Journal of Archaeological Science 40 (2013) 712–722

Contents lists available at SciVerse ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

On yellow and red pigmented bones found in Mayan burials of Jaina

Erasmo Batta [a,b], Carlos Argáez [a,b], Josefina Mansilla [c], Carmen Pijoan [c], Pedro Bosch [b,*]

[a] Facultad de Ciencias, Universidad Nacional Autónoma de México, Ciudad Universitaria 3000 Circuito Exterior, 04510 México Distrito Federal, Mexico
[b] Instituto de Investigaciones en Materiales, Universidad Nacional Autónoma de México, Apartado Postal 70-360, 04510 México Distrito Federal, Mexico
[c] Dirección de Antropología Física, Instituto Nacional de Antropología e Historia, Gandhi s/n, Polanco, 11560 México Distrito Federal, Mexico

ARTICLE INFO

Article history:
Received 11 June 2012
Received in revised form
1 August 2012
Accepted 22 August 2012

Keywords:
Pigment
Cinnabar
Hematite
Iron hydroxide
Ritual
Warrior
Burial
Mesoamerica
Yucatan

ABSTRACT

In the island of Jaina, Campeche, red and yellow pigmented bones have been found. The study of the yellow and red colors in these burials is important for their possible interpretation, either religious, intentional coloring, or to understand taphonomic processes such as reactions of the original pigments with other compounds. Yellow color on bones is unusual in prehispanic burials.

In this work, the red bones are shown to be pigmented with cinnabar as mentioned for tombs of important Mayan rulers. The yellow pigment is mainly constituted by Fe as shown by X-ray fluorescence. It was identified to be goethite (iron hydroxide) by electron diffraction. By scanning electron microscopy, the thickness of the pigment layer was measured to be *ca.* 5 microns. Note that hematite iron oxide is red and that it turns out to be yellow with hydroxylation. Hence, it seems that the nowadays yellow bones were originally red; indeed, yellow goethite may be the result of red hematite hydroxylation.

1. Introduction

In Mesoamerican cultures, as in many human societies, colors were elements of everyday and ceremonial life. Not only façades, temples, figurines, ceramics or murals were painted with symbolic colors, also human remains. For instance, the tomb of king *Yuknom Yich'ak K'ak* found in Calakmul (Vázquez de Agredos, 2007), as well as the tomb of the Red Queen in Palenque, was totally covered by cinnabar, a red dust. Color symbolism can vary among cultures, especially if they are related to death rituals.

Archaeological pigments usually contain heavy or transition metals, and similar colors may be obtained from different compositions. Black may be prepared from carbon, from bitumen (Argáez et al., 2011) or from magnesium oxide (López-González et al., 2006). In Xochicalco paintings, orange has been identified as a pigment rich in S and Fe (Rodríguez-Lugo et al., 1999) but in the Templo Mayor of Mexico City, ochre color has been attributed to goethite which is a hydrated iron oxide (Ortega et al., 2001). In Mayan mural paintings yellow ochre is present; in Ek'Balam, it is mainly constituted by goethite and limonite (Vandenabeele et al., 2005; Vázquez de Agredos, 2007). Yellow can also be obtained from fungi or from betalains which are chromo-alkaloid pigments specific of some plants: Amanita and Hygrocybe (Zryd et al., 2003). Doménech et al. (2011) have reported on "Maya yellow", a nano-structured pigment composed by indigoids attached to palygorskite.

Yellow and yellow–red pigmented bones of men, women, and children have been found in the archaeological site of Jaina, Campeche, which was occupied by Mayan culture during Classical Period, 250–900 AD (Piña-Chan, 1948, 1968; Benavides, 2007). Jaina is an island of 42 ha, 750 m at its broadest part. A ceremonial center and some living spaces have been also found. Jaina is located in the coast of the Gulf of Campeche to about 32 km of the city of the same name, Fig. 1. Since 1940, there have been several archaeological field seasons (Mansilla et al., 1990; Benavides, 2007). For the exploration seasons of 1973 and 1974, Serrano and López (2007) claim that some groups of graves suggest that domestic nuclei or large families occupied the place for several generations. Indeed, they were constituted by 95 individuals of variable ages and by children up to adults of both sexes. According to the funerary furnishings, *i.e.* the objects found with the graves, these authors claim that the individuals belonged to a large sector of the society and not to the elites; due to the quality and variety of the objects accompanying the

* Corresponding author.
E-mail address: croqcroq@hotmail.com (P. Bosch).

0305-4403/$ – see front matter
http://dx.doi.org/10.1016/j.jas.2012.08.013

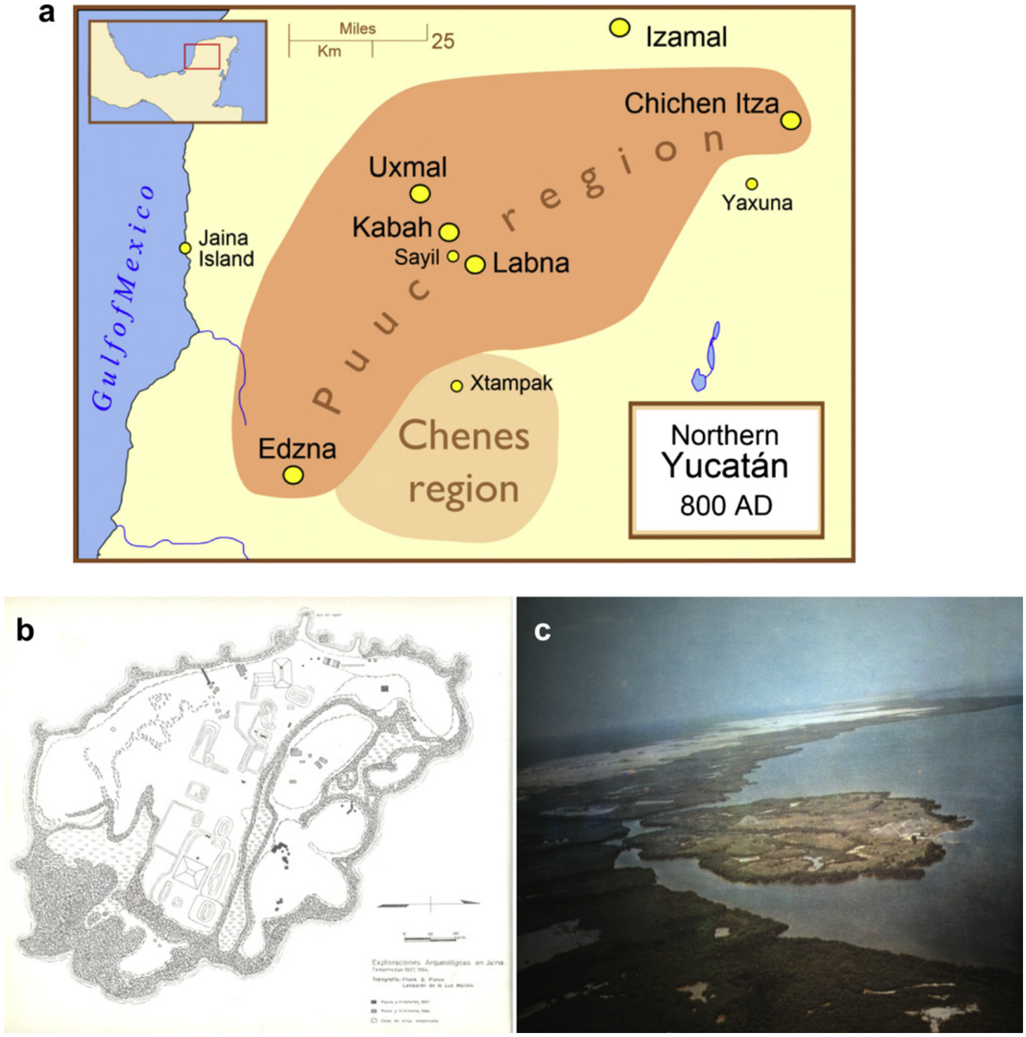


Fig. 1. a) Jaina in the Yucatán peninsula (taken from http://en.wikipedia.org/wiki/Jaina_Island), b) map of the island showing the ritual places and c) aerial view of the site (Piña-Chan, 1948, 1968).

corpses, it seems that several social status are represented. There were materials related to common funerary rituals, and even some graves had no offerings at all, but, at least 8 individuals seem to have had a significant status, such as burials 23 (1973) and 1 and 2 (1974) from our samples Fig. 2.

Red pigment has been found not only in tombs of Mayan personages but also in many ancient Mesoamerican graves. In Jaina, all burials had red pigment; only 12 burials had yellow in addition to red, among them are, for example, burial 23 and burials 1, 5, 6 and 18, included in this study. Besides, just one report on Jaina yellow pigmented bones can be found in the Mesoamerican bibliography (López-Alonso and Serrano-Sánchez, 1997). Another one corresponds to the main interment of the burial pit of *Pakal Na* in Belize, reported as a *four-ka'tun* lord, with bones individually removed, painted red and yellow ochre, and repositioned (Harrison-Buck et al., 2007). Our samples comprise, at least, eight burials which can be considered to correspond to high rank individuals due to their dental decorations with different stones such as pyrite, hematite and jadeite. These decorations are associated to an intentional modeling of the skull (Tiesler, 2001), along with their grave goods, Fig. 3. Only, in North Patagonia, Argentina, similar red and yellow bones have been studied (Darchuk et al., 2009).

The aim of the present contribution is, then, to analyze samples of the yellow and red pigmented bones from Jaina, Figs. 4 and 5, and to determine, through physical and chemical analyses the composition of the pigment. The results should provide the bases to propose a mechanism explaining how the color went onto the bones, showing if it has to be attributed to a natural phenomenon, *i.e.*, a reaction of the original pigment with other compounds, or if it was intentional. Bones from the explorations of 1973 (burial 23) and 1974 (burials 1, 5, 6, and 18) were studied separately.

2. Experimental

2.1. Samples

Two yellow samples from the same individual (burial 23), A1jaina and A2jaina, Fig. 5, were studied. They are representative of the large number of yellow colored bones. The pigmented zone of A1jaina was scraped to obtain a very small amount of colored dust. Instead in A2jaina sample, it was possible to separate small yellow chips from the bone, in this way the preferential orientations of the compounds, if any, may be studied. For comparison purposes a red sample also from Jaina (skull 8), R1jaina, was chosen. The detailed

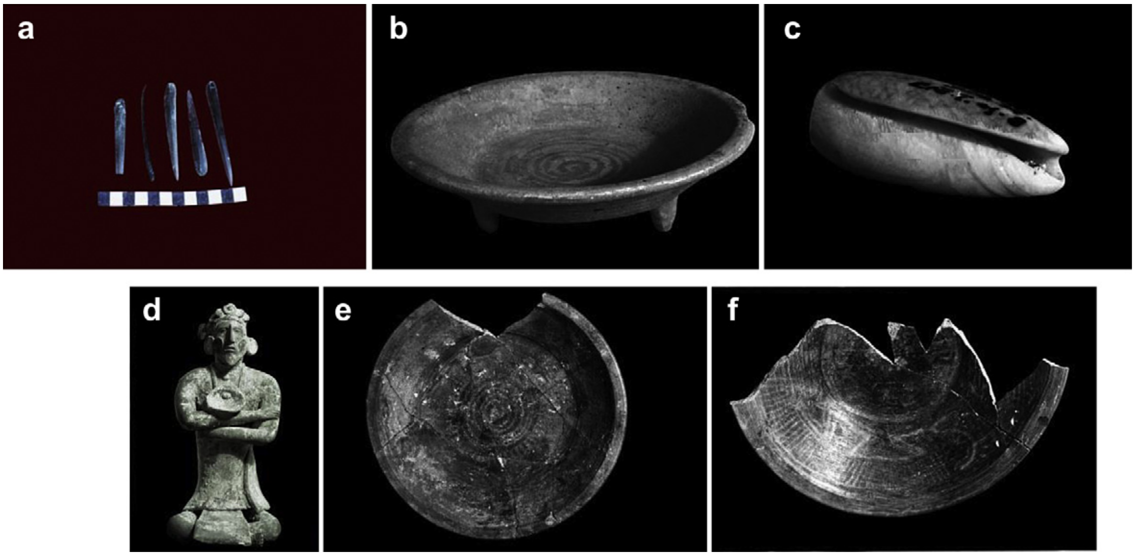


Fig. 2. Offerings found in Jaina. (a) Obsidian knifes found in burial 23, (b), (c) and (d) dish, shell and figurine from burial 1 excavated in 1974, (e) and (f) dishes from burial 2 excavated in 1974.

description of the samples and their color is presented in Table 1. All these materials are deposited at the INAH.

The previous yellow samples are from the 1973 and the red one from the 1957 explorations, Fig. 6.

They were studied with several techniques to understand their composition. Using the conclusions of this work, a second group of samples, corresponding to the exploration of 1974, was studied. These materials were characterized by SEM and EDS only, Table 2.

2.2. X-ray fluorescence

To estimate the elemental composition, the samples of the 1957 and 1973 explorations were analyzed by X-Ray Fluorescence (XRF). The empty sample holder spectrum was used as a reference. The X-ray fluorescence spectra were recorded on a Siemens SRS 303 spectrometer using an LiF(100) analyzer crystal, and pentaerythrite. The data were analyzed with the Semi-Quant program.

2.3. Scanning electron microscopy

Sample A2jaina was covered with gold to avoid conduction problems in the scanning electron microscope. We studied regions with and without pigment, as well as regions at the pigment frontier. Such pictures were taken in two positions: with the sample, either perpendicular, or parallel, to the electron beam. The corresponding elemental analyses by EDS of the pigmented bone zones were compared to the not-pigmented bone analysis. We used a Leica Cambridge microscope Stereoscan 440, with software Leica Optics Electron to characterize the samples from the 1957 and 1973 explorations. The 1974 samples were studied without any coverage at a very low voltage (10 kV) in a JEOL JSM-7600F, field emission microscope coupled to and EDS system, Oxford INCAX-Act.

2.4. Atomic force microscopy

Atomic Force Microscope (AFM) images of the A2jaina were obtained. In the same bone, pigmented and not-pigmented sections

Fig. 3. Burial 23 from Jaina 1973, adult male with intentional modeling of the skull and dental decoration with pyrite, hematite and jadeite stones.

Fig. 4. Burial 23 found in 1973. Red and yellow samples were taken from this burial for the present study. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

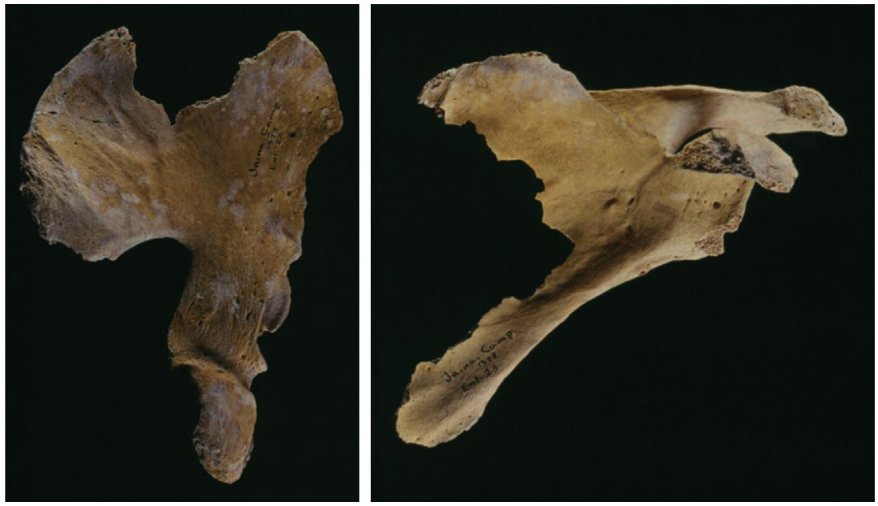


Fig. 5. Yellow pigmented bones from Jaina, exploration of burial 23, 1973. Samples were taken from these bones for the present study. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

were compared (labeled respectively as A2jaina and A2jainaH). In each case the corresponding three-dimensional image was obtained. The images were compared to find similarities and differences in the morphologies. It has to be emphasized that the atomic force microscope does not need any sample pretreatment, *i.e.*, the sample was not covered with gold and it was observed at atmospheric pressure. A Microscope JEOL JSPM4210 (Scanning Probe Microscope) was used to obtain images and maps in 3-D with a WinSPM program System.

2.5. Electron diffraction

In an effort to confirm our conclusions, an electron diffraction study of the sample A1jaina was performed to identify the surface compounds present in the yellow pigmented bone. Only this sample was studied as the samples, in this technique, have to be very thin *i.e.* powdered or, otherwise, incorporated to a polymer, and thinned; only sample A1jaina fulfilled such requirements. A transmission electron microscope JEOL model JEM-1200 eV was used at 120 kV.

3. Results

3.1. Yellow samples from 1973 exploration

3.1.1. Elemental composition

Table 3 compares the elemental composition of the two yellow samples as obtained by X-ray fluorescence. Both samples contain a high amount of iron, 9% in A1jaina and 4% in A2jaina, which cannot be due to bone whose composition is hydroxyapatite (Ca, P, O and H) and collagen (proteins). It is important to emphasize that sample A1jaina is a powder scratched from the surface and sample A2jaina is a chip. Therefore, as X-ray fluorescence technique is a bulk technique, *i.e.*, the results correspond to the sample volume, sample A1jaina should contain more pigment than sample A2jaina whose composition should be more representative of the pigment. It contains, indeed, twice as much iron. The samples clearly differ in the chlorine content as it is 20% in A1jaina (again the powder was scratched from the bone and, then, chlorine must be on the surface) but 2% in A2jaina, such variation may be attributed to the cleaning procedure of the bones during the exhumation and storage. The presence of elements such as Si or Al can be explained if the composition of soil is considered. Indeed, soil contains clays and sand, constituted by Al and Si, which may be adhered to bone. The X-ray fluorescence determinations are bulk analyses, as already said, whose error is close to 10% in our instrument and they are not able to detect elements whose atomic weight are smaller than F, thus carbon cannot be reported. Of course, a study by X-ray diffraction could be recommended to determine, straightforward, the compound nature, but, the amount of dust scratched from the

Table 1
Description and labeling of samples from the 1957 and 1973 exploration of Jaina.

Sample	File number (INAH)	Color	Shape	Label
Jaina, Cam. 1957, skull 8, male	2	Red	Dust	R1jaina
Jaina, Cam. 1973, male, burial 23	4A	Yellow	Dust	A1jaina
Jaina, Cam. 1973, male, burial 23	4C	Yellow	Chips	A2jaina

Fig. 6. Skull from the male individual from Jaina (1957) with red pigment. Samples were taken for the present study. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2
Description and label of samples from the 1974 exploration of Jaina.

Burial	Bone	Color	Shape	Label
1 Adult male	Left humerus	Yellow	Chip	Sample A2
1 Adult male	Left phalange	Red	Chip	Sample R10
1 Adult male	Ulna	Red	Chip	Sample R9
5 Adult male	Left os coxae	Yellow	Chip	Sample A4
6 Adult male	Left os coxae	Red	Chip	Sample R8
6 Adult male	Left os coxae	Yellow	Chip	Sample A3
6 Adult male	Right humerus	Yellow	Chip	Sample A5
6 Adult male	Right humerus	Red	Chip	Sample R11
6 Adult male	Left femur	Yellow	Chip	Sample A7
6 Adult male	Right tibia	Yellow	Chip	Sample A1
18 Adult female	Sacrum	Yellow	Chip	Sample A6

bones was not enough for the study and the flakes are too irregular to guarantee the flat surface required by the Bragg condition. The red sample was also studied by XRF. The red sample of Jaina (R1jaina) presented two elements that were not identified in the yellow materials, Hg and S. The obtained Hg:S atomic ratio (0.83) shows that, within error range it is cinnabar (HgS).

3.1.2. Morphology

Only sample A2jaina was studied in the scanning electron microscope as, being a flake, the distribution of the pigment should be maintained; instead, in the scratched powders the distribution and location of the pigment on the surface is lost. Fig. 7 shows the corresponding scanning electron micrograph, obtained from a pigmented zone. The image does not correspond to a well preserved or to a deteriorated bone surface (Pijoan et al., 2007). Indeed, a thick layer seems to be deposited on top, as shown in Fig. 7a); underneath, the porous morphology of bone can be observed. Fig. 7b), which is a frontal view of the adhered layer, shows a surface layer constituted by smooth and homogeneous flakes separated by cracks. The thickness of the yellow pigment layer can be estimated to be around 5 μm in this zone. On the left side of Fig. 7a), the diffusion of the pigment paste into the bone porosity can be appreciated.

To characterize the pigment morphology at a higher level, atomic force micrographs were obtained, Fig. 8. In yellow sample, Fig. 8a), the cracks are revealed to be only superficial and the size of the pigment flakes is confirmed. The layer is rather rough but it follows the bone surface topography, compare with Fig. 8b) which corresponds to a non-pigmented zone.

3.1.3. Local analysis

The local elementary analysis by EDS provided the composition of the pigmented layer in chosen zones of the sample A2jaina, Fig. 9. In the region without pigment the typical bone composition was obtained, *i.e.*, only two predominant elements (Ca and P). Instead, in the pigmented region Ca, Si, K, Mg, Fe and O were found. We did not find P. It seems, then, that yellow pigment is thick enough to mask the bone contribution and that the obtained spectrum corresponds only to the yellow pigment. The main elements are Si, Ca and Fe. Si, Ca and Fe could be all

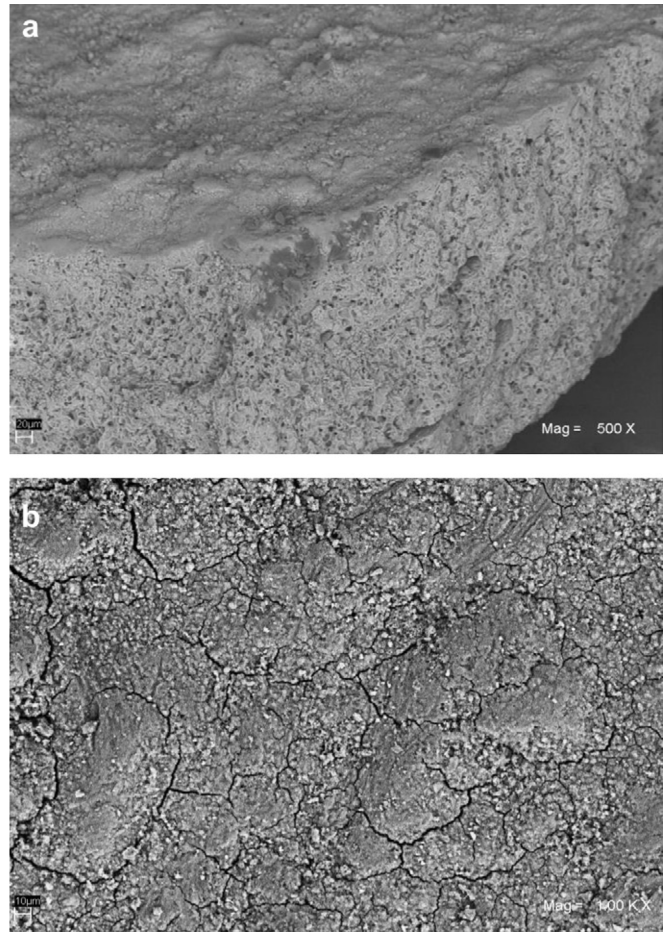


Fig. 7. SEM image of A2jaina sample, (a) lateral view at a magnification of ×500 and (b) surface view at a magnification of ×1000.

present in a yellow ochre, of which goethite, $Fe(OH)_3$, can be a component. Compounds as $KFe_3(SO_4)_2(OH)_6$ known as jarosite, $Na_2Fe(SO_4)_2(OH)\cdot 3(H_2O)$ (sideronatrite), and $Fe_2[O(SO_4)_2]\cdot 4(H_2O)$ which is metahohmannite are questioned as they contain sulfur and this element was observed by XRF in a very low percentage and not at all by EDS. The only probable one, from this group, would be jarosite as it contains a low amount of sulfur.

To check those conclusions the electron diffraction pattern of the sample A1jaina is presented in Fig. 10. The pattern definitely corresponds to $Fe(OH)_3$, JCPDS card: 00-038-0032, distances 1.72 and 2.33 Å. Therefore, yellow color in Jaina bones is due to iron hydroxide. As the reflection at 1.72 Å is the most intense, it can be concluded that the $Fe(OH)_3$ is preferentially oriented. Such orientation is most probably due to a strong surface interaction between the two hydroxides: iron hydroxide and hydroxyapatite in agreement with the atomic force micrographs.

3.2. Yellow samples from the 1974 exploration

The 1974 group of samples was studied by SEM-EDS to obtain the elemental composition of the surface and to compare it with the already clear results of the previous materials. Table 4 summarizes the EDS measurements obtained in the samples explored in 1974. All yellow samples contain high amounts of Fe. The ratio Fe:Ca varies between 0.10 and 0.55, these values are higher than those obtained by XRF in the 1973 samples, 0.12 and

Table 3
Relative elemental composition (weight %) of the yellow samples (burial 23 exploration of 1973), as determined by X-ray fluorescence spectroscopy. The atomic ratios Fe:Ca and Hg:S are also shown.

Sample	Fe	Ca	P	Cl	Si	S	P	Hg	Atomic ratio
A1jaina	0.16	1.27	0.38	0.56	0.17	0.06	0.02	0.00	Fe:Ca = 0.057
A2jaina	0.07	1.80	0.42	0.05	0.12	0.06	0.07	0.00	Fe:Ca = 0.024
R1jaina	0.01	0.50	0.18	0.03	0.02	0.04	0.18	0.20	Hg:S = 0.83

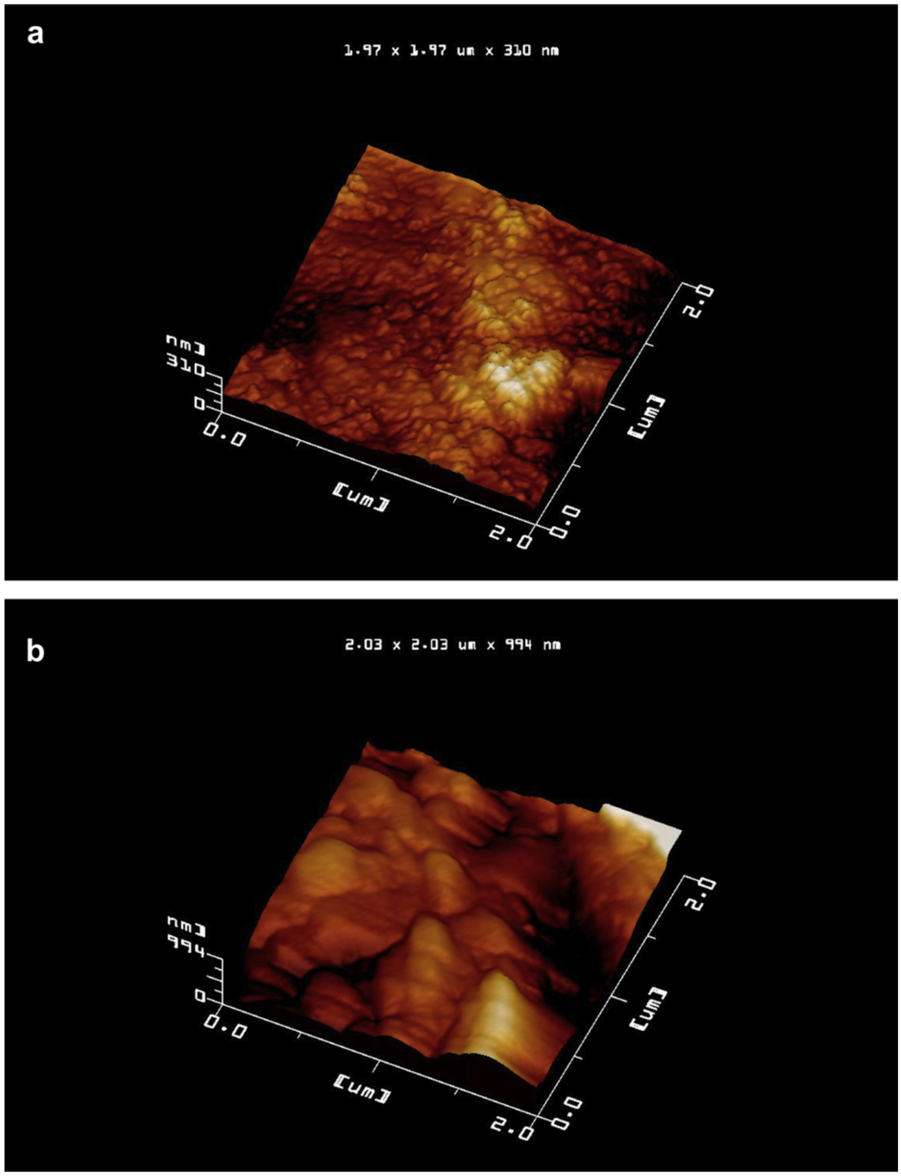


Fig. 8. Atomic force micrograph of (a) the A2jaina surface (yellow), and (b) Jaina non pigmented bone. In the yellow bone, the surface is covered by small particles less than 0.1 μm firmly adhered to bone surface. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

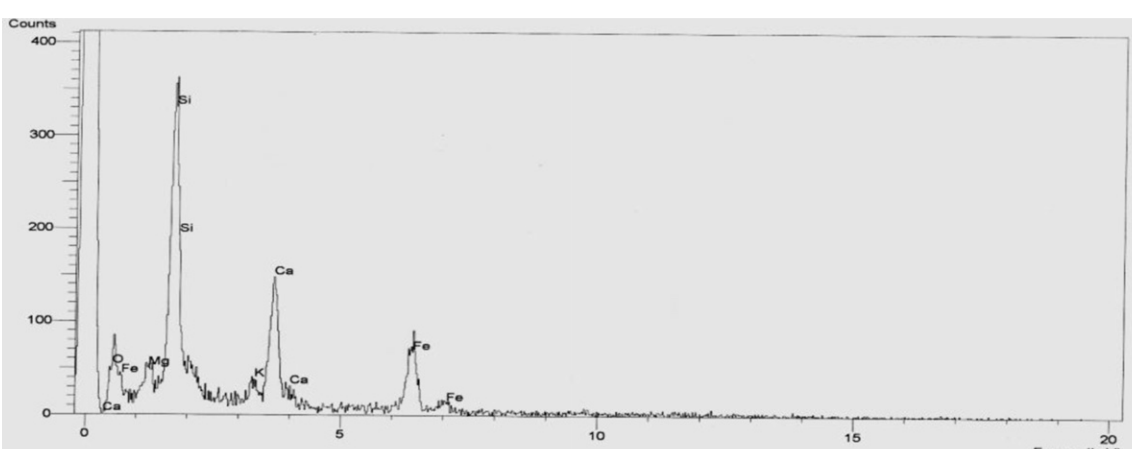


Fig. 9. EDS spectrum of the yellow layer present in sample A2jaina.

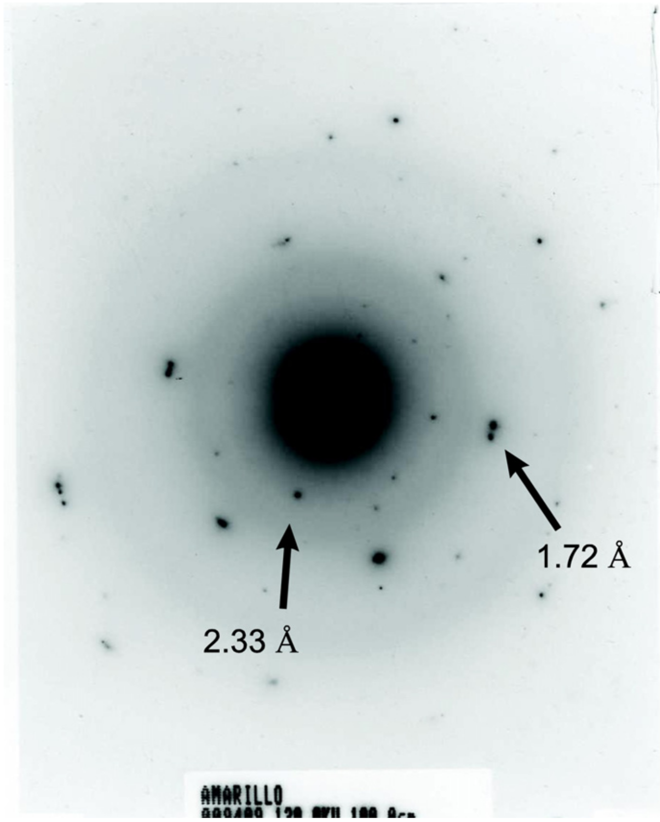


Fig. 10. Electron diffraction pattern of the A1jaina sample.

0.03. Remember that XRF is a bulk technique and the measurements correspond to the average of the sample whereas the EDS results correspond to a selected area of the sample. The presence of "other elements", mainly Si, has to be attributed to the composition of soil. Indeed, soil contains clays and sand, constituted by Al and Si, which may be adhered to bone.

In Fig. 11 two EDS spectra obtained in different zones of sample A4 are compared. Each spectrum is associated to the studied zone. Note how much the relative amount of iron may vary from zone to zone; thus, the pigment is distributed as patches. Such feature is evident macroscopically in Fig. 5.

3.3. Red samples from 1974 exploration

If the red samples of 1974 exploration are analyzed by EDS, no Fe peaks are observed; instead, clear and intense peaks of Hg, depending on the analyzed zone, appear, Table 5. Sulfur is also detected, the atomic ratios Hg:S are comprised between 2.53 and 0.66, the expected value was 1 as the chemical formula of cinnabar is HgS. The values obtained for samples R9 and R10 are close enough to 1 and may be attributed to cinnabar.

In Fig. 12, a spectrum EDS, showing Hg and S, is presented; in the corresponding SEM zone, brilliant particles, *ca.* 1 μm, appear, these are the cinnabar particles as Hg, due to its high atomic weight has a very different contrast.

The main conclusion of Tables 4 and 5 is that red color is due to cinnabar and yellow to iron hydroxide. The composition of the pigments present on the bone surfaces is the same independently of exploration, 1973 or 1974.

Table 4
Relative local elemental composition (atomic %) of the 1974 yellow samples, determined by EDS.

Sample	Bone	Fe	Ca	P	Other elements (more than 1%)	Atomic ratio Fe:Ca
A2	Left humerus	0.041	0.217	0.140	Si, Mg, Na, Cl	0.18
A4	Left os coxae	2.90	7.22	–	Si, Mg	0.40
A3	Left os coxae	1.25	8.24	4.13	Si, Na	0.15
A5	Right humerus	1.16	9.64	5.44	Si	0.12
A7	Left femur	0.072	0.17	0.10	Si, Mg	0.42
A1	Right tibia	5.61	10.10	2.61	Si, Mg, K, Cl	0.55
A6	Sacrum	1.43	13.85	2.73	S	0.10

4. Discussion

Our results may be summarized as follows. The yellow pigment on Mayan bones is iron hydroxide mixed with some sand or clay. The layer of color is adhered to bone and diffuses into it. Red color is due to some Hg and S compound, most probably cinnabar.

Yellow color can be due to many pigments, but, the one identified in this work is goethite, $Fe(OH)_3$. Goethite has been found in the *Templo Mayor* of Mexico city (Ortega et al., 2001), although it is not often used in Mayan culture (Vandenabeele et al., 2005; Harrison-Buck et al., 2007; Vázquez de Agredos, 2007). This compound may be obtained from hematite which is red, as already mentioned. Two possibilities can be advanced: Hydrolysis of hematite happened after burial, thus the pigmentation is not intentional; or the pigment was intentionally prepared to be yellow. In the following paragraphs we will discuss both hypotheses in an archaeological context.

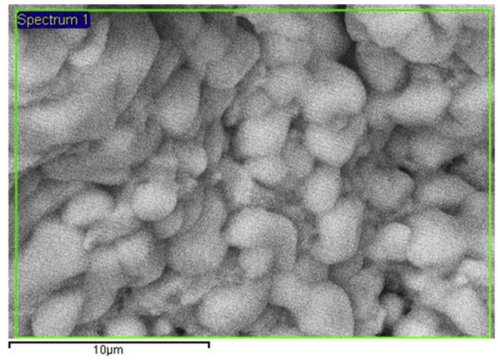
$FeO(OH)$ or $Fe(OH)_3$ may be obtained from hematite in contact with water. The reactions that describe hydrolyzation of hematite are (Cornell and Giovanoli, 1985):

$$Fe_2O_3 + H_2O \rightarrow 2FeO(OH)$$

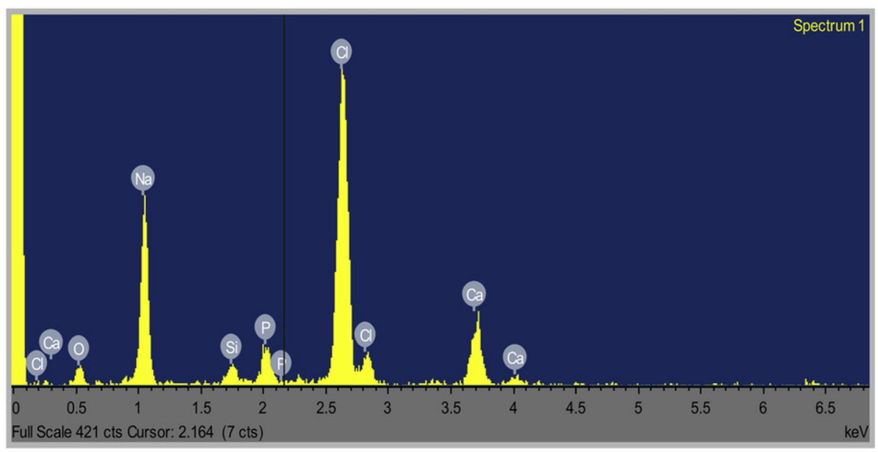
$$2FeO(OH) + 2H_2O \rightarrow 2Fe(OH)_3$$

Hydrolyzation is a surface reaction that progress towards the bone. However, as the layer of pigment is very thin it is very difficult to determine the differences in composition in the layer of pigment in the colored bones. Goethite may be, as well, a decomposition product of sulphates, carbonates or silicates of iron; such processes are frequent in the limits of marine zones such as Jaina, it was called *tecozáhuitl* or *tecuixtle* (López Luján et al., 2005). Still, the addition of carbonates or bicarbonates, which by the way are present in Mexican Southeastern soil, to an iron III solution precipitates the hydrated oxide, *i.e.* the yellow goethite (Magaloni, 1996). The obtained slurry, containing some soil, may diffuse into the bone cavities forming a homogeneous and well adhered yellow layer. Yellow color manages to penetrate into the accidents of the bone surface and forms a thin layer (5 μm) that follows the shape of the bone surface. Those mechanisms could explain that yellow goethite is well adhered to bones.

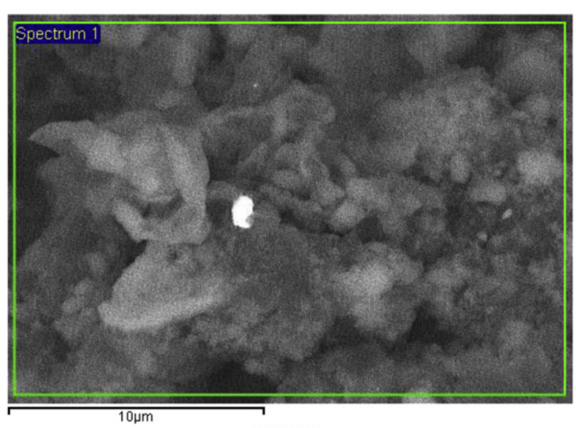
In red bones, the presence of cinnabar, suggested by the Hg and S contents, is not surprising as in the Red Queen tomb, the walls of the sarcophagus, the body and all its accompanying elements were heavily covered with a red dust identified as cinnabar (González-Cruz, 2000). Cinnabar is a stable compound in the Yucatán environmental conditions (Kuldvere, 1990; Wu et al., 2010). It seems, then, that, in Jaina, red cinnabar was put on all the dead corpses in a traditional way. The more economical and handy hematite, which is a red iron oxide, Fe_2O_3, could be expected to be used instead of cinnabar. Red hematite is composed by iron (wt 70%) and oxygen (wt 30%) and it has been found in many other Mesoamerican burials. Furthermore, Vázquez de



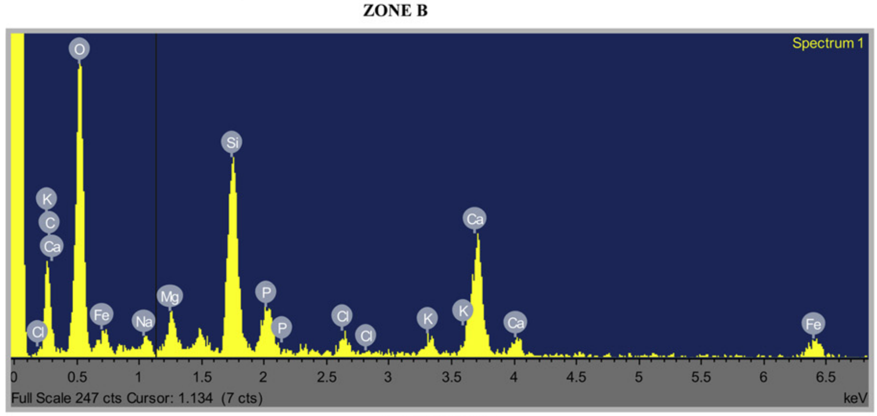
ZONE A



SPECTRUM A



ZONE B



SPECTRUM B

Fig. 11. Comparison of two EDS spectra (A and B) taken from the two corresponding zones (A and B) of the same 1974 sample, right tibia (A1 sample). In zone B Fe is clearly detected, in zone A no Fe is observed, showing that the pigment is not homogeneously distributed on bone surface.

Table 5
Relative local elemental composition (atomic %) of the 1974 red samples, determined by EDS.

Sample	Bone	Hg	Ca	P	Other elements (more than 1%)	Atomic ratio Hg:Ca	Atomic ratio Hg:S
R8	Os Coxae	6.71	–	0.73	Na, Cl, S	–	2.53
R9	Ulna	0.93	15.9	3.69	Si, Na, S	0.05	0.66
R10	Phalange	9.83	0.92	–	S, Si	10.68	0.86
R11	Right humerus	–	9.89	3.82	Si	–	–

Agredos (2007) has mentioned that hematite is often used in the Maya region, instead of cinnabar which is rare and which was one of the most expensive and symbolic pigment. Cinnabar was distinctive of high social hierarchies as in the tomb of the king of Calakmul, Campeche, *Yuknom Yich'ak K'ak* also known as Jaguar Paw. There, again, cinnabar covered everything: the ruler shroud as well as grave goods or tomb mural paintings. Hence, as red color in the studied bones can be always correlated to cinnabar and no hematite was observed, the yellow color on Jaina bones could be due to the hydrolyzation of hematite and this hypothesis could explain the presence of both pigments in the same individual as shown in Fig. 13.

Still, it is known that women used yellow clay to protect the skin from cold and that men going to war painted their body in yellow (López Luján et al., 2005). Then, after death, yellow pigment that was on the body could color the skeleton. However, till now no Mexica burials have been reported with those features. Yellow and red pigmentation has been reported on the bones of an elite male, from the burial pit of *Pakal Na* (Classic period) in zones of the body that suggest a post-depositional treatment (Harrison-Buck et al., 2007; Kuldvere, 1990). In this case, Buikstra (2007) quoted the following possible alternative: a water mediated redistribution of pigments. The possibilities related to secondary burials have to be rejected as, in Jaina, the burials are primary. Therefore, it seems that in our samples the corpses, depending on the zone, were initially covered with cinnabar (red) or hematite (red); this last pigment, with time and special environmental conditions, became yellow. The skeleton, then, nowadays, turns out to be red and yellow colored in some zones.

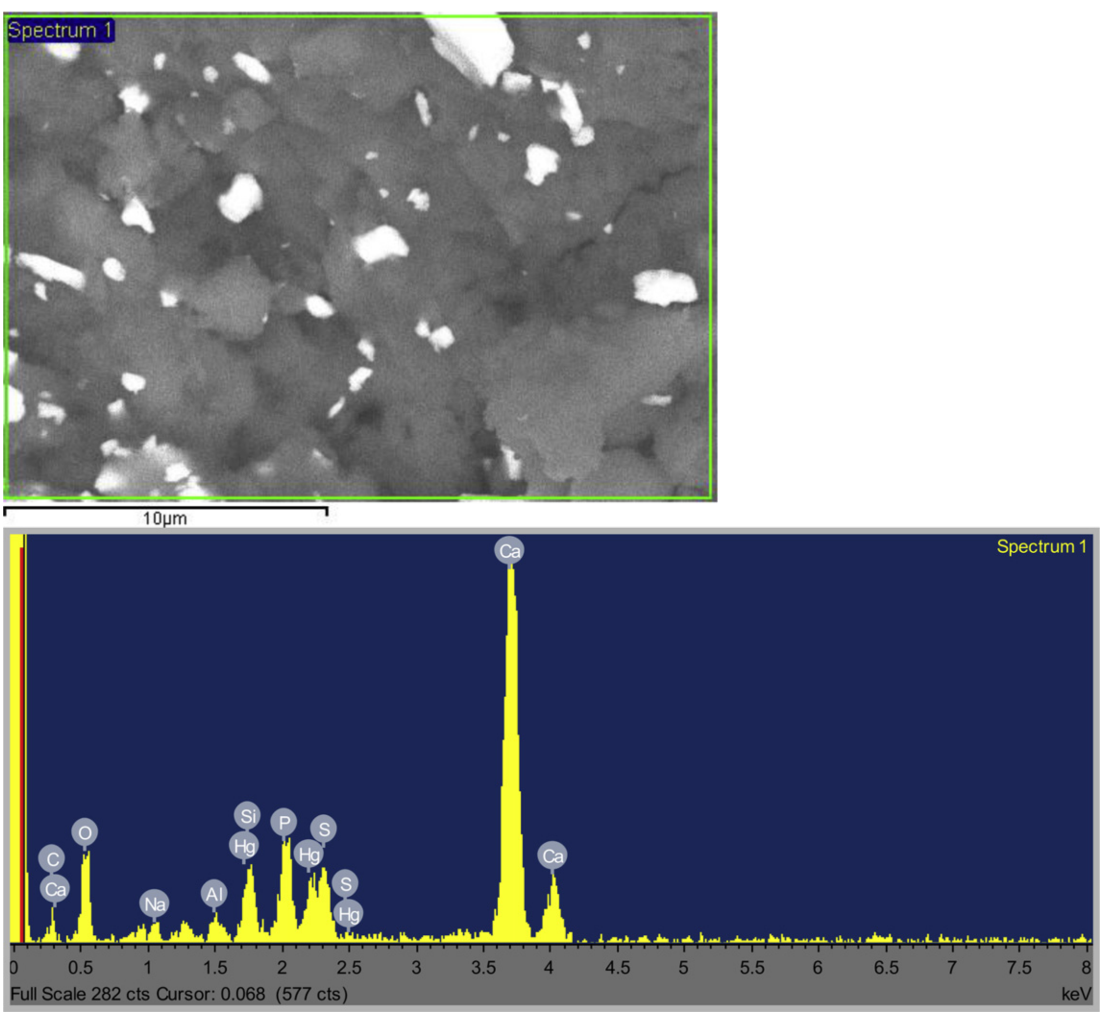


Fig. 12. EDS spectrum taken from the zone of the sample shown upwards with brilliant particles, such particles are then attributed to cinnabar.

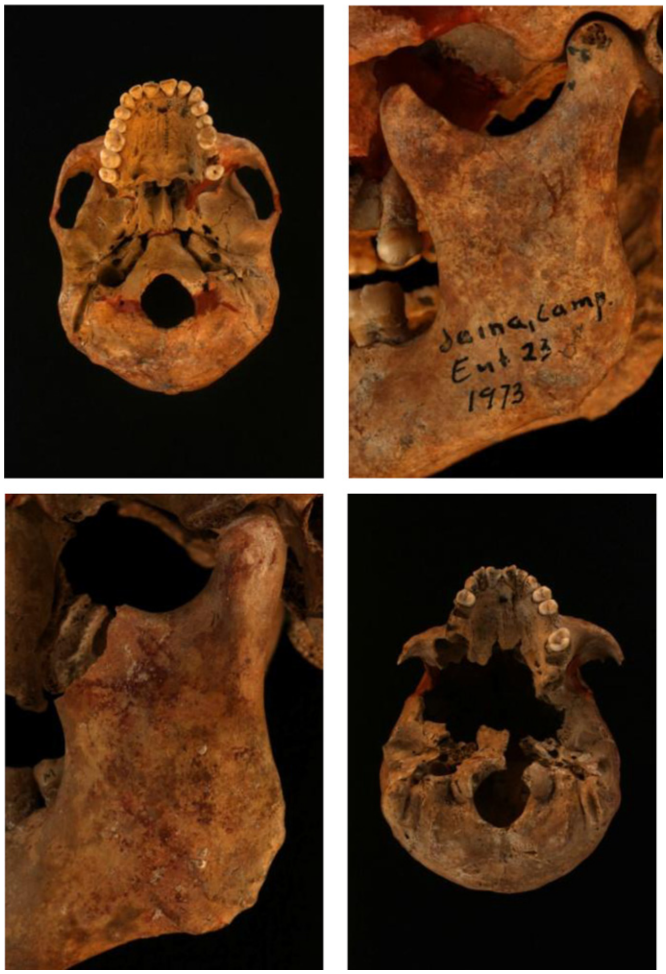


Fig. 13. Burial 1 (1974) and 23 (1973), the ramus part of the mandible shows red pigment and the basicranium yellow pigment. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

5. Conclusion

The yellow pigment on bones is goethite (iron hydroxide). Such pigment can be obtained from hematite as follows:

$$Fe_2O_{3(red)} + 3H_2O \rightarrow 2Fe(OH)_{3(yellow)}$$

Yellow, in our samples, was originally red (hematite) but special environmental conditions transformed it to yellow implying that the burial ritual was the usual one. Dead bodies were covered with red pigment (cinnabar and/or hematite) depending on the epoch, availability or cultural factors. Only the high ranked rulers, such as *Pakal*, the red Queen, or *Yuknom Yich'ak K'ak*, were covered with large amounts of cinnabar. The presence of two types of red pigment, in Jaina, cinnabar and hematite, strongly suggests that not only the valued ancestors were buried with cinnabar. One possible explanation could be that, given the difficult access to cinnabar, hematite or cinnabar were selectively used, depending on the body section; afterwards hematite became yellow. This hypothesis presents a scenario where the yellow color of the bones was not intentional and, therefore, it is not related to funerary customs.

Acknowledgments

The technical work of Leticia Baños, José Guzmán, Omar Novelo, Carlos Flores, Eduardo Caballero and Juan Salvador Rivera Sánchez in X-ray fluorescence spectroscopy, scanning electron microscopy and EDS, atomic force microscopy, and photographic support is gratefully recognized.

References

Argáez, C., Batta, E., Mansilla, J., Pijoan, C., Bosch, P., 2011. The origin of black pigmentation in a sample of Mexican prehispanic human bones. Journal of Archaeological Science 38, 2979–2988.

Benavides, A., 2007. Jaina en el contexto de las poblaciones del Clásico en el occidente peninsular. In: Patricia Hernández and Lourdes Márquez La población prehispánica de Jaina, Programa de Mejoramiento del Profesorado (PROMEP). Escuela Nacional de Antropología e Historia (ENAH), Consejo Nacional para la Cultura y las Artes (CONACULTA), México, pp. 13–31.

Buikstra, J., 2007. The bioarchaeology of Maya sacrifice. In: Tiesler, Vera, Cucina, Andrea (Eds.), New Perspectives on Human Sacrifice and Ritual Body Treatments in Ancient Maya Society. Springer Science & Business Media, LLC, New York, p. 299.

Cornell, R.M., Giovanoli, R., 1985. Effect of solutions in the proportion and morphology of goethite formed from ferrihydrite. Clays and Clay Minerals 33, 424–432.

Darchuk, L., Stefaniak, E.A., Vázquez, C., Palacios, O.M., Worobiec, A., Van Grieken, R., 2009. Composition of pigments on human bones found in excavations in Argentina studied with micro-Raman spectrometry and scanning electron microscopy. e-PS 6, 112–117.

Doménech, A., Doménech-Carbó, M.T., Vázquez de Ágredos-Pascual, M.L., 2011. From Maya blue to "Maya yellow": a connection between ancient nanostructured materials from the voltammetry of microparticles. Angewandte Chemie International Edition 50, 5741–5744.

González-Cruz, A., 2000. La Reina Roja. In: Proyecto Arqueológico Palenque, Chiapas, México. Instituto Nacional de Antropología e Historia (INAH), México D.F.. http://web.raex.com/~obsidian/Mayapan.html

Harrison-Buck, E., Mc Anany, P.A., Storey, R., 2007. Empowered and disempowered during the late to terminal Classic transition: Maya burial and termination rituals in the Sibun Valley, Belize. In: Tiesler, V., Cucina, A. (Eds.), New Perspectives on Human Sacrifice and Ritual Body Treatments in Ancient Maya Society. Springer Science & Business Media, LLC, New York, p. 88.

Kuldvere, A., 1990. Decomposition of cinnabar and organomercurials in geological materials with nitric acid-sulphuric acid for the determination of total mercury by cold vapour atomic absorption spectrometry. Analyst 115, 559–562.

López-Alonso, S., Serrano-Sánchez, C., 1997. Implicaciones culturales del tratamiento mortuorio en la necrópolis de Jaina, Campeche. In: Malvido, E., Pereira, G., Tiesler, V. (Eds.), El cuerpo humano y su tratamiento mortuorio. Consejo Nacional para la Cultura y las Artes (CONACULTA) and Instituto Nacional de Antropología e Historia (INAH), México, pp. 145–160.

López-González, F., Grandal-d'Anglade, A., Vidal-Romaní, J.R., 2006. Deciphering bone depositional sequences in caves through the study of manganese coatings. Journal of Archaeological Science 33, 707–717.

López Luján, L., Chiari, G., López Austin, A., Carrizosa, F., 2005. Línea y color en Tenochtitlan. Escultura policromada y pintura mural en el recinto sagrado de la capital mexica. Estudios de Cultura Náhuatl 36, 15–45.

Magaloni, D., 1996. Materiales y técnicas de la pintura mural maya. MSc thesis, Facultad de Filosofía y Letras Universidad Nacional Autónoma de México (UNAM). México.

Mansilla, J., Ochoa, P., Pijoan, C., Salas Ma, E., Salas, M., 1990. La isla de Jaina, Campeche: Un panorama cultural in Amalia Cardos de Méndez Coord. In: La época clásica: nuevos hallazgos, nuevas ideas. Museo Nacional de Antropología (MNA), Instituto Nacional de Antropología e Historia (INAH), México, pp. 393–410.

Ortega, M., Ascencio, J.A., San-Germán, C.M., Fernández, M.E., López, L., José-Yacamán, M., 2001. Analysis of prehispanic pigments from "Templo Mayor" of Mexico city. Journal of Materials Science 36, 751–756.

Pijoan, M.C., Mansilla, J., Leboreiro, I., Lara, V.H., Bosch, P., 2007. Thermal alterations in archaeological bones. Archaeometry 49, 713–727.

Piña-Chan, 1948. R. Breve estudio sobre la funeraria de Jaina, Campeche. Instituto Nacional de Antropología e Historia (INAH) and Gobierno del Estado de Campeche, Campeche, Cam, México.

Piña-Chan, 1968. Jaina. La casa en el agua. Instituto Nacional de Antropología e Historia (INAH), México.

Rodríguez-Lugo, V., Ortiz-Velázquez, L., Miranda, J., Ortiz-Rojas, M., Castaño, V.M., 1999. Study of prehispanic wall paintings from Xochicalco, Mexico, using PIXE, XRD, SEM and FTIR. Journal of Radioanalytical and Nuclear Chemistry 240, 561–569.

Serrano, C., López, S., 2007. Estatus social y contexto funerario durante el Clásico en Jaina, Campeche. In: Patricia Hernández and Lourdes Márquez La población prehispánica de Jaina, Programa de Mejoramiento del Profesorado (PROMEP). Escuela Nacional de Antropología e Historia (ENAH), Consejo Nacional para la Cultura y las Artes (CONACULTA), México, pp. 77–110.

Tiesler, V., 2001. Decoraciones dentales entre los antiguos mayas, Ediciones Euro-americanas. Consejo Nacional para la Cultura y las Artes (CONACULTA), Instituto Nacional de Antropología e Historia (INAH), México.

Vandenabeele, P., Bodé, S., Alonso, A., Moens, L., 2005. Raman spectroscopic analysis of the Maya wall paintings in Ek'Balam, Mexico. Spectrochimica Acta Part A 61, 2349–2356.

Vázquez de Agredos, Ma. L., 2007. Los colores y las técnicas de la pintura mural maya. Anales del Museo de América 15, 55–66.

Wu, S., Uddin, M.A., Nagano, S., Ozaki, M., Sasaoka, E., 2010. Fundamental study on decomposition characteristics of mercury compounds over solid powder by temperature-programmed decomposition desorption mass spectrometry. Energy Fuels, Online, 1–10.

Zryd, J.-P.H., Christinet, L., Zaiko, M., 2003. A new dioxygenase involved in plant betalain biosynthesis, secondary metabolism. In: American Society of Plant Biologists Abs # 293.