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1 **Wax finishing in Roman polychrome statuary:**
2 ***ganosis* on the colossal head from Dougga (Tunisia)**

3
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1 Abstract

2
3 3 The material evidence for the wax finish on ancient marble statues, known as *ganosis*, is scarce and
4 4 controversial, although Greek and Latin sources describe the recipes and cultural value of this treatment.
5 5 The surface treatment of a colossal Roman head from the Roman theatre of Dougga (Tunisia), dated to the end
6 6 of the second century CE, is studied by a multi-analytical protocol (video-microscope, cross section, and time-
7 7 of-flight secondary ion mass spectrometry of one sample). The results of this physico-chemical analysis and the
8 8 comparison with ancient recipes, prove the use of *ganosis* on a Roman statue and explore, for the first time, the
9 9 application of the recipes described in ancient sources. This result shows the potential of the Time-of-Flight
10 10 Secondary Ion Mass Spectrometry analysis, detecting at the same time organic and inorganic materials and their
11 11 stratigraphy, to study the ancient recipes.

12 12
13 13 Keywords: beeswax, *ganosis*, statues, TOF-SIMS

14 14 15 15 16 16 1. Introduction

17 17
18 18 The polychromy of Roman statues is increasingly documented thanks to remarkable work
19 19 carried out in the last 20 years, which has revealed the original appearance of painted statues
20 20 thanks to the analysis of the pigments [1, 2]. Conversely, the binders are less well
21 21 documented; egg, proteinaceous and beeswax binders are rarely detected on the statues [3, 4]
22 22 although many Greek and Latin written sources (Plutarch, *Quaest. Rom.*, 287 b-d; Ovid, *Fasti*
23 23 III, 831; Lucian, *Imagines* 23; Eusebius, *Vita Costantini*, I, 13) describe the use of wax, and a
24 24 technique called *ganosis*. This wax finishing was specifically employed to fix a chromatic
25 25 rendering, offering a weather-resistant protection for the statues which frequently stood out of
26 26 doors. In particular, Pliny the Elder and Vitruvius offer further details about the type of wax
27 27 employed and the recipes followed for the application of the wax on the wall and on the
28 28 statues, and these have been long interpreted and debated [5, 6, 7]. Pliny distinguishes two
29 29 older methods (*Naturalis Historia*, 35, 41) and one invented by Carthaginians for ships, the
30 30 so-called “Punic wax”. The first two methods consist in applying the hot wax in its molten
31 31 state using a kind of broad-ended iron spatula-like tool (*cauterium*) or a punch (*cestrum*). The
32 32 third method requires the application of the cold wax as a saponified emulsion. According to
33 33 the recipe for the preparation of this emulsion (*Naturalis historia*, 21, 149), the wax is made
34 34 soluble by boiling it in sea water with *nitrum*, a sodium carbonate. The process for its
35 35 application on the statues is referred to in Vitruvius (*De architectura*, 7, 9, 3-4) and repeated
36 36 by Pliny (*Naturalis Historia* 33, 122): punic wax and oil were mixed and applied with a
37 37 brush, then charcoal was used to heat the surface and partially melt the coating to guarantee a
38 38 better penetration and, finally, it is polished using candles and a white cloth. Greek sources
39 39 attribute a ritual importance to the act of covering statues with wax [8]. Some sources, such as
40 40 Plutarch (*Moralia*, 287b-c et d), consider it as a ritual procedure (*therapeia*) reserved to
41 41 statues which are part of religious rites, and carried out before religious holidays. However,
42 42 Vitruvius and Pliny, referring to the application of *ganosis* to wall painting, do not specify
43 43 whether this practice was still ongoing as part of ritual care.

44 44 Despite this specific ancient literature and the detailed descriptions, material evidence relating
45 45 to the use of Punic wax on statues has not been recognised with any certainty. The use of
46 46 encaustic painting with Punic wax, widely documented in the series of portraits of the Fayum

[9], is now evaluated with greater caution because of evident contamination with elements deriving from restoration procedures [10]. Only in the statue of the “beauty of Palmyra” (190-210 CE), silicates and beeswax probably without fatty acids have been detected by FT-IR. The absence of fatty acids is interpreted as the use of Punic wax, without being able to specify whether this is a binder or a surface finish [11]. Conversely, two Hellenistic statues testify to a hot beeswax application. The presence of a thick layer of wax without mineral addition is detected, by SEM-EDS, chromatography and FT-IR, on a head of Berenice II (3rd C. BC) at the Mariemont museum [12, 13]. The same treatment is presumed for the “Sinnende Muse” of Dresden, but analytical results are still unpublished and just a mention is known [14]. In other Greek statues the detection of modern synthetic resin and oil mixed with wax suggests a modern conservative intervention [15, 16]. Beeswax may be applied as a protective agent during a modern conservation treatment to confer water repellency to prevent degradation by salts.

1.1. Research aims

In this study we present the analysis of a colossal marble head from the theatre in Dougga, not restored after the discovery, in which the a multi-layered application of different types of beeswax is demonstrated for the first time. The complexity of multi-material (organic and inorganic) and multi-layered samples, as well shown for the gilding by Bonaduce and Boon [17], request a multi-analytical approach and an imaging technique such as the Time-of-Flight Secondary Ion Mass Spectrometry (TOF-SIMS), detecting at the same time organic and inorganic materials and their stratigraphy. In this paper we apply for the first time this technique to a polychromy remains of a roman statues and we compare our results with the roman recipes of *ganosis* described by Pliny and Vitruvius.

2. *Material and methods*

In the frame of the project «Corpus of the statues of the Bardo museum», directed by Francois Baratte and Fathi Bejaoui, an unpublished marble head from Dougga has been studied (Inv. 010326 14). This statue was discovered during the 1927 excavation by the «Direction des Antiquités », against the west wall of the theatre, at the main gate (fig. 1 and 2). The position of the discovery and the dimension of the head (44.5×26×31 cm) indicate that it belonged to a colossal statue decorating the theatre, standing outside. After its entrance to the Bardo museum (on 13th May 1927), this head was not restored and has been stored in a museum warehouse in Carthage.

The formal study [18] suggested that this head was reworked from a Julio-Claudian statue - because of the treatment of the hair- during the final part of the 2nd or at the beginning of the 3rd century CE. The features do not allow for its identification as an official portrait of the Emperor, and the identity of the character remains unknown. The formal treatment and the style of the head, make it close to the portrait of Probus in the Capitoline Museums [19, p. 139-141, n° 116, pl. 143-144].

88 This head was examined in situ with a video-microscope (Dino-lite 500-550×) in white light
89 and UV light. A micro-sample was taken from the lips, embedded in an epoxy resin polished
90 and observed with a Nikon Eclipse LV100ND microscope under different light conditions.

91 This sample was analysed by TOF-SIMS to investigate the nature of the pigments and binders
92 in the different layers. Each layer can be examined independently thanks to the imaging
93 abilities of the TOF-SIMS technique, giving simultaneous localisation and identification of
94 both inorganic and organic materials from the analysed surface on a sub-micrometre scale.
95 The mass spectrum allows identification, and in addition the imaging spatially separates the
96 information, which gives the localisation of the identified compounds. Combining the two, we
97 can then access the individual composition of each layer in a stratigraphy. The recorded ion
98 images reveal spatial information with a 390 nm pixel size [20, 21] and the mass spectra are
99 generated with a mass resolution (that is $M/\Delta M$, FWHM) of a few thousands thanks to the
100 delayed extraction of secondary ions with which the instrument is equipped [22]. Micrometre
101 size pigment grains can be identified [23], and layers thinner than 10 μm are adequately
102 resolved so their composition can be discriminated in the spectral data using regions of
103 interest (ROIs).

104 The TOF-SIMS analyses were performed on a TOF-SIMS IV (IONTOF GmbH, Germany) in
105 the Laboratory of Molecular and Structural Archaeology (LAMS, CNRS – Sorbonne
106 University, Paris, France). The raw data were acquired using SurfaceLab 6.7 software
107 (IONTOF GmbH, Germany) and processed with SurfaceLab 7.0. The instrument is equipped
108 with two ion sources. A Liquid Metal Ion Gun (LMIG) serves as the primary ion source for
109 analysis purposes, while an argon Gas Cluster Ion Beam (GCIB) allows one to gently sputter
110 the surface without damaging the underlying layers.

111 The GCIB was used to clean the sample surface in the instrument chamber prior to analysis.
112 The source was tuned to emit a beam of 2000 Ar atoms clusters with a total kinetic energy of
113 10 keV, and the sputtered area was a square more than twice the size of the analysed area, to
114 avoid border effects of the cleaning step. The contaminants on the surface were sputtered, as
115 shown by the decrease of the signal associated to the SiC_3H_9^+ ion (m/z 73.05) coming from
116 the recurring surface plastic additive polydimethylsiloxane (PDMS). After that step, the
117 cleaned surface was analysed using the LMIG tuned to emit a bismuth cluster pulsed ion
118 beam of 25 keV kinetic energy (Bi_3^+), impacting the surface at an angle of 45°. A low energy
119 electron flood gun neutralizes the residual charges on the surface between the various steps of
120 the analysis.

121 The analyses were carried out with the so-called “burst alignment with delayed extraction”
122 (BA+DE) focusing mode of the LMIG beam, giving the best spatial resolution on this
123 instrument. The focusing mode termed “high current bunched” (HCBU) was used in parallel
124 to calibrate the mass spectra, thanks to the linearity between the time-of-flight and the m/z ,
125 which is lost when using BA+DE. In this latter case, the mass calibration is refined by using
126 known heavy ions peaks from the marble, like Ca_mO_n^+ in positive ion mode and Ca_nO_m^- in
127 negative ion mode ($m>n$).

128 Two areas (see Fig. 3) were imaged with TOF-SIMS, spanning all the stratigraphy: marble,
129 pigmented red layer, first finishing layer, second finishing layer. To help identify which
130 secondary ions are to be sought in the sample spectra in order to then identify the ingredients,
131 reference compounds were analysed in the same analytical conditions: modern beeswax,

132 commercial Punic wax (Rami, Lavaris) and sodium carbonate (dehydrated natron, which was
1 133 used in its natural hydrated form in Pliny's recipe (*Naturalis historia*, 21, 49). Beeswax is an
2 134 organic compound in which the major component is myricyl palmitate, a fatty acid ester. In
3
4 135 the following, the presence of this molecule will be used as a wax marker.

5
6 136 BA+DE analyses of the statue sample were carried out on 100 μm \times 100 μm square surfaces
7 137 divided into 256 \times 256 pixels or 50 μm \times 50 μm square surfaces divided into 128 \times 128
8 138 pixels. The primary ion dose was 1.10^{12} ions per cm^2 , below the so-called "static SIMS limit",
9 139 which ensures that the analysed surface is free of any damage during and after the
10
11 140 measurement. HCBU analyses of the reference compounds were carried out with a primary
12 141 ion dose of about 1.10^{12} ions per cm^2 , on 150 μm \times 150 μm square surfaces divided into 256
13
14 142 \times 256 pixels.

15 16 143 17 144 18 145 3. *Results and discussion*

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20 146
21
22 147 The visual examination shows the remains of colours in lips (red), hair (black), nose (yellow).
23 148 These traces of colour could also be observed with the video-microscope: black in the eyes
24 149 and the eyebrows, red partially superimposed on yellow on the lips, brown and black in the
25 150 hair with some blue points between the nape and the hair (fig. 2). The skin displayed a yellow
26 151 treatment. A slight fluorescence was observed under UV illumination in the skin, lips, hair
27 152 and in the forehead. Some parts of the statue were particularly accentuated, such as the eyes,
28 153 lips and hair.

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32 154 The micro-sample taken between the lips shows a red layer above the marble layer, and two
33 155 white layers on top of this one, slightly fluorescent (fig. 3).

34
35 156 The TOF-SIMS data give access to the chemical composition and the stratigraphy of the
36 157 different layers in the two areas analysed, which were chosen so as to include all the layers,
37 158 from the marble to the uppermost surface. Their composition, identified by the detection of
38 159 characteristic ions, attested also in the modern standard references with wellknown
39 160 compositions, are described in Table 1.

40
41
42
43 161 The hematite is identified through iron peaks, the pure beeswax is identified through the
44 162 detection of characteristic fragment ion peaks of myricyl palmitate, which is its major
45 163 component, as well as in Bonaduce and Boon [17]. Another type of beeswax, showing the
46 164 same peaks, co-localized with the characteristic peaks of natron, could be the Punic wax. The
47 165 same peaks have observed in the reference of modern "Punic wax" and according the Pliny
48 166 recipes (*Naturalis historia*, 21, 149), the "Punic wax" is made boiling the common beeswax in
49 167 sea water with *nitrum*. In this paper, we call "Punic wax" this peculiar beeswax mixed with
50 168 salts, following the Pliny definition of "Punic wax".

51
52
53
54 169 The analysis indicates that the marble is covered by a layer made of grains of haematite with
55 170 "Punic wax" as the binder (fig. 4). In the superficial white layers calcium and lead are not
56 171 detected, which rules out the presence of white paint in these two layers. The red pigment
57 172 layer is covered with a layer of "Punic wax" which is in turn covered with a layer of pure
58 173 beeswax.

174 Comparing the reference mass spectra with those extracted from the different layers of the
1 175 samples, as shown in Fig.4, the spectra from both analysed areas (showing positive ions for
2 176 area A and negative ions for area B), are comparable to the reference spectra of pure beeswax,
3 177 haematite-rich ochre (Kremer Pigmente) and dolomite marble (Kremer Pigmente), in the
4 178 positive ion mode; and pure beeswax, saponified wax and sodium carbonate (dehydrated
5 179 natron), in the negative ion mode.

8 180 Other ions like those at m/z 473, 509, 557 and 767 are detected in the sample but not in the
9 181 reference. As described by Stacey et al. [5], compounds like sodium carboxylate are formed in
10 182 the preparation processes both in cases of Punic wax and alkali-treated wax, but the
11 183 composition of the media is dependent on the treatments made. It is therefore difficult to link
12 184 the detection of a compound to a specific processing technique. In this work, we show that the
13 185 two layers containing wax are however distinguishable through the detection of sodium
14 186 carbonate characteristic ions, only present in the deeper layer, suggesting a difference in
15 187 preparation. As free fatty acids are also detected, it can suggest that the wax was not fully
16 188 saponified, explaining why we are able to detect natron characteristic ions as well.

21 189 However, these ions mentioned in the previous paragraph can be attributed to the adducts of
22 190 the beeswax characteristic ion $C_{24}H_{57}O_2^-$ with several sodium-containing ions. Such
23 191 compounds could be explained by a long-term degradation process due to the reaction
24 192 between wax molecules and natron, consistent with their absence in the reference. Regert et
25 193 al. [24], whose study aimed at understanding the composition of ancient beeswax residues,
26 194 make no mention of the apparition of such sodium-containing compounds, so another
27 195 explanation could be that the wax used had a slightly different composition than the
28 196 references, or that the natron contained some impurities.

32 197 The comparison between the negative ion mass spectra extracted from the two superficial
33 198 layers and the reference mass spectra of beeswax, saponified wax and pure natron (fig. 5a)
34 199 allows one to discriminate the localisation of the Punic wax in the stratigraphy, thanks to the
35 200 characteristic ions detected in the Punic wax and not in beeswax. These ions are detected in
36 201 the paint layer and the one above it, while only the beeswax markers are detected in the
37 202 uppermost layer.

41 203 The spatial distribution of the components corresponds to the stratigraphy observed in the
42 204 cross section (marble, painting and two white layers) (fig. 3; fig. 5e), showing the localisation
43 205 of Punic wax and beeswax respectively in the lower and upper white layer. The analysis
44 206 suggests the use of Punic wax as the binder, since it is mixed with haematite in the paint layer,
45 207 and as a protecting agent, notably in the surface. The presence and the distribution of Punic
46 208 wax in these two layers are corroborated by the distribution of the markers of the sodium
47 209 carbonate reference. The distribution of sodium-containing ions has in fact the same shape as
48 210 these red and white layers superimposed on the marble. The use of hematite in the lower layer
49 211 is consistent with the shadowing using brown-red pigments, as formerly observed by Delaney
50 212 et. al on ancient techniques [26].

55 214 The analysis of this sample not only confirms the use of wax as a binder and a protecting
56 215 agent, but also shows that the recipes described by Vitruvius and Pliny (*De architectura*, 7, 9,
57 216 3-4; *Naturalis Historia* 33, 122) are applied to this second-third-century African statue.
58 217 According to the recipes, the Punic wax is applied at first with a brush on the pigment, and

218 secondly a polishing with beeswax candles is performed. A change in the application
1 219 technique can be deduced from the comparison between this treatment and the two other
2 220 Hellenistic statues in which the presence of wax is attested [11, 12, 13]. If the wax is applied
3 221 hot in the two Hellenistic statues, in the Dougga head it is the cold technique that is employed
4 222 with the Punic wax. This proves that the recipe transmitted by the Roman Imperial written
5 223 sources is not only a literary tradition, but that the recipe is actually followed in practice at
6 224 least until the end of second century CE.

9
10 225 In the colossal head of Dougga the act of covering the painted surface of first covering the
11 226 painted surface with Punic wax, and then again with Punic wax before a final polish with
12 227 beeswax, is a remarkable effort, because paintings with wax were highly prized [25, p. 67].
13 228 Moreover, the finishing with wax has undoubtedly a practical function, as a fixing and
14 229 protecting agent for the colour.

17 230 4. Conclusion

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19 231
20
21 232 The chemical results highlight the importance of this statue, which stood outdoors, probably
22 233 depicting an important private citizen. The dimensions of this statue and the finish evidence
23 234 underline its high value. The analytical protocol adopted allows one to document with
24 235 precision the waxing recipes followed, and to identify for the first time the new treatment of
25 236 *ganosis* and to compare the stratigraphy of the samples with the gestures and the material
26 237 described by Vitruvius and Pliny. Moreover, the analysis suggests a possible link between the
27 238 archaeological materials and the recipes of Pliny and Vitruvius: a wax finishing with Punic
28 239 wax and a polishing with wax from candles.

30
31
32 240 In the future, an increased number of identifications on statues of different chronologies and
33 241 provenance will make it possible to understand further in which chronological period and
34 242 which geographical area these ancient recipes have been used and how the Greek use of
35 243 *ganosis* [26, 27] evolves in the Roman period. By extending the analysis to statues of a
36 244 different nature (cultural and decorative), it will be possible to understand if, as the sources
37 245 state, the waxing had a socio-religious meaning.

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51
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58 259 decision to publish, or preparation of the manuscript.

262 Captions

263

264 Fig. 1: The context of the discovery of the statue analysed: the theatre of Dougga. (a) Plan
 265 drawn after the excavations; (b) view in 1931; the main entrance in the west wall, where the
 266 statue was discovered, is highlighted (Archives de la Planète - Collection Albert Kahn – photo
 267 F. Gadmer).

268

269 Fig. 2: (a) Head of male statue from Dougga (Inv. 010326 14) in its actual state of
 270 conservation; (b) macro-photography of the lips with traces of red and yellow painting and (c)
 271 black on the hair; micro-photography (Dino-lite $\times 200$) of the same areas showing the
 272 stratigraphy: (d) on the lips yellow, red and white layer superposed; (e) on the hair yellow and
 273 black superposed.

274

275 Fig. 3 Cross-section of the sample (lips), (a) observed in visible light in cross-polarisation,
 276 showing the stratigraphy (from the bottom to the top): marble, red layer with pigment
 277 particles, white opaque layer and white translucent layer observed only on the right; (b) UV
 278 fluorescence confirms the stratigraphy: pigment layers appear black, and the two white layers
 279 have a fluorescence different to that of the marble. Yellow squares highlight the analysed
 280 areas (A) and (B).

281 Fig. 4: Mass spectra from the analysed areas of the statue sample, and reference compounds:
 282 (a) positive ions, statue sample, zone (A) (see Fig. 3a), with inserts showing haematite,
 283 marble, beeswax and ions characteristic of Punic wax; (b) positive ions, dolomite reference
 284 (Kremer Pigmente n°58740) (blue) and red ochre reference (Kremer Pigmente n°40510)
 285 (red); (c) positive ions, pure beeswax reference. (d) negative ions, statue sample, zone (B)
 286 (see Fig. 3a), with beeswax and Punic wax characteristic ions; (e) negative ions, natron
 287 reference (dark red) and saponified wax (blue); (f) negative ions, pure beeswax reference.

288 Fig. 5: (a) Negative ion mass spectrum of layer 4; (b) Negative ion mass spectrum of layer 3;
 289 (c) negative ion mass spectrum of saponified wax reference, in red the negative ion mass
 290 spectrum of pure natron reference; (d) negative ion mass spectrum of pure beeswax reference;
 291 (e) Microscope image of the cross-section with the locations of the two analysed areas A and
 292 B. The four small images are from left to right, the optical, total ion images and images of
 293 characteristic ions from Table 1 for wax (red), and for natron (blue). The images on the right
 294 are their overlays. Images have a 50 μm side for zone A and a 100 μm side for zone B. The
 295 layers are delineated with dotted white lines to guide the eye.

296 Table 1 : Characteristic ions from reference mass spectra and detected in the sample.

297

298

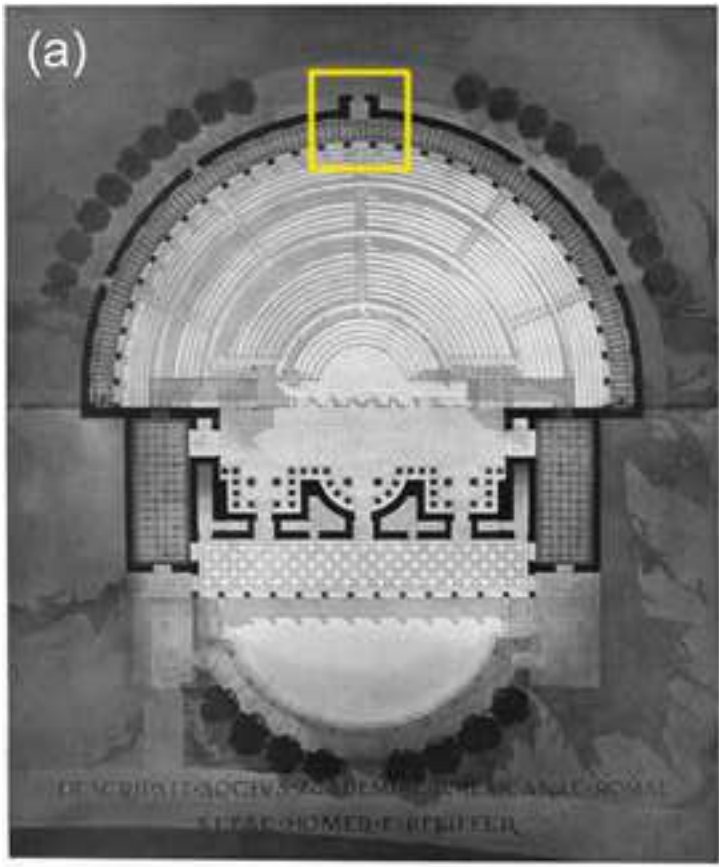
299 References

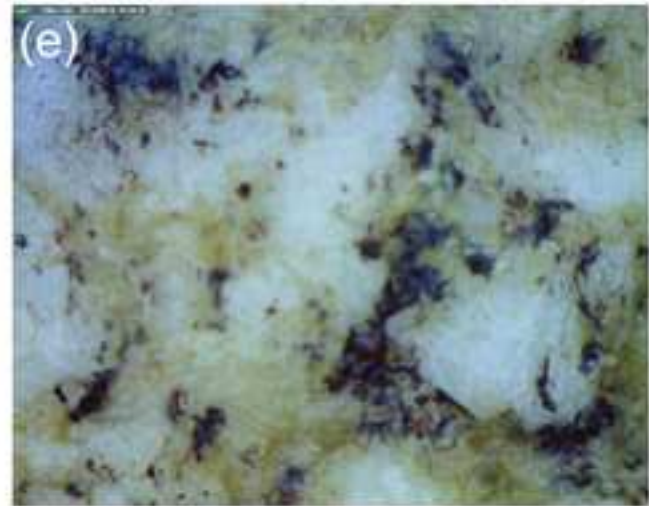
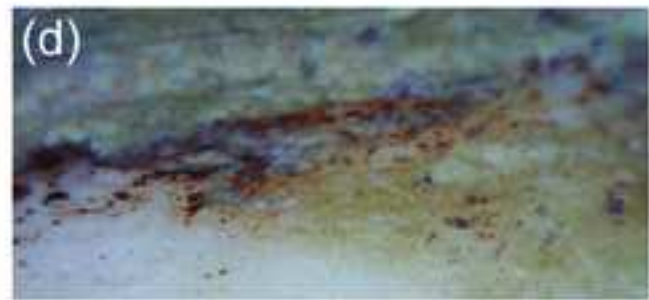
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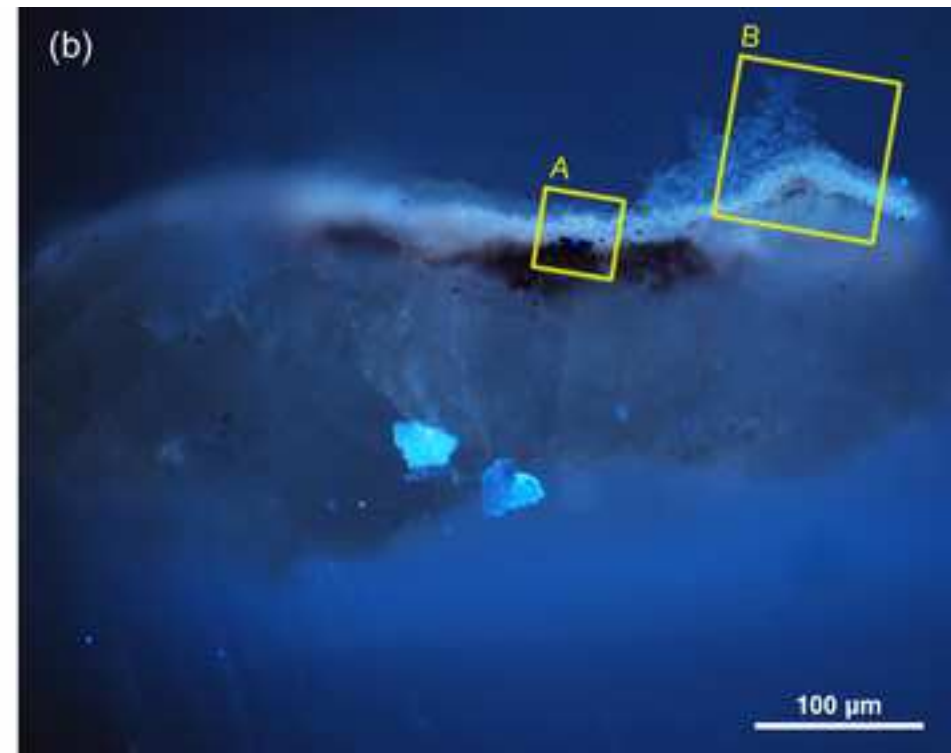
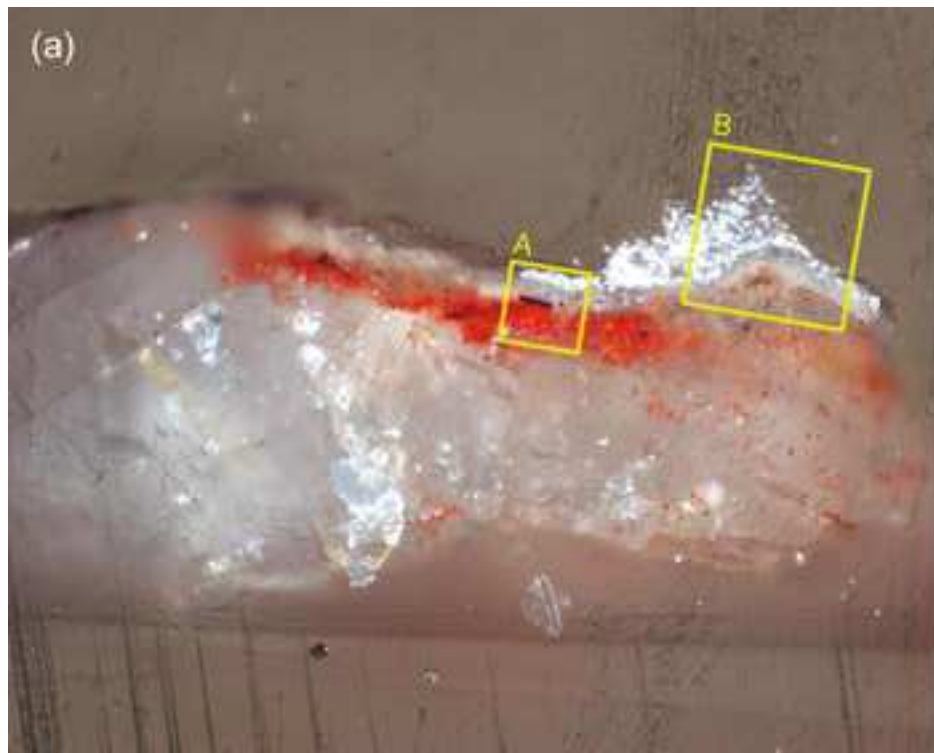
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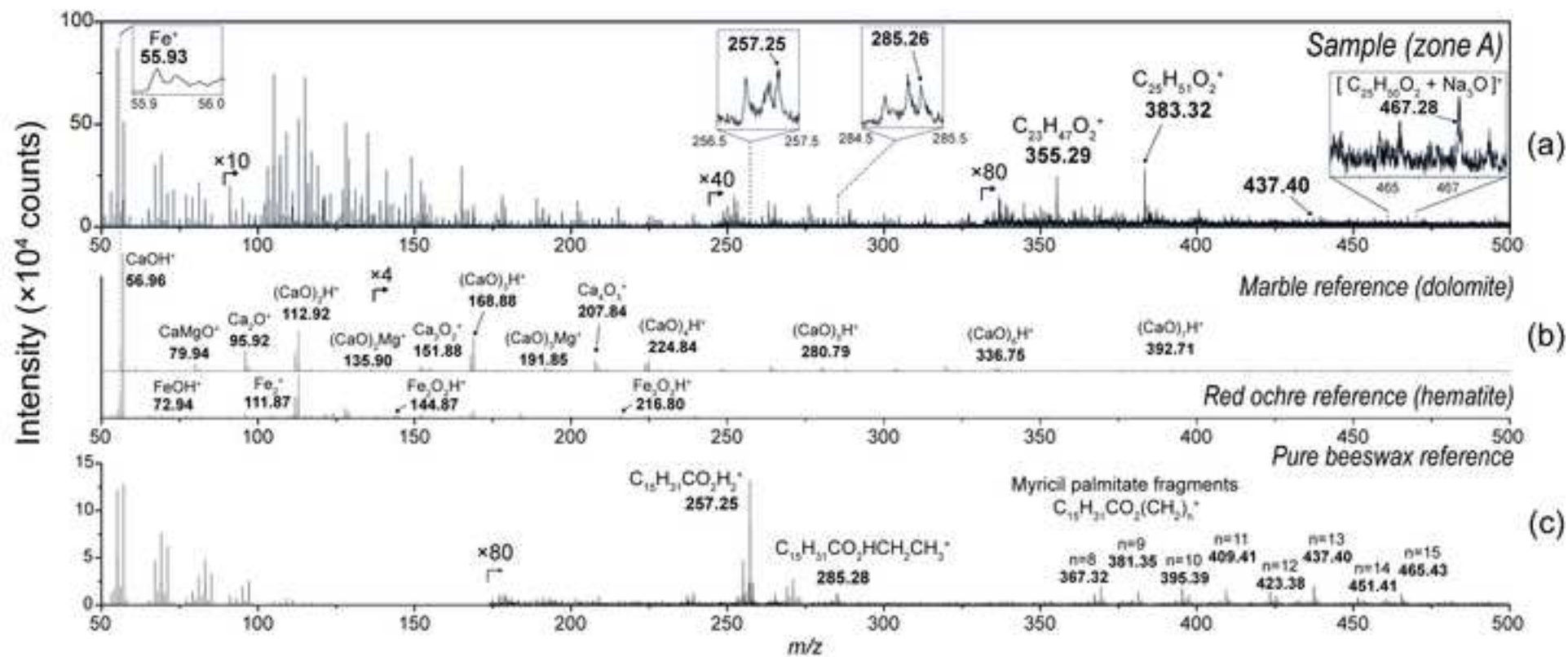
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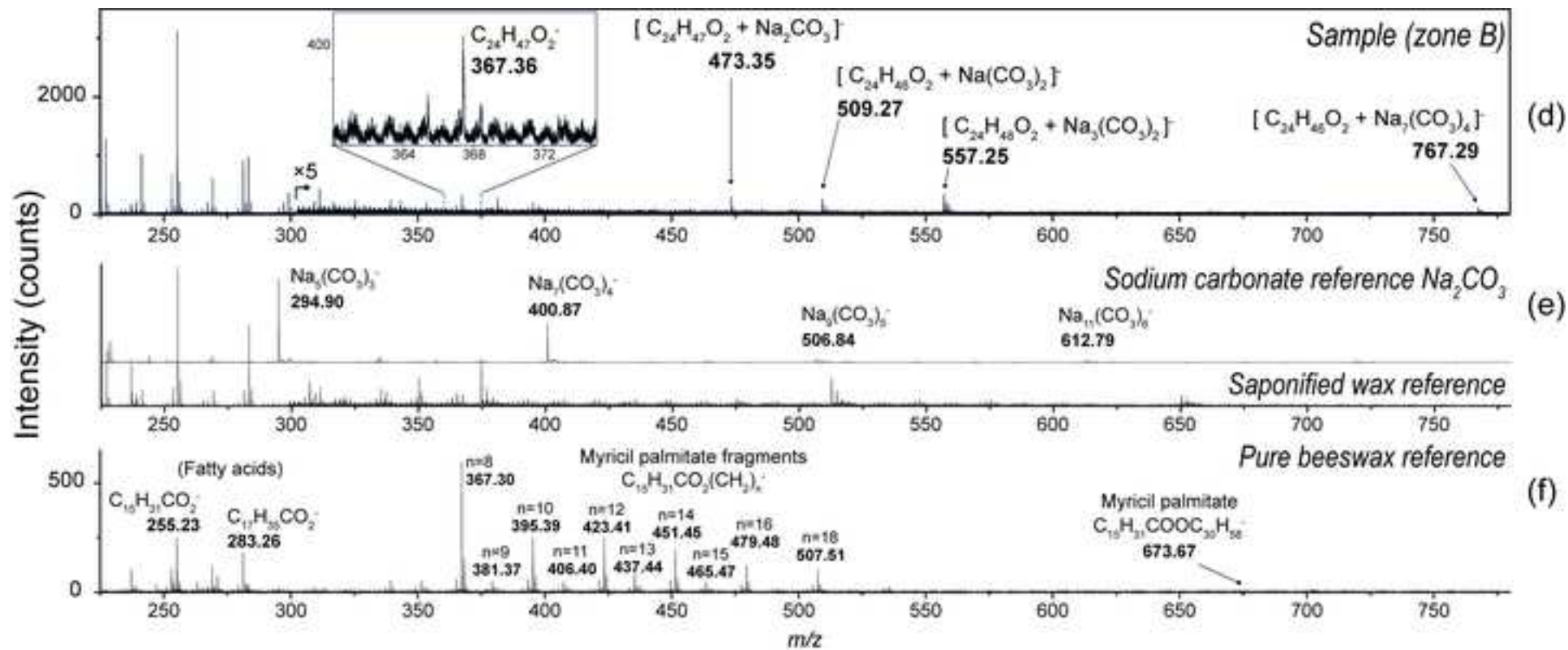
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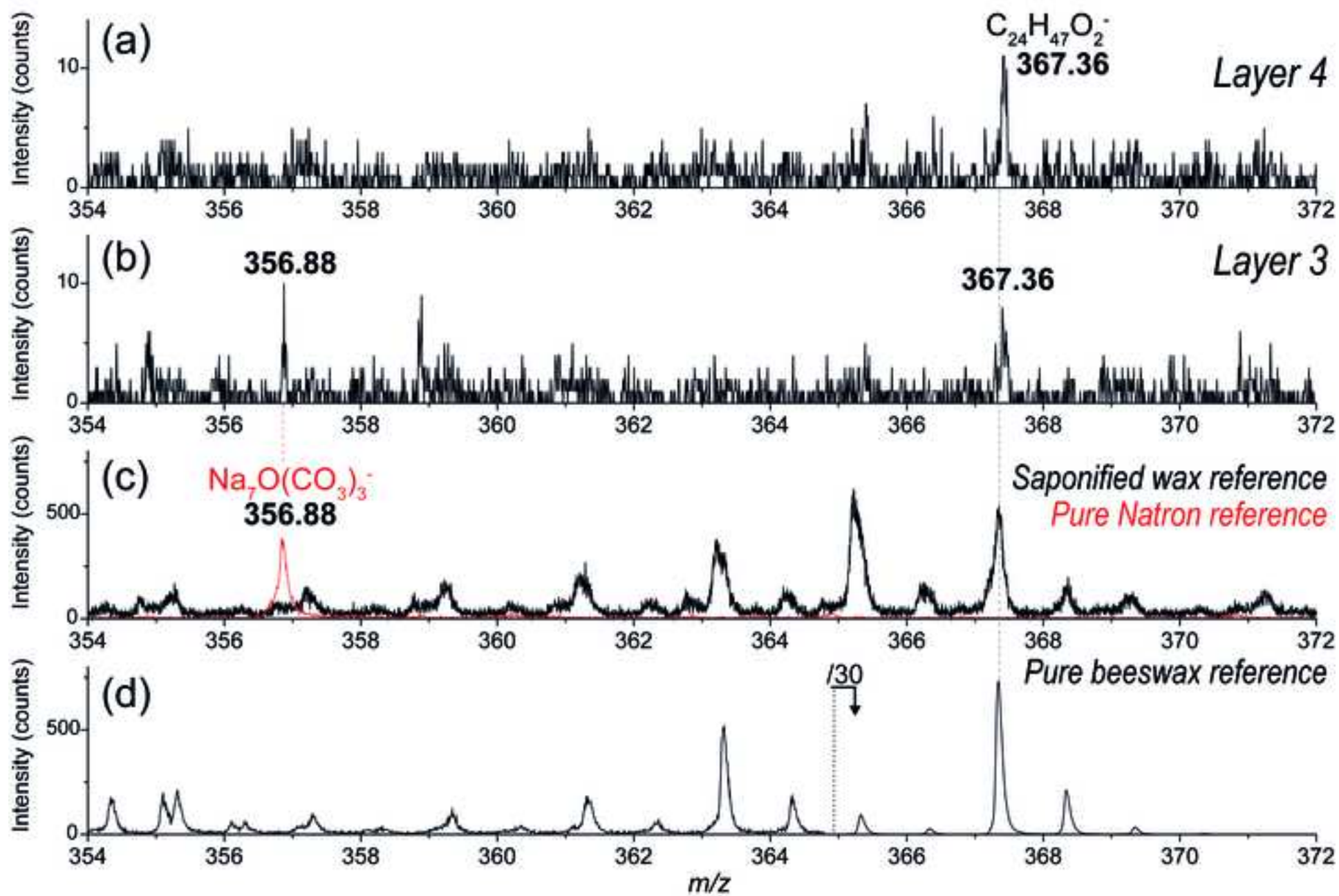












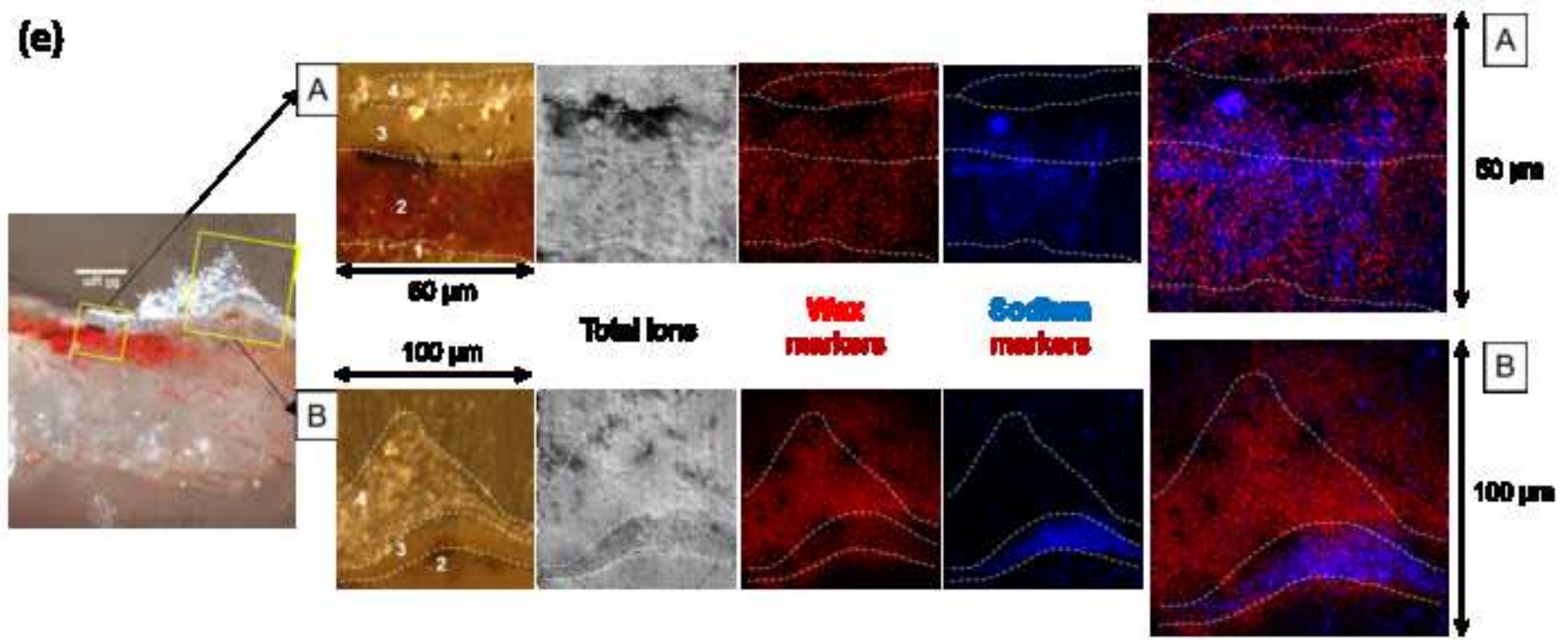


Table 1 : Characteristic ions from reference mass spectra and detected in the sample

Measured m/z Δ : standard deviation (ppm)		Characteristic ions for positive polarity (tentative assignments)	Detected in...		
m/z	Δ (ppm)		Reference	Sample	
39.96	15	Ca^+	Marble Kremer Pigmente n°58740	Layer 1	
56.96	-51	$\text{H}(\text{CaO})^+$ and associated $\text{H}(\text{CaO})_n^+$ (n=2-7) m/z 112.92, 168.88, 224.84, 280.79, 336.75, 392.71			
79.94	-15	$\text{Mg}(\text{CaO})^+$ and associated $\text{Mg}(\text{CaO})_n^+$ (n=2-7) m/z 135.90, 191.85, 247.83, 303.76, 359.73, 415.68			
95.92	40	$\text{Ca}(\text{CaO})^+$ and associated $\text{Ca}(\text{CaO})_n^+$ (n=2-5) m/z 151.88, 207.84, 263.80, 319.74			
55.93	-50	Fe^+	Hematite Kremer Pigmente n°40510	Layer 2 (particles below 5 μm)	
111.87	30	Fe_2^+			
72.94	-14	FeOH^+ and associated $\text{H}(\text{FeO})_n^+$ (n=2-3) m/z 144.87, 216.80			
257.26	8	$\text{C}_{15}\text{H}_{31}\text{CO}_2\text{H}_2^+$	Beeswax (pure)	Layer 2 Layer 3 Layer 4	
285.26	-30	$\text{C}_{15}\text{H}_{31}\text{CO}_2\text{HC}_2\text{H}_5^+$			
355.29	-93	$\text{C}_{15}\text{H}_{31}\text{CO}_2\text{H}(\text{CH}_2)_6\text{CH}_3^+$			
369.34	-79	$\text{C}_{15}\text{H}_{31}\text{CO}_2\text{H}(\text{CH}_2)_7\text{CH}_3^+$			
383.32	-99	$\text{C}_{15}\text{H}_{31}\text{CO}_2\text{H}(\text{CH}_2)_8\text{CH}_3^+$			
353.35		n=7 or m=23			
367.32		n=8 or m=24			
381.35		n=9 or m=25			
395.39		n=10 or m=26			
409.41		n=11 or m=27			
423.38		n=12 or m=28			
437.40		n=13 or m=29 ($\text{C}_{30}\text{H}_{61}\text{O}^+$)			
451.41		n=14			
465.43		n=15			
Measured m/z Δ : standard deviation (ppm)		Characteristic ions for negative polarity (tentative assignments)	Detected in...		
m/z	Δ (ppm)		Reference	Sample	
297.26		$\text{C}_{15}\text{H}_{31}\text{CO}_2(\text{CH}_2)_n^-$ or $\text{O}(\text{CH}_2)_m\text{CH}_3^-$	Beeswax (pure)	Layer 2 Layer 3 Layer 4	
311.28					n=3 or m=19
325.30					n=4 or m=20
339.32					n=5 or m=21
353.34					n=6 or m=22
367.36					n=7 or m=23
381.37					n=8 or m=24
395.39					n=9 or m=25
409.46					n=10 or m=26
423.41					n=11 or m=27
437.44					n=12 or m=28
451.45	55				n=13 or m=29 ($\text{C}_{30}\text{H}_{61}\text{O}^+$)
465.47	7				n=14
479.48	83				n=15
493.48	-88	n=16			
507.51	2	n=17			
573.67	78	n=18			
673.67	78	$\text{C}_{15}\text{H}_{31}\text{COOC}_{30}\text{H}_{58}^-$			

82.98	37	NaCO_3^-	Beeswax (saponified)*	Layer 2 Layer 3
137.96	30	Na_2CO_5^-		
154.97	63	$\text{Na}_2\text{CO}_6\text{H}^-$		
162.96	35	$\text{NaO}_5\text{CO}_3^-$		
178.96	37	$\text{Na}_2(\text{CO}_2)_3\text{H}^-$		
188.95	30	$\text{Na}_3(\text{CO}_3)_2^-$		
294.90	-11	$\text{Na}_5(\text{CO}_3)_3^-$		
334.91	25	$\text{Na}_6(\text{CO}_3)_3\text{OH}$		
356.88	25	$\text{Na}_7(\text{CO}_3)_3\text{O}^-$		
66.98	7	NaCO_2^- and associated Na_nCO_m^- (n=1-2 ; m=2-5) <i>m/z</i> 82.98, 89.98, 98.97, 105.97, 121.96, 137.96	Natron (pure)	Layer 2 Layer 3
156.95	-18	$\text{Na}_3(\text{CO}_2)_2^-$		
268.91	43	Na_7CO_6^-		
308.91	4	$\text{Na}_3(\text{CO}_3)_4^-$		
334.90	-25	$\text{Na}_6(\text{CO}_3)_3\text{OH}$		
356.89	-32	$\text{Na}_7(\text{CO}_3)_3\text{O}^-$		
400.87	5	$\text{Na}_7(\text{CO}_3)_4^-$		