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The Protohistoric 'Quicklime Burials' from the Balearic Islands: Cremation or Inhumation

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ABSTRACT Traditionally, the Balearic so-called 'quicklime burials' of the Iron Age have been considered to be inhumations in quicklime. The general appearance of the bones, however, resembles more closely that of cremated bones. Laboratory tests reveal that the observed features of the bones from these burials, including cracks, thumbnail fractures and warping, cannot be explained by an inhumation in quicklime. The $\delta\ ^{13}C$ value, Fourier transform infrared spectra, SF values and the low carbon content of the apatite moreover indicate a thermal manipulation of the bones. The ^{14}C content is depleted with regard to the accepted archaeological age of the sample, which can best be explained by carbon exchange between bio-apatite and fossil CO_2 released during the heating of limestone. This implies that the Balearic 'quicklime burials' must be interpreted as an elaborate cremation practice in presence of limestone. Copyright © 2013 John Wiley & Sons, Ltd.

Key words: quicklime burial; Iron Age; Balearic Islands; cremation; radiocarbon; stable isotopes; FTIR-SF
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Introduction: quicklime burials

The Balearic Islands (Mallorca and Menorca - Spain) (figure S1) are the only place in the Mediterranean region where, during the Balearic protohistory, people were systematically buried in quicklime [CaO] (Stuiver & Waldren, 1975; Van Strydonck & Waldren, 1990), but since the origins of this burial practice are unknown, the debate is still ongoing on whether this rite started early or later in the protohistory (Micó Pérez, 2005, 2006). Since this kind of deposits are often found in natural caves or rock shelters where they are hardly visible, not all may yet be catalogued as archaeological sites, but the presence of about a hundred of these deposits can be estimated (figure S2). The ritual must have been rather uniform all over the islands since identical lead pectorals and necklaces, made from the same mold, were found in different sites (Enseñat Enseñat, 1975, Waldren & Cubi Grimalt, 1995) (figure S3). Metal grave goods in the lime burials were found to be intentionally bent out of shape, and pottery was smashed before it was placed with the bodies, a practice that has its parallels in the Iron Age of Northwestern Europe (Mariën, 1958; Fokkens & Jansen, 2004). This burial practice lasted until the early Roman occupation.

Lime burials can be very large and contain up to 480 m^3 of lime conglomerate, in which bone fragments and artifacts are disorderly scattered (Figure 1) (Waldren & Van Strydonck, 1995). The appearance of the bones is diverse: some are light brown, others are black or pale white. Some of the white ones show cracks, thumbnail fractures and exhibit bone warping (Figure 2), typical for bones submitted to high temperature (Gonçalves *et al.*, 2011).

Traditionally, however, the burial rite is interpreted as an inhumation in quicklime (Waldren, 1982; Rosselló-Bordoy, 1973). Waldren (1982) stated that the lime burials were preceded by cremation burials, although the possibility must be considered that these cremations were no more than the onset of the lime burial (L. Plantalamor-Massanet, 2011, personal

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Figure 1. Bone fragments are found very disorderly, out of any anatomical order in the lime conglomerate, as are the artifacts. Muertos Gallard: 1 lime, 2 iron hair piece, 3 part of a skull. This figure is available in colour online at wileyonlinelibrary.com/journal/oa.

Figure 2. Son Matge rock shelter: bones from quicklime burial showing cracks, thumbnail fractions and bone warping. This figure is available in colour online at wileyonlinelibrary.com/journal/oa.

communication). Waldren (1982) also stated that there are indications that the bodies were dismembered prior to being deposited in quicklime. However, all investigations to the nature of the rite were counteracted by a lack of good stratigraphical evidence, since it was unclear whether the disordered appearance of the bones and the destruction of the grave goods were the result of the burial rite itself or were caused by digging out new graves in the carbonate of older burials.

It has been argued that inhumation in quicklime has the same effect on bones as calcination by heat (Waldren, 1982). Burial experiments in quicklime under laboratory conditions nevertheless reveal that contact with quicklime only delays the decay of the carcass, without any violent chemical action as in an incineration (Laudermilk, 1932, Schotsmans *et al.*, 2011).

In order to get more information on the burial rite and to explain the above-mentioned contradictions, bones from the *Son Matge* and *Muertos Gallard* rock shelters on the island of Mallorca (Deià Archaeological Museum and Research Center) as well as samples from *Binigaus* and *Sant Joan De Misa* (Museu de Menorca) on the island of Menorca were analyzed (figure S1). Laboratory cremation tests in the presence of limestone and inhumation tests in quicklime were performed to confront the archaeological evidence with laboratory samples.

Material and methods

Materials

Laboratory samples

Laboratory calcination in the presence of limestone. Several recent studies (Van Strydonck *et al.*, 2010a, Hüls *et al.*, 2010 and Zazzo *et al.*, 2012) have shown that exogenous carbon from the burning environment is incorporated during calcination into the calcined bone carbonate. Although Olsen *et al.* (2012) concluded that the old wood effect of a pyre is relatively small, a more significant effect was expected if a calcination process took place in the presence of limestone: fossil CO_2, liberated during the decomposition of the limestone by heat, can be considered as a possible carbon source in cremated bones. To test this assumption, a fresh pig shank, covered with manually crushed limestone, was calcined at 700 °C and 950 °C in a muffle oven (Nabertherm – controller P320). Beside the pig shank, the limestone and the natural atmosphere, no carbon containing materials were present in the oven.

Properties of the limestone
type of stone: Maastricht (upper Cretaceous >65 Ma yrs);
no ^{14}C (0 pMC)
condition: dried and crushed (granularity: $<500\,\mu m$)
% $CaCO_3$: 84% by weight
$\delta\,^{13}C = +1.6‰$

Laboratory inhumation in quicklime. A fresh pig shank was left in a 20 liter bucket filled with CaO (quicklime Proviacal® ST by Lhoist Recherche et Développement S.A.) under natural conditions (at 50°50′33″N, 4°23′40″E in a moderate climate with a lot of rainfall) for 18 months. After that time, the shank was recovered, visually inspected and the % collagen, $\delta\,^{13}C$ and FTIR-SF were calculated.

Both the laboratory calcination and the inhumation tests were performed on fresh pig shanks (bones and flesh), similar in size and weight to the shanks used earlier by Van Strydonck *et al.* (2010a) to determine the carbon origin of structural carbonate in bone apatite of cremated bones. They were not analyzed prior to treatment, but similar properties to the 2010 material can be assumed: $^{14}C = 103.78 \pm 0.39$ pMC; $\delta^{13}C = -14.81‰$, collagen content >20%, C/N =3.2 (Van Strydonck *et al*. 2010a, experiment F, KIA-38945).

Archaeological samples

A set of lime burial bones (Table 1) of different colours (light brown, black and white) and bones from the so-called Talayotic cremation graves (contact zone with natural soil) were analyzed and compared with the laboratory experiments and reference samples from other archaeological contexts.

Methods

Radiocarbon and stable isotopes

Bone samples were pretreated as cremated bones for AMS bio-apatite dating (Van Strydonck *et al*., 2009), in order to avoid contamination:

(1) Removal of the surface with HCl and cleaning with acetic acid after grinding to remove secondary carbonate;
(2) CO_2 extraction with phosphoric acid;
(3) Cleaning of the CO_2 by heating for 30 min. at 1000 °C in the presence of Ag and CuO, followed by an extra cleaning with $KMnO_4$.

The amount of carbon in the bones was calculated by comparing the weight of the dry bones after pretreatment with the volume of released CO_2, measured in a calibrated volume under standard conditions and recalculated to ‰ by weight.

After cleaning, part of the CO_2 was transformed into graphite (Van Strydonck & Van der Borg, 1991) and AMS dated (Nadeau *et al*., 1998), and, from the remaining CO_2, the $\delta^{13}C$ was measured using a Finnigan-Mat-δ. $\delta^{13}C$ measurements on bone samples from laboratory experiments were executed without pretreatment, but the archaeological samples were pretreated. Because sample pretreatment with acetic acid can influence the isotopic fractionation (Lee-Thorp & van der Merwe, 1991; Metcalfe *et al*., 2009; Yoder & Bartelink, 2010), the data are compared with a set of published (Van Strydonck *et al*., 2010b) and unpublished data from the inhumation burials at the 'Cova des Pas' cave in Menorca, Spain, pretreated in the same way. Twelve measurements on inhumation graves containing no collagen gave an average value of $\delta^{13}C = -14.10 \pm 0.86‰$.

The collagen from the inhumated bone from the laboratory experiment was extracted using the Longin method (Longin, 1971). One black sample was treated as a charcoal sample. The bone was grinded and treated successively with 1% HCl (80 °C, 30 min.), 1% NaOH (80 °C, 30 min.), 1% HCl (80 °C, 30 min.); the so-called AAA-method.

Fourier transform infrared spectroscopy

Infrared spectra were collected on KBr pellets of fresh and pretreated bone sample powder, using Bruker

Table 1. Archaeological sites and samples

#	Location	Site	Description	Lime consensus age (BP) (Van Strydonck *et al*., 2011)
1	Binigaus (Menorca)	Lime burial in a rock shelter	White bone fragment in lime	2105 ± 25
2	Muertos Gallard (Mallorca)	Lime burial in a rock shelter. Sample from a lime pit	White bone (warping) fragment in lime	2155 ± 25
3	Muertos Gallard (Mallorca)	Lime burial in a rock shelter. Sample of a skull with hair band	White/beige part of a skull with cracks	2325 ± 25
4	Son Matge (Mallorca)	Lime burial in a rock shelter (quadrant ref.2200–2204)	Black bone	2525 ± 25
5			Very white and hard bone	
6			Contact zone with natural soil. Black bone with grey–white surface (Figure 4)	
7	Son Matge (Mallorca)	Lime burial in a rock shelter. Samples found outside talayotic wall.	White bone with cracks and warping	2095 ± 25
8			Black bone. Contains deteriorated collagen	
9			Brown bone. Contains deteriorated collagen	
10	Sant Joan de Misa (Menorca)	Lime burial in a rock shelter.	Large white bone with cracks and warping.	2155 ± 55 on lime 2215 ± 30 on charcoal Average: 2201 ± 26 (χ^2-test: df = 1, T = 0.9 (5% 3.8)

Optics Vertex 70, by accumulation of 16 scans with a resolution of 4 cm^{-1}.

These Fourier transform infrared (FTIR) spectra were used to evaluate the process of transformation of the bone mineral by calculating the splitting factor of the ν_4 vibration mode of PO_4^{3-} between 495 and 750 cm^{-1} (FTIR-SF) (Weiner & Bar-Yosef, 1990; Thompson *et al.*, 2009), which rises with increasing bone crystallinity. Although sample pretreatment can slightly influence the FTIR-SF (Surovell & Stiner, 2001), the values still allow to differentiate between unburned bones (SF ca. 2.5–2.9) and well-calcined bones (SF ca. 7) (Stiner *et al.*, 1995).

A vibration intensity around 2012 cm^{-1} may refer to cyanamide-apatite [$Ca_{10}(PO_4)_6CN_2$] or calcium deficient cyanamide-apatite [$Ca_9(PO_4)_5(HPO_4)(HCN_2)$], formed during heating of the apatite under an ammonia atmosphere (Dowker & Elliott, 1979; Habelitz *et al.*, 2001; Vignoles *et al.*, 1987). A recent study suggests that this peak may be specific to bones calcined along with body tissues (skin, muscles, fat, etc.), where the thermal decomposition of soft tissue could form ammonia, in contrast with calcined, defleshed bones or bones without any heat treatment (Hüls *et al.*, 2010). Consequently, peaks around 2012 cm^{-1} and 700 cm^{-1} may cautiously be considered an indicator for a cremation ritual.

Results

Laboratory tests

Calcination test in presence of limestone

The calcination test was set up mainly to determine whether a possible presence of limestone around the corps in a pyre could influence the ^{14}C content of the bone. Table 2 compares the pig shank calcined in contact with decomposing limestone, with a similar fresh pig shank calcined using burning coal (δ ^{13}C = 24.4 ± 0.6‰, ^{14}C = 0 pMC) (Tables 2 and 3) (Van Strydonck *et al.*, 2010a). In both cases, the carbon content is low compared to unburnt bones [0.8–0.9‰ versus 3–9‰ of carbon in unburnt bone (McKinley, 1997)]. Furthermore, fossil carbon (without ^{14}C), released during the decomposition of the limestone or the burning of the coal, is exchanged with the carbon within the apatite structure, resulting in lower ^{14}C content (measured as a lower pMC) and positive (burnt with lime) or more negative (burnt with coal) δ ^{13}C values. The δ ^{13}C value in this experiment is clearly higher (less negative) than unburnt or other calcined bones. This value is influenced by kinetic processes during calcination (the partial decarbonatation of the bio-apatite and the uptake of CO_2 from the pyre's atmosphere). However, the obtained result is more extreme compared with an archaeological situation since the atmosphere in a closed furnace contains a higher partial pressure of CO_2. The FTIR-SF value reflects in both cases that of calcined bones.

When heated, limestone absorbs a large amount of energy before decomposing at 825 °C, slowly forming quicklime (Stuiver & Smith, 1965). Meanwhile, it functions as a heat shield, protecting the underlying bone shank from swift calcination. It was observed that full calcination of the bone shank was delayed by the presence of the limestone powder (Table 3).

Inhumation in quicklime experiment

The inhumation experiment confirmed the observations by Schotsmans *et al.* (2011), who observed delayed decay of the pig corps (*Sus scrofa*) after quicklime treatment. After 18 months, 70% of the CaO was transformed into $CaCO_3$. Although some decomposition was visible [score 1 using the Bradford score index for soft tissue conditions (Schotsmans *et al.*, 2011)],

Table 2. Results of calcination test on a fresh pig shank covered with limestone in an electric furnace compared to a previously published test on a similar fresh pig shank incinerated in presence of coal test 2C and 2D

Lab ref.	Calcination conditions	δ ^{13}C	pMC	$C_{apatite}$/bone	SF (FT-IR)	reference
(KIA-)		‰	(% modern carbon)	weight after pretreatment (‰)		
45487	Bone covered with crushed limestone	−2.43 ± 0.31 (N = 3)	29.15 ± 0.16	0.9	6.98 ± 0.27 (N = 4)	this study
38453 and 38452	Bone and coal in the furnace	−19.75 ± 0.01 (N = 2)	56.09 ± 0.16	0.8 ± 0.28	5.05 ± 0.54	Van Strydonck *et al.* 2010a
38945	No calcination	−14.81	103.78 ± 0.39	3–9[a]	3.09	

[a]Estimated value based on measurements performed on natural, not calcined bone (McKinley, 1997).

Table 3. Decomposition of the limestone and degradation of bone and tissue during a calcination test of a fresh pig shank covered by limestone powder in an electric furnace

Calcination test pig shank	Temperature (°C)	Amount of limestone powder used to cover the shank (g)	Heating time (°C)	% $CaCO_3$ remaining in the limestone	Observations
1	700	123	45 min.	82	Only the surface of the shank was charred, the flesh and the bone were not altered
2	700	122	120 min. + cooling down overnight	83	All organic material is combusted. The bone is white–grey at the surface, the inside is grey–black.
3	950	179	240 min. + cooling down overnight	0.8 (δ ^{13}C remaining carbon = −11.3‰)	All organic material is combusted. The bone is pale white, the surface as well as the inside of the bone.
Van Strydonck *et al.*, 2010a (experiment E)	800	0	300 min. + cooling down overnight		All organic material is combusted. The bone is pale white at the surface, the inside is light grey.

the skin and muscular tissue were still present. The bone itself showed no visual deformation (no warping, fractures nor discolouration; figure S4). The results of the analyses are resumed in Table 4. The high collagen content of the sample [23.2% collagen versus about 25–27% in fresh bone (Marks & Popoff, 1988; Triffitt, 1980)] corroborates the visual observation that no severe chemical or physical degradation took place. The FTIR spectrum and FTIR-SF as well as the C content of the inorganic fraction is typical for uncalcined bones. The sample of the inhumation experiment is slightly depleted in ^{13}C (−15.6 versus −14.8‰ for a fresh bone), but far less than the bone calcined in presence of limestone (−2.4‰).

Tests on archaeological bones

The results from the analyses performed on archaeological bones are resumed in Table 5. The carbon concentration in the apatite of the white-coloured bones is of the same order and variability as in cremated bones (Van Strydonck *et al.*, 2009, 2005, 2010a; Hüls *et al.*, 2010), while it is higher in the black and brown bones. ^{13}C values are more negative in the white bones than in the black and brown bones, the former reflecting the situation of a cremated bone (Van Strydonck *et al.*, 2009, 2005, 2010a; Hüls *et al.*, 2010), while the latter more resembles untreated bones like the ones from the Cova des Pas inhumation site.

Table 4. Results of an inhumation test on a fresh pig shank covered with CaO for 17 months

% collagen	$C_{apatite}$/total bone (‰)	δ ^{13}C apatite (‰)	SF
23.2	4.8	−15.6	2.74 ± 0.04 (N = 2)

The radiocarbon age of the white bones is systematically older than the consensus value of the lime (Van Strydonck *et al.*, 2011). Within the same context (samples 5, 6 and samples 7, 8, 9), there is also a very good correlation between the shift in radiocarbon age (Δ) and the FTIR-SF (Figure 3). The higher the FTIR-SF, the more the sample is depleted in ^{14}C, reflected in an older radiocarbon age. Even if the bones were heated less or during a short time, resulting in a black or brown bone, the carbon exchange can already influence the ^{14}C content rather dramatically, as the results for samples 8 and 9 indicate (Table 5).

The pretreated carbon black from a black bone of Son Matge (ref. 2200–2204) (Table 1 sample 6) was dated. The result [sample nr.4, KIA-45373] is in agreement with the consensus value of the lime date [X^2-test: df = 1 T = 1.7 (5% = 3.8)]. The consensus value of the lime is also in agreement with the bio-apatite date of another black bone from the same location [KIA-45045] [X^2-test: df = 1 T = 1 (5% = 3.8)], but not with the white bone [KIA-44322], which is dated older.

Figure 5 depicts the FTIR spectra from a white, brown and black bone from the same area at Son Matge (samples 7, 8, 9). The calcium-deficient cyanamide-apatite peak at 2012 cm^{-1} can be noticed in the spectrum of the white bone, but is absent in

Table 5. Summary of results: ^{14}C, deviation from consensus value, FTIR-SF, isotopic fractionation and carbon content from archaeological bones

#	Lab ref. (KIA-)	Dated material (bone colour)	Radiocarbon age (BP)	Δ(sample age – lime consensus age) ^{14}C year	FTIR-SF	δ^{13}C‰	Capatite/total bone (‰)	$C_{apatite}$/total bone (‰)
1	40796	Bone apatite (white bone)	2240 ± 25	135 ± 35	-	−20.6	1.1	1.1
2	43626	Bone apatite (white bone)	3390 ± 115	1150 ± 117	5.2 ± 0.4 N = 3	-	0.6	0.6
3	43562	Bone apatite (white/beige bone)	2565 ± 30	240 ± 39	4.8 ± 0.3 N = 4	−28.2	0.7	0.7
4	45373	Carbon black extracted with the AAA-method (black bone)	2580 ± 30	55 ± 39	-	-	2.4	-
5	44322	Bone apatite (white bone)	2995 ± 30	470 ± 39	5.7 ± 1.5 N = 3	−22.8	7.2	2.4
6	45045	Bone apatite (black bone)	2490 ± 25	−35 ± 35	3.0 ± 0.9 N = 4	−15.0	1.4	7.2
7	44830	Bone apatite (white bone)	3155 ± 25	1060 ± 35	8.1 ± 1.4 N = 5	−21.4	7.1	1.4
8	44832	Bone apatite (black bone)	2710 ± 25	615 ± 35	4.1 ± 0.4 N = 3	−14.6	7.8	7.1
9	44831	Bone apatite (brown bone)	2650 ± 25	555 ± 35	3.8 ± 0.5 N = 3	−15.5	1.2	7.8
10	42766	Bone apatite (white bone)	3525 ± 35	1324 ± 43	7.0 ± 1.2 N = 2	−23.4		1.2

the black and brown bone. This absorbance was noticed in all other white samples (2, 3, 5, 7, 10 – sample 1 was not analyzed with FTIR), but was not present in the spectra of all other the black and brown bones (4, 6, 8, 9). Accordingly, a faint peak at 700 cm^{-1} (cyanamide-apatite) could be discerned in samples presenting a clear 2012 cm^{-1} peak (samples 2, 3 and 7). Furthermore, the black and brown bones show a higher absorbance around 1630 and 3400 cm^{-1}, associated with remaining poorly preserved organic material. Their spectra also show a ν_4 PO_4^{3-} double peak at ca. 602 and 565 cm^{-1}, whereas the white bones show a triplet (~633 cm^{-1} [liberation of –OH, Ross 1974], 602 and 565 cm^{-1}), typical for higher crystalline hydroxyl apatite of calcined bones.

Discussion and conclusions

The traditional interpretation of the Balearic inhumation in quicklime has to be revised since the hypothesis that the observed bone deformation is caused by the action of quicklime is untenable. Laboratory tests have shown that inhumation in quicklime does not provoke the same physical features (warping, cracks, black and white discolouration, higher crystallinity) and chemical alterations (loss of collagen, loss of apatite carbon and carbon exchange) of the bones as observed in lime burials. All these parameters on the contrary do point towards a cremation ritual (Squires *et al.*, 2011).

FTIR analyses, δ^{13}C values and visual inspection show that the bones must have been subjected to heat. The cremation hypothesis is corroborated by the infrared absorbance at 2012 cm^{-1} in the FTIR spectra of the white bones, since the presence of this absorbance peak points to a cremation of the entire body rather than a calcination of defleshed bones.

It has been observed that the archaeological bones and, more in particular the white ones, are depleted in ^{14}C, in such an extent that it cannot be explained by an old wood effect of the pyre. The low ^{14}C content implies that there must have been carbon exchange at some time between a fossil carbon source and the bone apatite. This exchange is not possible after the deposition of the remains because the pH of the slaked quicklime (due to the addition of water or due to rainfall) is too high to enable recrystallization of bio-apatite (Berna *et al.*, 2004). In addition, the crystalline structure of cremated bones protects the bio-apatite from exchanging carbon with the environment (Van Strydonck *et al.*, 2005). All other types of contamination do not affect the bio-apatite carbon and are removed during pretreatment.

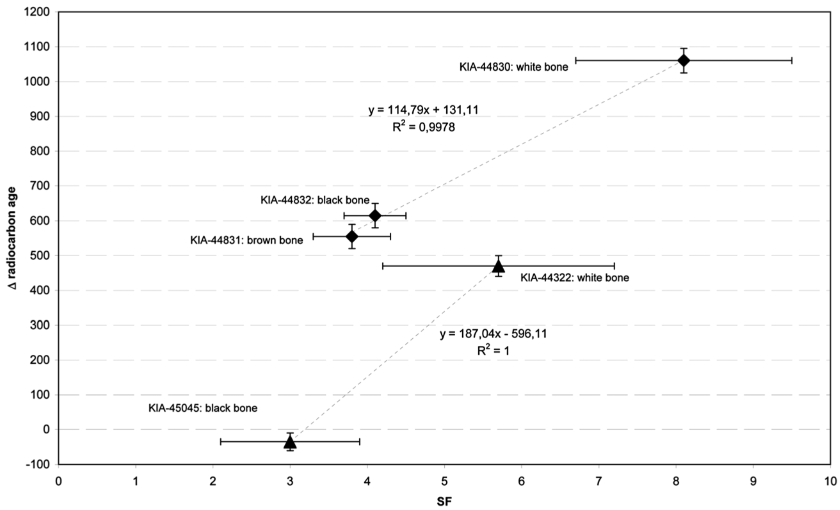

Figure 3. The difference in ^{14}C between the bone and the consensus value plotted versus the SF factor. Samples from two areas within the Son Matge Rock Shelter: Outside talayotic wall (◊) and location 2200–2204 (▲).

Figure 4. Black bone with grey–white surface from contact zone with natural soil. Lime burial in a rock shelter (quadrant ref. 2200–2204), Son Matge, Mallorca. This figure is available in colour online at wileyonlinelibrary.com/journal/oa.

Taking into account that no coal, peat or fossil wood was available to replace wood as fuel for cremations on the Balearic Islands, CO_2 released during the decomposition of carbonate rock is the only source of very old carbon left. The calcination tests with a pig shank in presence of crushed rock lime confirm that the released CO_2 during cremation can be incorporated into the bone apatite. The observation that the white bones with pronounced calcination properties deviates more from the consensus value than black and brown bones with less pronounced calcination properties corroborates the idea of a pyre atmosphere containing a lot of fossil CO_2.

The above-mentioned observations show the possibility of a burial rite comprehending a cremation of the bodies in the presence of rock carbonate, but how

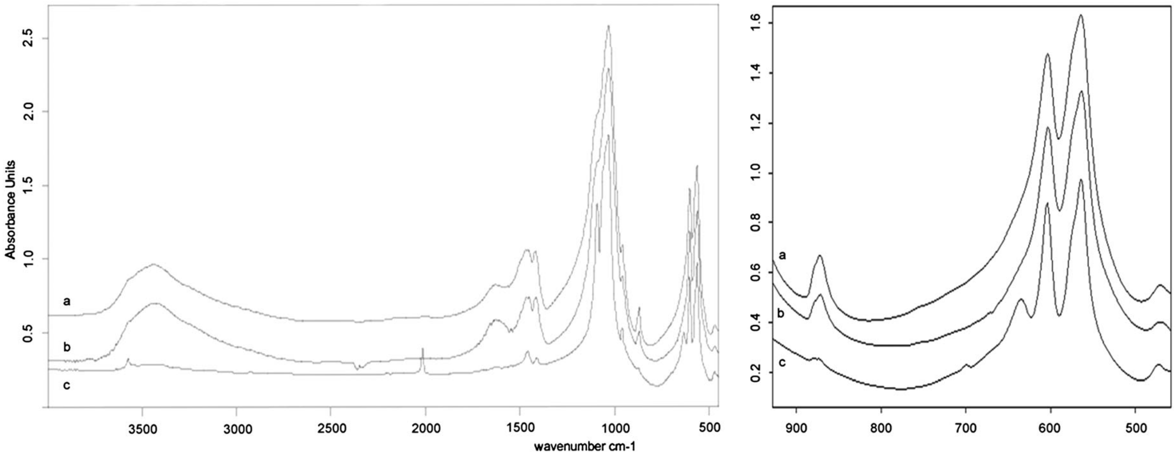

Figure 5. FTIR spectra of three bones of the same lime burial context at Son Matge rock shelter: a- brown bone (sample 9); b- black bone (sample 8); c- white bone (sample 7). Wavenumber cm^{-1} versus absorbance units.

this rite was carried out is still unclear. Whatever may have been the method, an almost complete outgassing of the rock carbonate was obtained (Van Strydonck *et al.*, 2011). A possible unintended production of quicklime during the incineration process (Hernández-Gasch, 1998) has therefore to be rejected. Although $CaCO_3$ decomposes relatively easily at the temperature obtained during cremation, it is very difficult to decompose substantial amounts of limestone from a floor of a rock shelter simply by heating its surface by a pyre (Baxter & Walton, 1970). Also, a decomposition of limestone blocks from architectural features, (re)used as an oven for the cremation of the deceased, has to be rejected. In the case of the site of Son Oms (a talayot (re)used as a granary, Mallorca), a transformation of limestone into CaO has been noticed due to an intensive fire, but in contradiction to the lime in the lime burials, the material still contained a lot of fossil carbonate, an indication of incomplete outgassing of the limestone (Van Strydonck *et al.*, 2011). It is more probable to state that the rite involved crushed rock carbonate in close contact with the body of the deceased during cremation, similar to the incineration experiment described above, since this is the easiest way to obtain virtually complete outgassing. This explains well the incorporation of fossil carbon in the bio-apatite. It also explains the large scatter in the degree of calcination of the body, reflected in the varied appearance of the bones. The laboratory tests revealed that covering a pig shank with limestone powder slows down the burning and calcination process, so the degree of calcination depends partly on the coverage of the different body parts by limestone. The cremation rite involving crushed rock carbonate would corroborate the general idea of a purification rite: not of the burial site, as has been suggested (Piga *et al.*, 2010), but of the body itself. It must be noted that during heating, the brown–greyish rock powder becomes bright white.

Waldren (1982) describes the presence of charcoal lenses in the lime burials. It is remarkable that charcoal seems to be concentrated at certain areas and is hardly found in the lime/bone concretions. This may be due to outwashing during the burial rite.

Finally, Waldren (1982) noticed cist-like formations in the lime burial. It may be the case that sporadically an inhumation (without quicklime) took place. This would explain the almost intact vertebral column on display in the DAMARC museum (Deià) as well as the presence of complete intact skulls among the finds at the cave of Son Bauçà (Garralda, 1975). The presence of these inhumation graves may have led to the wrong interpretation of the lime burials as inhumation burials.

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