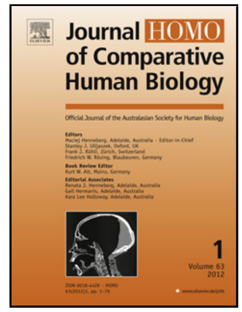
Accepted Manuscript



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PII: S0018-442X(15)00077-3
DOI: http://dx.doi.org/doi:10.1016/j.jchb.2015.09.001
Reference: JCHB 25410

To appear in:

Please cite this article as: Piga, G., Guirguis, M., Thompson, T.J.U., Isidro, A., Enzo, S., Malgosa, A.,A case of semindashcombusted pregnant female in the Phoenician-Punic necropolis of Monte Sirai (Carbonia, Sardinia, Italy), *Journal of Comparative Human Biology* (2015), http://dx.doi.org/10.1016/j.jchb.2015.09.001

A case of semi–combusted pregnant female in the Phoenician-Punic necropolis of Monte Sirai (Carbonia, Sardinia, Italy).

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Received 28 December 2014, accepted 11 May 2015

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Abstract

We present a case of a pregnant woman with the fetus skeletal remains *in situ*, belonging to the Phoenician-Punic necropolis of Monte Sirai (Sardinia, Italy). The burial dates back to the late 6th to early 5th century BCE. Of the unborn fetal cases documented in the literature this is amongst the oldest four and it represents the first documented case of a pregnant woman in the Phoenician and Punic necropolis literature. A physico-chemical investigation of bones combining X-ray diffraction and Fourier transform-infrared spectroscopy suggests that the female skeleton and fetus were subjected to an incomplete heat treatment according to a funerary practice, perhaps limited to the period of early 5th century BCE, that appears to be peculiar to this site.

Introduction

Generally ancient populations are characterized by a high level of female mortality, mainly related to the reproductive period, and mostly associated with childbirth complications (Campillo, 1995; Molleson, 1986; Wells et al., 1975). However, very few cases of pregnant females have been documented in the archaeological record during the prehistory and early history, although complications of pregnancy and childbirth should be regarded as causes of numerous deaths in the past (Malgosa et al., 2004). This could be due to several reasons. People who normally exhume skeletons from archaeological sites may confuse fetal remains with microfaunal evidence (Rascón et al., 2007). It may not be until anthropologists carry out meticulous observations at a laboratory that the fetal elements are recognized. On the other hand, biases on fetal preservation could occur by a combination of physical and chemical processes affecting drastically their fragile parts (Lewis, 2007; Stojanowski, 2002). It is also possible that the remains are placed in large collective burials, where commingled bones sometimes show the presence of fetuses together with skeletons of adult persons (De Miguel, 2010). In the case of double burials, which contain a woman and a child, the cause of death could be unrelated to childbirth but rather to violence, sacrifice, illness or accidents, among others. Also, if birth took place, and both mother and baby died, they may have been buried independently (Malgosa et al., 2004).

In this paper we present a case of a pregnant woman with skeletal remains of a fetus *in situ*, belonging to the Phoenician–Punic necropolis of Monte Sirai (Carbonia, Sardinia, Italy). This case is significant because: a) it represents the first documented case of a buried pregnant woman in the Phoenician and Punic contexts; b) of all the cases documented in the literature of women entombed with a fetus inside the abdominal cavity this is amongst the oldest four; c) the bones of the woman and fetus seem to have undergone an heat treatment unconventional with respect to classical incineration practice.

Materials and methods

a) Brief archaeological information about the Monte Sirai necropolis

The site of Monte Sirai is located in the south-western part of Sardinia near the city of Carbonia (Fig.1). It is thought to have been established by the Phoenicians of Sulky (today known as *S. Antioco*) or by the early settlers living in the village of Portoscuso around 740 BCE. Soon after its foundation, the site assumed an importance for its strategic position near the coastline and as a gateway to the Campidano plain of the island (Bartoloni, 2000).

INSERT Fig. 1 ABOUT HERE

Excavations of the site were conducted between 1963 and 1966 and then again in 1980 and between 2005 and 2010 (Bartoloni, 2000; Guirguis, 2005, 2010, 2012). These research excavations identified three distinct burial areas. The first is a broad valley that opens just east of the chambers tombs and is of Punic Age (Hypogeum sector), with two other distinct areas along the north–east direction. The southern sector has returned the oldest evidence to date (late 6th century BCE), while the Y8 square directed eastward and northern to the so-called "parking area" gradually achieved the horizons of late archaic and early Punic Age. Tomb T316, which contained the skeletal remains of a pregnant woman belongs to this decentralized sector of the necropolis. The pottery elements in use from the end of 6th to the beginning of the 5th century BCE have been used to date the grave (Guirguis, 2011). In the period between 2005 and 2010, 96 burials were identified and subsequently attributed to an extended chronological period between the end of the 7th and the second half of the 4th century BCE.

In the documentation gathered during the latest excavations it was noted that the oldest contexts do not go further back than the 7th century BCE. During the early development of the necropolis (i.e., from the end of the 7th to the second half of the 4th century BCE) there is some variety in funeral rites adopted among which primary incineration is the predominant (Guirguis, 2010, 2011).

b) Osteoprofiling

Two individuals were recovered from grave T316: the adult body was in supine position, head turned to the east, arms outstretched alongside with slightly bent elbows (Fig. 2). Moreover, a fetal skeleton, in good condition and fairly well represented was found inside the mother's abdominal cavity.

INSERT Fig. 2 ABOUT HERE

We can observe the integrity of the articulations: the temporomandibular joint and other weak articulations (phalangeal, feet, etc.) were conserved. A dark-brown colour was observed for the bones that may be attributed to a burning process. We can appreciate the total absence of deformations, warping and thumbnail fractures on skeletal remains.

Sex of the adult skeleton was determined using morphological criteria based on the pelvis and the skull (Buikstra and Ubelaker, 1994; Ferembach et al., 1979; Mays and Cox, 2000; Ubelaker, 1989). For the age-at-death estimation of adult skeletons, the methods based on changes in the auricular surface of the ilium (Lovejoy et al., 1985), pubic symphysis (Brooks and Suchey, 1990) and sternal ends of ribs (İşcan et al., 1985) were considered. Secondarily, cranial suture closure (Meindl and Lovejoy, 1985) was taken into account.

Stature was calculated from the physiological length of the femur of both extremities using Mendonça formulae (Mendonça, 2000).

Gestational age of the fetus was estimated from cranial (Ohtsuki, 1976; Redfield, 1970; Scheuer and Black, 2004; Weaver, 1979) and long bone measurements (Fazekas and Kósa, 1979; Scheuer et al., 1980).

c) *Physico-chemical techniques*

In order to ascertain more objectively whether the skeletons belonging to T316 grave were subjected to burning and to determine the distribution of temperature, representative parts of the whole body belonging to the adult individual and the fetus were investigated by X-ray diffraction (XRD) and Fourier transform-infrared spectroscopy (FT-IR) techniques. To evaluate the temperature to which the bones were subjected, we made use of the method reported by Piga et al. (2008, 2009), which is based on a calibration of the heat treatment as a function of temperature and time by following the average grain size of hydroxylapatite biomineral phase determined from XRD data.

The FT–IR approach has nonetheless good potential for the identification of burned bones, particularly if the crystallinity index (CI) –also called splitting factor (SF) – values are interpreted in association with the carbonate/phosphate ratio according to Thompson et al. (2009, 2011), Squires et al. (2011) and Piga et al. (2015). These investigations have mainly focused on the changes of hydroxylapatite crystals and on the heat-related variations of the SF.

The XRD patterns were recorded overnight using Bruker D8 and Rigaku D/MAX diffractometers in the Bragg–Brentano geometry with CuKα radiation (λ = 0.154178 nm). As it is our standardised laboratory practice the goniometer was equipped with a graphite monochromator in the diffracted beam and the patterns were collected with 0.05° of step size. The X-ray generator worked at a power of 40 kV and 30 mA and the resolution of the instruments (divergent and antiscatter slits of 0.5°) was determined using LaB_6 standard free from the effect of reduced crystallite size and lattice defects. Total of 0.5 g of bone was ball milled in an agate jar for one minute using a SPEX mixer–mill model 8000. Our sample holder for XRD analysis is a circular cavity of 25 mm in diameter and 3 mm in depth, containing about 420 mg of bone powder (e.g., Piga et al., 2010:149)

The powder patterns were collected in the angular range 9°-140° in 2θ, with counting time of 40 s per point. Digitized diagrams were initially subjected to a pre-processing for qualitative phase recognition according to the programs Highscore® and Match® and then analyzed quantitatively according to the Rietveld method (Rietveld, 1967), using the programme MAUD (Lutterotti, 2010). It is worth noting that one stringent requirement of any Rietveld program is the correct loading of the crystal structure solution of substances not only concerning space group and lattice parameters but including also atomic location of the asymmetric unit (Grazulis et al., 2009).

FT-IR spectra were collected with a Bruker Vertex 70V interferometer in terms of absorbance vs wavenumber ν in the range 4000-45000 mm^{-1}, with a resolution of 40 mm^{-1}. About 3 mg of bone was hand-ground and mixed with KBr to a weight ratio 1:100, respectively, to make pellets suitable for beam irradiation. Each spectrum was obtained by averaging 250 interferograms.

The absorption bands at 6050 and 5650 mm^{-1} were used following baseline correction, and the heights of these absorption peaks were summed and then divided by the height of the minimum between them (Weiner and Bar-Yosef, 1990).

Results

a) Skeletal remains

The anthropological examination revealed that the T316 grave contained a young adult with an estimated age at death of 20-25 years. The morphological analysis along with the metric study, indicated that the individual was female, with an estimated stature of 1554 mm (SD= 59.2). The fetus was in good condition and fairly well represented (Fig. 3). An age of 38-40 gestational weeks could be attributed to the fetus (fetus to term) (Table 1). Skeletons from both individuals did not present signs of long-term disease or trauma, and no signs of pathologies related to the pregnancy or the labor could be diagnosed.

INSERT Fig. 3 AND Table 1 ABOUT HERE

The comparison of the excavation images and rebuilding of bone material has allowed us to determine the position of the fetus. Figure 4a shows the arrangement of fetal bones *in situ*. Some of the bones have remained inside the mother's abdominal cavity (ribs fragments of the right side, left humerus, left ulna and left radius) while others are outside (right tibia, right femur, left tibia and femur). The frontal bone of the skull is located over the left hip bone of the mother, between the sacrum and L3, L4 and L5 vertebrae. Taphonomical processes such as the collapse of the bones after the disappearance of soft tissues justify this specific location, however the position of ribs and skull clearly suggests a transverse position of the fetus (Fig. 4b).

INSERT Fig. 4a AND Fig. 4b ABOUT HERE

b) XRD/FT–IR analysis

An XRD diagram of a representative specimen (T316 woman, right tibia) is reported in Figure 5. The phase analysis by the Rietveld method of the XRD patterns suggests that the specimen is almost hydroxylapatite single phase, apart from a minor contamination of quartz and calcite that seems likely of endogenous origin. In fact the varying amount of calcite found here and in some Monte Sirai bone specimens may be related to the ground that was filling the excavated sepulchres capped on top by flat stones.

In unburned bones, the characteristic size from XRD line broadening varies from 8 to 16 nm (Piga et al., 2013). This behavior can be accounted for by the MAUD program with the Popa model (Popa, 1998). In general, the model fit results suggest very small average crystallite size whose shape is elongated along the c-axis. The (001) peak narrower than the other profile indices was taken as an indication of the anisotropic shape of the crystallites (Piga et al., 2013). However, the XRD broadening analysis of the specimen reported in Figure 5 revealed an isotropic average crystallite size of the apatite component of ca. 30 nm, corresponding to a relatively mild heat treatment of about 700° C.

INSERT Fig. 5 ABOUT HERE

In Figure 6a we display the XRD pattern of T316 right tibia sample compared with an incinerated bone (top pattern) as well as with an untreated buried bone (lower pattern) belonging to bone samples from the same site (Monte Sirai necropolis).

The bioapatite average crystallite sizes calculated from the three patterns are: 200 nm (cremated bone), 30 nm (T316 woman, right tibia) and 16.5 nm (untreated bone).

As it can be better appreciated from the magnification in Figure 6b, the patterns put in evidence three different degrees of apatite crystal growth, witnessed by their relevant peak sharpening which were interpreted according to specific funerary practices, i.e., inhumation, semi-combustion and full cremation, respectively.

INSERT Fig. 6a AND Fig. 6b ABOUT HERE

Further support comes from four representative FT-IR spectroscopic data presented in Figure 7a in the wave number range $\Delta\nu$ from 4000 to 17000 mm^{-1}. It is possible to recognize three main groups of band in the range 5000-7000 mm^{-1}, 10000-12000 mm^{-1} and 14000-16000 mm^{-1}, which are generally assigned to the energy mode ν_4 of phosphate groups, ν_3 of phosphate groups and to the ν_3 of carbonate groups respectively. Also, the smaller bands at 8750 mm^{-1} and 9600 mm^{-1} have been attributed to ν_2 CO_3^{2-} (Ratner, 2004) and ν_1 PO_4^{3-} (Destainville et al., 2003) modes, respectively.

These carbonate bands assessed by spectroscopy may refer either to CO_3^{2-} groups from calcite or to CO_3^{2-} groups that are substituting for phosphate groups in the structure of hydroxylapatite.

The graph of Figure 7b is a magnification of FT-IR spectra in the range 5000-7000 mm^{-1} and highlights the band structure of ν_4 phosphate groups. It is customary to represent the sharpening of the phosphate ν_4 band (e.g., Weiner and Bar-Yosef, 1990; Stiner et al, 1995; Piga et al., 2010), using the splitting factor SF. The shoulder at ca. 6330 mm^{-1} for the less crystalline specimens is replaced by a further peak in the specimens which appeared to have been treated at higher temperature. Even here, the presence and the intensity of this shoulder indicates the occurrence of thermal treatments at different temperatures. In our previous calibration of FT-IR spectra (Piga et al., 2010) it was established that the appearance of the shoulder at ca 6330 mm^{-1} indicates fire temperature of ca 700° C. It was verified that such features persist and increase until 1000° C

Both the X-ray crystallinity and the SF value of the ν_4 phospate band converge to similar values of temperature. Data obtained with the two techniques are concordant; differences do not exceed 100° C and are not significant.

INSERT Fig. 7a AND Fig. 7b ABOUT HERE

Table 2 shows in detail the results obtained through the use of XRD/FT–IR techniques on representative parts of woman and fetus whole bodies. Therefore, we conclude that both bodies belonging to T316 grave have been treated with fire in a temperature range of 600° C to 750° C.

INSERT Table 2 ABOUT HERE

Discussion and concluding remarks

We have conducted a survey of previous cases of unborn fetuses involving women who died during pregnancy and/or who were buried in gestation for integrating the available information about the general custom and its chronology (Table 3).

In spite of the difficulties related to pregnancy and delivery in evidence by history and ethnography, very few references of pre- and peri-natal deaths during prehistory and protohistory have been published. The majority of data are obtained from more recent times.

The oldest cases are essentially three. Persson and Persson (1984) presented the oldest case found in Scandinavia from the Mesolithic period (4300-4000 BCE). Willis and Oxenham (2013) discussed the burial of a young female buried with an *in situ* fetus from a Neolithic cemetery site in southern Vietnam. Malgosa et al. (2004) analysed the skeletal remains of the pregnant woman belonging to the Argaric site of '*El Cerro de las Viñas de Coy*' (Lorca, Murcia, Spain). The site belongs to the Argaric Culture, that existed during the Bronze Age in the southeast region of the Iberian Peninsula (1500-1000 BCE). This is the most ancient case in which the cause of death was determined. In this pre- and proto-historical context, our case is placed among the oldest four cases.

INSERT Table 3 ABOUT HERE

When fetal remains are found in the mother's pelvis it most probably means that the woman died during pregnancy or delivery, even if no skeletal abnormalities are observed. Usually, the cause of death of pregnant women is due to a situation of dystocia caused by a position and/or presentation of the fetus incompatible with the proper development of an eutocic delivery (Mercado Pedroza, 2010). Cases have been described in which disproportion between fetal head and pelvic dimensions existed (Cruz and Codinha, 2010; Wells, 1978), dystocic childbirths in which babies' extremities were protracted through the mother's pelvic canal (Malgosa et al., 2004) and they were in a podalic position (Campillo et al., 1998).

Also embryotomy has been diagnosed by the identification of severe cuts in fetal bones made to extract the baby from the mother's womb while still alive (Molleson and Cox, 1989). Only one case found in the literature suggests postmortem movements to explain the unusual fetus location out of the abdominal or pelvic cavity (Møller-Christensen, 1982).

With regard to our case, according to the fetal maturity (38–40 gestational weeks), labor could have started. The position of the remains of fetus in the abdominal cavity shows a transversal position with the head situated in the left and inferior extremities in the right; the position of right ribs and left arm indicate a dorso–anterior posture. The transverse position is the biggest pelvic-fetal disproportion that could be presented, and occurs in the 0.003% of childbirth cases (Mercado Pedroza, 2010). At the beginning of the labor the incorrect position of the fetus implies a dystocic labor. It is one of the worst cases in obstetrics because it inevitably leads to uterine rupture and fetal death (Botella and Clavero, 1993).

The only way of overcoming this incorrect position with success nowadays is by Caesarean section, mainly in a term pregnancy. In this situation and without performing a Caesarean section, the uterine muscle continues to contract for a certain period of time (maybe hours or days) and – eventually - it cannot perform its function because of the impossibility of overcoming this difficulty (Botella and Clavero, 1976; Hellman and Pritchard, 1975; Iffy and Charles, 1984; Käser et al., 1979; Malgosa et al., 2004; Taber, 1979).

We can therefore hypothesize that the cause of mother's death (for example, sepsis, haemorrhage and exhaustion) may be related to complications of labor due to the incorrect position of the fetus.

In addition, the evidence of semi-combustion practice confirmed by physical–chemical analysis makes our case unique. A very particular practice that included exposure of the body to an intense heat source for a short period of time, at present documented only at *Monte Sirai* necropolis, was recently inferred by Piga et al. (2010, 2015).

Recent studies on the effects on bone of the pre-burning condition of human remains also conducted with the use of modern crematoria, have demonstrated that the frequency of warping and thumbnail fractures is not a completely reliable indicator of the pre-burning condition of the skeletons (Gonçalves et al., 2015). So far, temperature of combustion is the only identified variable having a significant effect on their frequency, but collagen content may also have a significant effect (Gonçalves et al., 2011, 2015).

According to classifications commonly used in forensic anthropology (Eckert et al.; 1988), four stages were distinguished for the degree of thermal alteration based on visual inspection of the bones. Nevertheless, from the physico-chemical investigation conducted here we have surmised that the pregnant woman and fetus were subjected to a partial cremation, i.e., bones were articulated and no evidence for complete incineration was found. Our temperature determination for the bones of Monte Sirai alone cannot disregard the case of accidental fire, but we reject it here essentially for four reasons:

i) The presence of similar features in tenth of bodies buried in different circumstances, but all of them ascribable to a period between 6th and 5th century BCE (ca. 100-110 years) (Piga et al., 2010, 2015).

ii) The presence of *ustrinum* (i.e., the site dedicated to funeral pyres) inside the sepulchral area of the cemetery located within a distance of ca. 3 m from the tomb considered.

iii) Widespread use of rituals involving fire practiced by the Phoenician-Punic civilization considering both so called “primary” and “secondary” (in urns) incinerations (e.g. Piga et al., 2015).

iv) The body was interred at a depth between 0.60 and 1.20 m from the average soil level and covered on the surface by stone plates, protective enough to avoid accelerated and unusual decomposition processes suffered by the bones.

Moreover, the properties of some inhumed bones in a nearby area attributed to a different period did not show such concomitant evidence. This context strongly suggests that the reported fire afflictions discovered in our skeletons were intentional. The precise modalities according to which the bodies were exposed to fire cannot be totally clarified. The realistic option is that the bodies were first burned in the “*ustrinum*” and later transferred and deposited into the burials together with the funerary ceramic miscellanea (Guirguis, 2012). The preservation of the anatomic connection during transportation appears difficult to justify, unless the combustion process occurred within a limited time at a moderate fire intensity.

Acknowledgements

The authors thank the Superintendency for Archaeological Heritage of Cagliari and Oristano provinces, Prof. Piero Bartoloni and Dr. Rosana Pla Orquín (University of Sassari, Italy) for supplying the osseous materials employed in this study and for allocating the laboratory facilities. This work is supported by Autonomous Region of Sardinia, within the project titled: “Archaeometric and physico–chemical investigation using a multi-technique approach on archaeological, anthropological and paleontological materials from the Mediterranean area and Sardinia" and by Generalitat de Catalunya (grant no. 2014 SGR 1420).

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Table 1. Bone fragments recovered of the fetus, measurements taken on some cranial and long bones and fetal age determined through the use of Scheuer and Black (2004) and Scheuer et al. (1980) formulae.

Bone fragments recovered	**Side**	**Dimensions (mm)**	**fetal age (weeks) (according to: Scheuer and Black, 2004 Scheuer et al., 1980)**
Skull: squamous portion, petrous portion + tympanic ring, basioccipital bone + 2 exooccipital bones, sphenoidal wings, Different crushed skull fragments		Basiocciptal bone: Maximum width: 15.3 Sagittal length: 12.3	40
Humerus	left + right	right: 64	38
Radius	left	55	40
Ulna	left	–	
17 rib fragments	right		
7 Vertebral bodies			
Vertebral hemiarches	5 left + 1 right + 6 undetermined		
Femur	left + right	left: 76	40
Tibia	left + right	right: 70	40
Fibula	left	–	

Table 2. Average crystallite size of hydroxylapatite, splitting factor and estimated temperatures calculated on representative woman/fetus bone specimens with both spectrometric techniques, according to Piga et al. (2008, 2009, 2010) and Thompson et al. (2009, 2011). Both techniques give concordant results.

Part of the body examined	Average crystallize size / (nm) (± 10%)	Estimated Temperature/°C (XRD technique)	Splitting factor (SF) calculated (± 0.05)	Estimated Temperature/°C (FT-IR technique)
Skull (woman)	25.1	≅650	4.20	694
Right humerus (woman)	25.8	≅650	3.96	≅ 640
Left humerus (woman)	24.5	650	4.21	≅ 695
Right radius (woman)	23.3	≅650	4.23	700
Left radius (woman)	24.1	650	3.83	≅600
Right ulna (woman)	25.0	650	3.90	618
Left ulna (woman)	23.7	≅650	3.75	≅580
Right femur (woman)	23.9	650	4.32	≅ 717
Left femur (woman)	26.0	650<T<750	4.30	≅ 717
Right tibia (woman)	30.0	≅700	4.26	≅703
Left tibia (woman)	26.4	< 750	4.45	750
Right fibula (woman)	24.0	650	4.20	694
Left fibula (woman)	28.6	≅700	4.26	≅703
Skull (fetus)	22.2	600<T< 700	3.90	618
Left humerus (fetus)	22.4	≅600	3.88	613
Left ulna (fetus)	22.3	≅600	3.93	626
Right femur (fetus)	25.0	650	3.87	610
Left tibia (fetus)	24.8	≅650	3.83	600
Left fibula (fetus)	21.8	≅650	3.55	613

Table 3. Cases of unborn fetuses reported in literature.

Reference	Number of cases	Chronology
Persson and Persson, 1984	1	4300 – 4000 BCE
Willis and Oxenham, 2013	1	Neolithic (2100 – 1050 BCE)
Malgosa et al., 2004	1	Bronze age (1500 – 1800 BCE)
Guirguis, 2011	1	6^{th} – 5^{th} century BCE
Sublimi Saponetti et al., 2013	1	3^{rd} – 2^{nd} century BCE
Pounder et al., 1983	1	< 2000 years old
De Miguel Ibáñez, 2008	3	8^{th} century CE
Campillo et al., 1998	1	5^{th} Century CE (Late Roman Period)
Agustí and Codina, 1992	1	Late Roman Period
Ruiz Macián-Dagnino, 2013	1	Late Roman Period (5^{th} – 6^{th} century CE)
Hawkes and Wells, 1975	1	Late 6^{h} – early 7^{th} century CE
De Miguel Ibáñez, 2008	5	Visigoth (7^{th} century CE)
		Islamic culture (715 – 770 CE)
		Islamic culture (9^{th} – 11^{th} century CE)
Møller-Christensen, 1958	1	Middle Age (1050 – 1536 CE)
Wells, 1978	1	Middle age (11^{th} – 13^{th} century CE)
Rascón et al. 2007	1	11^{th} – 14^{th} centuries CE
Mendoza et al., 2008	1	1280 – 1400 CE
Lopez Seguì et al., 2005	1	Islamic culture (13^{th} century CE)
De Miguel Ibáñez et al., 2007	1	13^{th} – 14^{th} century CE
Högberg et al., 1987	3	Middle Age
Sjøvold et al., 1974	1	Middle Age
Owsley and Bradtmiller, 1983	2	Arikara Indians (1600 – 1832 CE)
Flores and Sánchez, 2007	2	12^{th} – 13^{th} century CE
		17^{th} century CE
Cruz and Codinha, 2010	1	19^{th} century (1834 – 1853 CE)

Figure 1

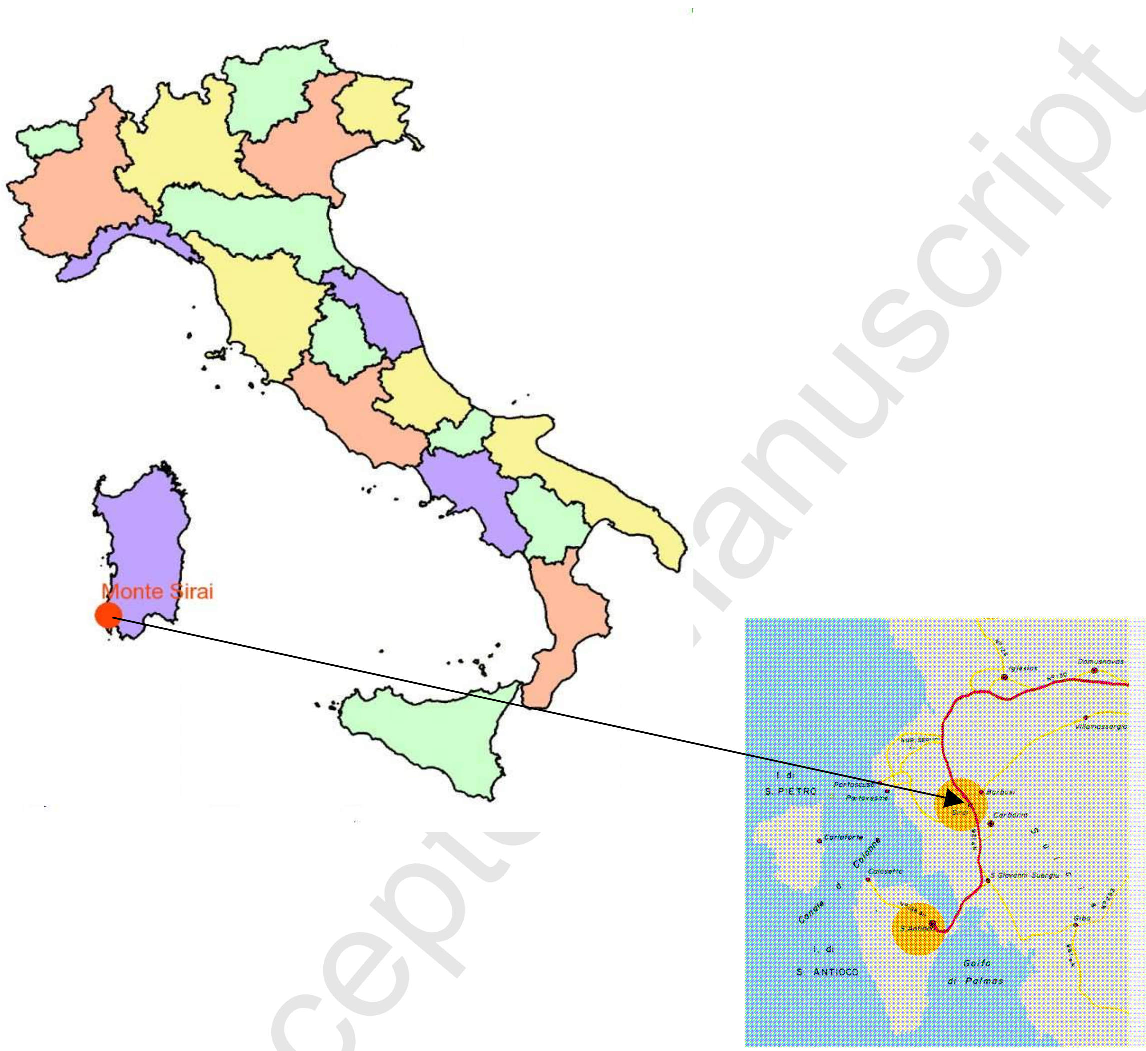
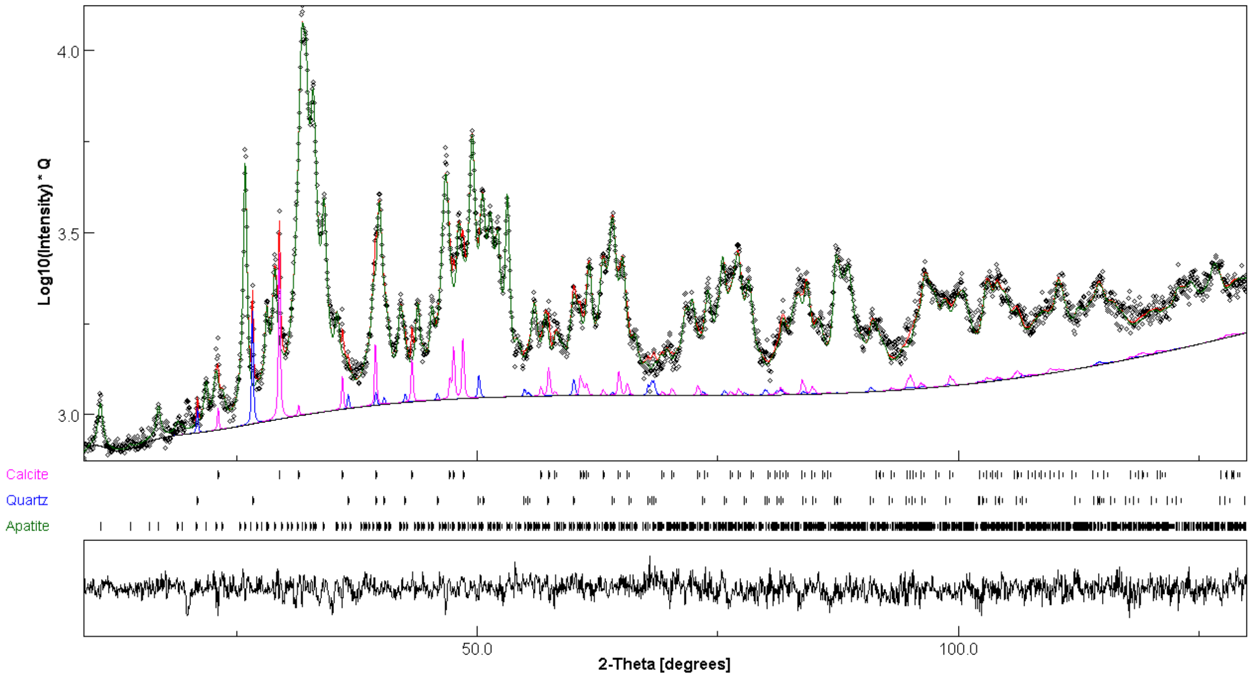

Monte Sirai
I. di
S. PIETRO
Portoscuso
Portovesme
Iglesias
Domusnovas
Villamassargia
Barbusi
Carbonia
Carloforte
Calasetta
Canale di Colonne
S. Giovanni Suergiu
Giba
I. di
S. ANTIOCO
Golfo
di Palmas

Figure 2

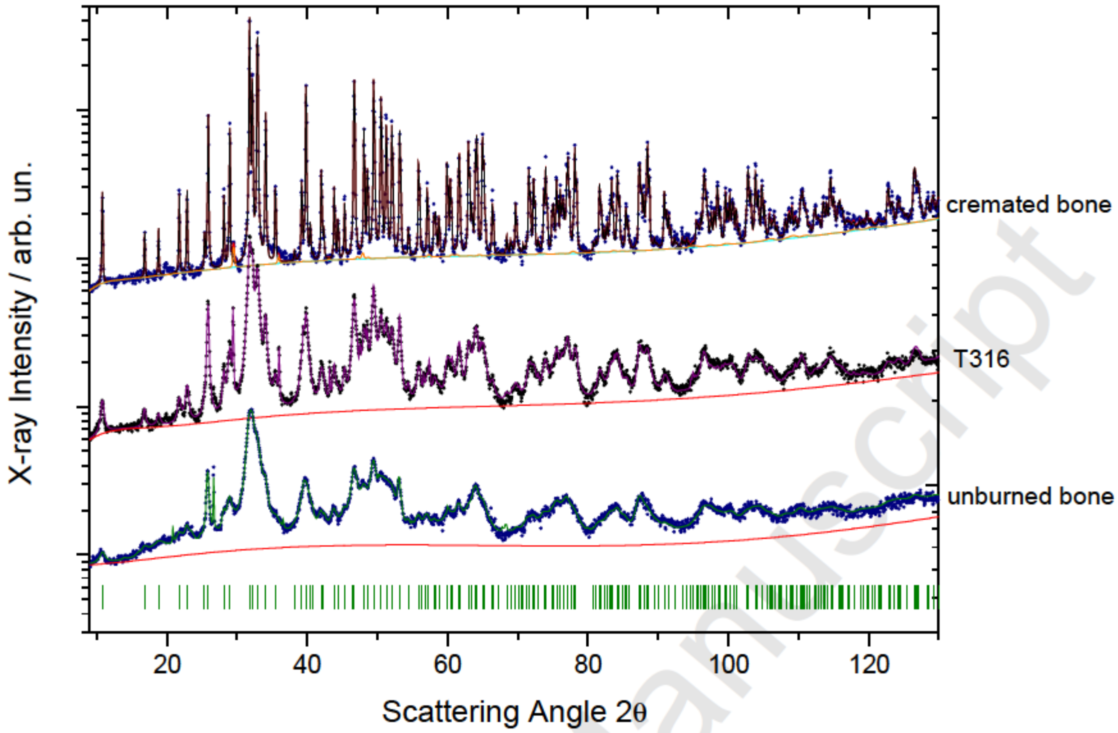
Figure 3

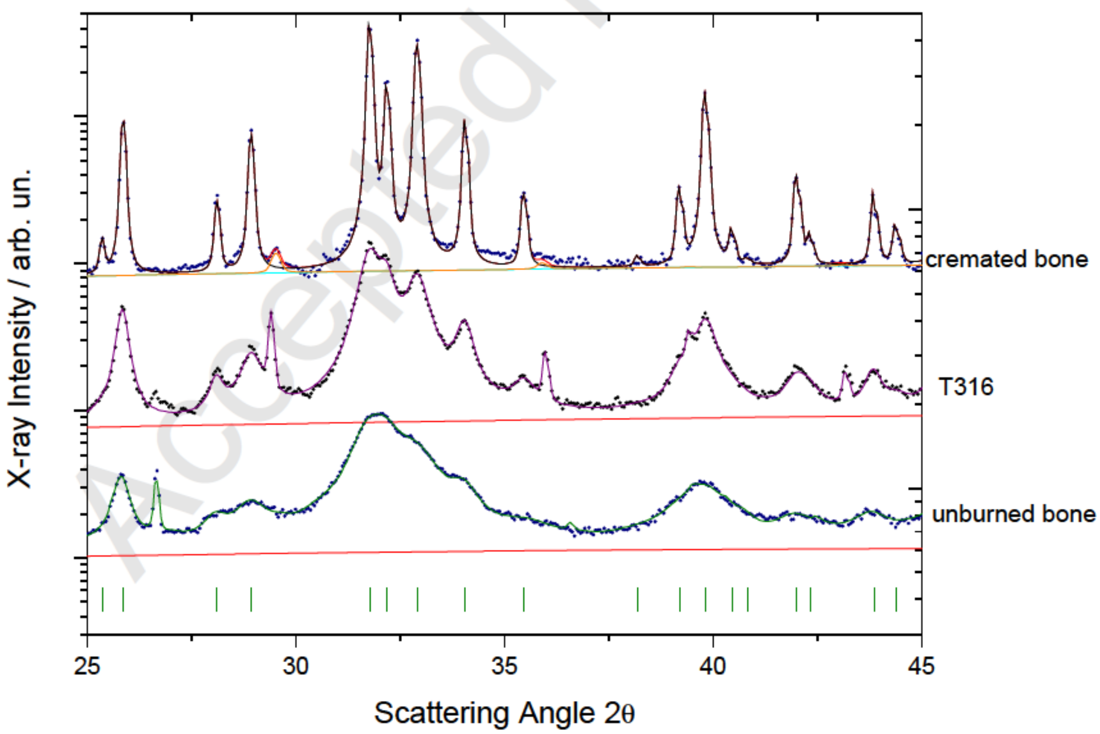
Figure 4a and 4b

Figure 5

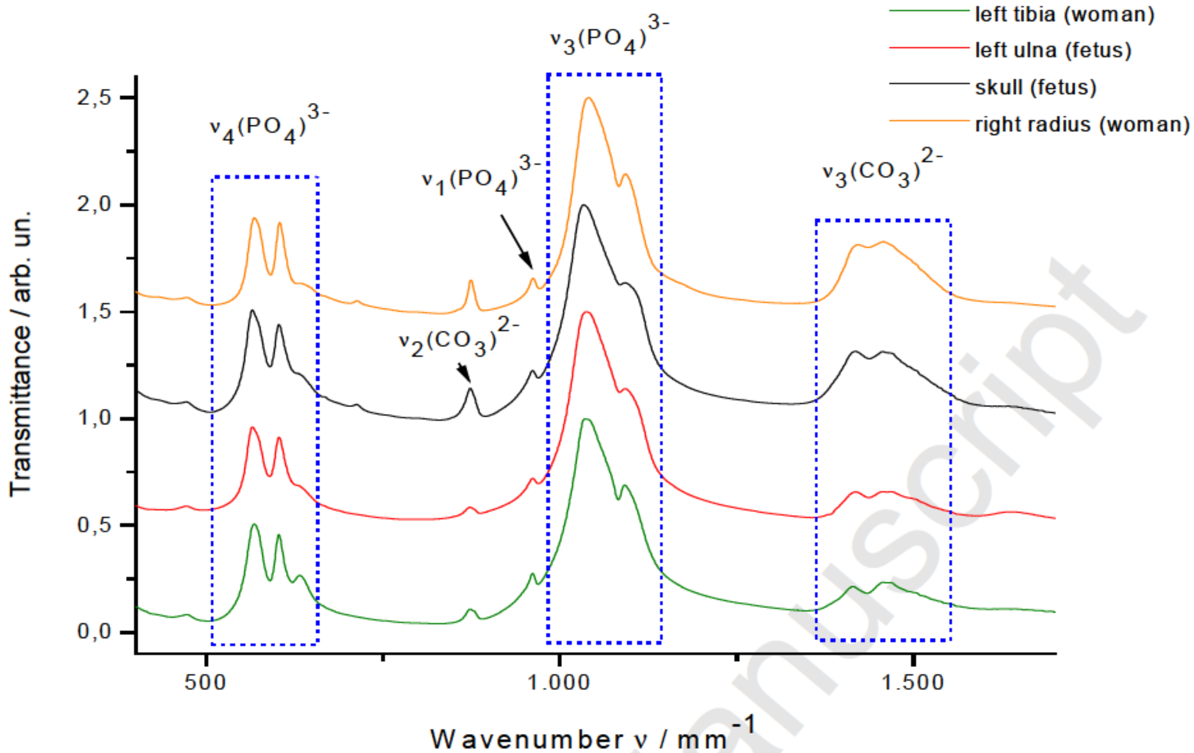


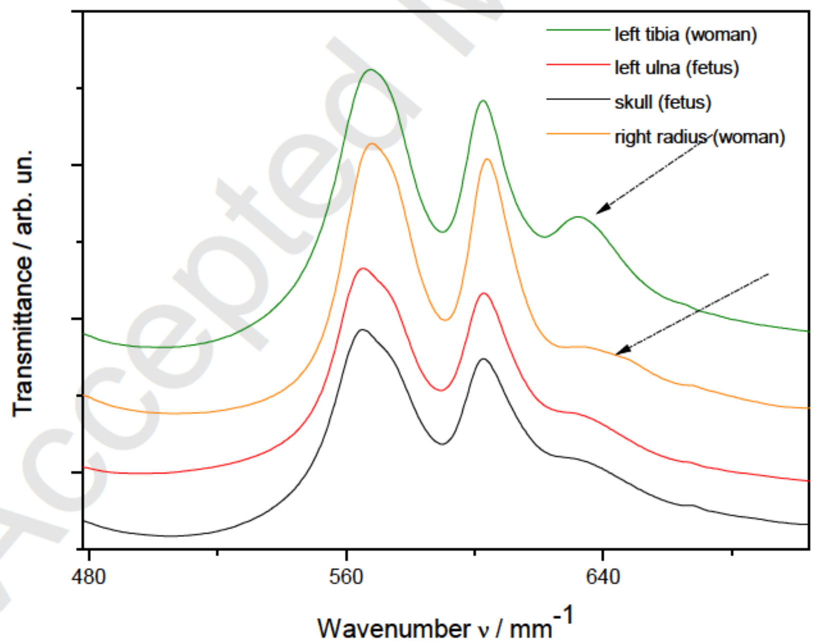
Figures 6a and 6b





Figures 7a and 7b


left tibia (woman)
left ulna (fetus)
skull (fetus)
right radius (woman)
ν3(PO4)3-
ν4(PO4)3-
ν1(PO4)3-
ν2(CO3)2-
ν3(CO3)2-
Transmittance / arb. un.
2,5
2,0
1,5
1,0
0,5
0,0
500
1.000
1.500
Wavenumber ν / mm-1


left tibia (woman)
left ulna (fetus)
skull (fetus)
right radius (woman)
Transmittance / arb. un.
480
560
640
Wavenumber ν / mm-1

Captions to the Figures

Fig. 1. Map of Italy where the position of the Monte Sirai necropolis, in the south-western Sardinia is highlighted.

Fig. 2. Context of the tomb T316 containing the skeleton of a pregnant woman.

Fig. 3. The skeleton of the fetus belonging to the T316 grave.

Fig. 4. a) Detail of the fetal bones and their position in the grave; 1) skull (frontal bone) 2) right ribs 3) left humerus 4) left ulna 5) left radius 6) right femur 7) right tibia 8) left tibia 9) left femur.
b) Reconstruction of the T316 fetus position.

Fig. 5. The XRD pattern of T316 woman, right tibia specimen highlights a bioapatite single-phase mineral constitution with a little contamination of endogenous quartz and calcite. Experimental data points are dots, full curves are the background line and from Rietveld refinement respectively. The bar sequence at the bottom refers to the peak positions expected from crystalline components on the basis of their lattice parameters refined for the top curve. The isotropic average crystallite size of the apatite component of 30 nm suggests heat treatment of about 700° C.

Fig. 6a. T316 right tibia bone specimen XRD pattern compared with an incinerated bone (top pattern) and with an untreated buried bone (lower pattern), all belonging to bone samples from the Monte Sirai necropolis. The peak positions of biopatite can be assumed substantially unchanged but with increased peak broadening because of smaller average crystallite size.

Fig. 6b. Magnification of Figure 6a; showing from bottom to top pattern three different degrees of apatite crystal growth according to specific funerary practices, i.e., inhumation, semi-combustion and full cremation, respectively.

Fig. 7a. The FT-IR patterns of four representative burned specimens. The spectra are reported in the wave-number ν range from 4000 to 17000 mm^{-1}. It is possible to recognize three main groups of band in the range 5000-7000 mm^{-1}, 1000-1200 mm^{-1} and 14000-16000 mm^{-1}, which are generally assigned to the energy mode ν_4 of phosphate groups, ν_3 of phosphate groups and to the ν_3 of carbonate groups respectively. Also, the smaller bands at 8750 mm^{-1} and 9600 mm^{-1} have been attributed to ν_2 CO_3^{2-} and ν_1 PO_4^{3-} modes, respectively.

Fig. 7b. Magnification of FT-IR spectra in the range 5000-7000 mm^{-1}; it shows the FT-IR transmittance peaks of the phosphate group where the SF is evaluated. Note the appearance of a shoulder at ca. 6330 mm^{-1} for temperatures above 700 °C, as indicated by arrows.