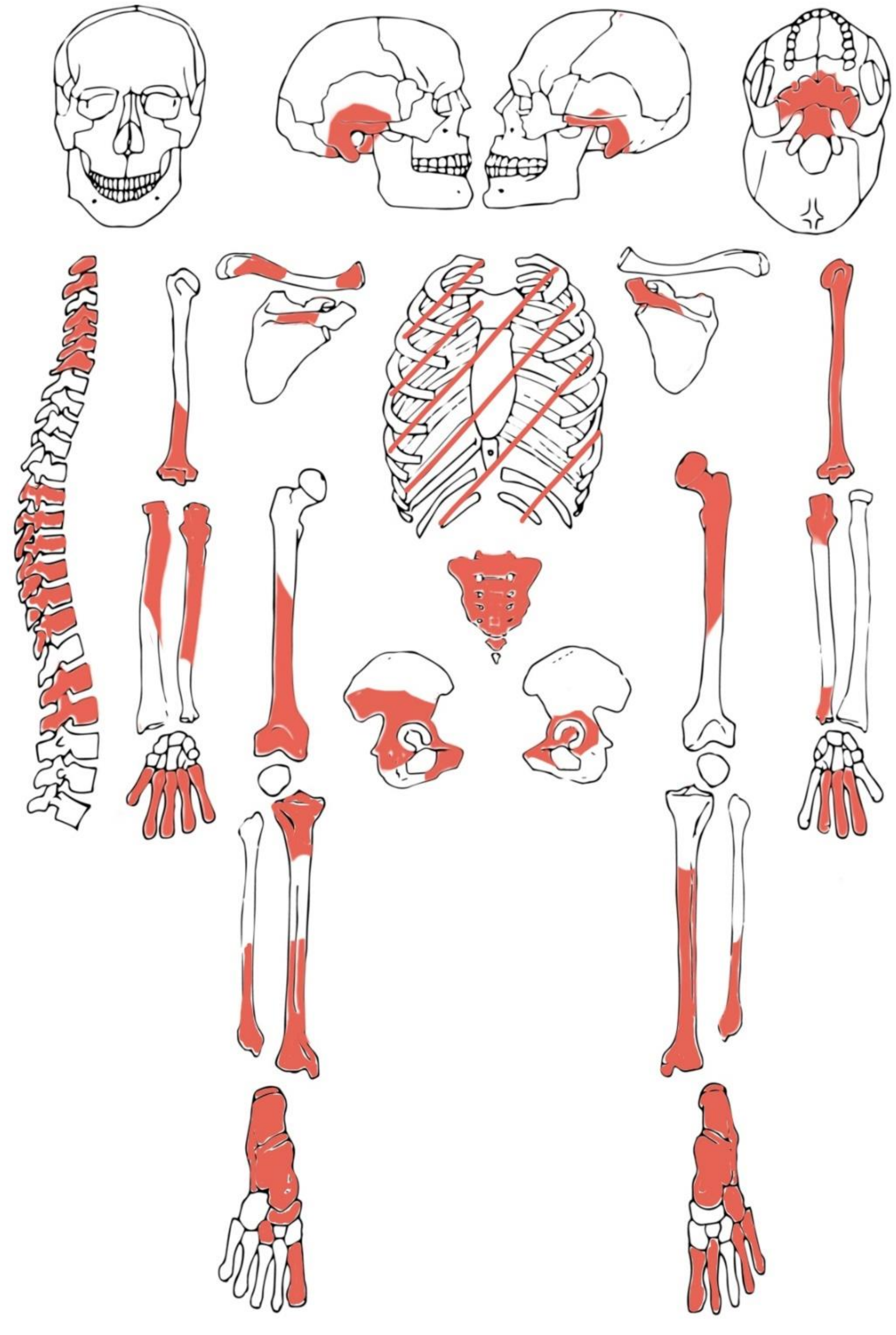

Figure 70 Monte Luna. Tomb 87cB.

APPENDIX B

List of measurements taken in the present work.

	Clavicle
Maximum Length	
Vertical Diameter ½	
Sagittal Diameter ½	
Minimum Circumference	
Strength Index	Min Circumference/ Max Length*100
Side	
Sex	

	Humerus
Maximum Length	
Maximum Mid Shaft Diameter	
Minimum Mid Shaft Diameter	
Minimum Circumference	
Maximum Proximal Width	
Head Diameter	
Maximum Distal Width	
Strength Index	Min Circumference*100/ Max Length
Diaphysiatic Index	Min Midshaft*100/Max Midshaft
Side	
Sex	

	Radius
Maximum Length	
Physiological Length	
Diameter on Crest	
Diameter Perpendicular to Crest	
Minimum Circumference	
Maximum Proximal Width	
Strength Index	Min Circumference*100/ Physiological Length
Diaphysiatic Index	Diam Perp to Crest*100/Diam on Crest
Side	
Sex	

	Ulna
Maximum Length	
Physiological Length	
Medio Lateral Diameter on Incisure Maxima	
Antero Posterior Diameter on Incisure Maxima	
Minimum Circumference	
Strength Index	Min Circumference*100/ Physiological Length
Diaphysiatic Index	Min Circ*100/Ant Post Diam on Inc Max
Side	
Sex	

	Femur
Maximum Length	
Physiological Length	

Medio Lateral Mid Shaft Diameter	
Antero Posterior Mid Shaft Diameter	
Mid Shaft Circumference	
Medio Lateral Sub Trocanteric Diameter	
Antero Posterior Sub Trocanteric Diameter	
Diameter of Head	
Strength Index	Mid Shaft Circ*100/ Physio Length
Pilastric Index	Ant Post MS Diam*100/Med Lat MD Diam
Platimetric Index	Ant Post ST Diam*100/Med Lat ST Diam
Side	
Sex	

	Tibia
Maximum Length	
Antero Posterior Diameter on Foramen	
Medio Lateral Diamater on Foramen	
Minimum Circumference	
Strength Index	Min Circ*100/ Max Length
Cnemic Index	Med Lat Diam*100/ Ant Post Diam
Side	
Sex	

	Patella
Maximum Length	
Maximum Width	
Breadth	
Side	
Sex	

	First Metatarsal
Maximum Length	
Mediolateral Diameter of the Proximal Articulation	
Dorsoplantar Diameter of the Proximal Articulation	
Dorsoplantar Diameter of the Distal Articulation	
Mediolateral Diameter of the Distal Articulation	
Side	
Sex	

	Coxale
Acetabulo – Symphyseal Pubic Length PUM	
Cotylo-Pubic Width SPU	
Innominate or Coxal Length DCOX	
Ischium Post – Acetabular Length ISMM	
Iliac or Coxal Breadth SCOX	
Spino – Sciatic Length SS	
Spino – Auricular Length SA	
Cotylo – Sciatic Breadth SIS	
Vertical Acetabular Diameter VEAC	
Side	
Sex	

Clavicle	Clavicle - Maximum Length	Clavicle - Vertical Diameter 1/2	Clavicle - Sagittal Diameter 1/2	Clavicle - Minimum Circumference	Strength Index	Side	Sex
TPV_CL2		1.08	1.10	3.80		RX	
TPV_CL11	14.00	1.20	1.10	4.00	28.57	LX	
V1_CL1		1.20	0.90	3.40		LX	
T6_CL4		1.30	1.15	4.10		LX	
T121_CL1		1.00	0.90	3.50		RX	
TPII_CL1	12.60	1.10	0.70	3.00	23.81	RX	
TPII_CL2	13.00	0.80	1.00	3.00	23.08	LX	
T16_1A_CL1	13.00	1.00	0.70	2.90	22.31	RX	
T16_1A_CL2	13.00	0.90	0.70	2.90	22.31	LX	
DDJ1_CL1		1.10	1.05	3.50		RX	
T120.1_1A_CL1		1.00	1.40	4.00		RX	
T120.1_1A_CL2		1.00	1.35	4.00		LX	
TNI_CL2	13.70	1.10	1.30	4.00	29.20		
TNI_CL4		1.00	0.90	3.50			
T25_1A_CL1		1.00	0.85	3.25		RX	
T25_1A_CL2		1.00	0.95	3.20		LX	
T115_1A_CL1	13.40	1.20	0.80	3.70	27.61	RX	
T115_1A_CL2	13.30	1.29	0.92	3.70	27.82	LX	
T4_INDB_CL1	13.30	1.10	0.90	3.30	24.81	RX	
T4_INDB_CL2	13.30	1.10	0.90	3.40	25.56	LX	
T26_INDA_CL1	13.90	1.00	1.00	3.40	24.46	RX	F
T26_INDA_CL2	13.90	0.90	1.00	3.40	24.46	LX	F
DDJ1_BIO_CL1	13.20	0.90	1.00	3.70	28.03	RX	
T57_BIO_CL1	13.85	0.90	1.30		0.00		
T63_BIO_INDA_CL1		1.45	1.10	4.30		RX	M
T63_BIO_INDA_CL2	14.10	1.35	1.10	4.10	29.08	LX	M
T7_BIO_INDB_CL1	13.00	1.50	1.00		0.00	LX	F
ML_TM_BIO_CL1	14.30	1.35	1.00	1.60	11.19	RX	
ML_T27.2_CL1		1.40	0.80	3.00		RX	F
ML_T27.2_CL2		1.20	0.90	3.20		LX	F
ML_T55_BIO_CL1	13.95	1.00	1.15	3.70	26.52	LX	

Adults: metrics. the post-cranium											
Humerus	Humerus - Maximum Length	Humerus - Maximum Mid Shaft Diameter	Humerus - Minimum Mid Shaft Diameter	Humerus - Minimum Circumference	Humerus - Maximum Proximal Width	Humerus - Head Diameter	Humerus - Maximum Distal Width	Strength Index	Diaphysiatic Index	Side	Sex
TPV_HU1					4.60	4.15				LX	
TPV_HU2					4.65	4.20				LX	
TPV_HU3		2.05	19.05	6.05			6.30		92.27	LX	
TPV_HU4	31.50	2.10	2.00	6.50	5.21	5.40	6.40	20.63	95.24	RX	
TPV_HU5	30.50	1.82	1.60	5.44	4.69	4.25	5.40	17.84	87.91	RX	
TPV_HU6		2.10	1.20	6.30			6.50		57.14	RX	
T120_HU4							5.70			RX	
T120_HU5		1.70	1.45	5.10			5.10		85.29	RX	
T81_HU1	31.40	7.60	7.00	7.30	5.29	4.72	6.40	23.25	92.11	RX	
T81_HU2					4.50	4.10				LX	
T81_HU3							5.90			LX	
T84_HU2							5.25			RX	
T4_HU1							6.30			LX	
T16_HU1	32.20	2.80	1.90	6.70	4.90	4.70		20.81	67.86	LX	
T16_HU2	25.95	2.00	1.70	6.00			5.20	23.12	85.00	RX	
T16_HU3					5.00	4.95	5.30			RX	
T10_HU1		2.00	1.50	5.55					75.00	LX	
TNR6_HU1		1.95	1.70	5.90					87.18	LX	
TNR6_HU2		2.20	1.70	6.00					77.27	LX	
TNR6_HU3		2.10	1.90	6.40					90.48	LX	
TNR6_HU4		2.10	1.90	6.00					90.48	RX	
TNR4_HU1		1.70	1.65	5.20					97.06	LX	
TPII_HU1					4.25	3.70				RX	
TPII_HU2							5.10			LX	
TPII_HU3	26.80	1.40	1.20	5.40	4.15	3.69	5.19	20.15	85.71	LX	
T84_HU1		2.10	1.85	5.60			5.80		88.10	LX	
DDJ2_HU1		2.10	2.00	6.40					95.24	RX	
T120.1_1A_HU1		2.30	1.90	6.80					82.61	LX	
T120.1_1A_HU2		2.30	0.85	6.80					36.96	RX	
ENK_HU1		1.10	0.90	5.00	3.69	3.35			81.82	RX	
T116_HU1		2.05	1.60	5.90					78.05	RX	
T116_HU3		2.25	1.85	7.00					82.22	LX	
T120.0.2_HU1		1.90	1.70	5.80			5.50		89.47	LX	
TNI_HU1							5.50			RX	
TNI_HU3							5.60			RX	
TNI_HU4							5.40			RX	
TNI_HU5		1.92	1.60	6.00					83.33	RX	

TNI_HU6		1.95	1.55	6.00					79.49	RX	
TNI_HU7		2.00	1.60	3.60					80.00	RX	
TNI_HU8					4.15	3.85				RX	
TNI_HU9							6.30			LX	
TNI_HU10		2.10	1.80	6.20					85.71	LX	
TNI_HU11		1.90	1.49	5.80			5.32		78.42	LX	
TNI_HU13							5.42			LX	
TNI_HU14		1.90	1.50	5.60					78.95	LX	
TNI_HU15					5.40	5.00				LX	
T25_1A_HU1		1.90	1.40	5.70					73.68	RX	
T25_1A_HU2		2.00	1.40	5.80					70.00	LX	
T115_HU1	29.30	1.54	1.85	5.50	4.35	4.00	5.45	18.77	120.13	LX	
T0_HU1		1.98	1.72	6.00			6.00		86.87	RX	
T0_HU2		2.00	1.50	5.90			5.30		75.00	RX	
T4_INDB_HU1	29.00	2.00	1.50	5.80	4.95	4.00	5.70	20.00	75.00	RX	F
T4_INDB_HU2	29.00	1.90	1.60	5.80			5.60	20.00	84.21	LX	F
T14_HU1		2.00	1.50	6.00					75.00	RX	F
T26_1A_HU1	29.60	1.75	1.40	5.50	4.20	3.85	5.42	18.58	80.00	RX	F
T26_1A_HU2		1.85	1.50	5.50		3.70			81.08	LX	F
TR1_HU1		2.10	1.80	6.40					85.71	RX	
TR1_HU2		2.50	1.60	6.30					64.00	LX	
T57_BIO_HU8					3.80	4.40					
T57_BIO_HU9					4.00	4.65					
T57_BIO_HU10		2.05	1.75		4.00	4.75	6.20		85.37		
T87_BIO_1A_HU1	33.60	2.30	1.40		4.30	4.25		0.00	60.87		F
T63_BIO_INDA_HU1		2.50	2.00	7.50		4.45	6.60		80.00	RX	M
T63_BIO_INDA_HU2	30.90	2.00	1.90	6.25		4.45	6.51	20.23	95.00	LX	M
T7_BIO_INDA_HU1	30.00	2.30	1.60	6.30		4.35		21.00	69.57	LX	M
T7_BIO_INDB_HU2	28.70	1.75	1.60	2.50		4.05	5.70	8.71	91.43	RX	F
TM_BIO_1A_HU1	32.90	2.10	1.80	6.30		4.50	6.20	19.15	85.71	RX	
TM_BIO_1A_HU2		2.10	1.90	6.20			6.10	#DIV/0!	90.48	LX	
T59_BIO_INDA_HU1	28.20	1.90	1.40	5.30		4.00	5.15	18.79	73.68	RX	F
T59_BIO_INDA_HU2	27.90	1.90	1.45	5.50		4.00	5.45	19.71	76.32	LX	F
T59_BIO_INDB_HU1	27.40	2.00	1.60	5.70		4.30	5.75	20.80	80.00	RX	F
T59_BIO_INDB_HU2	26.20	2.10	1.10	5.70			5.60	21.76	52.38	LX	F
T85_BIO_IND1_HU1	31.40	2.30	2.15	8.10		4.40	6.15	25.80	93.48	RX	M
T85_BIO_IND1_HU2	30.90	2.20	2.00	8.00		4.40	6.15	25.89	90.91	LX	M
T70_BIO_1A_HU1		2.00	1.85	5.70		4.70			92.50	RX	M
T70_BIO_1A_HU2		2.10	1.90	6.20			6.00		90.48	LX	M
T61_BIO_1A_HU1	30.40	2.15	2.00	6.40			5.70	21.05	93.02	LX	M
T7_BIO_1A_HU1	30.00	2.30	1.60	6.30		4.35		21.00	69.57	LX	M
ML_TM_1A_BIO_HU1	32.90	2.10	1.80	6.30		4.50	6.20	19.15	85.71	RX	
ML_TM_1A_BIO_HU2		2.10	1.90	6.20			6.10		90.48	LX	
ML_DDJ_CA_19/11/80_BIO_HU1		2.50	1.70			6.00	6.40		68.00	RX	

Adults: metrics. the post-cranium									
Radius	Radius - Maximum Length	Radius - Physiological Length	Radius - Diameter on Crest	Radius - Diameter Perpendicular to Crest	Radius - Minimum Circumference	Strength Index	Diaphysiatic Index	Side	Sex
ML_TPV_RA1	23.80	22.70	1.50	1.20	4.00	17.62	80.00	RX	
ML_T81_RA1	23.00	22.50	1.50	1.00	4.05	18.00	66.67	LX	
ML_T81_RA2			1.50	1.00	3.99		66.67	LX	
ML_T84_RA1			1.60	1.10	3.70		68.75		
ML_T84_RA2			1.65	1.00	3.50		60.61	RX	
ML_T4_RA1					4.50			LX	
ML_T6_RA1	23.40	22.90	1.10	1.00	4.00	17.47	90.91	LX	
ML_T6_RA2			1.35	1.00	3.70		74.07		
ML_T6_RA3		23.00	1.60	1.20	4.40	19.13	75.00		
ML_T6_RA4		21.10	1.40	1.05	3.80	18.01	75.00	RX	
ML_TNR6_RA1			1.30	1.20	4.00		92.31	RX	
ML_TNR3_RA1					4.00			RX	
ML_TPII_RA1	19.80	18.60	1.40	1.00	3.60	19.35	71.43		
ML_T84_RA1					4.10			RX	
ML_DDJ0_RA1			1.65	1.22	4.00		73.94	RX	
ML_120.1_RA1			1.60	1.25	4.50		78.13	RX	
ML_120.1_RA2			1.59	1.70	4.40		106.92	LX	
ML_T116_RA1			1.45	1.10	4.00		75.86	RX	
ML_TNI_RA1	24.50		1.25	1.20	4.40		96.00	RX	
ML_TNI_RA2			1.20	1.15	4.60		95.83	LX	
ML_TNI_RA3					4.30			LX	
ML_T25_RA1			1.30	1.00	3.70		76.92	RX	
ML_T115_RA1					3.80			LX	
ML_T115_RA2	22.20	21.50	2.00	2.10	3.50	16.28	105.00	RX	
ML_T0_RA2			1.10	1.40	4.00		127.27	RX	
ML_T0_RA3					4.10			LX	
ML_T0_RA4			1.00	1.30	3.90		130.00	LX	
ML_T4_INDB_RA1			1.40	1.00	4.00		71.43	LX	
ML_T4_INDB_RA2	21.30	20.40	1.40	1.00	4.00	19.61	71.43	RX	
ML_T26_RA1	21.90	21.50	1.20	1.00	3.70	17.21	83.33	RX	F
ML_T26_RA2	21.90	21.30	1.20	1.00	3.80	17.84	83.33	LX	F
ML_TR1_RA1			1.50	1.20	4.15		80.00	RX	
ML_TR1_RA2			1.40	1.15	4.00		82.14	LX	

ML_T97_BIO_RA13	21.35	20.70	1.55	1.10	4.00	19.32	70.97		
ML_T97_BIO_RA14	22.30	21.40	1.80	1.10	4.00	18.69	61.11		
ML_T60_BIO_RA1	20.30	19.70	1.50	1.00	4.00	20.30	66.67	RX	
ML_T63_BIO_INDA_RA1	23.80	22.75	1.80	1.20	4.60	20.22	66.67	RX	M
ML_T63_BIO_INDA_RA2	24.00	22.70	1.55	1.20	4.40	19.38	77.42	LX	M
ML_T7_BIO_INDA_RA1	23.70	22.55	1.45	1.10	4.10	18.18	75.86	LX	M
ML_T7_BIO_INDB_RA1		21.00	1.40	0.95	3.60	17.14	67.86	RX	F
ML_T7_BIO_INDB_RA2		20.80	1.30	0.90	3.50	16.83	69.23	LX	F
ML_T55_BIO_IND1_RA1		22.30	1.80	1.30	4.70	21.08	72.22	RX	
ML_T55_BIO_RA2	21.50	20.60	1.35	1.00	3.70	17.96	74.07	RX	

Adults: metrics. the post-cranium									
Ulna	Ulna - Maximum Length	Ulna - Physiological Length	Ulna - Medio Lateral Diameter on Incisure Maxima	Ulna - Antero Posterior Diameter on Incisure Maxima	Ulna - Minimum Circumference	Strength Index	Diaphysiatic Index	Side	Sex
ML_TPV_UL1			1.35	1.60				LX	
ML_T81_UL1			1.70	1.20	3.50		34.29	LX	
ML_T84_UL1			1.60	1.09				RX	
ML_T6_UL1			1.32	1.10				LX	
ML_T6_UL2	26.00	24.80	1.80	1.30	4.20	16.94	30.95	LX	
ML_T6_UL3			1.70	1.30					
ML_T6_UL4			1.30	1.10					
L_T10_UL1			1.20	1.70				RX	
ML_TPII_UL1			1.40	1.09	3.50		31.14	LX	
ML_120.1_UL1			1.60	1.40	4.00		35.00	LX	
ML_120.1_UL2			1.65	1.42	3.90		36.41	RX	
ML_TNI_UL1			1.50	1.40				RX	
ML_TNI_UL2			1.70	1.40				RX	
ML_T25_UL1			1.40	1.09				RX	
ML_FR1984_UL4			1.10	0.90				LX	

ML_T4_INDB_UL1			1.65	1.10				RX	
ML_T4_INDB_UL2	29.00	22.90	1.55	1.10	3.50	15.28	31.43	LX	
ML_T26_UL1		24.00	1.10	1.50	3.30	13.75	45.45	RX	F
ML_T26_UL2			1.00	1.45	3.30		43.94	LX	F
ML_TR1_UL1	26.40	25.50	1.30	1.40	3.70	14.51	37.84	RX	
ML_TR1_UL2			1.00	1.50	3.40		44.12	LX	
ML_DDJI_ST4_CA_UL1	26.90	25.50	1.45	1.55	2.80	10.98	55.36	RX	
ML_DDJI_ST4_CA_UL2	NR	24.90	1.45	1.80	2.65	10.64	67.92	LX	
ML_T63_BIO_INDA_UL1	26.00	25.70	1.90	1.30	4.20	16.34	30.95	RX	M
ML_T7_BIO_INDB_UL1		22.55	1.55	1.00	3.50	15.52	28.57	RX	F
ML_TM_BIO_UL1	25.00	24.40	1.50	1.10	3.50	14.34	31.43	RX	
ML_T55_BIO_IND2_UL1	26.40	25.45	1.40	1.80	4.00	15.72	45.00	LX	

Adults: metrics. the post-cranium													
Femur	Femur - Maximum Length	Femur - Physiological Length	Femur - Medio Lateral Mid Shaft Diameter	Femur - Antero Posterior Mid Shaft Diameter	Femur - Mid Shaft Circumference	Femur - Medio Lateral Sub Trocanteric Diameter	Femur - Antero Posterior Sub Trocanteric Diameter	Femur - Diameter of Head	Strength Index	Pilastric Index	Platimetric Index	Side	Sex
ML_TPV_FE1			2.85	3.00	8.65	3.30	2.81	4.50		105.26	85.15	LX	
ML_TPV_FE2								4.10				LX	
ML_TPV_FE3						3.12	2.85	3.80			91.35	LX	
ML_TPV_FE4						3.25	2.41	4.20			74.15	LX	
ML_TPV_FE5						3.95	2.80				70.89	LX	
ML_TPV_FE6			2.42	2.60	7.52					107.44		RX	
ML_TPV_FE7						2.95	2.45	4.09			83.05	RX	
ML_TPV_FE8						2.95	2.60				88.14	RX	
ML_TPV_FE9			3.00	3.00	9.00		3.42			100.00		RX	
ML_TPV_FE10			2.70	3.10	9.00					114.81		RX	
ML_TPV_FE11	45.50	45.00	2.65	2.90	8.60	3.20	2.60		19.11	109.43	81.25	RX	
ML_T81_FE1			2.30	2.40	7.50	3.20	2.40	4.05		104.35	75.00	LX	
ML_T81_FE2						3.50	2.70	4.20			77.14	LX	
ML_T81_FE3			2.50	2.92	8.70	3.00	2.50			116.80	83.33	LX	
ML_T81_FE4								4.50				LX	
ML_T96_FE2						3.80	2.80	4.25			73.68	RX	

ML_T2_FE1						3.60	2.50	4.20			69.44	LX	
ML_T6_FE1			2.80	2.45	8.90					87.50		LX	
ML_T6_FE2			2.50	2.90	8.69	2.70	2.59	4.00		116.00	95.93	RX	
ML_T6_FE3	43.00	42.70	2.60	3.01	8.80	3.00	2.50	3.95	20.61	115.77	83.33	LX	
ML_T6_FE4								4.60				LX	
ML_T10_FE1			3.01	2.70		3.60	2.80			89.70	77.78	RX	
ML_TNR4_FE1			2.40	2.55	7.50	3.00	2.50			106.25	83.33	LX	
ML_TNR4_FE2			2.20	2.50	7.40	2.80	2.50			113.64	89.29	RX	
ML_TPII_FE1			3.10	2.55	8.90	3.35	2.30			82.26	68.66		
ML_TPII_FE2			2.34	2.22	7.30					94.87		RX	
ML_TPII_FE3	37.40	37.20	2.45	2.29	7.60	2.40	2.70	4.00	20.43	93.47	112.50	LX	
ML_TPII_FE4								4.10				LX	
ML_TPII_FE5								4.10				RX	
ML_120.1_FE1			2.95	2.90	9.00	3.40	2.50			98.31	73.53	LX	
ML_120.1_FE2			3.00	2.79	9.00	3.15	2.70			93.00	85.71	RX	
ML_ENK_FE1						3.25	2.75				84.62	LX	
ML_T116_FE1						3.65	2.95				80.82	RX	
ML_T120.0.2_FE1						3.30	2.49				75.45	LX	
ML_T120.0.3_FE1			2.40	2.24	7.40	2.90	2.40			93.33	82.76	RX	
ML_T120.0.3_FE2			2.25	2.20	7.10	2.90	2.32			97.78	80.00	RX	
ML_T120.0.3_FE3			2.60	2.45	8.00	2.90	2.50			94.23	86.21	LX	
ML_T120.0.3_FE4			2.40	2.10	7.10	2.80	2.20			87.50	78.57	LX	
ML_TNI_FE1			2.70	2.80	7.80	3.25	2.71			103.70	83.38	RX	
ML_TNI_FE2						2.90	2.45	3.85			84.48	RX	
ML_TNI_FE3			2.50	2.85	8.60	2.90	2.42	4.30		114.00	83.45	RX	
ML_TNI_FE4			2.40	2.62	8.00	2.92	2.30			109.17	78.77	LX	
ML_TNI_FE5			2.70	2.50	8.10	3.00	2.60	3.80		92.59	86.67	LX	
ML_TNI_FE6			2.90	2.78	9.00	3.35	3.80			95.86	113.43	NR	
ML_TNI_FE7			3.10	2.75	9.10	3.70	2.85			88.71	77.03	NR	
ML_TNI_FE8			2.40	2.90	8.60	2.82	2.50			120.83	88.65	RX	
ML_T25_FE1			2.50	2.30	7.50	3.95	2.32	3.90		92.00	58.73	RX	M
ML_T25_FE2			2.40	2.35	7.70	3.10	2.40	3.90		97.92	77.42	LX	M
ML_FR1984_FE1						3.30	2.70				81.82	RX	
ML_FR1984_FE2								3.65				LX	
ML_T0_FE1			2.10	2.30	7.40	2.70	2.30			109.52	85.19	RX	
ML_T0_FE2			2.10	2.40	7.50	2.65	2.40			114.29	90.57	LX	
ML_T4_INDB_FE1			2.50	2.70	8.10	3.00	2.40	4.30		108.00	80.00	RX	
ML_T4_INDB_FE2	41.30	41.00	2.60	2.60	8.20	3.10	2.98	4.40	20.00	100.00	96.13	LX	
ML_T26_FE1	42.00	40.80	2.40	2.70	8.20	3.00	2.50	4.20	20.10	112.50	83.33	RX	F
ML_T26_FE2	42.50	40.80	2.50	2.90	8.40	3.00	2.60	4.00	20.59	116.00	86.67	LX	F
ML_TR1_FE1			2.60	3.00	9.00	3.30	2.55	4.40		115.38	77.27	RX	
ML_TR1_FE2			2.70	3.20	9.30	3.30	2.90	4.20		118.52	87.88	LX	
ML_TR1_FE3			2.30	2.35	7.40					102.17	#DIV/0!	LX	
ML_T57_BIO_FE1			2.45	2.90		3.30	2.85	4.00		118.37	86.36	LX	
ML_T97_BIO_INDA_FE21	40.40	39.00	2.50	2.75	8.40	3.30	2.80	3.85	21.54	110.00	84.85		
ML_T60_BIO_INDA_FE1	40.30	38.80	2.40	2.70	8.00	3.20	2.65	3.95	20.62	112.50	82.81	RX	
ML_T60_BIO_INDA_FE2	40.40	38.55	2.45	2.80	8.20	3.10	2.70	3.80	21.27	114.29	87.10	LX	

ML_T63_BIO_INDA_FE1	45.10	44.00	2.80	2.95	9.00	3.60	3.25	4.60	20.45	105.36	90.28	RX	M
ML_T63_BIO_INDA_FE2	45.90	44.40	2.80	2.90	8.90	3.55	3.05	4.45	20.05	103.57	85.92	LX	M
ML_T7_BIO_INDA_FE1	44.20	39.20	2.50	2.80	8.40	3.20	2.65		21.43	112.00	82.81	LX	M
ML_T7_BIO_INDA_FE2	44.35		2.50	2.80	8.50	3.20	2.60	4.50		112.00	81.25	RX	M
ML_T7_BIO_INDB_FE1	41.20	38.90	2.00	2.35	7.00	2.80	2.60	4.00	17.99	117.50	92.86	LX	F
ML_TM_1B_BIO_FE1	47.20	44.70	2.70	2.90	9.00	3.30	3.00	4.55	20.13	107.41	90.91	RX	
ML_T55_BIO_IND1_FE1			2.45	2.60	8.00	3.00	2.30			106.12	76.67	LX	
ML_T55_BIO_IND1_FE2			2.50	2.55	8.00	2.90	2.30			102.00	79.31	RX	
ML_T55_BIO_IND2_FE1			2.80	2.80	9.00					100.00		LX	
ML_T55_BIO_IND2_FE2			2.80	2.80	9.00					100.00		RX	

Adults: metrics. the post-cranium								
Tibia	Tibia - Maximum Length	Tibia - Antero Posterior Diameter on Foramen	Tibia - Medio Lateral Diameter on Foramen	Tibia - Minimum Circumference	Strength Index	Cnemic Index	Side	Sex
ML_TPV_TI1	36.00	3.70	2.80	8.01	22.25	75.68	LX	
ML_TPV_TI2		3.60	2.30			63.89	LX	
ML_TPV_TI3		3.00	2.10			70.00	LX	
ML_T120_TI1		3.15	2.19			69.52	LX	
ML_T6_TI1		3.00	2.30	8.40		76.67	RX	
ML_T6_TI2	35.62	3.00	2.10	7.90	22.18	70.00	LX	
ML_T6_TI3		2.40	1.80	6.80		75.00	RX	
ML_T6_TI4		2.50	2.30	6.70		92.00	LX	
ML_T2_TI1		2.32	2.10	7.00		90.52	LX	
ML_ENK_TI1		3.20	2.40			75.00	LX	
ML_TNI_TI3		2.90	2.25	7.80		77.59	LX	
ML_T115_TI1	34.20	2.70	1.80	6.50	19.01	66.67	RX	
ML_T115_TI2	34.15	2.60	1.75	6.30	18.45	67.31	LX	
ML_T0_TI1		2.40	2.30			95.83	LX	
ML_T4_INDB_TI1		2.70	2.05			75.93	RX	
ML_T4_INDB_TI2	34.15	2.90	2.00	7.50	21.96	68.97	LX	
ML_TR1_TI1		2.80	1.70	7.00		60.71	RX	
ML_TR1_TI2		3.00	2.75			91.67	LX	
ML_TR1_TI3		2.60	1.70			65.38	LX	

ML_TR1_TI4		2.40	1.55	6.00		64.58	LX	
ML_DDJI_ST4_CA_TI43	33.30	3.00	2.15	6.40	19.22	71.67	LX	
ML_T57_BIO_TI1		2.45	1.90		!	77.55	LX	
ML_T97_BIO_INDA_TI29	33.70	3.30	2.75	7.30	21.66	83.33		
ML_T97_BIO_INDB_TI30	34.00	3.20	2.15	7.20	21.18	67.19		
ML_T60_BIO_TI1	33.55	2.65	1.85	6.90	20.57	69.81	RX	
ML_T60_BIO_TI2	33.50	2.65	1.90	7.00	20.90	71.70	LX	
ML_T63_BIO_INDA_TI1	37.80	2.40	3.40	8.20	21.69	141.67	RX	M
ML_T63_BIO_INDA_TI2	38.45	2.45	3.45	8.20	21.33	140.82	LX	M
ML_T7_BIO_INDA_TI1		2.20	2.75	7.40		125.00	LX	M
ML_T7_BIO_INDA_TI2		2.10	2.90	7.50		138.10	RX	M
ML_TM_1B_BIO_TI1	37.80	2.10	2.80	7.30	19.31	133.33	RX	
ML_T27.2_TI1				7.00			RX	F
ML_T27.2_TI2				7.00			LX	F
ML_DDJ_CA_NONLAVATE_BIO_TI1	34.40	1.95	2.90	7.80	22.67	148.72	LX	

Adults: metrics. the post-cranium					
Patella	Patella - Maximum Length	Patella - Maximum Width	Patella - Breadth	Side	Sex
ML_TPV_PA1	4.00	4.18	1.99	LX	
ML_TPV_PA2	3.82	4.20	1.80	LX	
ML_TPV_PA3	3.60	3.91	1.70	LX	
ML_TPV_PA4			2.20	LX	
ML_TPV_PA5		4.10	1.90	LX	
ML_TPV_PA6			1.60	LX	
ML_TPV_PA7	4.30	4.30	2.20	RX	
ML_TPV_PA8		3.90	1.75	RX	
ML_T120_PA1	3.69	3.92	1.60	RX	
ML_T120_PA2		4.65	2.72	RX	
ML_T120_PA3	4.21	4.52	2.12	RX	
ML_T120_PA4	3.70	3.90	1.60	RX	
ML_T120_PA5	4.05	4.60	2.00	RX	
ML_T120_PA6	3.60	4.02	1.60	RX	
ML_T120_PA7	3.90	3.50	1.70	RX	
ML_T120_PA8	3.80	4.20	1.80	RX	
ML_T120_PA9	4.30	4.30	1.80	RX	
ML_T120_PA10	3.70	3.90	1.60	LX	
ML_T120_PA11		4.50	2.72	LX	
ML_V1_PA1			2.01	LX	
ML_V1_PA2			1.90	LX	
ML_V1_PA3			1.80	LX	
ML_T84_PA1			1.70	RX	
ML_T6_PA1	4.45	4.20	2.10	RX	
ML_T10_PA1		4.45	1.80	RX	
ML_TPII_PA1	3.50		1.70	RX	

ML_TPII_PA2	3.70	3.60	1.70	RX	
ML_TPII_PA3				LX	
ML_TPII_PA4	3.35	3.55	1.70	LX	
ML_TPII_PA5	3.20			LX	
ML_T28.2_PA1	4.20	4.02	1.72	RX	F?
ML_T48_PA1	3.90	4.10	2.00	LX	
ML_ST1C_PA1				RX	
ML_ST1C_PA2				LX	
ML_ST1C_PA3				LX	
ML_DDJ1_PA1				RX	
ML_T116_PA1	3.40	3.95	1.70	RX	
ML_T116_PA2	3.90	3.80	1.75	LX	
ML_T116_PA3		4.35	2.10	LX	
ML_T116_PA4	4.30		2.00	LX	
ML_TNI_PA1	4.65	4.81	1.90	RX	
ML_TNI_PA2	3.90	4.40	2.31	LX	
ML_T115_PA1	4.25	4.10	1.70	RX	
ML_T115_PA2	4.15	4.10	1.80	LX	
ML_FR1984_PA1	4.60		2.00	RX	
ML_FR1984_PA2		3.80	1.60	RX	
ML_FR1984_PA3			1.70	RX	
ML_T4_INDB_PA1	3.80	3.85	1.80	RX	
ML_T4_INDB_PA2	3.80	4.00	1.89	LX	
ML_TN_PA1	3.90	4.10	1.79	RX	
ML_TN_PA2	3.90	4.10	1.80	LX	
ML_DDJI_ST4_CA_PA30	4.00	4.70	1.90	RX	
ML_DDJI_ST4_CA_PA32	3.55	4.20	1.95	RX	
ML_DDJI_ST4_CA_PA34			1.70	RX	
ML_DDJI_ST4_CA_PA36			1.55	RX	
ML_DDJI_ST4_CA_PA39	3.79	3.80	1.50	RX	
ML_DDJI_ST4_CA_PA40		3.70	1.50	RX	
ML_DDJI_ST4_CA_PA42		3.65	1.70	RX	
ML_DDJI_ST4_CA_PA31		4.35	2.05	LX	
ML_DDJI_ST4_CA_PA33		3.65	1.55	LX	
ML_DDJI_ST4_CA_PA35		4.35	2.00	LX	
ML_DDJI_ST4_CA_PA38	3.75	3.82	1.65	LX	
ML_DDJI_ST4_CA_PA41		3.60	1.60	LX	
ML_DDJI_ST4_CA_PANN		3.60	1.50	LX	
ML_DDJI_ST5_CA_PA1		3.80	1.75	LX	
ML_DDJI_ST5_CA_PA2			2.00	LX	
ML_DDJI_ST5_CA_PA3			1.85	LX	
ML_DDJI_ST5_CA_PA4			1.10	RX	
ML_DDJI_ST5_CA_PA5	3.60	3.50	1.50	RX	
ML_DDJI_ST5_CA_PA6		4.05	1.75	RX	
ML_DDJI_STNR_24/09/80_PA1		3.95	1.75	RX	
ML_DDJI_STNR_24/09/80_PA2	3.34	3.35	1.50	LX	
ML_DDJI_ST3_CA_PA1		3.85	1.70	RX	
ML_DDJI_ST3_CA_PA2	4.30	4.65	2.10	LX	
ML_TV_BIO_PA1	3.20	3.40	1.09	RX	
ML_TV_BIO_PA2		3.20	1.10	RX	
ML_TV_BIO_PA3	3.85	3.45	1.70	RX	
ML_TV_BIO_PA4		4.25	1.90	RX	
ML_TV_BIO_PA5		3.90	1.60	RX	
ML_T97_BIO_INDB_PA25	3.65	4.10	1.85		
ML_T97_BIO_INDA_PA26	3.80	4.10	1.85		
ML_T97_BIO_PA27	3.50	3.90	1.15		
ML_T97_BIO_INDC_PA28	3.40	3.80	1.50		

ML_T55.1_BIO_PA1			1.60	RX	
ML_T55.2_BIO_PA39	4.00		2.15		
ML_T55.2_BIO_PA40	3.70		1.75		
ML_T60_INDA_BIO_PA1	3.70		1.65	RX	
ML_T60_BIO_PA2	3.60		1.05		
ML_T63_BIO_INDA_PA1	4.30	4.65	2.50	RX	M
ML_T63_BIO_INDA_PA2	4.25	4.40	2.10	LX	M
ML_T7_BIO_INDA_PA1	4.20	4.00	1.90	LX	M
ML_T7_BIO_INDA_PA2	4.30	3.90	1.90	RX	M
ML_T7_BIO_INDB_PA1	3.50	3.40	1.45	RX	F
ML_TM_BIO_PA1	3.95	4.25	1.95	RX	
ML_TM_BIO_PA2	4.30	4.55	2.00	LX	
ML_T55_BIO_PA1	3.70	4.20	2.10	LX	
ML_DDJ_CA_18/11/80_BIO_PA1		4.62	1.95	RX	
ML_DDJ_CA_18/11/80_BIO_PA2	3.05	3.80	1.60	RX	
ML_DDJ_CA_18/11/80_BIO_PA3		2.00		RX	

Adults: metrics. the post-cranium							
First Metatarsal	Metatarsal Length	Mediolateral Diameter of the Proximal Articulation	Dorsoplantar Diameter of the Proximal Articulation	Dorsoplantar Diameter of the Distal Articulation	Mediolateral Diameter of the Distal Articulation	Side	Sex
ML_T28.2_MT1	6.30	1.90	2.80	1.90	2.20	RX	F
ML_T28.2_MT2				1.90	2.20	LX	F
ML_T48_MT1	6.00	2.00	2.80	2.00	2.10	RX	
ML_T48_MT2	5.80	1.90	2.70	2.10		LX	
ML_T16.1A_MT1	5.60	1.80	2.50	1.65	1.85	RX	F
ML_T84_MT1	5.80	2.00	2.80	2.00	2.00	RX	
ML_DDJ1_MT1	6.00			2.10	2.20	LX	
ML_T116_MT1	6.10	2.05	2.80	1.90	2.92	RX	
ML_T116_MT2	6.00	2.00	2.80	1.90	2.90	LX	
ML_TNI_MT1	5.40	1.75	2.60	1.92	2.00	RX	
ML_T115_MT1	5.82	1.80	2.70		1.90	RX	

ML_T115_MT2	6.00	1.75	2.70	1.85	2.05	LX	
ML_FR1984_MT1	5.52	1.65	2.55	1.85	2.10	RX	
ML_T4_INDA_MT1	6.00			2.20		LX	
ML_T4_INDB_MT1	6.15	1.85	3.10			RX	F
ML_T4_INDA_MT2		1.70	2.70			RX	
ML_TZ_MT1	5.40	1.90	2.65		2.10	RX	
ML_TZ_MT2	5.40	2.00	2.70	2.00		LX	
ML_TN_MT1	5.60	1.70	2.55	2.00	2.30	RX	F
ML_TN_MT2	5.60	1.70	2.55			LX	F
ML_TV_MT1	6.21	2.10	2.80	2.12	1.92	RX	
ML_TV_MT2	5.90		2.65	1.85	2.05	RX	
ML_TV_MT3	6.12	2.30	2.90	2.39	2.32	RX	
ML_TV_MT4	6.20	2.10	2.92	2.21	2.40	LX	
ML_TV_MT5		2.00	2.80			RX	
ML_DDJI_ST4_CA_MT1	5.50	1.90	3.20	1.90	2.20	RX	
ML_DDJI_ST4_CA_MT2	6.00	1.90	2.80			RX	
ML_DDJI_ST4_CA_MT3	5.70	1.90	2.80	1.90	2.29	RX	
ML_DDJI_ST4_CA_MT4				1.90	2.10	RX	
ML_DDJI_ST4_CA_MT5	5.10					LX	
ML_DDJI_ST4_CA_MT6	6.00		2.80	2.05	2.30	LX	
ML_DDJI_ST4_CA_MT7	5.50	1.65	2.40	1.70	1.75	RX	
ML_DDJI_ST3_CA_MT1	6.40	2.00	2.75	2.00	2.40	RX	
ML_TV_BIO_MT1	6.25	1.90	2.90	2.10	2.40	RX	
ML_TV_BIO_MT2	5.90			1.95	2.00	RX	
ML_TV_BIO_MT3				1.80	1.90	RX	
ML_TV_BIO_MT4	5.90			2.10	2.50	RX	
ML_TV_BIO_MT5	5.60		2.90	2.00	2.20	RX	
ML_TV_BIO_MT6				2.00	2.50	LX	
ML_T97_BIO_MT1	6.00		2.75		2.20	RX	
ML_T97_BIO_MT2	5.90		2.75		2.25	RX	
ML_T97_BIO_MT3	6.00		2.65		2.15	LX	
ML_T97_BIO_MT4					2.10	LX	
ML_T87_BIO_1A_MT1	5.70		2.45		1.80	RX	F
ML_T87_BIO_1A_MT2	5.72		2.50		1.90	LX	F
ML_T60_BIO_MT1	5.80		2.50	1.75		RX	
ML_T60_BIO_MT2		5.80	2.50	1.70		LX	
ML_T63_BIO_INDA_MT1	6.22		2.90		2.30	RX	M
ML_T63_BIO_INDA_MT2	6.35		2.80		2.25	LX	M
ML_T7_BIO_INDA_MT1	6.10		2.70		2.20	LX	M
ML_T7_BIO_INDA_MT2	6.10		2.70			RX	M
ML_DDJ_CA_19/11/80_BIO_MT1	6.20		2.90			RX	

Adults: metrics. the post-cranium												
Pelvis	Acetabulo-symphyseal pubic length PUM	Cotylo-pubic width SPU	Innominate or coxal length DCOX	Greater sciatic notch height IIMT	Ischium post-acetabular length ISMM	Iliac or coxal breadth SCOX	Spino-sciatic length SS	Spino-auricular length SA	Cotylo-sciatic breadth SIS	Vertical acetabular diameter VEAC	Side	Sex
ML_T16_1A_CX1	7.30	2.40		5.05	10.70	13.20	6.60	6.10	4.00	5.15	RX	
ML_T16_1A_CX2		3.20		5.30	10.20				3.55	5.05	LX	
ML_T16_1B_CX3		3.20			11.40		7.50	7.20	2.50	5.80	RX	
ML_T16_1B_CX4				3.50	11.05		7.70	7.60	2.60	6.20	LX	
ML_T2_CX1				3.90						6.10	LX	
ML_T4_INDB_CX1	6.80	3.40	19.50	5.85	10.29	15.75	7.10	7.75	3.00	5.70	RX	F
ML_T4_INDB_CX2	7.00	3.60	19.75	5.50	10.30	16.00	7.00	8.50	3.00	5.50	LX	F
ML_TN_CX1				5.50				7.30	3.70	4.40	RX	F
ML_T14_1A_CX1									3.10	5.50	RX	
ML_T14_1A_CX2									3.00	5.50	LX	
ML_T26_CX				3.80	10.20		6.50	7.34	3.10	5.50	RX	F
ML_T26_CX			19.90	3.80	9.90	15.20	6.50	8.10	3.10	5.10	LX	F

APPENDIX C

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T27.1	13	IN SITU	15+-3					0.1; 0.2; 0.4				
ML_T27.1	14	IN SITU	15+-3					0.12; 0.2; 0.35; 0.45				
ML_T27.1	15	IN SITU	15+-3									
ML_T27.1	16	IN SITU	15+-3					0.15; 0.2; 0.3				
ML_T27.1	17	IN SITU	15+-3						OBLONG			
ML_T27.1	18	IN SITU	15+-3									GEM
ML_T27.1	25	IN SITU	15+-3									
ML_T27.1	26	IN SITU	15+-3									
ML_T27.1	27	IN SITU	15+-3									
ML_T27.1	28	IN SITU	15+-3									GEM
ML_T27.1	32	IN SITU	15+-3			0.2						
ML_T27.1	33	IN SITU	15+-3			0.2						
ML_T27.1	34	IN SITU	15+-3			0.2	TL					
ML_T27.1	35	IN SITU	15+-3				TVL					
ML_T27.1	36	IN SITU	15+-3				TL					
ML_T27.1	37	IN SITU	15+-3									
ML_T27.1	43	IN SITU	15+-3					0.1; 0.2; 0.3; 0.4; 0.5				
ML_T27.1	44	IN SITU	15+-3					0.1; 0.2				
ML_T27.1	45	IN SITU	15+-3									

ML_T27.1	46	IN SITU	15+-3					0.25				
ML_T27.1	47	IN SITU	15+-3									

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T27.2	12	IN SITU	C	18-22		0.3					FEMALE	
ML_T27.2	13	IN SITU	C	18-22		0.3					FEMALE	
ML_T27.2	14	IN SITU	C	18-22		0.3					FEMALE	
ML_T27.2	15	IN SITU	C	18-22		0.3					FEMALE	
ML_T27.2	16	IN SITU	C	18-22		0.3					FEMALE	
ML_T27.2	17	IN SITU	C	18-22		0.3					FEMALE	
ML_T27.2	18	IN SITU	C	18-22		0.3					FEMALE	
ML_T27.2	31	IN SITU	C/D	18-22		0.3					FEMALE	
ML_T27.2	32	IN SITU	C/D	18-22		0.3					FEMALE	
ML_T27.2	33	IN SITU	C/D	18-22		0.3					FEMALE	
ML_T27.2	34	IN SITU	C/D	18-22		0.3					FEMALE	
ML_T27.2	35	IN SITU	C/D	18-22		0.3					FEMALE	
ML_T27.2	36	IN SITU	C/D	18-22		0.3					FEMALE	
ML_T27.2	37	IN SITU	C/D	18-22		0.3					FEMALE	
ML_T27.2	38	IN SITU	C/D	18-22		0.3					FEMALE	
ML_T27.2	41	IN SITU	C/D	18-22		0.3					FEMALE	
ML_T27.2	42	IN SITU	C/D	18-22		0.3					FEMALE	
ML_T27.2	43	IN SITU	C/D	18-22		0.3		0.1; 0.2; 0.3; 0.4; 0.5			FEMALE	
ML_T27.2	44	IN SITU	C/D	18-22		0.3					FEMALE	
ML_T27.2	45	IN SITU	C/D	18-22		0.3		0.1; 0.2			FEMALE	
ML_T27.2	46	IN SITU	C/D	18-22		0.3					FEMALE	
ML_T27.2	47	IN SITU	C/D	18-22		0.3					FEMALE	
ML_T27.2	48	IN SITU	C/D	18-22		0.3					FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T16	12		B1	16-20			2M				FEMALE	
ML_T16	13		B1	16-20	1DC			0.1; 0.2; 0.4; 0.5			FEMALE	
ML_T16	32		B1	16-20			TMD				FEMALE	
ML_T16	42		B2	16-20			3L1V				FEMALE	
ML_T16	45		B2	16-20			T				FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T25_MAX	11	IN SITU	G/H	45-55		0.4					FEMALE	
ML_T25_MAX	13	IN SITU	G/H	45-55		0.4	2				FEMALE	
ML_T25_MAX	14	IN SITU	G/H	45-55		0.4					FEMALE	
ML_T25_MAX	15	IN SITU	G/H	45-55		0.4					FEMALE	
ML_T25_MAX	16	IN SITU	G/H	45-55		0.4					FEMALE	
ML_T25_MAX	17	IN SITU	G/H	45-55	1DC	0.4					FEMALE	
ML_T25_MAND	32	IN SITU	I	45-55		0.4					FEMALE	
ML_T25_MAND	33	IN SITU	I	45-55		0.4					FEMALE	
ML_T25_MAND	34	IN SITU	I	45-55		0.4					FEMALE	
ML_T25_MAND	35	IN SITU	I	45-55		0.4					FEMALE	
ML_T25_MAND	36	IN SITU	I	45-55		0.4					FEMALE	
ML_T25_MAND	37	IN SITU	I	45-55		0.4					FEMALE	
ML_T25_MAND	41	IN SITU	I	45-55		0.4					FEMALE	
ML_T25_MAND	42	IN SITU	I	45-55		0.4					FEMALE	
ML_T25_MAND	43	IN SITU	I	45-55		0.4		0.15; 0.2			FEMALE	
ML_T25_MAND	44	IN SITU	I	45-55		0.4					FEMALE	
ML_T25_MAND	45	IN SITU	I	45-55		0.4					FEMALE	
ML_T25_MAND	46	IN SITU	I	45-55		0.4					FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T26	12	IN SITU	B2	16-20		2-3	3V	NR x Calculus	SHOVEL		FEMALE	
ML_T26	13	IN SITU	B2	16-20		2-3	3V	NR x Calculus			FEMALE	
ML_T26	14	IN SITU	B2	16-20		2-3		NR x Calculus			FEMALE	
ML_T26	15	IN SITU	B2	16-20				NR x Calculus			FEMALE	
ML_T26	16	IN SITU	B2	16-20				NR x Calculus			FEMALE	
ML_T26	21	IN SITU	B2	16-20		0-2	3V	NR x Calculus	SHOVEL		FEMALE	
ML_T26	22	IN SITU	B2	16-20		0-2	3V	NR x Calculus	SHOVEL		FEMALE	
ML_T26	23	IN SITU	B2	16-20		0-2	3V	NR x Calculus			FEMALE	
ML_T26	24	IN SITU	B2	16-20		0-2	3V	NR x Calculus			FEMALE	
ML_T26	31	IN SITU	B2	16-20				NR x Calculus			FEMALE	
ML_T26	32	IN SITU	B2	16-20			3L	NR x Calculus			FEMALE	
ML_T26	33	IN SITU	B2	16-20				NR x Calculus			FEMALE	
ML_T26	34	IN SITU	B2	16-20			1L3M1D	NR x Calculus			FEMALE	
ML_T26	35	IN SITU	B2	16-20			1M	NR x Calculus			FEMALE	
ML_T26	36	IN SITU	B2	16-20			2L	NR x Calculus			FEMALE	
ML_T26	37	IN SITU	B2	16-20				NR x Calculus			FEMALE	
ML_T26	41	IN SITU	B2	16-20				NR x Calculus			FEMALE	
ML_T26	42	IN SITU	B2	16-20			1L3V	NR x Calculus			FEMALE	
ML_T26	43	IN SITU	B2	16-20			3L3V	NR x Calculus			FEMALE	
ML_T26	44	IN SITU	B2	16-20			2V	NR x Calculus			FEMALE	
ML_T26	45	IN SITU	B2	16-20			3L3V	NR x Calculus			FEMALE	
ML_T26	46	IN SITU	B2	16-20			3L3V	NR x Calculus			FEMALE	
ML_T26	47	IN SITU	B2	16-20			3L	NR x Calculus			FEMALE	
ML_T26	48	IN SITU	B2	16-20				NR x Calculus			FEMALE	INFIAMMATION
ML_T25_MAND	47	IN SITU	I	45-55		0.4					FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T28.1	12	IN SITU	9+-3									
ML_T28.1	16	IN SITU	9+-3									
ML_T28.1	17	IN SITU	9+-3									
ML_T28.1	23	IN SITU	9+-3									
ML_T28.1	84	IN SITU	9+-3									
ML_T28.1	85	IN SITU	9+-3									
ML_T28.1	46	IN SITU	9+-3									
ML_T28.1	47	IN SITU	9+-3									
ML_T28.1	32	IN SITU	9+-3									
ML_T28.1	73	IN SITU	9+-3									
ML_T28.1	75	IN SITU	9+-3									
ML_T28.1	36	IN SITU	9+-3									
ML_T28.1	37	IN SITU	9+-3									
ML_T28.1	44	IN SITU	9+-3									
ML_T28.1	45	IN SITU	9+-3									
ML_T28.1	33	IN SITU	9+-3									

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T28.2	15		A	12-18		0	3	0.9; 0.4			FEMALE	
ML_T28.2	16		A	12-18		0	3	0.11			FEMALE	
ML_T28.2	17		A	12-18		0	3				FEMALE	
ML_T28.2	18		A	12-18		0	2				FEMALE	
ML_T28.2	24		B1	16-20		0					FEMALE	
ML_T28.2	25		A	12-18		0					FEMALE	
ML_T28.2	26		B2	16-20		0					FEMALE	
ML_T28.2	27		A	12-18		0					FEMALE	
ML_T28.2	28		A	12-18		0					FEMALE	
ML_T28.2	41		B1	16-20		0	TV				FEMALE	
ML_T28.2	42		B1	16-20		0	TV				FEMALE	
ML_T28.2	43		B1	16-20		0					FEMALE	
ML_T28.2	44		B1	16-20		0	TV				FEMALE	
ML_T28.2	45		B1	16-20		0	TV				FEMALE	
ML_T28.2	46		F	30-35		0					FEMALE	
ML_T28.2	47		A	12-18		0					FEMALE	
ML_T28.2	48		A	12-18		0	T				FEMALE	
ML_T28.2	31		B1	16-20		0	T				FEMALE	

ML_T28.2	32		B1	16-20		0	T				FEMALE	
ML_T28.2	34		A	12-18		0					FEMALE	
ML_T28.2	36		B2	16-20		0	3				FEMALE	
ML_T28.2	37		A	12-18		0	3				FEMALE	
ML_T28.2	38		A	12-18		0					FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T59_INDA_CIT	13	IN SITU	C	18-22							FEMALE	
ML_T59_INDA_CIT	14	IN SITU	C	18-22							FEMALE	
ML_T59_INDA_CIT	16	IN SITU	I	45-55							FEMALE	
ML_T59_INDA_CIT	17	IN SITU	C	18-22							FEMALE	
ML_T59_INDA_CIT	21	IN SITU	C	18-22							FEMALE	
ML_T59_INDA_CIT	22	IN SITU	C	18-22							FEMALE	
ML_T59_INDA_CIT	24	IN SITU	C	18-22							FEMALE	
ML_T59_INDA_CIT	25	IN SITU	D	20-24							FEMALE	
ML_T59_INDA_CIT	26	IN SITU	F	30-35							FEMALE	
ML_T59_INDA_CIT	41	IN SITU	D	20-24							FEMALE	
ML_T59_INDA_CIT	43	IN SITU	D	20-24							FEMALE	
ML_T59_INDA_CIT	46	IN SITU	D	20-24							FEMALE	
ML_T59_INDA_CIT	31	IN SITU	C	18-22							FEMALE	
ML_T59_INDA_CIT	34	IN SITU	C	18-22							FEMALE	
ML_T59_INDA_CIT	36	IN SITU	G	35-40							FEMALE	
ML_T59_INDA_CIT	47	AMTL									FEMALE	
ML_T59_INDA_CIT	37	AMTL									FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T59_INDB_CIT	25	AMTL									FEMALE	
ML_T59_INDB_CIT	35	AMTL									FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T85_INDA_CIT	15	IN SITU	H	40-50							MALE	
ML_T85_INDA_CIT	17	IN SITU	H	40-50							MALE	

ML_T85_INDA_CIT	21	IN SITU	H	40-50							MALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T70_INDA_CIT	27	IN SITU	A	12-18							MALE	
ML_T70_INDA_CIT	15	IN SITU	C	18-22							MALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T87_CB_CIT	17	SINGLE	A	12-18							FEMALE	
ML_T87_CB_CIT	47	SINGLE	A2	12-18			T				FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T63_INDA_CIT	11	IN SITU	I	45-55							MALE	
ML_T63_INDA_CIT	13	IN SITU	I	45-55				0.2; 0.3; 0.35; 0.5; 0.6			MALE	
ML_T63_INDA_CIT	14	IN SITU	I	45-55							MALE	
ML_T63_INDA_CIT	15	IN SITU	I	45-55				0.05; 0.15; 0.2			MALE	
ML_T63_INDA_CIT	18	IN SITU	I	45-55	ABSV						MALE	
ML_T63_INDA_CIT	16	AMTL									MALE	
ML_T63_INDA_CIT	17	AMTL									MALE	
ML_T63_INDA_CIT	21	IN SITU	I	45-55							MALE	
ML_T63_INDA_CIT	23	IN SITU	I	45-55			TV	0.15; 0.2; 0.3			MALE	
ML_T63_INDA_CIT	24	IN SITU	I	45-55							MALE	
ML_T63_INDA_CIT	25	IN SITU	I	45-55							MALE	
ML_T63_INDA_CIT	26	IN SITU	I	45-55							MALE	

ML_T63_INDA_CIT	27	AMTL			ABS						MALE	
ML_T63_INDA_CIT	28	AMTL			ABS						MALE	
ML_T63_INDA_CIT	43	IN SITU	H	40-45							MALE	
ML_T63_INDA_CIT	44	IN SITU	H	40-45				0.1; 0.2; 0.3; 0.4			MALE	
ML_T63_INDA_CIT	45	IN SITU	H	40-45				0.1; 0.2; 0.35			MALE	
ML_T63_INDA_CIT	46	IN SITU	H	40-45				0.15; 0.25			MALE	
ML_T63_INDA_CIT	47	IN SITU	H	40-45							MALE	
ML_T63_INDA_CIT	48	IN SITU	H	40-45							MALE	
ML_T63_INDA_CIT	35	IN SITU	H	40-45							MALE	
ML_T63_INDA_CIT		IN SITU	H	40-45							MALE	
ML_T63_INDA_CIT		IN SITU	H	40-45							MALE	
ML_T63_INDA_CIT		AMTL									MALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T63_INDB_CIT	14	SINGLE										
ML_T63_INDB_CIT	16	SINGLE	A	12-18								
ML_T63_INDB_CIT	26	SINGLE	A	12-18								
ML_T63_INDB_CIT	27	SINGLE	12+-2.5									

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T7_INDA_CIT	21	SINGLE	C	18-22				0.1; 0.2; 0.3			MALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T7_INDB_CIT	42	SINGLE	C	18-22			1D				FEMALE	

ML_T7_INDB_CIT	22	SINGLE	C	18-22							FEMALE	DOUBLE ROOTH
ML_T7_INDB_CIT	14	SINGLE	B2	16-20							FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_TPV_MAX1	12	IN SITU	H	40-50								
ML_TPV_MAX1	13	IN SITU	H	40-50								
ML_TPV_MAX1	21	IN SITU	F/G	30-35/35-40								
ML_TPV_MAX1	22	IN SITU	F/G									
ML_TPV_MAX1	23	IN SITU	F/G									
ML_TPV_MAX2	22	IN SITU	C	18-22								
ML_TPV_MAX2	23	IN SITU	C	18-22								
ML_TPV_MAX2	24	IN SITU	C	18-22								
ML_TPV_MAX2	26	IN SITU	C	18-22								
ML_TPV_MAX2	27	IN SITU	C	18-22								
ML_TPV_MAX3	11	IN SITU	B1	16-20					Shovel			
ML_TPV_MAX3	12	IN SITU	B1	16-20					Shovel			
ML_TPV_MAX3	13	IN SITU	B1	16-20								
ML_TPV_MAX3	14	IN SITU	B1	16-20								
ML_TPV_MAX4	21	IN SITU	C	18-22								
ML_TPV_MAX4	22	IN SITU	C	18-22								
ML_TPV_MAX4	23	IN SITU	C	18-22								
ML_TPV_MAX4	24	IN SITU	NR									

ML_TPV_MAX4	25	IN SITU	NR									
ML_TPV_MAX5	16	IN SITU	C	18-22								
ML_TPV_MAX5	17	IN SITU	C	18-22								
ML_TPV_MAX5	18	IN SITU	amtl									CLOSED WITH POROSITY
ML_TPV_MAX6	11	IN SITU	D/E	20-24/24-30								
ML_TPV_MAX6	13	IN SITU	D/E									
ML_TPV_MAX6	14	IN SITU	D/E									
ML_TPV_MAX6	15	IN SITU	D/E									
ML_TPV_MAX7	15	IN SITU	D	20-24								
ML_TPV_MAX7	16	IN SITU	D	20-24								
ML_TPV_MAX8	15	IN SITU	B1	16-20								
ML_TPV_MAX9	7	IN SITU	NR						OBLONG			
ML_TPV_MAX9	8	IN SITU	NR						OBLONG			
ML_TPV_MND1	32	IN SITU	D	20-24		>5					MALE	
ML_TPV_MND1	33	IN SITU	D	20-24		>5		1: 0.2; 0.45			MALE	
ML_TPV_MND1	34	IN SITU	D	20-24		>5					MALE	
ML_TPV_MND1	35	IN SITU	D	20-24		>5					MALE	
ML_TPV_MND1	36	IN SITU	NR			>5					MALE	
ML_TPV_MND1	37	IN SITU	D	20-24		>5					MALE	
ML_TPV_MND1	38	IN SITU	D	20-24		>5					MALE	
ML_TPV_MND1	41	IN SITU	D	20-24		>5					MALE	
ML_TPV_MND1	42	IN SITU	D	20-24		>5					MALE	
ML_TPV_MND1	43	IN SITU	D	20-24		>5		1: 0.15; 0.35; 0.5			MALE	
ML_TPV_MND1	44	IN SITU	D	20-24		>5					MALE	
ML_TPV_MND1	46	IN SITU	NR			>5					MALE	
ML_TPV_MND1	47	IN SITU	D	20-24		>5					MALE	

ML_TPV_MND1	48	IN SITU	D	20-24		>5					MALE	
ML_TPV_MND2	31	IN SITU	A	12-18		<3					FEMALE	
ML_TPV_MND2	32	IN SITU	A	12-18		<3					FEMALE	
ML_TPV_MND2	33	IN SITU	A	12-18		<3		1: 0.1; 0.2; 0.4			FEMALE	
ML_TPV_MND2	34	IN SITU	A	12-18		<3					FEMALE	
ML_TPV_MND2	35	IN SITU	A	12-18		<3					FEMALE	
ML_TPV_MND2	36	IN SITU	A	12-18		<3					FEMALE	
ML_TPV_MND2	37	IN SITU	A	12-18		<3					FEMALE	
ML_TPV_MND2	38	IN SITU	A	12-18		<3					FEMALE	NOT ERUPTED
ML_TPV_MND2	42	IN SITU	A	12-18		<3					FEMALE	
ML_TPV_MND2	44	IN SITU	A	12-18		<3					FEMALE	
ML_TPV_MND2	46	IN SITU	A	12-18		<3					FEMALE	
ML_TPV_MND2	47	IN SITU	A	12-18		<3					FEMALE	
ML_TPV_MND2	48	IN SITU	A	12-18		<3					FEMALE	NOT ERUPTED
ML_TPV_MND3	34	IN SITU	C	18-22								
ML_TPV_MND3	35	IN SITU	C	18-22								
ML_TPV_MND3	36	IN SITU	C	18-22								
ML_TPV_MND3	37	IN SITU	C	18-22								
ML_TPV_MND4	41	IN SITU	B1	16-20								
ML_TPV_MND4	42	IN SITU	B1	16-20								
ML_TPV_MND4	43	IN SITU	B1	16-20								
ML_TPV_MND5	34	IN SITU	B1	16-20								
ML_TPV_MND5	36	IN SITU	B1	16-20								

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_DDJ1_MAX1	47	IN SITU	D	20-24		3-5						

ML_DDJ1_MAX2	46	IN SITU	E	24-30		2-3						
ML_DDJ1_MAX2	47	IN SITU	E	24-30		2-3						
ML_DDJ1_MAX3	13	IN SITU	D	20-24		3-5						
ML_DDJ1_MAX3	14	IN SITU	D	20-24		3-5						
ML_DDJ1_MAX3	22	IN SITU	D	20-24		3-5						
ML_DDJ1_MAX3	23	IN SITU	D	20-24		3-5						
ML_DDJ1_MAX3	24	IN SITU	D	20-24		3-5						
ML_DDJ1_MAX3	25	IN SITU	D	20-24		3-5						
ML_DDJ1_MAND1	36	IN SITU	E	24-30		3-5						
ML_DDJ1_MAND1	37	IN SITU	E	24-30		3-5						
ML_DDJ1_MAND2	74	IN SITU	5+-1									
ML_DDJ1_MAND2	34	IN SITU	5+-1									

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T4_MAX1	26	IN SITU	B2	16-20		0.4						
ML_T4_MAX1	27	IN SITU	B2	16-20		0.4						
ML_T4_MAX2	34	IN SITU	G	35-40		0.4	1LM					
ML_T4_MAX2	35	IN SITU	G	35-40		0.4						
ML_T4_MAND1	42	IN SITU	D	20-24		0.4	1LV					
ML_T4_MAND1	43	IN SITU	D	20-24		0.4						
ML_T4_MAND1	44	IN SITU	G	35-40		0.4		0.2				
ML_T4_MAND1	45	IN SITU	G	35-40		0.4		0.2				
ML_T4_MAND1	46	IN SITU	H	40-45		0.4						
ML_T4_MAND1	47	IN SITU	H	40-45	1CV	0.4	1V					
ML_T4_MAND1	31	IN SITU	D	20-24		0.4	1LV					
ML_T4_MAND1	32	IN SITU	D	20-24		0.4	1LV					
ML_T4_MAND1	33	IN SITU	D	20-24		0.4		0.4; 0.6				
ML_T4_MAND1	34	IN SITU	G	35-40		0.4		0.2				

ML_T4_MAND1	35	IN SITU	G	35-40		0.4						
ML_T4_MAND1	36	IN SITU	H	40-45		0.4						
ML_T4_MAND2	41	IN SITU	B2	16-20		0.25	1LV					
ML_T4_MAND2	33	IN SITU	C	18-22		0.25						
ML_T4_MAND2	36	IN SITU	E	24-30		0.25						
ML_T4_MAND2	37	IN SITU	E	24-30	1CV + 1PROOTH	0.25						
ML_T4_MAND2	38	IN SITU	E	24-30		0.25		0.15				

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_DDJ1_ST4_MAX1	13	IN SITU	AMTL		ABSCESS							P IN MA
ML_DDJ1_ST4_MAX1	14	IN SITU	AMTL		ABSCESS							
ML_DDJ1_ST4_MAX1	15	IN SITU	AMTL									
ML_DDJ1_ST4_MAX2	24	IN SITU	I	45-55		0.4						
ML_DDJ1_ST4_MAX2	25	IN SITU	AMTL									
ML_DDJ1_ST4_MAX2	26	IN SITU	AMTL									
ML_DDJ1_ST4_MAX2	27	IN SITU	AMTL									
ML_DDJ1_ST4_MAX2	28	IN SITU	AMTL									

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_FR1984_MAX	12	IN SITU	B2	16-20		2-3						
ML_FR1984_MAX	14	IN SITU	B2	16-20		2-3						
ML_FR1984_MAX	15	IN SITU	B2	16-20		2-3						
ML_FR1984_MAX	16	IN SITU	D	20-24		2-3						
ML_FR1984_MAX	24	IN SITU	B2	16-20		2-3						

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T81_MAX1	27	IN SITU	D	20-24	PCOLL	0.4			OBLONG			
ML_T81_MAX1	28	IN SITU	D	20-24		0.4			OBLONG			
ML_T81_MAX2	24	IN SITU	F	30-35		0.4						
ML_T81_MAND	35	IN SITU	G	35-40		0.4	T				FEMALE	
ML_T81_MAND	36	IN SITU	G	35-40		0.4	T				FEMALE	
ML_T81_MAND	37	IN SITU	G	35-40	1CROOTH	0.4	T				FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T120_MAX1	15	IN SITU	D	20-24		0.4	T					
ML_T120_MAX1	16				ABSCESS							
ML_T120_MAX2	22	IN SITU	H	40-50		0.4	T					
ML_T120_MAX2	23	IN SITU	H	40-50		0.4	T	0.23				26 PMTL AND 27 AMTL
ML_T120_MAX2	24	IN SITU	H	40-50		0.4	T					
ML_T120_MAX2	25	IN SITU	H	40-50		0.4	T					
ML_T120_MAX2	28	IN SITU	H	40-50		0.4	T					

ML_T120_MAX3	26	IN SITU	E	24-30		0.1	T					
ML_T120_MAX3	27	IN SITU	E	24-30		0.1	T					
ML_T120_MAND1	38	IN SITU	AMTL			0.3	T					
ML_T120_MAND2	44	IN SITU	B2	16-20		0.4					MALE	
ML_T120_MAND2	45	IN SITU	B2	16-20		0.4					MALE	
ML_T120_MAND2	46	IN SITU	B2	16-20		0.4					MALE	
ML_T120_MAND2	47	IN SITU	B2	16-20		0.4					MALE	
ML_T120_MAND2	48	IN SITU	B2	16-20		0.4					MALE	
ML_T120_MAND1	41	IN SITU	I	45-55	1MDC						FEMALE	
ML_T120_MAND1	42	IN SITU	I	45-55	3C						FEMALE	
ML_T120_MAND1	43	IN SITU	I	45-55	2MPC+1MDC						FEMALE	
ML_T120_MAND1	44	IN SITU	I	45-55	2MPC+1MDC						FEMALE	
ML_T120_MAND1	31	IN SITU	I	45-55							FEMALE	
ML_120_MAND2	84	IN SITU	3+-1								FEMALE	
ML_120_MAND2	52	IN SITU	3+-1									
ML_120_MAND2	16	IN SITU	3+-1									GEM
ML_120_MAND2	26	IN SITU	3+-1									GEM
ML_120_MAND2	24	IN SITU	3+-1									GEM
ML_120_MAND2	41	IN SITU	3+-1									GEM
ML_120_MAND2	31	IN SITU	3+-1									GEM

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_TP2_SUB_MAX_MAND	74	IN SITU	2+-8M									
ML_TP2_SUB_MAX_MAND	75	IN SITU	2+-8M									
ML_TP2_SUB_MAX_MAND	36	IN SITU	2+-8M									GEM
ML_TP2_SUB_MAX_MAND	82	IN SITU	2+-8M									
ML_TP2_SUB_MAX_MAND	83	IN SITU	2+-8M									
ML_TP2_SUB_MAX_MAND	84	IN SITU	2+-8M									

ML_TP2_SUB_MAX_MAND	85	IN SITU	2+-8M									
ML_TP2_SUB_MAX_MAND	46	IN SITU	2+-8M									GEM
ML_TP2_SUB_MAX_MAND	51	IN SITU	2+-8M									
ML_TP2_SUB_MAX_MAND	52	IN SITU	2+-8M									
ML_TP2_SUB_MAX_MAND	53	IN SITU	2+-8M									
ML_TP2_SUB_MAX_MAND	62	IN SITU	2+-8M									
ML_TP2_SUB_MAX_MAND	63	IN SITU	2+-8M									
ML_TP2_MAND1	42	IN SITU	C	18-22		<3	1D	0.1; 0.2; 0.3; 0.4; 0.5				
ML_TP2_MAND1	43	IN SITU	C	18-22		<3						
ML_TP2_MAND1	44	IN SITU	C	18-22		<3						
ML_TP2_MAND1	31	IN SITU	C	18-22		<3						
ML_TP2_MAND1	32	IN SITU	C	18-22		<3						
ML_TP2_MAND1	33	IN SITU	C	18-22		<3		0.1; 0.2; 0.3; 0.4; 0.5; 0.6				
ML_TP2_MAND1	34	IN SITU	C	18-22		<3						
ML_TP2_MAND1	35	IN SITU	C	18-22		<3						
ML_TP2_MAND1	36	IN SITU	C	18-22		<3						
ML_TP2_MAND1	37	IN SITU	C	18-22		<3						
ML_TP2_MAND1	38	IN SITU	A	12-18		<3						

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T116.1_MAND1	47	IN SITU	F	30-35		0.2					FEMALE	
ML_T116.1_MAND1	48	IN SITU	F	30-35		0.2					FEMALE	
ML_T116.1_MAND2	45	IN SITU	H	40-45				0.1; 0.2; 0.3			FEMALE	

ML_T116.1_MAND2	46	IN SITU	H	40-45							FEMALE	
ML_T116.1_MAND2	47	IN SITU			ABS						MALE	
ML_T116.1_MAX1	11	IN SITU	F	30-35							MALE	MATCHING MANDIBOLA2

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T0_MAND1	41	IN SITU	D	20-24		0.4	TV				FEMALE	
ML_T0_MAND1	42	IN SITU	D	20-24		0.4					FEMALE	
ML_T0_MAND1	43	IN SITU	C	18-22		0.4		0.2; 0.4			FEMALE	BI ROOTHED
ML_T0_MAND1	44	IN SITU	C	18-22		0.4					FEMALE	
ML_T0_MAND1	45	IN SITU	C	18-22		0.4					FEMALE	
ML_T0_MAND1	46	IN SITU	G	35-40		0.4					FEMALE	
ML_T0_MAND1	47	IN SITU	D/E			0.4					FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T4_INDA_MAND1	31	IN SITU	C	18-22		0.2	TV					
ML_T4_INDA_MAND1	32	IN SITU	C	18-22		0.2	TV					
ML_T4_INDA_MAND1	33	IN SITU	C	18-22		0.2	1L	0.12; 0.3; 0.5				
ML_T4_INDA_MAND1	34	IN SITU	C	18-22		0.2	TVM					
ML_T4_INDA_MAND1	35	IN SITU	C	18-22	1CD	0.2	TVM					
ML_T4_INDA_MAND1	36	IN SITU	C	18-22	1CVP	0.2	TLD					

ML_T4_INDA_MAND1	37	IN SITU	C	18-22		0.2						
ML_T4_INDB_MAND1	34	IN SITU	B2	16-20		0.2					FEMALE	
ML_T4_INDB_MAND1	35	IN SITU	B2	16-20		0.2		0.1			FEMALE	
ML_T4_INDB_MAND1	36	IN SITU	B2	16-20	1P+ABS	0.2					FEMALE	
ML_T4_INDB_MAND1	37	IN SITU	B2	16-20		0.2	TD				FEMALE	
ML_T4_INDB_MAND1	38	IN SITU	B2	16-20		0.2	TM				FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_TR1_MAND1	31	IN SITU	B2	16-20		0.3		0.2: 0.3			FEMALE	
ML_TR1_MAND1	35	IN SITU	B2	16-20		0-2		0.2: 0.3			FEMALE	
ML_TR1_MAND1	36	IN SITU	B2	16-20		0-2					FEMALE	
ML_TR1_MAND1	37	IN SITU	B2	16-20		0-2	TL				FEMALE	
ML_TR1_MAND1	38	IN SITU	B2	16-20	1V	0-2					FEMALE	
ML_TR1_MAND1	42	IN SITU	B2	16-20		0-2					FEMALE	
ML_TR1_MAND1	43	IN SITU	B2	16-20		0-2		0.3; 0.35			FEMALE	
ML_TR1_MAND1	45	IN SITU	B2	16-20		0-2					FEMALE	
ML_TR1_MAND1	46	IN SITU	B2	16-20		0-2					FEMALE	
ML_TR1_MAND2	35	IN SITU	F	30-35								
ML_TR1_MAND2	37	IN SITU	E	24-30								INFLAMMATION / PITTING
ML_TR1_MAND2	38	IN SITU	E	24-30								INFLAMMATION / PITTING
ML_TR1_MAND3	42	IN SITU	E	24-30			3L				FEMALE	48/38 INFL AMTL

ML_TR1_MAND3	47	IN SITU	E	24-30				0.25			FEMALE	
ML_TR1_MAND3	32	IN SITU	E	24-30			3L				FEMALE	
ML_TR1_MAND3	37	IN SITU	F	30-35				0.25			FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_DDJ1_ST4_CA_27/10/80_CIT_MAND1	45	IN SITU	I	45-55							MALE	
ML_DDJ1_ST4_CA_27/10/80_CIT_MAND1	46	IN SITU	G	35-40							MALE	
ML_DDJ1_ST4_CA_27/10/80_CIT_MAND2	46	IN SITU	E	24-30		0.1	TD					
ML_DDJ1_ST4_CA_27/10/80_CIT_MAND2	47	IN SITU	E	24-30		0.1						
ML_DDJ1_ST4_CA_27/10/80_CIT_MAND2	48	IN SITU	E	24-30		0.1						
ML_DDJ1_ST4_CA_27/10/80_CIT_MAND3	47	IN SITU	H	40-45			3V					
ML_DDJ1_ST4_CA_27/10/80_CIT_MAND3	48	IN SITU	H	40-45			3V					
ML_DDJ1_ST5_CA_CIT_MAND1	46	IN SITU	H	40-45		0.6						
ML_DDJ1_ST5_CA_CIT_MAND2	46	IN SITU	H	40-45	1OCC	0.3						
ML_DDJ1_ST5_CA_CIT_MAND2	47	IN SITU	H	40-45		0.3						
ML_DDJ1_ST5_CA_CIT_MAND3	46	IN SITU	H	40-45		0.6						
ML_DDJ1_ST5_CA_CIT_MAND4	33	IN SITU	B1	16-20								
ML_DDJ1_ST5_CA_CIT_MAND4	36	IN SITU	B1	16-20	1PV							
ML_DDJ1_ST5_CA_CIT_MAND5	38	IN SITU	G	35-40	POCC	0-2						
ML_DDJ1_ST5_CA_24/10/80_CIT_MAND1	43	IN SITU	C	18-22								
ML_DDJ1_ST5_CA_24/10/80_CIT_MAND1	45	IN SITU	C	18-22								
ML_DDJ1_ST5_CA_24/10/80_CIT_MAND1	46	IN SITU	D	20-24								
ML_DDJ1_ST5_CA_24/10/80_CIT_MAND1	47	IN SITU	D	20-24		0-2						
ML_DDJ1_ST5_CA_24/10/80_CIT_MAND1	34	IN SITU	C	18-22								
ML_DDJ1_ST5_CA_24/10/80_CIT_MAND1	35	IN SITU	C	18-22								
ML_DDJ1_24/09/80_CIT_MAX1	12	IN SITU	G	35-40								

ML_DDJ1_24/09/80_CIT_MAND1	37	IN SITU	F/G			0.5						
ML_DDJ1_ST3_CA_20/10/80_CIT_MAX1	11	IN SITU	G/H									

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T97_CIT_MAX1	11	IN SITU	B2	16-20		0.1			SHOVEL		FEMALE	COMP WITH MAND1
ML_T97_CIT_MAX1	12	IN SITU	B2	16-20		0.1	TV		SHOVEL		FEMALE	
ML_T97_CIT_MAX1	13	IN SITU	B2	16-20		0.1					FEMALE	
ML_T97_CIT_MAX1	14	IN SITU	B2	16-20		0.1					FEMALE	
ML_T97_CIT_MAX1	15	IN SITU	B2	16-20		0.1					FEMALE	
ML_T97_CIT_MAX1	16	IN SITU	B2	16-20		0.1					FEMALE	
ML_T97_CIT_MAX1	17	IN SITU	B2	16-20		0.1					FEMALE	
ML_T97_CIT_MAX1	21	IN SITU	B2	16-20		0.1			SHOVEL		FEMALE	
ML_T97_CIT_MAX1	22	IN SITU	B2	16-20		0.1			SHOVEL		FEMALE	
ML_T97_CIT_MAX1	26	IN SITU	B2	16-20		0.1	TM				FEMALE	
ML_T97_CIT_MAX1	27	IN SITU	B2	16-20		0.1					FEMALE	
ML_T97_CIT_MAND1	42	IN SITU	B2	16-20		0.15	TV				FEMALE	COMP WITH MAX1
ML_T97_CIT_MAND1	43	IN SITU	B2	16-20		0.15		0.25; 0.4			FEMALE	
ML_T97_CIT_MAND1	44	IN SITU	B2	16-20		0.15					FEMALE	
ML_T97_CIT_MAND1	45	IN SITU	B2	16-20		0.15					FEMALE	
ML_T97_CIT_MAND1	46	IN SITU	B2	16-20		0.15					FEMALE	
ML_T97_CIT_MAND1	47	IN SITU	B2	16-20		0.15					FEMALE	
ML_T97_CIT_MAND1	48	IN SITU	B2	16-20		0.15					FEMALE	
ML_T97_CIT_MAND1	33	IN SITU	B2	16-20		0.15					FEMALE	
ML_T97_CIT_MAND1	34	IN SITU	B2	16-20		0.15					FEMALE	
ML_T97_CIT_MAND1	75	IN SITU									FEMALE	

ML_T97_CIT_MAND1	37	IN SITU	B2	16-20		0.15					FEMALE	
ML_T97_CIT_MAND1	38	IN SITU	B2	16-20		0.15					FEMALE	
ML_T97_CIT_MAX2	15	IN SITU	G	35-40			TV				FEMALE	COMP WITH MAND2
ML_T97_CIT_MAX2	16	IN SITU	G	35-40			TV				FEMALE	
ML_T97_CIT_MAX2	17	IN SITU	G	35-40			TV				FEMALE	
ML_T97_CIT_MAND2	43	IN SITU	C	18-22		0.4					FEMALE	COMP WITH MAX2
ML_T97_CIT_MAND2	44	IN SITU	G	35-40		0.4					FEMALE	
ML_T97_CIT_MAND2	45	IN SITU	G	35-40		0.4					FEMALE	
ML_T97_CIT_MAND2	46	IN SITU	G	35-40		0.4					FEMALE	
ML_T97_CIT_MAND2	47	IN SITU	G	35-40		0.4					FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T96_CIT_MAX1	13	IN SITU	F	30-35							MALE	COMP WITH SKULL AND MAND1
ML_T96_CIT_MAX1	14	IN SITU	F	30-35							MALE	
ML_T96_CIT_MAX1	15	IN SITU	F	30-35							MALE	
ML_T96_CIT_MAND1	43	IN SITU	I	45-55		0.4					MALE	COMP WITH SKULL AND MAX1
ML_T96_CIT_MAND1	44	IN SITU	I	45-55		0.4					MALE	
ML_T96_CIT_MAND1	45	IN SITU	I	45-55		0.4					MALE	
ML_T96_CIT_MAND1	46	IN SITU	I	45-55		0.4					MALE	
ML_T96_CIT_MAND1	47	IN SITU	I	45-55		0.4					MALE	
ML_T96_CIT_MAND1	48	IN SITU	I	45-55		0.4					MALE	
ML_T96_CIT_MAND1	35	IN SITU	I	45-55		0.4					MALE	
ML_T96_CIT_MAND1	36	IN SITU	I	45-55		0.4					MALE	
ML_T96_CIT_MAND1	37	IN SITU	I	45-55		0.4					MALE	
ML_T96_CIT_MAX2	24	IN SITU	C	18-22								

ML_T96_CIT_MAND2	46	IN SITU	E	24-30		0.2						
ML_T96_CIT_MAND2	47	IN SITU	E	24-30		0.2						
ML_T96_CIT_MAND3	33	IN SITU	C	18-22								
ML_T96_CIT_MAND3	34	IN SITU	C	18-22								
ML_T96_CIT_MAND3	35	IN SITU	C	18-22								
ML_T96_CIT_MAND3	36	IN SITU	D	20-24								
ML_T96_CIT_MAND3	37	IN SITU	C	18-22								
ML_T96_CIT_MAND3	38	IN SITU	C	18-22								
ML_T96_CIT_MAND4	34	IN SITU	E	24-30								
ML_T96_CIT_MAND4	35	IN SITU	E	24-30								
ML_T96_CIT_MAND4	36	IN SITU	E	24-30								
ML_T96_CIT_MAND4	37	IN SITU	E	24-30								

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T5_CIT_MAX1	25	IN SITU	B2	16-20			TV					
ML_T5_CIT_MAX2	15	IN SITU	C	18-22		0.18						
ML_T5_CIT_MAX2	16	IN SITU	C	18-22		0.18						
ML_T5_CIT_MAX2	17	IN SITU	C	18-22		0.18						
ML_T5_CIT_MAX3	26	IN SITU	I	45-55								
ML_T5_CIT_MAX3	27	IN SITU	I	45-55								
ML_T5_CIT_MAND1	36	IN SITU	F	30-35		0.5						
ML_T5_CIT_MAND1	37	IN SITU	F	30-35		0.5						
ML_T5_CIT_MAND2	38	IN SITU	B2	16-20								
ML_T5_CIT_MAND3	34	IN SITU	B2	16-20								
ML_T5_CIT_MAND3	35	IN SITU	B2	16-20								

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T75_CIT_MAND1	31	IN SITU	G	35-40							FEMALE	
ML_T75_CIT_MAND1	32	IN SITU	G	35-40							FEMALE	
ML_T75_CIT_MAND1	33	IN SITU	G	35-40							FEMALE	
ML_T75_CIT_MAND1	34	IN SITU	G	35-40							FEMALE	
ML_T75_CIT_MAND1	35	IN SITU	G	35-40							FEMALE	
ML_T75_CIT_MAND1	36	IN SITU	I	45-55							FEMALE	
ML_T75_CIT_MAND1	37	AMTL									FEMALE	
ML_T75_CIT_MAND1	38	IN SITU	G	35-40							FEMALE	
ML_T75_CIT_MAND1	41	IN SITU	G	35-40							FEMALE	
ML_T75_CIT_MAND1	42	IN SITU	G	35-40							FEMALE	
ML_T75_CIT_MAND1	43	IN SITU	G	35-40							FEMALE	
ML_T75_CIT_MAND1	44	IN SITU	G	35-40							FEMALE	
ML_T75_CIT_MAND1	45	IN SITU	G	35-40							FEMALE	
ML_T75_CIT_MAND1	46	IN SITU	G	35-40							FEMALE	
ML_T75_CIT_MAND1	47	IN SITU	G	35-40							FEMALE	
ML_T75_CIT_MAND1	48	IN SITU	G	35-40							FEMALE	

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T5_SACCA1_CIT_MAND1	45	IN SITU	G	35-40			1L					
ML_T5_SACCA1_CIT_MAND1	46	IN SITU	G	35-40								
ML_T5_SACCA1_CIT_MAND2	37	IN SITU	B2	16-20								

ML_T5_SACCA1_CIT_MAND2	38	IN SITU	B2	16-20								

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_TM_CIT_MAX1	23	IN SITU	C	18-22							MALE	COMP WITH MAND1
ML_TM_CIT_MAND1	24	IN SITU	C	18-22							MALE	COMP WITH MAND1
ML_TM_CIT_MAND1	25	IN SITU	C	18-22							MALE	COMP WITH MAND1
ML_TM_CIT_MAND1	43	IN SITU	C	18-22							MALE	COMP WITH MAX1
ML_TM_CIT_MAND1	33	IN SITU	C	18-22							MALE	COMP WITH MAX1
ML_TM_CIT_MAND1	34	IN SITU	C	18-22							MALE	COMP WITH MAX1
ML_TM_CIT_MAND1	35	IN SITU	C	18-22							MALE	COMP WITH MAX1

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_DDJ1_09/09/80_CIT_MAX1	14	IN SITU	C	18-22								
ML_DDJ1_09/09/80_CIT_MAX1	15	IN SITU	C	18-22								
ML_DDJ1_09/09/80_CIT_MAX1	16	IN SITU	C	18-22								
ML_DDJ1_09/09/80_CIT_MAX1	17	IN SITU	C	18-22								SOVRANNUMERAL CUSP

ML_DDJ1_09/09/80_CIT_MAX1	24	IN SITU	C	18-22								
ML_DDJ1_09/09/80_CIT_MAX1	25	IN SITU	C	18-22								
ML_DDJ1_09/09/80_CIT_MAX1	26	IN SITU	C	18-22								
ML_DDJ1_09/09/80_CIT_MAX1	27	IN SITU	C	18-22								
ML_DDJ1_24/09/80_CIT_MAND1	36	IN SITU	F	30-35								
ML_DDJ1_24/09/80_CIT_MAND1	37	IN SITU	E	24-30								
ML_DDJ1_24/09/80_CIT_MAND1	38	IN SITU	E	24-30								

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_DDJ_CA_19/11/84_SUB_CIT_MAND1+2	33	IN SITU GEM	9+-2.5	9+-2.5								M2. M3 GEM. M1 COMPLETE
ML_DDJ_CA_19/11/84_SUB_CIT_MAND1+2	43	IN SITU GEM	9+-2.5	9+-2.5								
ML_DDJ_CA_19/11/84_SUB_CIT_MAND1+2	74	IN SITU	9+-2.5	9+-2.5								
ML_DDJ_CA_19/11/84_SUB_CIT_MAND1+2	84	IN SITU	9+-2.5	9+-2.5								
ML_DDJ_CA_19/11/84_SUB_CIT_MAND1+2	75	IN SITU	9+-2.5	9+-2.5								
ML_DDJ_CA_19/11/84_SUB_CIT_MAND1+2	85	IN SITU	9+-2.5	9+-2.5								
ML_DDJ_CA_19/11/84_SUB_CIT_MAND1+2	36	IN SITU	9+-2.5	9+-2.5								
ML_DDJ_CA_19/11/84_SUB_CIT_MAND1+2	46	IN SITU	9+-2.5	9+-2.5								
ML_DDJ_CA_19/11/84_SUB_CIT_MAND1+2	37	IN SITU GEM	9+-2.5	9+-2.5								
ML_DDJ_CA_19/11/84_SUB_CIT_MAND1+2	47	IN SITU GEM	9+-2.5	9+-2.5								

ML_DDJ_CA_19/11/84_SUB_CIT_MAND1+2	48	IN SITU GEM	9+-2.5	9+-2.5								
ML_DDJ_CA_19/11/84_SUB_CIT_MAND1+2	38	IN SITU GEM	9+-2.5	9+-2.5								
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND1	45	IN SITU	F	30-35		0.2					MALE	
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND1	46	IN SITU	F	30-35		0.2					MALE	
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND1	47	IN SITU	F	30-35		0.2					MALE	
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND1	48	IN SITU	F	30-35		0.2					MALE	
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND2	45	IN SITU	D	20-24								
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND2	46	IN SITU	D	20-24	1PC							
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND3	48	IN SITU	A	12-18								
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND4	46	IN SITU	F	30-35								
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND5	48	IN SITU	A	12-18								
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND6	47	IN SITU	E	24-30								
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND6	48	IN SITU	E	24-30								
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND7	44	IN SITU	B2	16-20								
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND7	45	IN SITU	B2	16-20								
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND8	35	IN SITU	E	24-30								
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND8	36	IN SITU	E	24-30								
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND9	34	IN SITU	E	24-30								
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND9	35	IN SITU	E	24-30								

ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND10	36	IN SITU	F	30-35								
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND11	36	IN SITU	F	30-35								
ML_DDJ_CA_19/11/84_SUB_CIT_NON LAVATE_MAND11	37	IN SITU	F	30-35								

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_TN/I_MAX1	13	IN SITU	C	18-22		0.4	T	0.12; 0.29; 0.4				
ML_TN/I_MAX1	14	IN SITU	C	18-22		0.4	T	0.2; 0.32				
ML_TN/I_MAX1	15	IN SITU	C	18-22		0.4	T	0.15; 0.3				
ML_TN/I_MAX1	16	IN SITU	C	18-22		0.4	2V	0.2; 0.3				
ML_TN/I_MAX1	17	IN SITU	C	18-22	3CD	0.4						
ML_TN/I_MAX1	18	IN SITU	C	18-22	3CMV - 1ROOTH	0.4						
ML_TN/I_MAX1	24	AMTL										
ML_TN/I_MAX1	25	AMTL										
ML_TN/I_MAX2	14	IN SITU	D	20-24		0.2	2V					
ML_TN/I_MAX2	15	IN SITU	D	20-24		0.2	1V					
ML_TN/I_MAX2	16	IN SITU	D	20-24	1M	0.2	2V					
ML_TN/I_MAX2	17	IN SITU	D	20-24		0.2	2V					

ML_TN/I_MAX3	14	IN SITU	C	18-22		0.35	1V	0.2; 0.25				
ML_TN/I_MAX4	27	IN SITU	C	18-22		0.25						
ML_TN/I_MAX4	28	IN SITU	C	18-22		0.25						
ML_TN/I_MAX5	13	IN SITU	D	20-24		0.2	2V					
ML_TN/I_MAX5	14	IN SITU	D	20-24	1DC	0.2	2V					
ML_TN/I_MAX5	15	IN SITU	NR		3ROOTH	0.2	2V					
ML_TN/I_MAX6	14	IN SITU	D	20-24		0.15		0.2; 0.3				
ML_TNI_MAND_F	45	AMTL										
ML_TNI_MAND_F	46	AMTL										
ML_TNI_MAND_F	47	AMTL										
ML_TNI_MAND_F	48	AMTL										
ML_TNI_MAND_F	35	AMTL										

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_TNR1_CASS48.8.38_MAND1	24	IN SITU	D	20-24		1V						
ML_TNR1_CASS48.8.38_MAND1	25	IN SITU	D	20-24		1V						
ML_TNR1_CASS48.8.38_MAND1	26	IN SITU	D	20-24		T						
ML_TNR1_CASS48.8.38_MAND1	27	IN SITU	D	20-24								
ML_TNR1_CASS48.8.38_MAND1	28	IN SITU	D	20-24		1V						

ID	Tooth	Conservation	Age (Lovejoy_Scheuer. Black)	Range	Caries/Abscess	Retraction	Calculus (Brothwell)	LEH	ASUDAS	Burnt	Sex	Note
ML_T120.0.2_MAX1	11	IN SITU	D	20-24		0.45						
ML_T120.0.2_MAX1	12	IN SITU	D	20-24		0.45						
ML_T120.0.2_MAX1	13	IN SITU	C	18-22		0.45	2V					
ML_T120.0.2_MAX1	14	IN SITU	C	18-22		0.45	2V					
ML_T120.0.2_MAX1	18	IN SITU	A	12-18	3D	0.45						
ML_T120.0.2_MAX1	19	IN SITU	D	20-24		0.45	T					
ML_T120.0.2_MAX1	20	IN SITU	D	20-24		0.45	T					

ML_T120.0.2_MAX1	21	IN SITU	D	20-24		0.45						
ML_T120.0.2_MAX1	22	IN SITU	D	20-24		0.45						
ML_T120.0.2_MAX1	23	IN SITU	D	20-24		0.45						
ML_T120.0.2_MAX1	24	IN SITU	D	20-24		0.45						
ML_T120.0.2_MAX1	25	IN SITU	D	20-24		0.45						
ML_T120.0.2_MAND1	32	IN SITU	D	20-24		0.3	2V					
ML_T120.0.2_MAND1	33	IN SITU	D	20-24		0.3	T					
ML_T120.0.2_MAND1	34	IN SITU	D	20-24		0.3	T					
ML_T120.0.2_MAND1	36	IN SITU	H	40-50		0.3						
ML_T120.0.2_MAND1	37	IN SITU	F	30-35		0.3						
ML_T120.0.2_MAND2	47	IN SITU	H			0.3						
ML_T120.0.2_SUB1_MAX1+2	64	IN SITU	3+-1									
ML_T120.0.2_SUB1_MAX1+2	24	IN SITU	3+-1									
ML_T120.0.2_SUB1_MAX1+2	53	IN SITU	3+-1									
ML_T120.0.2_SUB1_MAX1+2	54	IN SITU	3+-1									
ML_T120.0.2_SUB1_MAND1	41	IN SITU	3+-1									

APPENDIX D

Pau. Permanent tooth count and EH frequencies.

Tooth	Tot	N Affected Teeth*	N Hypoplastic lines	%[1]	% Tot[2]
I^1	32	1	0	3.13%	5.56%
I^2	21	1	5	4.76%	5.56%
C^1	30	2	4	6.67%	11.11%
P^3	24	1	0	4.17%	5.56%
P^4	16	1	0	6.25%	5.56%
M^1	16	2	2	12.50%	11.11%
M^2	14	2	2	14.29%	11.11%
M^3	9	1	1	11.11%	5.56%
I_1	3	0	0	0.00%	0.00%
I_2	14	2	0	14.29%	11.11%
C_1	14	0	0	0.00%	0.00%
P_3	16	0	0	0.00%	0.00%
P_4	20	1	2	5.00%	5.56%
M_1	25	2	0	8.00%	11.11%
M_2	21	2	3	9.52%	11.11%
M_3	2	0	0	0.00%	0.00%
Tot	277*	18	19		

* Affected teeth including both evidence in form of lines and pits. Although only lines are analysed.
.**160 teeth are excluded by this counting because the grade of wear prevented an assessment by type.
[1]Percentage is between A/O teeth of the same category.
[2]Percentage is between affected teeth for each type on total amount of affected teeth (18).

Monte Luna. Permanent tooth count and EH frequencies.

Tooth	Tot	N Affected Teeth*	N Hypoplastic lines	%[1]	% Tot[2]
I^1	173	13	40	7.51	9.77
I^2	152	3	7	1.97	2.26
C^1	166	25	68	15.06	18.80
P^3	118	6	12	5.08	4.51
P^4	89	4	10	4.49	3.01
M^1	168	6	9	3.57	4.51
M^2	153	0	0		
M^3	34	0	0		
I_1	81	1	2	1.23	0.75
I_2	104	6	17	5.77	4.51
C_1	153	37	90	24.18	27.82
P_3	152	13	22	8.55	9.77
P_4	147	11	19	7.48	8.27
M_1	207	3	3	1.45	2.26
M_2	251	4	5	1.59	3.01
M_3	59	1	1	1.69	0.75
Tot	2207**	133	305		

* Affected teeth including both evidence in form of lines and pits. Although only lines are analysed.
** 22 teeth are excluded by this counting because they were not assessed between type but considered generically upper/lower of premolar/molar.
[1]Percentage is between A/O teeth of the same category.
[2]Percentage is between affected teeth for each type on total amount of affected teeth (133).

APPENDIX E

Supplementary material Chapter Two: Map with all the mentioned locations.

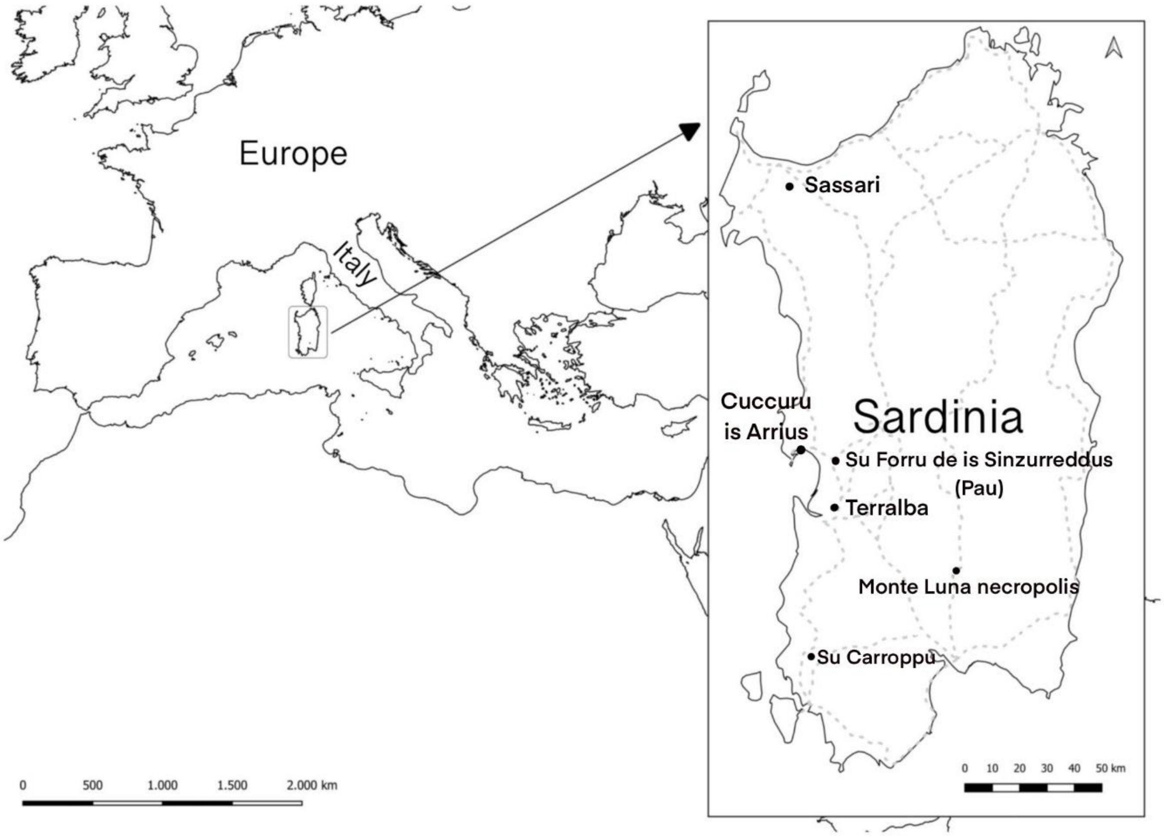

Figure 71 Sardinia cited sites and locations.

Supplementary material Chapter Seven: Video representation of traumatic injuries and nailing simulation.

Paba et al. 2022 Un unusual case of prone deposition 3Dmodels.mp4

APPENDIX F

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Rising from the ashes: A multi-technique analytical approach to determine cremation. A case study from a Middle Neolithic burial in Sardinia (Italy)

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Western Mediterranean

ABSTRACT

This study presents a multidisciplinary approach to identifying the degree and the patterns of thermal alterations of bones from collective burials. Archaeological practice is combined with the integrated application of spectrophotometry, XRF and FTIR-ATR analysis of human remains from a Middle Neolithic burial at Su Forru de is Sinzurreddus cave (Sardinia, Italy). This approach has shown to be effective to assess the intentionality, and reconstructing the modality, of body cremation. This is the most ancient case of cremation in Sardinia, which reflects a cultural change in the symbolic attitude and suggests interaction with contemporary groups in northern Italy.

1. Introduction

The study of cremated human remains from archaeological contexts has traditionally been viewed as less valuable than the study of inhumed bodies, due to the complexity of the adulterated material and the false belief that little survives the burning process (Thompson, 2016). This lack of attention is being remedied more recently through several publications (e.g. Mayne Correia, 1997; McKinley, 2000; Fairgrieve, 2008; Schmidt and Symes, 2008), summaries (e.g. Ubelaker, 2009; Goncalves, 2012), and frequent continuous research (e.g. Thompson, 2002, 2004, 2005, 2009; Garrido Varas and Thompson, 2011; Gonçalves et al., 2013a; Gonçalves et al., 2013b; Sandholzer et al., 2013, 2014). Recent methodological and theoretical developments aiming to reconstruct the taphonomic transformation of the human body during cremation have highlighted their potential for understanding past funerary and cultural practices. State of the art technologies show some benefit. Shipman's work (1984) started the study of considering colour change in burnt bone and now it is possible to study the chemical composition of the bone and burnt through X-Ray Fluorescence (XRF), X-Ray diffraction (XRD) and Fourier-Transform Infrared spectroscopy (FTIR). The application of these methods has usually combined XRF, XRD and FTIR (Dal Sasso et al., 2014, 2016; Stiner and Kuhn, 1995; Stiner and Surovell, 2001; Piga et al. 2009), or XRD and FTIR (Piga et al. 2016).

Traditionally, the archaeological context of cremation presented in many studies is usually derived from either the presence of a container such as an urn or of a distinct burial. In complex multiple burials, due to the difficulty of identifying each individual, the study of cremated remains is more challenging. This is the case for the Middle Neolithic (MN) collective burial studied here. This burial was brought to light inside the Su Forru de is Sinzurreddus cave (Sardinia, Italy), during excavations carried out in the frame of the Monte Arci research project, which aimed to identify the diachronic trend of obsidian exploitation from the Early Neolithic to the Late Bronze age (Fig. 1, Lugliè, 2003b).

During the excavation it was clear that most of the approximately 50,000 skeletal fragments recovered showed to have been affected by thermal alterations with different degrees of combustion (Fig. 2).

Nonetheless, no evidence of firing inside the cave has been recorded. This peculiar archaeological context raised an unexpected issue: were we facing a secondary burial rite through the systematic and repeated cremation of several individuals? If this was the case, it would be the oldest and only example in Sardinian Neolithic. Very few examples of cremation even appear in coeval sites abroad (Bernabò Brea et al. 2010). Such a crucial shift of ritual behavior from primary inhumation to body cremation in the interregional MN required greater understanding of

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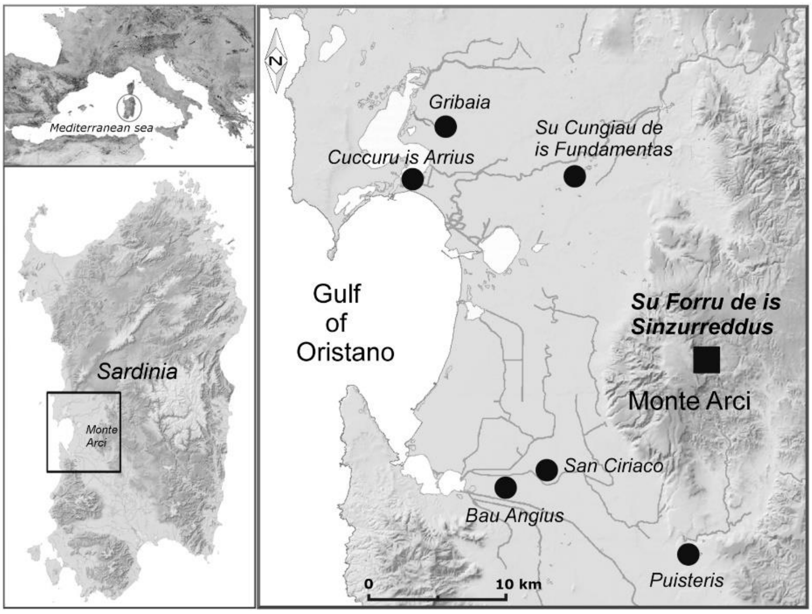

Fig. 1. General map of central-western Sardinia (Italy) with Su Forru de is Sinzurreddus-Pau (OR) and other major Middle Neolithic sites. (Map: C. Lugliè, L. Fanti).

Fig. 2. Heat induced colour change on archaeological human bones from US 1064 and US 1070. (Photo: C. Lugliè, R. Paba).

this specific symbolic behavior.

The anthropological material was affected by high fragmentation, and in the dispersal of both artefacts and human remains, a key role was clearly played by the natural exfoliation of the cave roof. Thus, it is very difficult to rely only on the spatial analysis and the evaluation of taphonomic processes to determine the funerary practices. This context required the application and integration of several analytical methods, in order to understand the ritual and post-depositional distribution of thousands of fragmented humans remains. As a consequence, a multidisciplinary approach, combining, for the first time, the application of spectrophotometry, XRF, and FTIR was undertaken.

The approach is articulated in the following steps:

1) Selection and spatial distribution analysis of the MN artefacts and anthropological materials by GIS;
2) Analysis of bone's colour change (and, by association, temperature) through spectrophotometry;
3) Characterization of the elemental composition of bone by means of XRF;
4) Molecular composition and Crystallinity Index analysis of bone through FTIR.

All the data were then statistically processed, according to each technique. They underwent statistical analysis via T-test and correlation measures.

This aims to develop a methodological tool suitable to apply to similar cases and encourages the study of cremated human remains in collective burials to understand their relevance to funerary symbolic behaviour in the Mediterranean and European context.

2. Archaeological setting

2.1. Geographic and cultural context

The site of Su Forru de is Sinzurreddus is situated in Sardinia, a 24.1 km^2 island far from the mainland that in prehistory was reached exclusively by seafaring. Consequently, every new arrival of human groups was striking because it introduced clear innovation that is recorded in the archaeological realm both in the material and in the symbolic record. Since the first population on the island during the Early Neolithic (VI millennium BCE), interregional contacts and bidirectional interactions ensured a symmetrical cultural evolution of the human communities settled on the island with those in the surrounding western Mediterranean (Lugliè, 2018a). Among the few raw materials, obsidian gives evidence of human displacements from the island towards the Italian mainland and the north-western seashores of the Mediterranean. In fact, from the Monte Arci volcanic complex, in the immediate central-

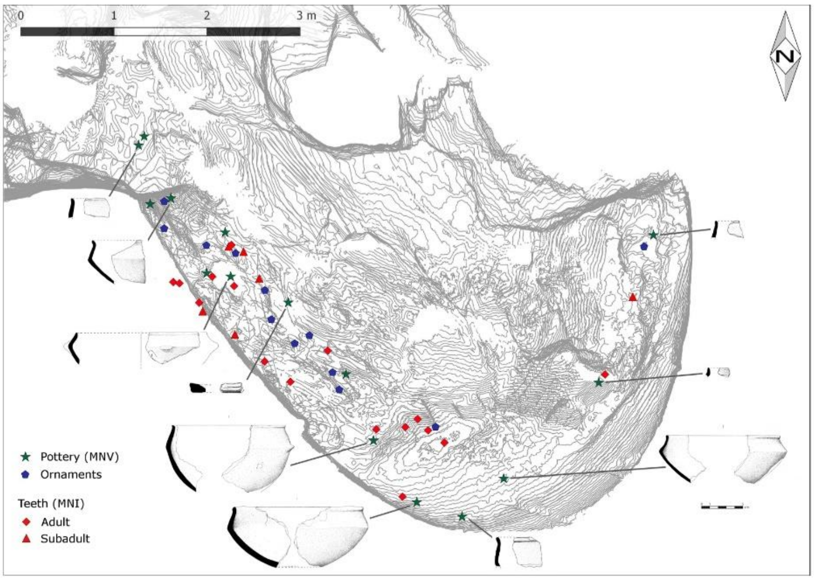

Fig. 3. Spatial distribution of MN-B San Ciriaco pottery vessels (MNV: minimum number of vessels identified, with drawings of the main vessel profiles), ornaments (beads) and human teeth selected for determining the minimum number of individuals (MNI). (Map: C. Lugliè, R. Paba, L. Fanti; vessel drawings: L. Fanti, C. Lugliè).

west backshore of Sardinia, several discrete obsidian sources of this rare volcanic glass were exploited and distributed (SA, SB1, SB2 and SC geochemical groups: Tykot, 1997; Lugliè et al., 2006; Lugliè, 2009) (Fig. 1). Between the VI and V millennium BCE, the exchange of polished stone rings linked the island with the north of Italy (Tanda, 1977), strengthening the building of interregional exchange networks, according to the internal development of social complexity.

On the other hand, the transmission of symbolic behavior is almost exclusively confined to the figurative expressions of pottery decoration, to scant convergence in lithic technology and, weaklier, to funerary rituals. In the late V millennium BCE, for instance, several traditional pot types belonging to the advanced MN *San Ciriaco* culture, previously undecorated, show the adoption of carved graphic schemes like wavy lines and spirals that marked a wide dissemination in the coeval Square-Mouthed-Pottery (SMP) culture of the Po Plain (Bagolini and Biagi, 1976). This cultural horizon was certainly in contact with the Tyrrhenian region due to the bidirectional distribution of obsidians and metamorphic (steatite) small stone beads between Sardinia and several workshops in the Apennine around Tuscany and Emilia (Micheli, 2012; Micheli and Mazzieri, 2012).

As to the funerary practice, by contrast, evidence from Sardinia gives very little information to date, limited exclusively to the case of the hypogeal necropolis at Cuccuru is Arrius - Cabras. Belonging to the former MN-A *Bonu Ighinu* culture, a series of nine small underground chambers, dated to around the middle of the V millennium BCE, showed a specific ritual of individual primary burial with the body lying along the left side and flexed like in fetal position (Santoni, 1982b; Lugliè and Santoni, in press). Pots, obsidian artifacts and sometimes food may be buried with the body, yet from one to three human figurines made in stone are always placed in the burial. This ritual and specific symbolic behavior matches the usual funerary SMP culture in many sites of the Po Plain (Bernabò Brea et al., 2010). Surprisingly, during the following and more widespread MN-B *San Ciriaco* phase, this burial practice is almost totally unknown. With the exception of the conjectural attribution to this culture of the stone circle necropolis at *Li Muri* near Arzachena (Antona, 2003), where ritual was not identified due to the lack of preservation of the human bones, there are no other funerary custom discovered thus far.

2.2. The collective burial of the Su Forru de is Sinzurreddus

The Su Forru de Is Sinzurreddus burial site is located at 508 m above sea level on the eastern flanks of the Monte Arci volcanic massif in the district of Pau, province of Oristano (central west Sardinia) (Fig. 1). The funerary locus is a small cave (around 17 m^2) opening onto a steep fault which runs through a massive rhyolitic dome with a main SW-NE direction. Before the long-term backfilling of the fault, the original entrance of the cave was several meters above the Neolithic ground level, thus providing a protected and barely accessible space (Figs. 3 and 5).

A long-term excavation (2003–2015) of the stratigraphic sequence inside the shelter revealed the succession of several phases of massive vault collapse and human frequentations, spanning from the MN to the present. The first and main phase of occupation belongs to the MN-B San Ciriaco culture, dated back to the second half of the V millennium BCE. Therefore, Su Forru de is Sinzurreddus bears the oldest direct evidence of a long-term human presence on Monte Arci. Further settling of the cave during the Copper Age and Nuragic Middle Bronze Age were almost episodic, possibly due to the progressive reduction of the room, because of the filling and obstruction following the vault collapse events. The anthropogenic layers brought to light bore a very thin and powdery matrix, inserted between large rhyolite boulders and slabs, which resulted in a cautious, thorough and lengthy excavation.

Su Forru de is Sinzurreddus is located near the eastern border of the *Sennixeddu* workshop, which is on an outcrop of SC obsidians, its relationship with this raw material exploitation may be asserted. This inference is supported by the presence of obsidian flakes inside the cave, in stratigraphic association with the MN human remains. The same stratigraphic position of a few ornaments and, mainly, of several pottery sherds exclusive of the MN-B *San Ciriaco* culture led, firstly, to assign the

Fig. 4. Excavation of the stratigraphic units in the Su Forru de is Sinzurreddus cave, with detail of dispersion of burnt bones, notably teeth (detail in the focus window). (Photo: C .Lugliè; image: L. Fanti).

Fig. 5. Excavation of the stratigraphic units in the Su Forru de is Sinzurreddus cave, with detail of a MN-B San Ciriaco bowl (white arrow). (Photo: C .Lugliè; image: L. Fanti).

graves to this horizon and, secondly, to confirm that during the second half of the V millennium BCE the systematic and massive exploitation of the SC obsidian primary deposits on the mountain took place (Lugliè, 2012). All the diagnostic artefacts were displaced randomly but mainly along the western and south/south-eastern walls of the cave, entangled in a huge amount of hyper-fragmented human bones and intermingled with several areas of concentrated human remains (Figs. 4 and 5).

Pottery is the most reliable cultural and chronological indicator of the archaeological burial context at Su Forru de is Sinzurreddus. It appears within all the stratigraphic anthropogenic layers, matching the distribution of human bones along the southern and western walls of the cave (Fig. 3).

Despite the relatively high fragmentation of the assemblage and the small dimensions of many sherds, the morphology of vessels with well-preserved profiles (mainly carinated bowls) and the technological features shared by all the pottery assemblage are clearly recognizable as distinctive of MN-B *San Ciriaco*. This pottery is characteristic of numerous contemporaneous sites across the island (Fig. 3; Santoni, 1982a, 1982b; Ugas, 1990; Santoni et al., 1997; Lugliè, 1998; Lugliè, 2003a; Usai, 2009; Lugliè, 59-63, 2017, fig. 19–22; Fanti et al., 2018, Figs. 1 and 10; Fanti, 2019, Fig. 8). Based on a count of rim types and family sherds from the study of all the assemblage (Rice, 1987; Voss and Allen, 2010), a minimum number of 15 vessels has been assessed.

Alongside the closest morpho-typological similarities among the vessels from Su Forru de is Sinzurreddus and pottery from the sites located along the main approaches to the Monte Arci massif, notably Puisteris-Mogoro (Meloni, 1994; Santoni et al., 1997), and in the central-western Sardinia area surrounding the gulf of Oristano, such as Gribaia-Nurachi, Bau Angius-Terralba and the eponym site of San Ciriaco-Terralba (Fig. 1; Lugliè, 2003a, 2017; Fanti, 2019), the spectrum of comparisons connects the pottery assemblage of this funerary site to a broader scenario which reflects a wide network of relationships and contacts, encompassing and overtaking the regional domain towards the near island of Corsica and the north Tyrrhenian area (Tramoni et al., 2007; Le Bourdonnec et al., 2011; Tramoni and D'Anna, 2016; Lugliè, 2017).

3. Materials and methods

3.1. Human remains

Besides a restricted number of contemporary, not-burnt, small faunal bones, the number of pieces of human remains found is more than 50,000, characterised by a high level of fragmentation. During the recovery, it was observed that these remains were partially inhumed but a consistent number of them had been exposed to fire (as evidenced through colour change) (Fig. 2). In fact, the remains were characterised by heat-induced fracture patterns, bone warping, shrinkage and chromatism described in the literature (Bonucci and Graziani, 1975; Shipman et al., 1984; Reverte Coma, 1984; Holck, 1986; McCutcheon, 1992; Mays, 1998; Wahl, 2008; Walker et al., 2008; Gonçalves et al., 2011). For this study teeth (565) and phalanges (500) were selected from all the excavated Stratigraphic Units (US), because they are the only complete elements in the excavated sample. A further selection of mixed fragmented humans remains from US1070 and US1064 (372) was studied to confirm the presence of burning. These bones were found underneath a stone slab from the collapse of the roof and have been associated with a well-defined chronology, based on the associated pottery. Teeth, phalanges and the mixed material were recorded following standard methods (Buikstra and Ubelaker, 1994; White and Folkens, 2005). The fragments were sorted according to skeletal area (cranium, axial or appendicular skeleton) and then identified to skeletal element or assigned to an 'unidentified' category.

3.2. Minimum number of individuals and health conditions

Teeth and phalanges were the only whole skeletal elements recovered and were used to estimate the minimum number of individuals. They were sorted by name, date, US, present state, skeletal element, burnt/unburnt, and then each category for specific traits. Teeth were studied for dental wear (Brothwell, 1981; Lovejoy, 1985), dental health (hypoplasia, calculus, caries) (Hillson, 2005), and age estimation. Phalanges were recorded by hand/foot, number, side, age estimation, and some measurements were taken (for the first proximal phalanx of the hand) (Garrido Varas and Thompson, 2011).

3.3. Heat-induced colour change

Colour change is a well-known indicator of cremation (Shipman et al., 1984; Gonçalves et al., 2011; Ellingham et al., 2014). The coloration varies with temperature as follows: a yellow brown at 200 °C, a dark brown-black at 300°-400°, an ash-grey at 500°-600 °C, chalk-white over than 700 °C, and white with blue/yellow shades between 800°-1000 °C. Therefore, the selected samples from US1070 and US1064 underwent spectrophotometry (XRite, Ci 6X) to assess colour. The equipment was calibrated with white, black and green blanks supplied by the company. The osteological controls and the selected samples were recorded in Munsell and CIELAB (Munro et al., 2007; Ellingham et al.,

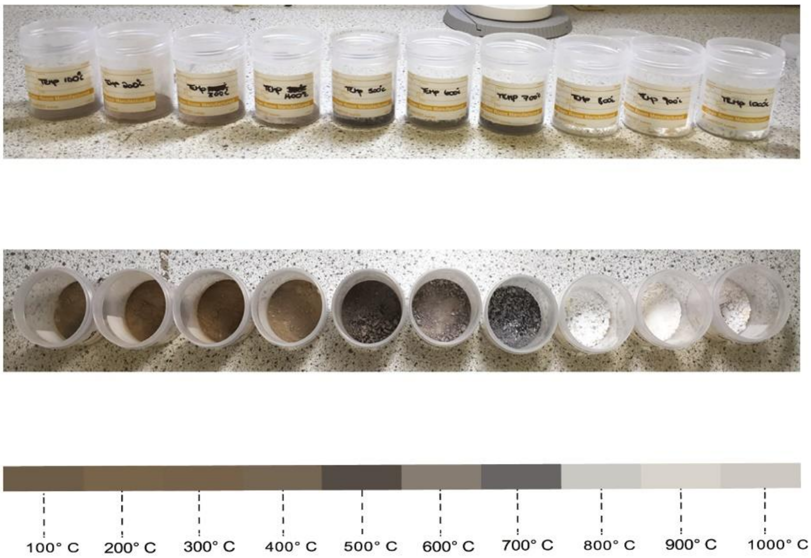

Fig. 6. Osteological controls of sheep bones burnt at known temperatures (Controls: T.J.U. Thompson; photo: R. Paba).

2014). The samples were cleaned with a brush to create a 7 mm diameter space, enough to be covered by the spectrophotometer lens. The measurement was taken on the colour which equated to the highest temperature of burning. Each sample was recorded three times at the same point and the mean result used. The averages were exported to Excel Office365 and SPSS (v23).

3.4. Osteological controls

The effective analysis of heat-induced change in bone from archaeological sites requires comparison to experimentally burned bone in order to validate the features observed in the field. As such, a significant amount of sheep bone (an accepted animal analogue) has been burned, both fleshed and defleshed, at known temperatures (100 to 1100 °C, in 100 °C intervals) for specified durations (60mins). Samples were crushed and combined together to produce a composite sample for fleshed and defleshed at each temperature interval (Fig. 6).

These experimental studies (documented for example in the likes of Ellingham et al., 2014; Ellingham et al., 2016; Piga et al., 2008; Thompson, 2005; Thompson et al., 2013, 2016; Marques et al., 2018) permit an understanding of the effect of temperature, oxygen, timing, the presence of soft tissues, clothing, etc on heat-induced changes visible on the skeleton. Once burned, the samples were subjected to FTIR, XRF and colour analysis to create standards for use in the field. Results and application of these experimental studies can be seen in the likes of Thompson et al., 2016.

3.5. XRF

X-Ray fluorescence (XRF) has shown promise in the study of fire use in archaeology (Reidsma et al., 2016) and in determining whether a set of remains belongs to a single or multiple individual by analysing elemental concentrations in human bones (Gonzalez-Rodriguez and Fowler, 2013). A portable X-Ray Fluorescence Niton XL3t GOLDD + Spectrometer analyser from Thermo Scientific (UK) was used. After the calibration and safety control protocol was performed, it was set up under Mining exploration and Geochemical analyses to detect all the elements. First, the osteological controls were performed, then the sample from the chosen US. The samples were cleaned to minimize surface contamination; however, surface contamination should be minimal because X-Rays penetrate a few millimetres beyond the surface (Shackley and Dillian, 2002; Shackley, 2011). All recordings were taken three times and the averages were exported to Excel and SPSS.

3.6. FTIR

Fourier Transform Infrared Spectroscopy (FTIR) is the latest technology to be used in the study of burnt human remains. It has shown how changes in the Crystallinity Index (CI), C/P and CO/P ratios are useful to estimate temperature (Gonçalves et al., 2018; Thompson, 2015, 2016; Thompson et al., 2009, 2011; Thompson et al., 2015). The scans were undertaken by a Bruker Alpha II Platinum ATR controlled by OPUS software and calibrated using previous known data from the same equipment. For each sample, a portion of 0.5 g fragment was selected, then background spectra were collected. The diamond stage was cleaned with propanol before all use. The spectra for each sample were recorded three times following published methods (Squires et al., 2011; Thompson et al., 2013) between 2000 cm^{-1} and 200 cm^{-1} at a resolution of 4 cm^{-1} with 32 scans in each analysis. Because the positions on the FTIR spectra and the ratio themselves examine different aspects of burning intensity, in this study measures proposed by Thompson et al. (2013) were used:

$CI = (565\ cm^{-1} + 605\ cm^{-1})/595\ cm^{-1}$

$C/P = (1415\ cm^{-1}/1035\ cm^{-1})$

$CO/P = (1650\ cm^{-1}/1035\ cm^{-1})$

Therefore, CO/P describes low temperature, 100°-500 °C; CI middle intensity, 500°-800 °C and C/P high intensity burning events, 800°-1000 °C (Thompson et al., 2013).

4. Results and discussion

4.1. MNI

Analysis of the teeth allowed four age ranges to be defined

Table 1
Su Forru de is Sinzurreddus teeth analysis. RI[1]: Upper right permanent incisor; Rdi[1]: Lower right deciduous incisor.

	Total n	RI[1]	Rdi[1]	Hypoplashia	Calculus	Caries
Teeth	565	18	6	24	7	45

(Brothwell, 1963; Bouville et al., 1983; Lovejoy, 1985): subadult, 0–12 y; young adult, 12–24 y; mature adult, 24–40 y; old adult, 40–55 y. The incisors, both permanent and deciduous, estimate the minimum number of individuals at 18 adults between 12 and 55 yr, the majority of which were between 12 and 24 yr, and the presence of six subadults between 0 and 7 yr (Fig. 4). Furthermore, 18 teeth of young adults showed hypoplasia of which 13 were consistent (level 2, 3) (Brothwell, 1981); seven young adult's teeth were recorded with dental calculus at level 1 (Brothwell, 1981); 45 caries were observed in teeth of all age ranges, of which the age group with the most caries is between 12 and 24 y (Table 1). Hand and foot bones supported the MNI and the presence of different age ranges (Table 2).

4.2. Heat-induced changes

Due to the high level of fragmentation, 131 samples were recorded in CIELAB and Munsell colour data. Here, the prevalence of darker and lighter-shade colours indicates that most of the individuals were burned at temperatures over 400 °C (Mays, 1998; Ellingham et al., 2014; Gonçalves et al., 2018). The 3D chart shows that most of the sample was burnt around 400° and 1000 °C (Fig. 7).

4.3. Elemental composition

The elemental composition of 157 fragments from the original sample were able to be analysed. Thirteen elements were detected in high enough concentrations to be measured: calcium (Ca), aluminium (Al), silicon (Si), phosphorus (P), sulphur (S), chlorine (Cl), potassium (K), titanium (Ti), chromium (Cr), manganese (Mn), iron (Fe), strontium (Sr), and hafnium (Hf). High levels of silicon suggest that the bone mineral composition has been affected by soil adhering (Burton and Price, 2000; Perrone et al., 2014). The presence of Al, used to package the human remains after the excavation, has also affected the results. Subsequently, following the previous studies (Christensen et al., 2012;

Table 2
Su Forru de is Sinzurreddus phalanges analysis. Proximal left and right phalanges have been sided following Garrido Varas and Thompson, 2010.

	Total		Hand		Feet	N/D
n	500[a]		280		174	46
		Metacarpals	**Prox. Lx phalanges**	**Prox. Rx phalanges**	**Metatarsals**	
n of identified bones		16	10	7	34	

[a] of which 71 of subadult age range.

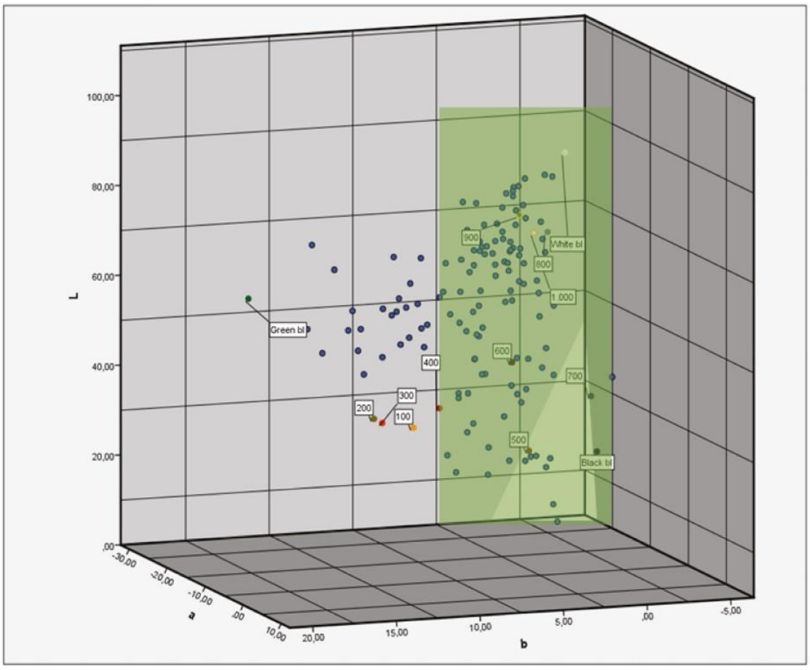

Fig. 7. CIELAB 3D chart of controls (labels) and bones sample (blue dots) from US1064 and US1070. The part in green indicates that most of the sample was burnt around 400° and 1000 °C. (Graph: R. Paba).

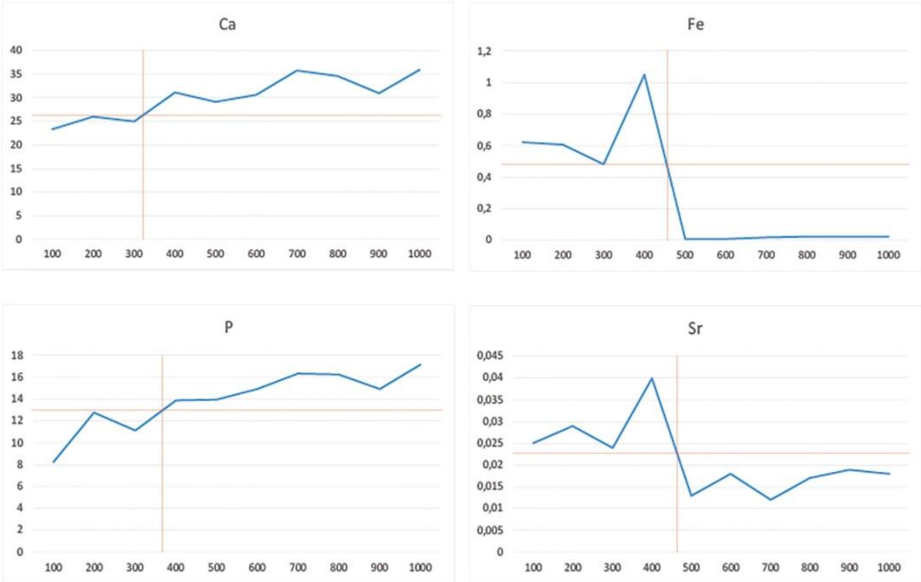

Fig. 8. Controls element percentage of Ca, P, Fe and Sr. Where X axis shows temperature and Y axis elemental presence in percentage. The red bars define the point over which is reached a temperature over 300° and 490 °C, based on the elements. (Graph: R. Paba).

Table 3
Su Forru de is Sinzurreddus sample from US 1064 and US 1070 analysed by the multi-technique approach.

	Total	XRite	XRF	FTIR	XRite + XRF + FTIR
n	366	131	157	253	124

Fulton et al., 1986; Gonzalez-Rodriguez and Fowler, 2013) it was decided to focus on Ca, P, Sr, Fe and K. Lead and zinc were not detected in the samples. Still, the controls show that a percentage of Ca, P, Fe and Sr can be find in burning beyond 300° and 490 °C (Fig. 8).

K shows a nonlinear evolution through the increasing of the temperature. The ratio Ca/P is stable at 2:1 for the majority of temperatures and Sr/Ca shows lower levels with the increase of the temperature. This indicates that the application of XRF on cremated bones, associated with colour examination, gives enough information that this method could be used in the cases where destructive techniques on the samples are not permissible. Furthermore, nutritional information deduced by the Ca/P and by the Sr/Ca ratio suggests an omnivore balanced diet (Elias et al., 1982; Sillen et al., 1982; Lambert and Weydert-Homeyer, 1993) with most of the contribution from vegetable proteins, because of the minimum presence of calculus. This is consistent with the study of the food content residues in coeval pottery from the nearest settlements (Fanti et al., 2018).

4.4. *Fragment composition*

FTIR was applied to 253 samples, again due to the fragmentation of the sample, of which, 124 were also analysed by the XRite and XRF (Table 3).

The osteological control measurements of CI, C/P and CO/P follow the trends provided by Thompson (2013; 2015), which suggest the reliability of the dataset. The 124 values show that 53.71% of the sample has been burnt at high temperature, 38.40% at middle temperature and 14.87% at low temperature. The remaining sample is consistent with this trend (Fig. 9). As per Berna et al. (2012), the presence of the peak at 630 confirms that the burning happened above 500° and allow diagenesis to be excluded.

The results here suggest an intensity of heating that is not consistent with accidental burning (Carroll and Smith, 2018), absolutely excluded even by the archaeological evidence from Su Forru de is Sinzurreddus cave. As such, it was possible to confidently analyse the remains by anatomical regions to better clarify bodily position within the funerary practice (Table 4).

Based on the results, it is clear that the limbs and skull were frequently burned at the highest temperature, this suggests the position of the body relative to the fire, accounting for the presence on soft tissue. This is consistent with the statistical correlation performed by SPSS. Following this, seven sided ribs (4 left, Lx; 3 right, Rx) and one Rx humerus fragment were analysed and indicated that the left side of the body was most impacted by high intensity temperature, leading to the assumption of a left lateral decubitus position relative to the source of fire (Fig. 10).

4.5. *Understanding funerary rituals in the Middle Neolithic*

These results show a ritual of secondary interment specific to the San Ciriaco cultural horizon, as suggested by the combined findings of typical pottery and ornaments. In fact, to date, no specific San Ciriaco burial ritual was known in Sardinia; this cultural horizon spans almost entirely the second half of the V millennium BCE. This study revealed that the individuals buried inside Su Forru de is Sinzurreddus cave during the advanced MN were intentionally cremated elsewhere, undoubtedly outside of the hypogeum. During the cremation phase, the results suggest the bodies of the dead were placed on the fire with a left side decubitus, possibly keeping the traditional disposition of the buried individuals as in the MN-A Cuccuru is Arrius graves (Santoni, 1982b). Afterwards, carbonized bones and ashes were collected and placed along

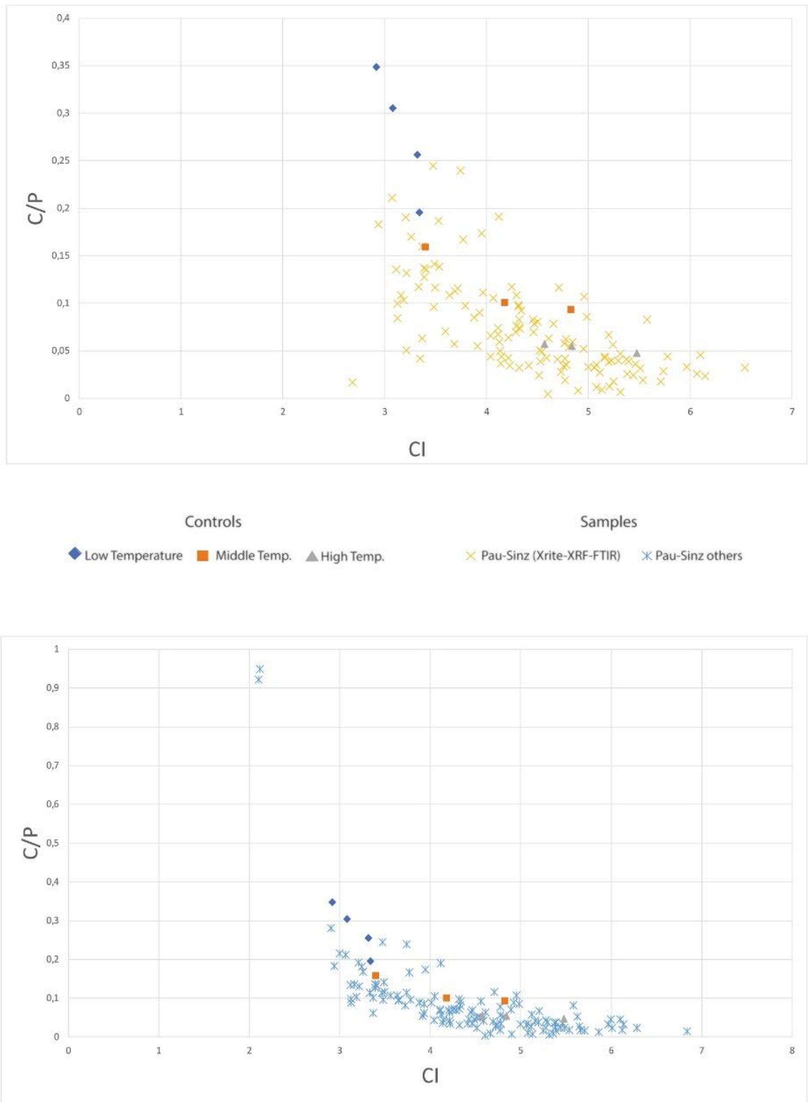

Fig. 9. CI/CP chart of controls and selected bones: most of the sample lies around mid-high intensity temperature. (Graph: R. Paba).

Table 4
Identified anatomical regions in sample from US 1064 and US 1070 analysed by the multi-technique approach.

	Total	ND	Skull	Ribs	Vertebras	Up. Limbs	Lw. Limbs	ND Limbs
n	174	91	18	22	16	5	4	18

the walls of the cave, possibly inside some container of perishable material, together with a fragment of a pot. Small lithic beads, according to the MN-A Cuccuru is Arrius graves (Santoni, 1982b), were probably part of the personal items of the deceased, due to the apparent lack of thermal alteration on their surfaces. Finally, it has been possible to establish that this uncommon rite was followed without any selection of the buried people as to age and, possibly, to sex.

The adoption of secondary burial after thermal treatment of the body clearly lies out of the local regional tradition. Earlier (Bonu Ighinu) and later (San Michele di Ozieri) funerary norms and practices seem to be exclusively primary -individual and collective, respectively- depositions

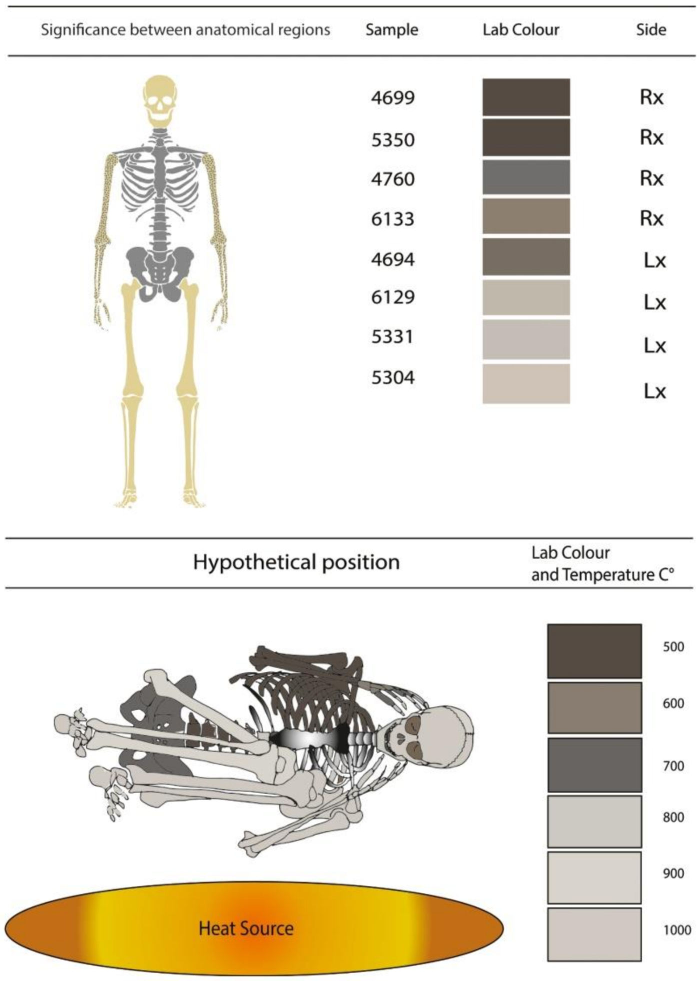

Fig. 10. Graphic representation of the correlation between anatomical regions. Ribs table with colour in CIELAB and hypothetical position. (Image: R. Paba).

into artificial hypogea. So far, in Sardinia and the near island of Corsica, there is no evidence of cremation both in EN and MN burials. Secondary depositions of burnt bones have been recorded in a few MN funerary contexts of Northern Italy: at Ponte Ghiara, Fidenza (Parma) and at Le Mose (Piacenza) belonging to the former Square Mouthed Pottery (SMP) 1 in the Po Valley and at Gaione - Cascina Catena (Parma), assigned to the following SMP 2 phase. At Ponte Ghiara di Fidenza, a unique secondary deposition of selected bones (grave n. 2) belonging to a cremated woman was associated with some remains of a dog and a single cylindrical calcite bead (Bernabò Brea et al., 2010). It has been suggested that burnt human remains were possibly contained by a receptacle made of organic material. At Ponte Ghiara, other burials of the same dwelling phase show both individual and collective primary inhumations placed inside pits, with bodies lying in several different positions including the contracted posture on the left side. Similarly, at Le Mose site up to 39 MN burials have been recognized scattered between the dwelling units, revealing a wide range of funerary rituals. Primary male and female inhumations are largely dominant (many of them in a contracted position lying on their left side), yet two possible females of the SMP1 phase (graves n. 27 and 34 in the Generali site), buried without any accompanying items, bear evidence of some ritual cremation. At the site of Gaione at least four graves including cremation evidence were recorded. Two of them (graves n. 16, 18) were identified as female and a rich series of small, ornamental, cylindrical steatite beads were recovered from the cremated body (Bernabò Brea et al., 2010). Strikingly, even at Su Forru de is Sinzurreddus, small beads are among the personal items associated with the cremated remains, though in this case, because of the high fragmentation rate of the bones, it was not possible to identify the gender of the cremated individuals. All the above-mentioned cremations from the Emilia territory were supposed to have gone over the temperature of 600 °C, due to patent bones' calcination (Bernabò Brea et al., 2010: 92). In the Northern Tyrrhenian region, further evidence of cremation of several individuals during the MN was recorded in the funerary cave of Grotta della Matta (also known as Grotta del

Sanguineto) in the Orco Feligno town, Savona (Liguria) (Delfino, 1981). Similarly, in Southern Italy a ritual of collective burial including at least 20 cremated subadults showing possible calcinated bones has been identified at Grotta Pavolella near Cassano Jonio (Cosenza): bodies were associated with painted pottery of the early MN and lithic artefacts, including some sickle blades. In the latter case, the ritual of cremation was clearly performed inside the cave, burning the bodies placed above previous burials of inhumated that were consequently affected by thermal alteration apparent in the periosteum of the bones (Carancini and Guerzoni, 1987).

This patchy geographic distribution of the occurrence of MN cremations, spanning virtually all the V millennium BCE, is possibly the result of inconsistent archaeological excavation approaches. In the past the scanty and scattered remains from this specific ritual were frequently disregarded, whenever ashes are not preserved by a resistant long-lasting container like pottery. In particular, this seems to be the case in Sardinia, considering the lack of information about the San Ciriaco funerary behaviour, despite the number of dwelling sites identified thus far. Since a close cultural tradition between the MN-A Bonu Ighinu and the MN-B San Ciriaco aspects has been argued in settlement strategies and, more clearly, in pottery production (Lugliè, 2003b, 2017; Fanti et al., 2018), the sharp shift in funerary rituals with the sudden appearance of cremation still deserves a sound explanation. The matching of both the circulation of obsidian and steatite beads and the ritual of cremation between Sardinia and the SMP 2 facies of the Po Plain, suggests that the north of Italy might have played a main role in the diffusion of this practice. The previous and coeval ritual of inhumations with contracted bodies placed on the left side may be considered another point of convergence and a bridge between the local tradition and the SMP 2 community, since this study suggested that Su Forru de is Sinzurreddus individuals have been cremated with their bodies lying in the same position. If further archaeological investigation will not foster the degree of adoption of cremation by the San Ciriaco groups at the regional scale, we must try to reconstruct the socio-economic role played by the specific community buried at Su Forru de is Sinzurreddus in the frame of the birth and development of the Monte Arci obsidian system of production and of its integration into the complex exchange networks encompassing Sardinia, Southern France and the North of the Italian mainland (Lugliè, 2009). Despite the success of this work, there are some limitations. The study would benefit from a greater array of comparative archaeological samples, and greater uptake of the methods in archaeological investigations would provide more confidence in our results. Future experimental studies would also support our key conclusions. A systematic application of the integrated analytic approach presented in this study to other cremated bones from the few MN sites known to date in the Po Plain will possibly shed a new light on the origin and circulation of this funerary ritual at the interregional level.

5. Conclusions

The application of this multidisciplinary approach to the study of the considerable amount of dispersed and fragmented bones in the Su Forru de is Sinzurreddus burial led to several crucial points raised regarding the recent prehistory not just of Sardinia but of a wider interregional context, embracing the western Mediterranean. The integration between Spectrophotometry, XRF and FTIR has been shown to be a powerful tool for such demanding sites, which could be applied in the future to better understand them and improve inferences on some symbolic attitude of Neolithic human groups. This approach allowed the successful examination of cremation-specific behaviour, with the estimation of the temperature reached by different anatomical regions during the burning. Subsequently, this led to suggest at least one case of the body position during the exposition to fire, making it possible to further infer ritual behaviour. This is a significant step forward in our attempts to formulate a bioarchaeology of cremation in the past.

CRediT authorship contribution statement

Rossella Paba: Conceptualization, Methodology, Formal analysis, Investigation, Visualization, Writing - original draft. **T.J.U Thompson:** Conceptualization, Methodology, Resources, Validation, Supervision, Writing - original draft. **Laura Fanti:** Conceptualization, Investigation, Visualization, Writing - original draft. **Carlo Lugliè:** Conceptualization, Resources, Project administration, Funding acquisition, Investigation, Validation, Supervision, Writing - original draft.

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An unusual case of prone position in the Punic/Roman necropolis of Monte Luna in Sardinia (Italy): A multi-disciplinary interpretation of Tomb 27

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ABSTRACT

Sardinia (Italy), noted for its wealth and strategic position, has been conquered through time by different populations and each one of them instilled their specific culture, ritual behaviour, and customs. Sometimes a clearcut distinction is evident between these cultures, while other times it is more of a natural progression with no marked moment of change evident. This study discusses a single grave from the Necropolis of Monte Luna, established by the Punic people, with depositional chambers and pits carved on a rockhill in front of the city settlement (Acropolis). Among the 120 tombs, Tomb 27 contained a young woman (T27.2) buried in an atypical prone deposition, having disturbed an earlier burial (T27.1), a subadult around 15 years of age. T27.2 suffered two distinctive types of perimortem trauma, a possible diastatic blunt force trauma to the occipital bone and a small quadrangular-shaped lesion reminiscent of a Roman era square shaped nail. The grave goods allow a quite specific dating to the period of transition between Punic and Roman cultures. These, and other characteristics of the young woman's skeleton, are of significance in understanding funerary and cultural behaviour at the time of this transition.

1. Introduction

In the last few decades, the highly detailed analysis of human skeletal remains, and the individuals they represent has seen a significant surge of interest (Buikstra and Beck, 2006). The creation of individual osteobiographies of past people has provided a nuanced understanding of individual lives, as well as adding data to the population perspective potentially allowing larger social phenomena to be examined (Binford, 1971; Domett et al, 2016). Key to the understanding of past people's lives based on their biological evidence, is the consideration of the context in which they lived, their social and physical environment, and died - a truly bioarchaeological approach (Gowland and Knusel, 2006).

A re-examination of an old photograph of Tomb 27 (Fig. 1), excavated from the Punic/Roman Necropolis of Monte Luna (Senorbì) in Sardinia, stimulated the present study. The photograph shows the individual in a prone deposition and surrounded by grave goods. An individual buried in a prone position is often considered deviant (Murphy, 2008, pp 12 – 17) if it is different than the norm for the period and/or populations on which the examination is focused. It has been widely observed that, regardless of culture, period and geographical area, humans tend to bury some individuals in their society in particular ways, differentiating them in death from others. These usually reflect specific circumstances such as an individual guilty of criminal behaviour, women who died during childbirth, and people affected by dangerous and inexplicable diseases or disabilities (Tsaliki, 2008). While each case reflects specific social and religious beliefs, they can generally be interpreted as an apotropaic way to prevent the person's return from the world of the dead, ensuring their permanent exile from the living community. There are testimonies from the Roman age to Medieval times, both in Italy and in Sardinia (Piga et al., 2015; Quercia, Cazzulo, 2016), that provide a basis for understanding the case presented here, however, there are some aspects that differ from the common profile of such deviant burials. The aim is to examine all the available archival evidence, the current literature, alongside a detailed archaeological

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Fig. 1. Tomb 27 (Costa, 1980, tab. XCIII). First layer of excavation exhibiting a prone deposition (red oval); in the right corner, representing a lower layer, is the cranium (yellow oval).

analysis of the region, the time period and grave goods, and the biological data from the skeletal remains themselves. All aspects may have relevance to the interpretation of the symbolic behaviour useful to reconstruct a story of a single individual to understand the ideology of the community that buried them.

2. Archaeological context

2.1. Geographic and historical background

The site of Monte Luna is in the central-southern part of Sardinia, near the town of Senorbì, which is 30 km north from Cagliari (Fig. 2). The necropolis is thought to be linked to the urban settlement of Santu Teru, a Punic-Roman town active from the 6th century BCE until mediaeval times, probably as a direct emanation of the city of Cagliari (KRLY in Punic language and Caralis/Carales or Karalis/Karales during the Roman phase). During the Punic phase KRLY was possibly in charge of the entire area where Santu Teru is located. In fact, this settlement is linked to an agricultural economy managed by the city of KRLY under the direction of the main Punic centre of the Western Mediterranean, Carthage. The town of Santu Teru was possibly-one of the main urban settlements linked to the management of cereal production, probably wheat, for the Punic city of KRLY and it demonstrated a high level of wealth, as suggested by the majestic funerary artefacts found in the Monte Luna necropolis active from the end of the 6th century BCE to the Roman Republican age (Todde, 2020). More is known about the settlement of Santu Teru during the Republican and Imperial ages, attested by an inscription (Forci, 2011) which states that the city was active during the first Imperial age. Information regarding the Imperial age phases is disjointed and incomplete. However, Santu Teru seems to have survived beyond the end of the Roman Empire dated to the 6th century CE as is evidenced by some Late Antique and mediaeval pottery (7th – 8th c. AD) found near the site of the so-called *acropolis*. The *acropolis* was a place where some scholars had hypothesised the existence of the mediaeval village attested by the agiotoponym of *Santu Teru*, which is linked to a church related to the worship of Saint Theodorus that gives name to the whole area (Costa and Usai 1990).

2.2. The necropolis of Monte Luna

The necropolis of Monte Luna (Fig. 3) was investigated archaeologically during the late 1970 s to the early 1980 s by Antonio Maria Costa as *Ispettore onorario* (Honorary Inspector) for the local *Soprintendenza ai Beni Culturali* (Superintendent for Cultural Heritage). Only a portion of the necropolis was excavated but at least 120 tombs were partially documented, though there is a significant lack of contextual information recorded (Costa, 1980; 1983a; 1983b; 1983c; Costa and Usai 1990).

During the investigation, Costa describes two different funerary areas. The first, Monte Luna, active from the 6th – 2nd century BCE, located immediately in front of the hill of Santu Teru, with its wealthy tombs and the second, the *necropoli romana* (Costa and Usai, 1990), a few metres north-west from Monte Luna, which was active from the 2nd – 1st century BCE until the 4th – 6th century CE. The original funerary area of Monte Luna is composed of chamber tombs with an access pit similar to the ones used in the necropolis of Tuvixeddu in Cagliari, pit-tombs, like Tomb 27, along with other types such as cist tombs and *enchytrismoi* (jar burials) (Costa, 1983c). Some of the tombs, such as Tomb 87, also known as the *tomba principesca*, suggests a number of the inhabitants of Santu Teru were wealthy as they were buried with funerary goods including masterpieces of Magna Graecia jewellery (Usai, 1981; Pisano, 1996). As to the rituals, there is evidence for both inhumation and cremation, but the former is the more common rite (Costa, 1983c). The *necropoli romana* instead is little known and only 10 tombs were excavated. This funerary area is composed of simple rectangular graves and cist tombs and were probably in use after the necropolis of Monte Luna.

2.3. The archaeological framework of the Tomb 27

Tomb 27 is a pit-tomb (Fig. 3) carved into the stone of the hill of Monte Luna. The funerary artefacts found in this tomb include a pitcher, a *balsamarium* (ointment jar) of Punic-era production, and a jug and cup of Punic Black gloss-ware, providing evidence of the chronology of the deposition. Two coins and some glass beads that were part of a necklace were also found (Fig. 4).Fig. 5..

The pitcher may be an example of the last evolution of the Cintas 61 type vase, which dates to the 3rd-2nd century BCE. One has clear similarities with some of the vessels from the necropolis of Tuvixeddu (Bartoloni, 2000, pp. 91) and could be considered to suggest a direct commercial, and perhaps cultural, connection between Cagliari and Santu Teru. The coins, one of Sardo-Punic era and one Roman emission overstruck on an earlier Sardo-Punic coin, are of particular interest (Hersch, 1953). The latter helps to date the context to between the last decade of the 3rd century BCE and the beginning of the 2nd. Even more precise, from a chronological point of view, is the Punic Black gloss pottery cup, identified as a Lamboglia 28F/Morel 2648 form, dated from the end of the 3rd until the 2nd century BCE (Morel, 1981, pp. 200-201). The funerary artefacts of Tomb 27 all confirm that the burial context dates from at least the last decades of the 3rd century BCE but, given the presence of the other artefacts, a more precise chronology into the early 2nd century BCE, perhaps from the very first decades, is suggested.

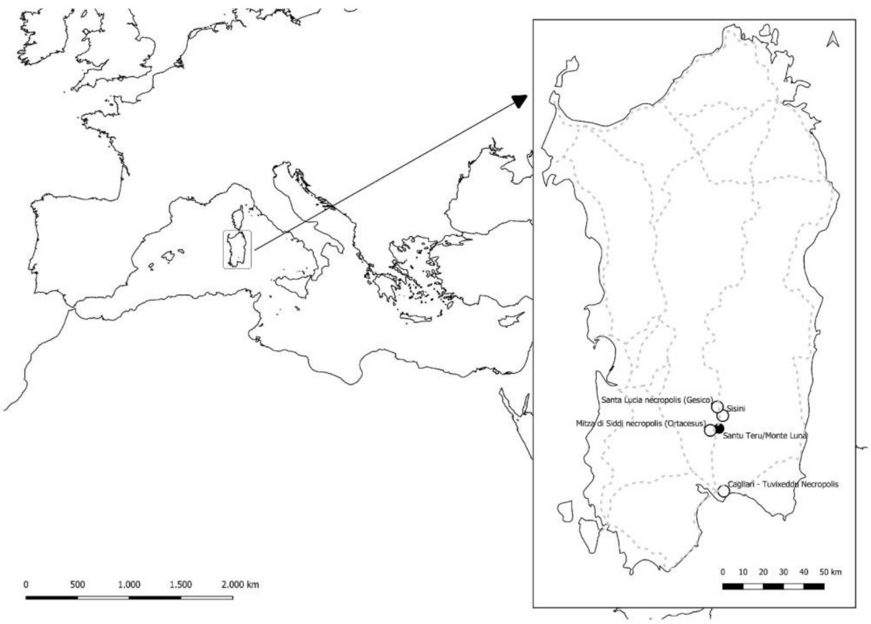

Fig. 2. General map of South-East Sardinia (Italy) with the archaeological area of Monte Luna (Senorbì) and other main sites mentioned in the present paper. (Map: D. D'Orlando).

3. Anthropological setting

The necropolis of Monte Luna contained 120 tombs, but human remains were recovered from only 70 tombs. The majority of these 70 tombs were also re-used, containing between two to 12 adults within one tomb. When subadults and young children are present in a tomb, there is only ever a maximum of two individuals (subadult included) within that tomb. Tomb 27 is located near two analogous tombs, Tomb 25 and 28, that each, like Tomb 27, contain two individuals, one adult female and one subadult. In addition, the individuals within Tomb 28 also have the same non - metric traits and presence of grave goods as Tomb 27. It is possible that within the necropolis, burials were located based on familial lineage. Whether the people in each tomb are family, will hopefully be confirmed through DNA analysis in further studies.

Due to poor preservation and comingling of the human remains within tombs, the recording of each tomb is undertaken in a systematic manner as follows: each element is sorted by anatomical region and side, and, where possible, upper limb bones (humerus, radius and ulna) are matched to an individual, as are lower limb bones (ilium, femur, tibia, fibula); for each bone, morphology is described and measurements are take; then, following standard methods, age-at-death and sex are estimated, and pathology and trauma are described (Buikstra and Ubelaker, 1994; White and Folkens, 2005; Schaefer, Black and Scheuer, 2009).

The minimum number of individuals (MNI), based on the same repeated element within tombs, in the 70 tombs studied has been calculated at 226 adults over 15 years (Brothwell, 1981; Lovejoy, 1985) and 59 subadults between 1 and 15 years (Schaefer, Black and Scheuer, 2009). No subadults less than 1 year have been found, which suggests the possible presence of a Tophet, a designated funerary area for unborn and newborn perinates, that was common in Phoenician and Punic times (Xella, 2013).

3.1. Human remains from the Tomb 27

Given that the excavation diary was missing, the analysis of the 1977 excavation photograph (Fig. 1) was essential in understanding the deposition of Tomb 27. In fact, from the image, it is possible to observe a deep grave (2.10 × 0.8 m), showing two distinct excavation levels. It shows the prone deposition of one articulated skeleton which occupies the entire space of the tomb located in the upper layer, and the location of another deeper deposition, a non-articulated skeleton in the upper right corner. Based on the articulated nature of the prone skeleton (ML_T27.2), it is evident that this individual was the second deposition. The cranium located in the upper right corner of the pit (Fig. 1) was the first deposition (ML_T27.1), that was disturbed by the burial of ML_27.2; the postcranial remains of ML_T27.1 were found at a deeper level. Seventy-five per cent of the skeletal remains were recovered for both individuals.

The former deposition (ML_T27.1) was estimated to be aged 15 years +/- 3 years based on tooth eruption and epiphyseal fusion. All second permanent molars were erupted, while the crowns of the third permanent molars were only half formed and unerupted. In addition, nonfusion is recorded at the proximal and distal epiphyses of both humeri, the right radius and the left ulna; the acromion process is partially fused, and the coracoid is unfused in the right scapula; the three bones of the pelvis are unfused; the unfused distal epiphysis of the right femur is also present (Schaefer, Black and Scheuer, 2009). Sex was estimated through pelvic and cranial morphology (Schaefer, Black and Scheuer, 2009), but given the very young age, skeletal sexual dimorphism may not yet be fully developed, and this estimation awaits further study, such as through enamel peptide analysis (Stewart et al. 2017).

The prone deposition (ML_T27.2) was estimated to be a young adult female, based on pelvic and cranial morphology (Buikstra and Ubelaker, 1994), aged between 18 and 22 years (Schaefer, Black and Scheuer, 2009). Age at death was estimated using a multifactorial approach

Fig. 3. Aerial photography of Monte Luna at present. Red arrow indicates Tomb 27 (Aerial photo and planimetry: R. Paba).

including dental eruption, dental wear, and epiphyseal fusion. The femoral head femur and iliac crest were partially fused. Stature and weight were estimated respectively as 153.0 cm and 49.2 kg (median on a CI of 95 % (Manouvrier, 1893; Pearson, 1899; Ruff, 2012).The stature and weight calculations used here are based on generic European populations, as there are no formulae based on Italians, nor Sardinians. The mean stature of the people buried in the Necropolis of Monte Luna, based on measurements of 32 adult long bones is 157.27 cm for women

Fig. 4. Tomb 27 grave goods. (D. D'Orlando). Licensed by MIC – Soprintendenza Archeologia, belle arti e paesaggio per la città metropolitana di Cagliari e le province di Oristano e Sud Sardegna; reproduction is prohibited.

and 160.62 cm for men.

3.2. Genetics factors

The cranial vaults of T27.1 and T27.2 both have a retained metopic suture and Wormian bones at the intersection of the lambdoidal and sagittal sutures (Fig. 6). These traits are not common in the necropolis. In other calvaria with ossicles they are located in other places, such along the sagittal suture, and not associated with metopism. These 'primary' discrete traits (Buikstra and Ubelaker, 1994) in both individuals and in the aforementioned Tombs 25 and 28, suggest that there are family areas within the necropolis.

The metopic suture usually closes by 2 years of age, though it can close later in childhood (Coppa, and Rubini, 1996) or adulthood (Zdilla et al. 2018). While some individuals with metopic sutures have been reported to have larger transverse, cranial dimensions suggesting this feature may be related to morphogenesis (Bolk, 1917; Schultz, 1929), this is not the case in T27 and T28 crania. Further support to a more genetic aetiology is the persistence of the metopic suture into adulthood, which can be hereditary and is more common in some ethnic groups than others (Berry & Berry, 1967). There are some external factors, such as frontal sinus abnormalities, or pathological conditions, such as hydrocephaly, that may also cause it to persist (Zdilla et al. 2018) but the above conditions are excluded in T27. In this case, according to the studies of Torgensen (1951) and Sjovold (1984), metopism is considered to be a hereditary trait.

Lambdoidal Wormian bones are the result of extra ossification centres, but their aetiology is not fully understood (Bellary et al., 2013). In some cases, they are a normal anatomical variation, associated with mechanical stress and the environment (Sanchez – Lara, 2007). For example, in some populations sleeping in a supine position places pressure on the occipital area that can lead to expansion of the occipital suture and brachycephaly (Sanchez – Lara, 2007). This can be excluded in the case of T27.1 and T27.2 because their skulls are not brachycephalic. In other cases, Wormian bones may be related to specific pathology, such as hydrocephaly or craniosynostosis, but these conditions are usually associated with numerous, more than 10, and large, Wormian bones and arranged in a mosaic pattern and size larger than 6 mm by 4 mm (Bellary et al. 2013). Other factors suggested to be correlated with the development of Wormian bones include epigenetic factors, cranial deformation, craniosynostosis, and premature suture closure, none of which are observed here. Other conditions, such as additive polygenic complex or osteogenesis imperfecta may have Wormian bones associated with them (Coppa and Rubini, 1996; Goto et al. 2004; Semler et al. 2010; Bellary et al., 2013). Wu et al. (2011) reported that geographic and ethnographic patterns in frequency suggest a possible genetic basis, with a low frequency in Europe populations.

The presence of both these variations in both these individuals and the absence of mechanical stress and cranial deformation, may suggest T27.1 and T27.2 were related to each other, but further evidence, such as DNA, would be required to be certain.

Interestingly, in the necropolis the same condition is present in Tomb 28, although the female adult (18–22 years old) has only a thin line of metopism, while the subadult (9+/-3 years old) has a complete opening through the frontal bone up to the coronal suture similar to both

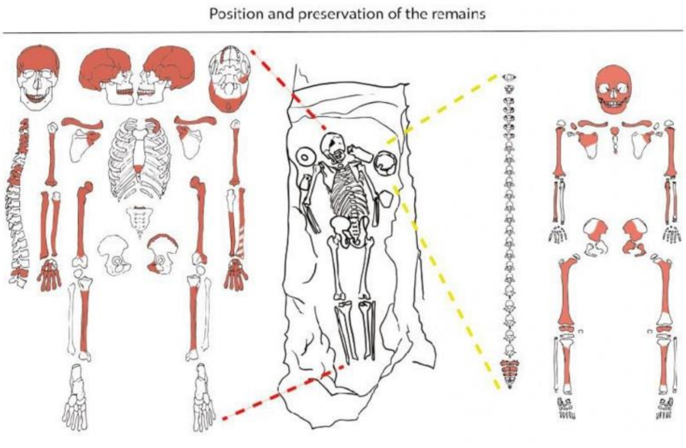

Fig. 5. Graphic representation of position and conservation of the human remains from Tomb 27. The yellow lines indicate the cranium around which was found the postcranial remains of T27.1. The preserved remains are indicated in the skeleton schema to the right. The red lines indicate the location of T27.2, found in the prone position, and represented by the preserved remains shaded in the skeletal diagram to the left. (Paba, R.).

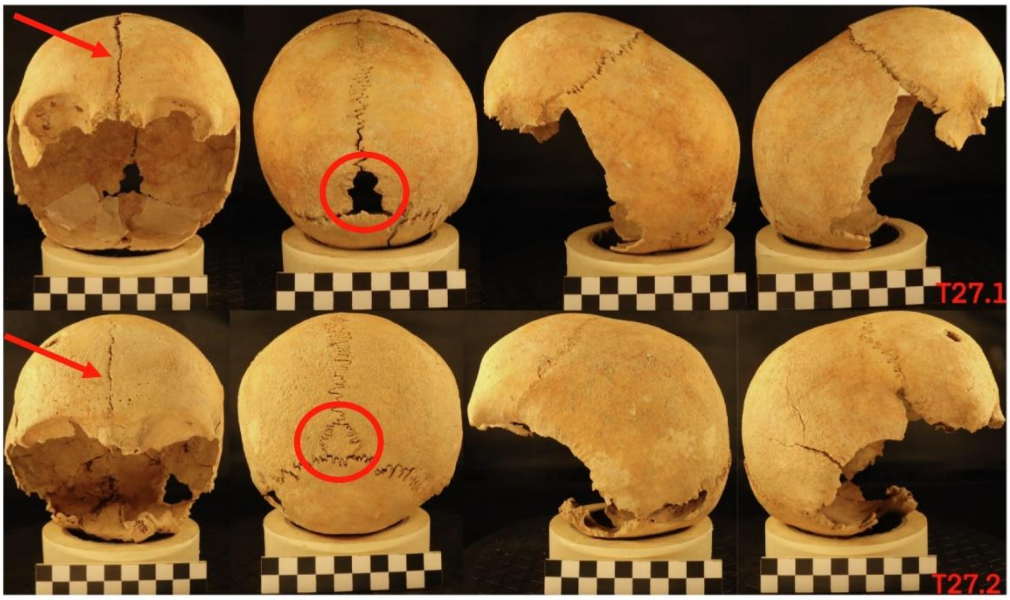

Fig. 6. Evidence of metopism (Red arrows) and Wormian bones (Red circles) in T27.1 and T27.2 calvarium (Paba, R.).

Fig. 7. Evidence of healed trauma in the midshaft of the right clavicle of T27.2. Superior view (A) with focus on the healed trauma in red rectangle, and posterior view (B), red arrow points at the trauma. (Lai, G.).

individuals in Tomb 27. The Tomb 28 individuals also have Wormian bones located in the lambdoidal suture, with the same shape and number of ossicles (2).

3.3. Trauma

Individual T27.2, the young adult female, presents with multiple traumatic lesions (Figs. 7, 8, 9), suggesting the presence of both antemortem and perimortem trauma.

There is a healed fracture in the midshaft of the right clavicle (Fig. 7). Healing has resulted in a thickened middle half of the clavicle. These types of fractures often occur in childhood and typically result from axial, longitudinal compressive forces (Nunn et al. 1989) commonly associated with a fall onto the shoulder or the outstretched hand, or from a direct blow to the humerus, either of which could be accidental or the result of intentional violence (Blount 1955; Thornton and Gyll 1999).

Two traumatic injuries are evident on the cranium, possibly occurring *peri* or postmortem. One triangular-shaped lesion, measuring 41 × 19 mm, is located on the inferior aspect of the left occipital bone, just posterior to the lambdoidal suture (Fig. 8) inferior to the hat brim line which is not consistent with an intentional blow (Kremer, 2009). Endocranially, there is an 'exfoliation' of a bone flake (Fig. 8D/E) which is commonly seen with blunt force trauma as the force moves from the external aspect, inwards (Wedel and Galloway, 2004). There is also evidence of two short radiating fracture lines out from the medial aspect of the lesion usually associated with a moderate- or high-velocity impact on a common point (Kieser et al., 2014) (Fig. 8B).

This traumatic lesion is possibly a short radiation fracture along the suture, leading to a possible diastatic lesion which caused the left lambdoid suture, at the point of trauma, to disarticulate (White et al, 2012, p.434). This suggestion is supported by the observation that most of the other sutures (coronal, sagittal, and right lambdoid) are slightly more fused than the left lambdoid (Buikstra and Ubelaker, 1994). In Fig. 8C, it is possible to see where the disarticulation has occurred as there is a change in the surface of the suture to a rounded and pitted area possibly as a result of osteoclastic reaction within the first week of the trauma (Barbian et al. 2008) though could also be remodelling from normal suture closure with aging. Considering the location of the lesion, the radiating fractures, and the opening along the lambdoid suture, this is likely blunt force trauma either from an object or a fall onto this area of the head.

The second cranial lesion was located on the right side of the frontal bone showing a penetration from the outside inward (Fig. 9). The shape (9.5 mm × 9.5 mm) of the lesion suggests a sharp force injury was inflicted using an object with a quadrangular section (Fig. 9). Intentional trephination is unlikely as there are no associated cut marks extending out from the lesion that would be consistent with the usual trephination practice in the Roman Era (Tullo, 2010; Giuffra and Fornaciari, 2017). There is a depression and exfoliation around the area of impact in the outer table due to the force of impact, and there is also bevelling of the inner table edges of the lesion (Fig. 9) (Barbian et al., 2008; Facchini et al. 2008; Amadasi et al. 2016); both are characteristic of penetrating

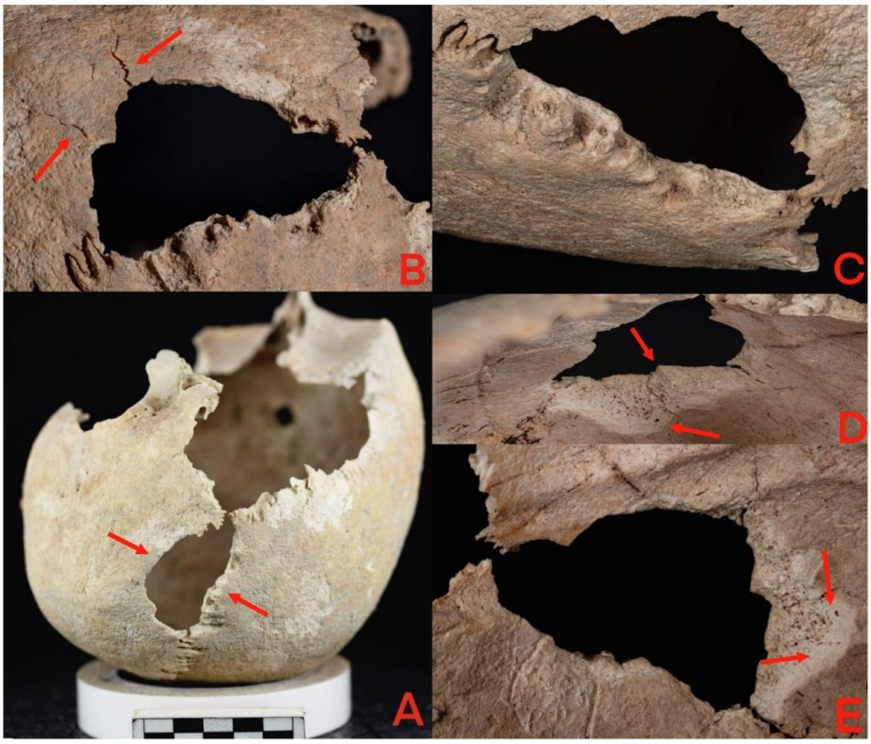

Fig. 8. Evidence of trauma on the occipital bone adjacent to the left lambdoid suture (A) (Paba, R.). (B) ectocranial surface with radiating fractures (red arrows). (C) the lambdoid suture (ectocranial view, showing remodelling likely from partial suture closure with normal aging) indicating a disarticulation due to a diastatic fracture along the suture has occurred. (D) and (E) show flaking is evident on the endocranial surface. The flake was not found.. (Lai, G.).

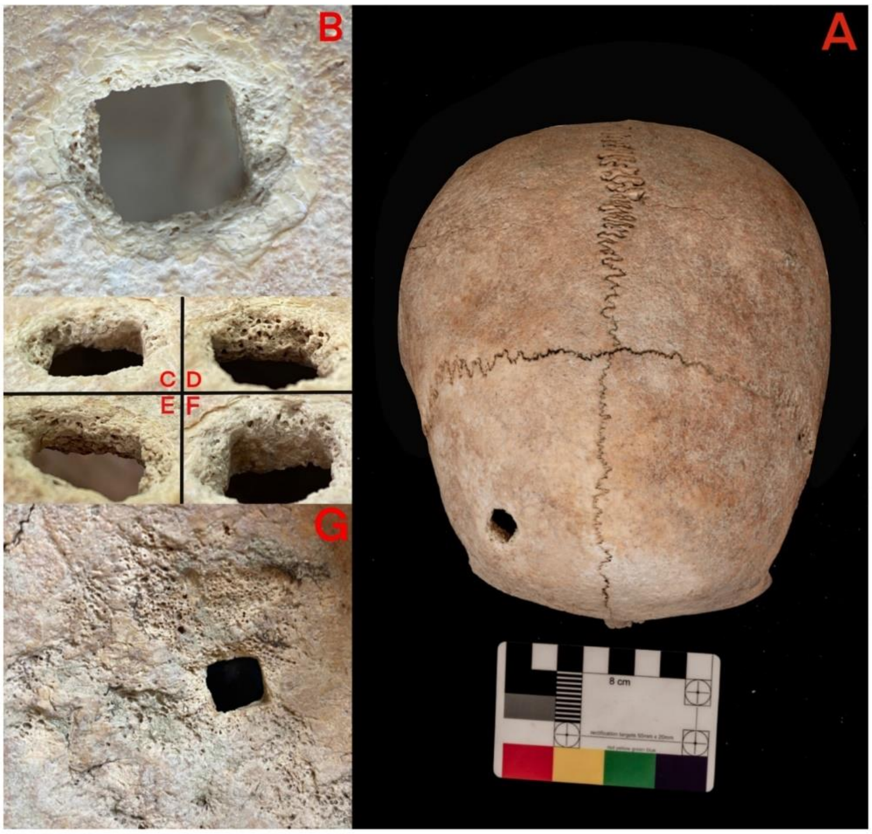

Fig. 9. T27.2 skull. Evidence of frontal trauma is shown (A) (superior view) (Lai, G.). (B-G) Close up of the right frontal bone trauma. (B) ectocranial view of the trauma showing bone flaking. (C - F) close up of the internal edges of the trauma (ectocranial view). (C) is the posterior side, (D) is the right side, (E) is the inferior and (F) the left. These edges show exposed diploe due to the perimortem trauma. (G) Endocranial view indicating bevelling of the inner table. (Paba, R.).

injuries with a highly localised point of impact associated with considerable power (Wedel and Galloway, 2004). There is no evidence of bone remodelling (Fig. 9), suggesting this incident occurred perimortem (Barbian et al., 2008). The shape of the lesion is similar to the cross section of ancient Roman nails. These nails are a common object in Roman settlements excavations in Sardinia (Fig. 10).

4. Discussion

The skeletal remains of T27.2, a young woman buried in a tomb at the Monte Luna necropolis, are noteworthy not only because of their unusual prone position, but also for the presence of perimortem trauma. The necropolis, and the people buried within it, is of significant interest from a cultural perspective as it provides an insight into a critical period of transition from the Punic period to the Roman dominion for the city of *Santu Teru*.

4.1. The trauma and its cultural significance

T27.2 presents with multiple traumatic lesions, one healed fracture of the right clavicle and two cranial, possibly perimortem, lesions.

The cranial lesions are in the posterior aspect of the lambda suture in

Fig. 10. Nail from Sisini. (Lai, G.).

the occipital bone and on the right frontal bone. The occipital lesion (Fig. 8) is typical of blunt force trauma most likely from a direct force such as from a fall, landing on the back of the head. Intentional cranial trauma is often associated with multiple traumatic lesions, often including facial trauma, and the lesions often occur on the left side (Guyomarc'h et al., 2010). T27.2 does have trauma on the left side and has another cranial trauma on the frontal bone, however this lesion does not fit the typical pattern of interpersonal violence-related trauma. In addition, the posterior fracture is within the 'hat brim line', suggesting the lesion is most consistent with an injury sustained from a fall (Kremer et al., 2009). It cannot be discounted, however, that the woman has fallen after being intentionally pushed.

The lesion on the right frontal bone, as discussed above, is quadrangular in shape and is typical of penetrating (sharp force) injuries (Wedel and Galloway, 2004; Amadasi et al. 2016; Facchini et al. 2008). The distinctive shape of this perimortem lesion is reminiscent of the square-shaped cross-section of nails commonly used in Roman times. Such nails can be directly compared to those found in the coeval and nearby site of Sisini (D'Orlando, 2019) (Fig. 10). The Sisini nail has a cross-section of 7.5 mm × 7.5 mm, which is consistent with the measurement of the trauma (9.5 mm × 9.5 mm). The nail length is 103 mm and this helps to exclude the possibility that the nail exited at the occipital lesion, as the sagittal measurement from the frontal trauma to the occipital lesion is 160 mm. The significance of a potential nail being used around the time of death is more fully discussed below.

Roman ballista bolts have a similar quadrangular cross section and size (Pental et al., 2014; Rossi et al., 2015). However, there are no findings of Roman ballista bolts in the area, and they tended to be used only during warfare. There is no evidence for siege or warfare at this time period or for the region around Santu Teru. In addition, the gender of T27.2 also makes it unlikely that a ballista bolt caused this injury as women presence as been reported as abnormal and transgressive (Boatwright, 2011).

4.2. *The burial archaeology*

Tomb 27 is a pit-tomb carved in the stone of the hill of Monte Luna. The funerary artefacts include burial objects from a transition phase between Punic and Roman cultures that date back to the Mid-Republican period of the Sardinian timeline. Based on the contemporary presence of the overstruck coin and the Punic Black gloss pottery cup, Tomb 27 is dated into the 2nd century BCE perhaps from the first decades of the 2nd century BCE.

The funerary artefacts also suggest that there was a widespread shared culture in the rural landscape of Cagliari and its hinterland during the Punic-Roman ages. A locally made *balsamarium* (ointment jar) found in Tomb 27, is similar to a form commonly found in the Tuvixeddu necropolis (Bartoloni 2000, p. 91) and in the Santa Lucia funerary area (Gesico, SU) (Tronchetti 1996, pp. 999-1000) (Fig. 1).

The entire funerary context of Tomb 27, including the placement of objects in the tomb, is more typical of a single deposition, rather than two interments. In the nearby necropolis of Mitza di Siddi, singular depositions such as Tomb 67 and 113 (with the same chronology asTomb 27 of Monte Luna) (Cocco 2009, pp. 60-63; 80-83) contain a similar number of artefacts as Tomb 27, leading to the hypothesis that the prone individual, T27.2, may have been interred without any objects. As such, T27.2 may exhibit further evidence of deviancy (Shay, 1985). Therefore, there are multiple lines of evidence to support the case of Tomb 27 representing an unusual funerary rite: the prone position of the body, the perimortem cranial trauma, and the lack of artefacts.

Ethnographic sources suggest a wide range of reasons for the prone deposition of an individual including as punishment for a perceived fault. For example, the Merovingian King Pepin "asked to be buried face down for the sins of his father" (Taylor, 2008, cited in Gilchrist and Sloane, 2005, p. 154). But perhaps the most common explanation is related to *necrophobia*, mostly associated with a fear that the corpse could disturb the living (Tsaliki, 2008). These transcultural superstitions across the Mediterranean region were linked to witches, werewolves, vampires, and other mythical creatures (Quercia, Cazzulo, 2016).

Atypical burial rites have also been associated with contagious diseases and epidemics in antiquity (Tsaliki, and Taylor, in Murphy, 2008, pp. 18-32; 102-123). For example, Pliny The Elder, in *Naturalis Historia* (AD 77), describes a connection between a cross-eyed person and beliefs about an evil eye. This led to Romans' beliefs around other misunderstood diseases such as epilepsy, or so called *morbo sacro*, that was previously described by Hippocrates of Coos (5th century BCE) in one of the first scientific treatises written on the topic (Hippocrates, *De Morbo Sacro*, 4). The disease was thought to include a powerful element of impurity both for the individual and for their community since they believed that epilepsy was contagious. For this reason, the treatment of the victims was mostly related to a purification rite dedicated to the divinity responsible for the sickness. Pliny the Elder wrote in the 1st century CE, that if a person died from an epileptic seizure it was suggested to nail the part of the body in which the trauma began to prevent the diffusion of the disease, miasma, into the community (Pliny the Elder, *Naturalis Historia*, 28 17, 63) and requires purification.

This raises the possibility that the frontal bone lesion in T27.2 was created by a ritual nail, though a nail was not left in this tomb. Elsewhere in the Mediterranean, sacred nails are usually left in the tomb, as attested in religious contexts. Sacred nails are usually marked with sacred symbols indicated as *charakteres*, letters and signs inscribed on a magic object, which are common in Graeco-Egyptian, Judeo-Christian, and other religious practices (Bevilacqua 2001). Such sacred objects were associated with auspicious and apotropaic functions. Nails were a powerful symbol in ancient times usually associated with the concept of *defigere*, meaning to fix down or fasten something. In a religious context, these objects are linked to specific rituals. The ritual of the *clavum figendi* (to nail) was used to celebrate recurring or official events, such as the foundation of a temple or the beginning of a new year. They are linked as well to the *tabulae defixionum*, curse tablets (usually made of lead), which were pierced by nails and hidden in places near to the underworld such as necropolises or wet places as the water was a useful medium to link the living and the dead (Dungworth, 1998). The practice described by Pliny is clearly linked to the power attributed to nails, which could prevent or avoid a particular occurrence (Bevilacqua, 2001, p. 133). The use of a ritual nail on a person usually occurred after death. Such is the nature of perimortem injuries, that it is impossible to determine whether the perimortem frontal lesion in T27.2 occurred just before or after death.

One such hypothetical explanation for T27.2 may be that they were suffered a series of epileptic seizures that could have first resulted in the clavicle fracture. A subsequent seizure may have led to the blunt force trauma to the occipital bone, perhaps occurring as the woman fell or knocked their head against something hard. In fact, as presented in contemporary clinic literature, people affected by epilepsy are three times more likely to injure themselves during seizures and among the most common types of injury (that might be seen on a skeleton) are head injuries, fractures, and dislocations (Nguyen et al., 2009; 2013; Camfield et. al., 2015). The blunt force trauma after an epileptic seizure may have been the cause of death and the sharp force trauma was inflicted around this time to prevent the miasma associated with the epilepsy spreading to the community. The woman was then buried in the prone position, further symbolising her aberrant life and/or death.

There are, of course, other possible explanations for this collection of archaeological and biological evidence. For example, prone burials are sometimes carried out on people who have committed particularly harsh crimes (Tsaliki, and Taylor, in Murphy, 2008, pp. 18-32; 102-123). However, if this was the case it is unlikely that such a person would be buried in another person's grave, possibly a relative's grave, and within the community necropolis. Another interpretation could be considering the clavicle fracture unrelated to a seizure and the occipital trauma as cause of a seizure which led to the unusual nailing to release pressure in the cranial vault.

4.3. Conclusion: Tomb 27 and its wider significance

The bioarchaeological analysis of a single tomb in the Monte Luna necropolis, Tomb 27, has detailed some striking possibilities around life and death and the cultural perception of these during a period of significant cultural change from Punic to Roman times. While, it is clear that T27.2, a young woman, suffered perimortem cranial injuries, the sequence of events and cause of these injuries is not conclusive but give clues and raise the possibility of a significant perimortem funerary rite associated with disease, a nail, and prone burial. This highlights the potential superstitious nature around death most similar to Roman Era culture, suggesting that Roman cultural practices had already been put in place at this early stage of the transition from Punic to Roman culture. Such analyses can focus on the nuances of life in the past, closer to the day-to-day realities of people in past communities in contrast to the larger scale histories of empires and battles.

CRediT authorship contribution statement

Rossella Paba: Conceptualization, Methodology, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing. **Dario D'Orlando:** Conceptualization, Methodology, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing. **Anna Willis:** Writing – review & editing. **Carlo Lugliè:** Methodology. **Kate Domett:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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