





## Article

# Shearwater Eggs in Lobos 3, a Holocene Site of Fuerteventura (Canary Islands)

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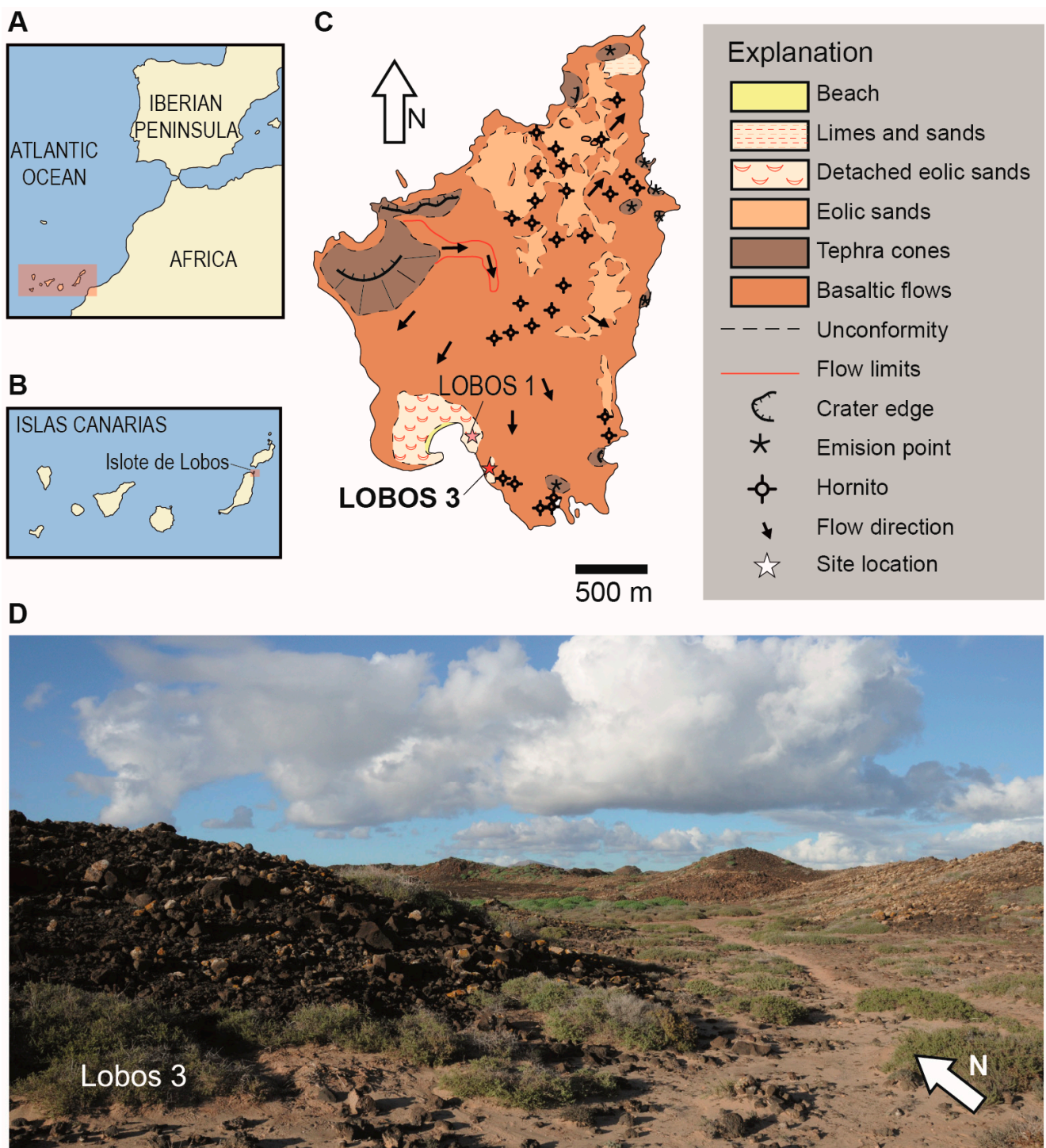
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**Abstract:** Two eggs (L29 and N28) were recovered in the Holocene site of Lobos 3, (Islote de Lobos, north Fuerteventura, Canary Islands), the site has been interpreted as a purple dye workshop from the Early Roman Empire Epoch. For the first time, eggs from a Holocene deposit of the Canary Islands have been analyzed in terms of size, shape, and biomineral structure, and studied on the basis of several thin sections and SEM analysis. The analysis of the remains allowed the assignation of both eggs to Procellariidae birds, thanks to the relative proportion of the eggshell layers and the vesiculation patterns. The size of the eggs allowed the assignation of L29 to cf. *Calonectris/Puffinus*, and to cf. *Puffinus* for N28. The absence of more structural analysis on Procellariiformes eggshells prevent a more specific assignation. The accumulation pattern of the eggs is compatible with a seasonal occupation pattern of the Roman site.

**Keywords:** *Calonectris*; *Puffinus*; complete eggs

## 1. Introduction

The Islote de Lobos is a small island located in the strait of La Bocaina, between the islands of Fuerteventura and Lanzarote, within the Canary Archipelago, in the Atlantic Ocean (Figure 1A,B). It is a small islet (467.9 ha), separated by 2 km from Fuerteventura and by 8 km from Lanzarote. Lobos and its surroundings are considered a key point for the ancient colonization of the archipelago, although it has not been continuously inhabited due to its small extension and low biological diversity [1,2]. Nowadays the islet is protected by the Islote de Lobos Natural Park since 1982. The islet appeared in the Pleistocene due to a basaltic fissural eruption in the north of Fuerteventura (Figure 1C) [3].



**Figure 1.** Geographical context of the Isote de Lobos: (A) Location of the Canary Archipelago; (B) Location of Isote de Lobos; (C) Geological map of the Isote de Lobos, the star indicates the position of the Lobos 3 Site (Modified from [4]); (D) Lobos 3 site during the field work campaigns in La Calera Beach.

In 2012 a Roman amphora Haltern 70 fragment and a shell of the murid mollusk red-mouthed rock shell (*Stramonita haemastoma*) with signals of anthropic manipulation were discovered in La Calera Beach (Figure 1D; [5,6]). The abundance of shells of *Stramonita* in spite of *Patellae* and *Osilinus* (abundant in other sites of Fuerteventura), the distinct breakage pattern, and the presence of the amphora, allowed the identification of the site (called Lobos 1) as a purple dye workshop from Early Roman Empire epoch [7] with

stational occupation. The absolute dating obtained by using pottery remains, place the site between the end of the republic and the beginning of the empire, between the Augustus and Tiberius principates (27a C–37 d. C) [8].

Archaeological prospecting in the surroundings of Lobos 1 allowed the identification of several areas with occupation signals. Among them the site of Lobos 3, which is located only a few hundred meters south-east from Lobos 1 and has the same temporal context (Figure 1C). The site of Lobos 3 is located over a Holocene Eolic sand Deposit (Figure 1C).

Faunal remains are relatively common around purple dye workshops. The vertebrate faunal assemblage of Lobos 1 includes the presence of indeterminate land and marine mammals, *Capra hircus*, *Ovis aries*, *Canis familiaris*, *Sus domesticus* and *Monachus* among other taxa [9]. Also, numerous bird remains, which are currently under analysis, were recovered from Lobos 1. Vertebrate remains from Lobos 3 site are still under analysis.

Faunal fossil remains from Canary Islands have been deeply analysed [10–12], its volcanic archipelago condition gives the fossil vertebrate fauna of Canary Archipelago a particular interest for the understanding of climatic change and insular effects in the evolution of the vertebrate faunas, with works concerning the lizard *Gallotia* or the chiropter faunas [13,14], among others. The studies about bird remains in the Fuerteventura Island, such Pecenescal or Hueso del Caballo [15,16], including remains from Isote de Lobos [17,18], can be highlighted in this context. The analysis of avian remains from Canarian sites allowed the description of new bird species, including *Coturnix gomerae* [19], *Carduelis triasi* [20], *Carduelis aureloi* [21], *Emberiza alcoveri* [22], *Puffinus olsoni* [23], and *Puffinus holeae* [24]. Also, the Canary Islands avifaunas have been deeply analysed in terms of their palaeontological record, evolutionary trends, and extinction patterns, providing also interesting results on the climatic change effects on the faunas [17,18,21,25–29].

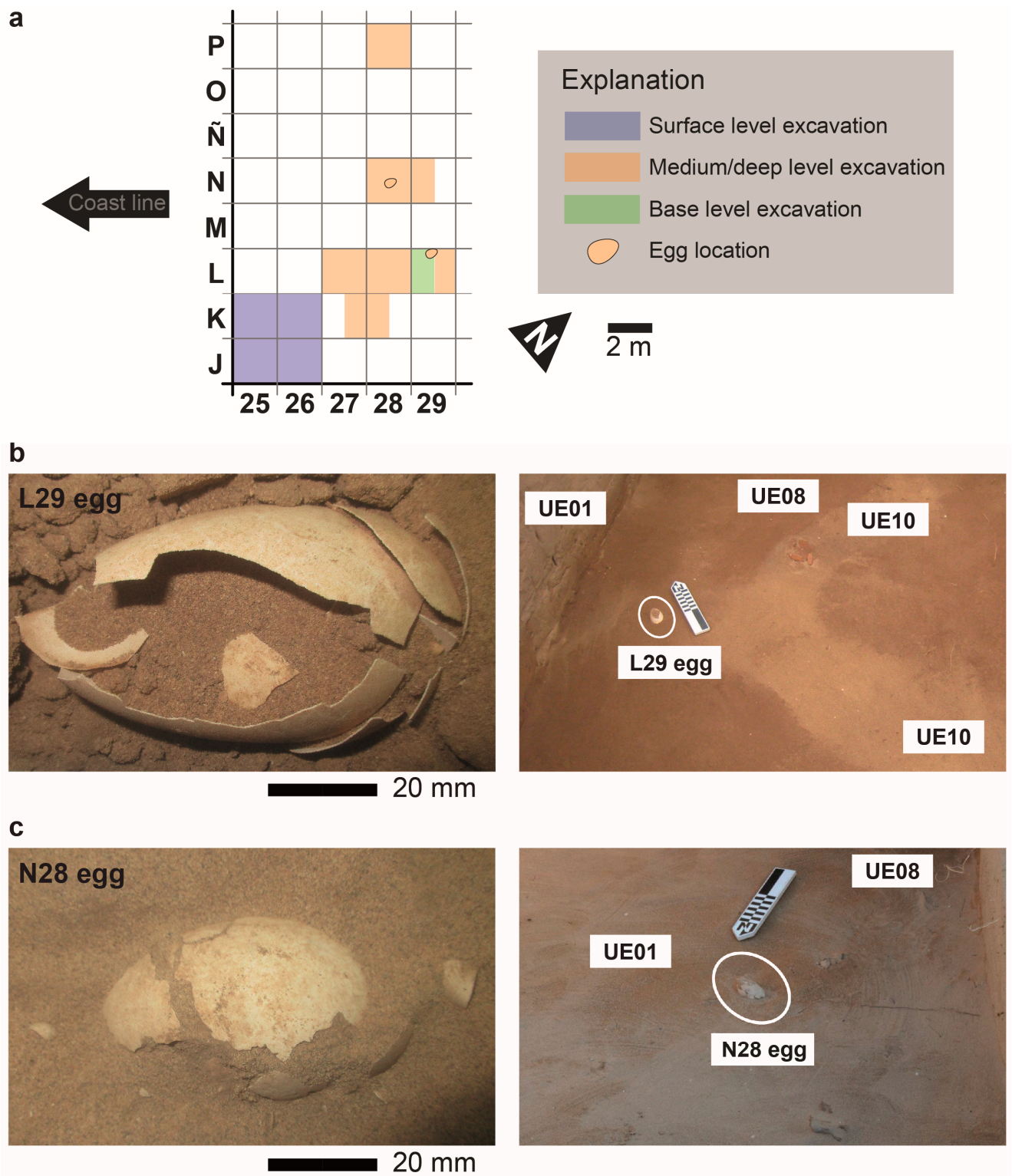
Egg remains have also been recorded in the area, although the studies concerning the biomineral analysis of the eggshells are scarce. The oldest record of eggshells come from the Pliocene of Lanzarote, assigned to *Struthio* and to an indeterminate Aepyornithidae [30], although this assignation needs to be reviewed. Ratite eggshells from Quaternary sites have been deeply studied, and even used to date sites [31–34]. The large size and thickness of the ratite eggshell's contrasts with the size of non-Ratite eggshells, which are more fragile, smaller, and considerably thinner. For this reason, the preparation of non-Ratite eggshells for analysis is very difficult, and so is the diagnosis. Thus, works on non-Ratite eggs and eggshells are much scarcer [35–37]. The analysis of eggshells can provide a lot of information concerning the palaeoenvironment [38] and the seasonality of the sites, although due to the difficulty of the methodology, eggshells from Quaternary sites are rarely analyzed with microscopy techniques.

Eggs and eggshell records are also common in the Canary Islands, appearing in sites such as Pecenescal or Hueso del Caballo, all of them related to Procellariiformes remains [15,16], but no structural analysis of the eggshells has been performed. The objective of this work is to perform for first time a systematic analysis of two non-Ratite eggs in the Canary Islands, including the analysis and characterization of their biomineral structure.

### *The Site of Lobos 3*

The site of Lobos 3 is located south-west of La Calera Beach, which is delimited by hornitos structures -small volcanic constructions- in its northern and southern edges (Figure 1C). Scattered Muricidae (murex snails) remains and roman pottery fragments found in the site confirm the Roman origin. Also, mammal (Ovicaprines), malacofaunal and fish remains, which are currently under analysis, have been recovered from the site. The Lobos 3 deposits are divided into several stratigraphic units (Figure 2a). Units UE01, UE02 and UE08 have signals of anthropic occupation.

L29 egg was recovered from the UE08 unit, lithologically light to dark yellowish-brown compacted sands. This unit is affected by the presence of a burrow, which conforms the unit UE10 (Figure 2b). N28 egg was recovered in the contact between units UE01 and UE08 (Figure 2c), UE01 is a less compacted yellow to light yellowish-brown sand deposit.



**Figure 2.** Situation of the analysed eggs: (a) Plan of the systematic excavation in Lobos 3 site; (b) L29 egg state of conservation and relative position within the Lobos 3 stratigraphic units; (c) N28 egg state of conservation and relative position within the Lobos 3 stratigraphic units.

## 2. Materials and Methods

Two complete eggs (L29, N28) from Lobos 3 site have been analysed (Figure 2b,c). They were extracted during the systematic excavation of the site in 2015. All materials were collected under the national and local legislation and are currently curated at the Museo Arqueológico de Tenerife.

### 2.1. Laboratory Work

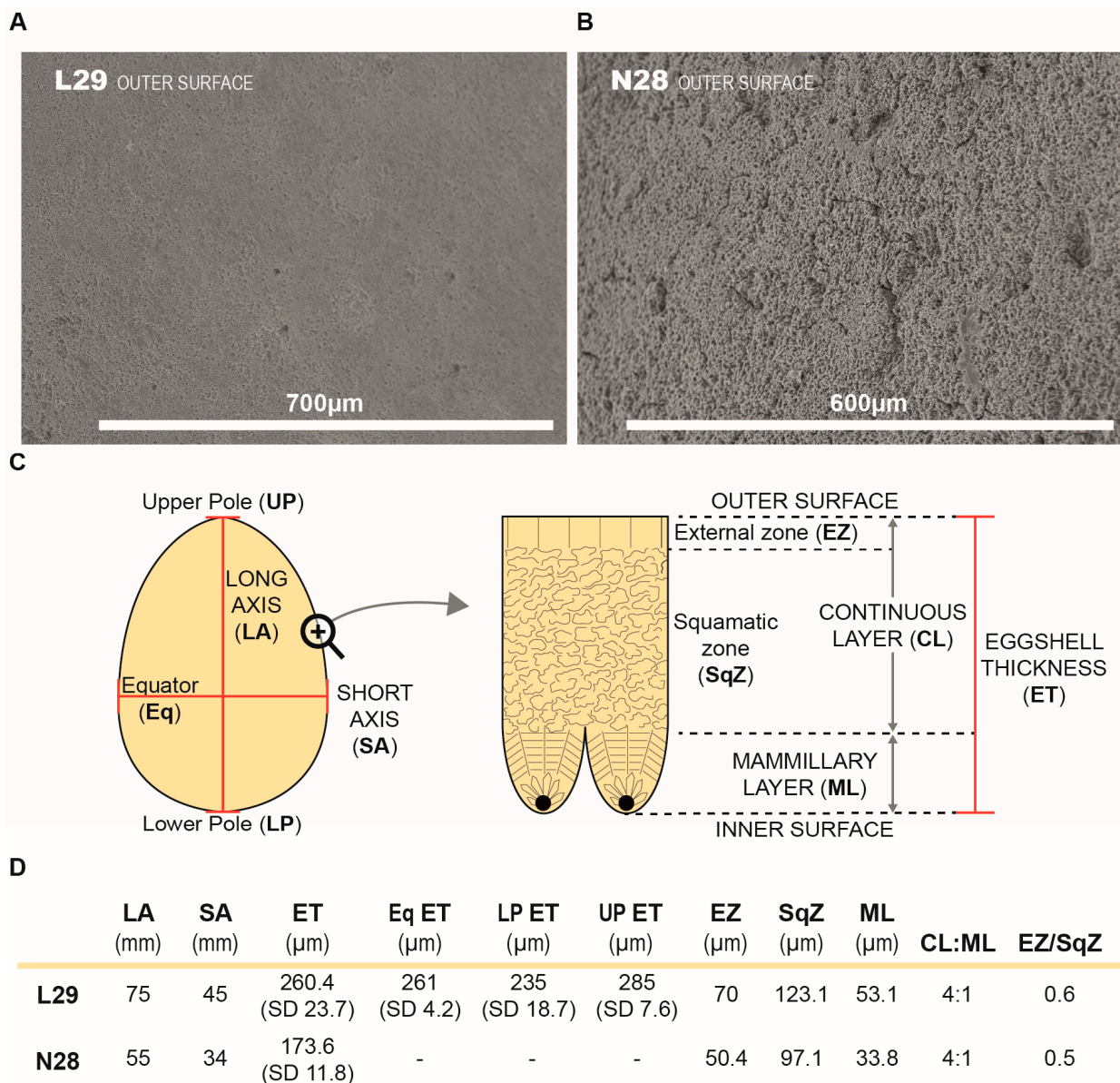
Whole eggs were photographed with a Sony- $\alpha$ 58 camera and measured using a digital-caliper (Mitutoyo Digimatic-Caliper CD-8<sup>°</sup>CX). Eggshell fragments were extracted from the complete eggs to perform microscopic analyses. Three millimetric fragments were extracted from both poles and the equatorial part of the L29 egg. Due to the fragility of the remains, only one eggshell fragment was extracted from the N28 egg. The fragments were cleaned with an ultrasound bath for three minutes and dried at “standard room conditions” overnight.

Two different sets of microscopic analysis were performed. Radial thin sections of the eggshell fragments were prepared at the Preparation of Rock and Hard Material Service of the Universidad de Zaragoza. The radial sections were performed following the methodology developed for egg and eggshell analysis [39]. The fragments were adhered to methacrylate boxes and embedded in epoxy resin, and then cut with diamond saws. The resultant sections were polished and adhered to the glass and cut again. Silicon carbide was used to polish the sections until the thickness reached 25 microns, as the high content in organic matter did not allow the observation the crystallographic features at the standard 30 microns thickness. Thin sections were observed with an Olympus BX53M petrographic microscope equipped with an Olympus DP27 digital camera, housed in the ‘Instituto Universitario de Ciencias Ambientales’ (IUCA) of the University of Zaragoza.

Scanning Electron Microscope (SEM) analysis were performed. The fragments were mounted, gold coated, and imaged with a JEOL6400 SEM using secondary electrons.

### 2.2. Identification of the Eggs

For the identification of the egg laying organism, external histo and ultra-structural characteristics were used for species identification. The data from the Birds of the World database [40] was used to compare the size and shape of the eggs with extant egg taxa. For the analysis of the structural characteristics of the eggshell, the methodology of Mikhailov [41] was applied to the SEM images. The analysed characters were the eggshell thickness, presence of different layers, the outer surface ornamentation, pore shape, and the size of the mammillae and the distance between them. The relative thickness of the different layers was also calculated (Figure 3). For each egg and character at least 20 measurements were taken using the ImageJ 1.51k Software [42]. The terminology used in the description of the eggshell follows the works of Mikhailov [41,43]. The obtained data were compared with the data provided in the Atlas developed by Mikhailov [44], which include the description of 20 orders of extant birds’ eggshell structure.



**Figure 3.** Avian eggshell parameters measured: (A) L29 egg outer surface (SEM); (B) N28 egg outer surface (SEM); (C) Avian eggshell nomenclature [41,43,44]; (D) Parameters measured in this work (SD Standard Deviation).

### 3. Results

The eggs are almost complete but crushed, thus the obtained measurements are approximated: L29 is 75 mm × 45 mm (Figure 2b), and N28 is 55 mm × 34 mm and is partially embedded in sand (Figure 2b).

Both L29 and N28 eggs present a centimetric size and a rigid structure. They are light in colour and no ornamentation patches are observed on the surface. They are asymmetrical, with a more pointed pole. Both eggs show smooth outer surfaces, with straight, narrow and individual pores (angusticanaliculated pore system), the mammillae are densely packed, and the structure shows different layers, as expected in birds' eggs [41].

The outer surfaces are smooth and pore openings are observed (Figure 3A,B). The average thickness varies between the eggs, being 260.3 µm in L29 and 174 µm in N28 (Figure 3D). No cuticles are preserved in the analyzed eggs.

### 3.1. L29 Egg

L29 egg is almost complete but broken. The size of the egg is approximated, as the fragments are not in their original position (Figure 2b). The egg is 75 mm in the long axis, and 45 mm in the short axis, with an ellipticity index of 0.58. The egg has a white colour, with brown stains due to the incubation process, no colour patches or external ornamentation are observed.

Outer surface is smooth with abundant pore openings (Figure 3A). The eggshell has an average thickness of 260.4  $\mu\text{m}$  (number of measurements  $n = 60$ , standard deviation  $\text{SD} = 23.7$ ) though it varies along the egg, being the average in the equator (261  $\mu\text{m}$ ,  $n = 20$ ,  $\text{SD} = 4.2$ ), slightly thinner in the lower pole (235  $\mu\text{m}$ ,  $n = 20$ ,  $\text{SD} = 18.7$ ) and thicker in the upper pole (285  $\mu\text{m}$ ,  $n = 20$ ,  $\text{SD} = 7.6$ ). No cuticle is preserved.

The transition between the Mammillary (ML) and Continuous Layer (CL) is clear (Figure 4A), and the CL:ML proportion is 4:1. The CL is divided in Squamatic Zone (SZ), and External Zone (EZ), the EZ/SZ ratio is 0.6.

Vesiculation is present through the eggshell, only absent on the lower part of the mammillae (Figure 4A,B). The vesicles reach the outer surface and are more abundant in the EZ, and in upper and lower parts of the SZ (Figure 4A).

The mammillae are loosely packed, and wider than taller. Mammillary reabsorption is evident in the inner surface, pointing to the high development of the embryo (Figure 4D).

In thin section, the eggshell shows no signs of recrystallization (Figure 4E,F). There is not secondary calcite growths in the outer and inner surfaces. The organic matter is concentrated in the outer surface of the eggshell, although it is present along all the structure (Figure 4E). This organic matter shows a laminar distribution in the central part of the structure, revealing the herringbone pattern in the Squamatic Zone. The extinction pattern under cross polarised light is columnar (Figure 4F).

### 3.2. N28 Egg

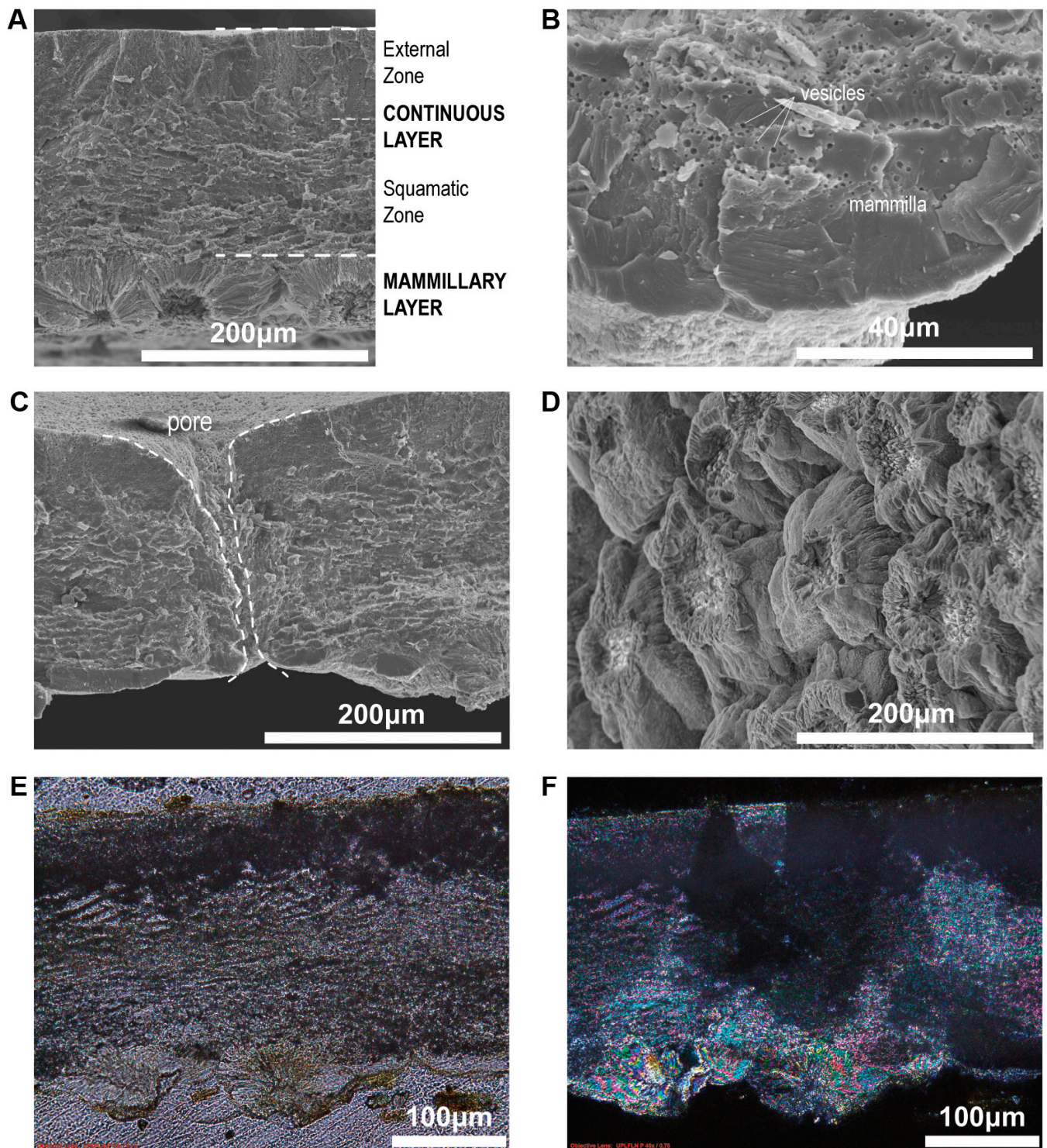
N28 egg is smaller than L29. It is also broken and embedded in sand. The fragments are apparently in their original position, although not all the egg surface is visible, thus the size calculations are also approximated (Figure 2c). The visible part of the egg is 55 mm in the long axis, and 34 mm in the short axis, though the egg probably has a bigger size. N28 egg also has a light brown colour, and no colour patches or external ornamentation are observed.

Outer surfaces are smooth, although the crystals provide a rough appearance. Due to the preservation of the egg only one fragment from the equatorial part of the egg has been analysed. N28 eggshell is thinner than L29 (average thickness 174  $\mu\text{m}$ ,  $n = 20$ ,  $\text{SD} = 11.8$ ). No cuticle has been observed.

The transition between the ML and CL is clear, and the CL:ML (Figure 5A) is 4:1. The CL is also divided in SZ and EZ, the EZ/SZ ratio is 0.5.

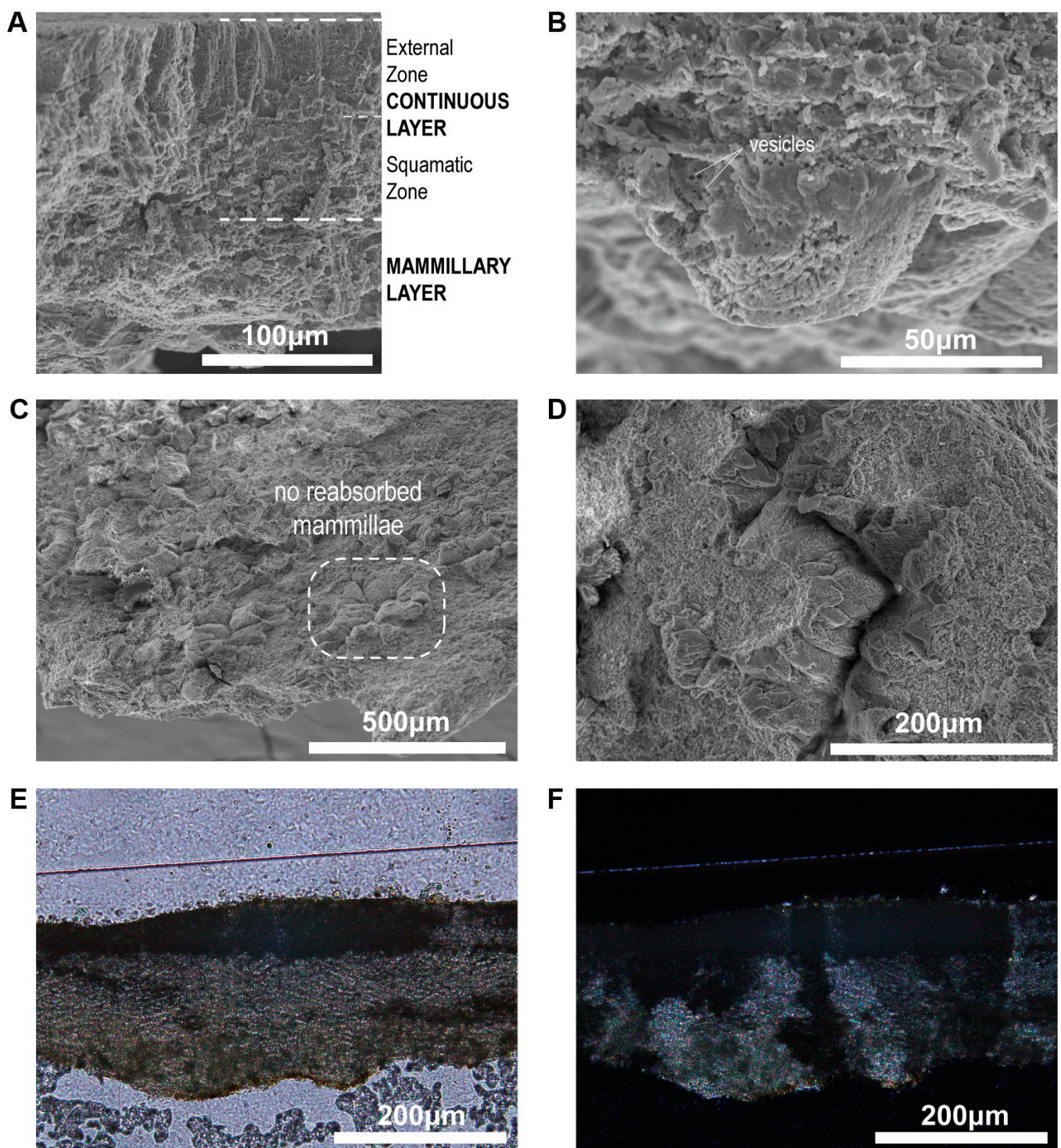
Vesiculation is present through the eggshell section, being more abundant in the EZ (Figure 5A). The ML is hard to analyse due to the preservation of the egg. Some of the mammillae are completely unabsorbed, suggesting a low to non-development of the embryo in this case (Figure 5C), although the inner surface of the egg is mostly eroded, even delaminated in some parts (Figure 5D).

The thin section is obscured by the high amount of organic matter, although no signs of recrystallization are evident. The eggshell external surface shows an irregular profile under microscope analysis (Figure 5C,D). As in L29, the organic matter is concentrated in the outer surface of the eggshell, although it is present along all the structure (Figure 5E), also the herringbone pattern in the Squamatic Zone can be observed. The extinction pattern under cross polarised light is columnar, but it is obscured due to the large amount of organic matter in most of the thin section (Figure 5F), and no signs of autogenic crystals are observed.



**Figure 4.** L29 eggshell under scanning electron microscope (SEM) and petrographic microscope (PM): (A) Radial section (SEM) showing the ultrastructure of the eggshell and position of the layers; (B) Detailed SEM image of a mammilla with vesiculation; (C) Radial section (SEM) with an angusticanaliculated pore; (D) Detailed SEM image of the inner surface of the egg; (E) Thin section (PM, non-polarised light); (F) Thin section (PM, polarised light).





**Figure 5.** N28 eggshell under secondary electron microscope (SEM) and petrographic microscope (PM): (A) Radial section (SEM) showing the ultrastructure of the eggshell and position of the layers; (B) Detailed SEM image of a mamilla with vesiculation; (C) Inner surface with no reabsorbed mammillae; (D) Inner surface with eroded mammillae; (E) Thin section (PM, non-polarised light); (F) Thin section (PM, polarised light).

#### 4. Discussion

##### 4.1. Systematic Analysis

Both eggs show a similar distribution of layers and zones, although the average thickness of the eggs varies (Figure 3D). Average thickness of N28 is lower than L29, this

could be due to the general smaller size of the N28 egg, nevertheless the numerous signs of abrasion in the N28 surfaces points to an uncertain degree of material lost in the egg, which could be partially responsible for the reduced thickness (Figure 3B). The average thickness of both eggs (174–260  $\mu\text{m}$ ) fits with several groups [44], including several coastal nesters such as Gaviiformes, Podicipediformes, Procellariiformes, Charadriiformes and Gruiformes, among others. The relative proportions between the CL and ML (Figure 3C,D) allows us to narrow the list to Procellariiformes and representatives from the families Rallidae and Laridae. In Rallidae, the contact between the layers is diffuse, the vesiculation pattern is different, and there is a thick cuticle [44]. These characters differ from those of L29 and N28 (Figures 4 and 5), as the limits between layers are clear, and there is no cuticle, thus Rallidae can be discarded. In Laridae the vesiculation is absent in the mammillae, but it is present in L29 and N28 eggs (Figures 4B and 5B). The outer surface of Laridae eggs is rough and with a mosaic pattern, absent in L29 and N28 (Figure 3A,B). In addition, pigment patches are common in Laridae [44]. These patches are not observed in the analysed samples. This set of characters allow discarding Laridae. Thus, both L29 and N28 eggs belong to Procellariiformes species.

The order Procellariiformes is composed of four families: Diomedidae, Oceanitidae, Hydrobatidae and Procellariidae, and of around 140 species, of which 96 belong to the family Procellariidae. Nowadays, 19 Procellariiformes species belonging to 8 genera (the petrels *Oceanites*, *Pelagodroma*, *Hydrobates*, *Bulweria* and *Pterodroma*, and the shearwaters *Calonectris*, *Ardenna* and *Puffinus*) inhabit the Canary Archipelago and surrounding areas. The egg size in *Oceanites*, *Pelagodroma*, *Hydrobates* and *Bulweria* representatives is clearly smaller than the size of the analysed eggs, varying around 30 to 35 mm length and 20 to 25 mm breath [45–47]. *Ardenna* eggs are clearly bigger (77–80 mm length, 48–51 mm breath) [45,48]. *Pterodroma* eggs have a similar size, though they are rounder in shape, (58.4, 43.6 mm) [45]. Only two genera fit with the size of the eggs of Lobos 3, *Calonectris* and *Puffinus*.

*Calonectris diomedea* inhabits the Canary Islands and has an egg size of 61.2 to 78.9 mm length and 41.3 to 49 mm breath [49] Among the genus *Puffinus*, two species have an egg size similar to the size of the analysed eggs: *Puffinus puffinus* and *Puffinus mauretanicus*, although only *P. puffinus* inhabits the Canary Island nowadays. *P. puffinus* egg size varies between 59.7 to 60.3 mm length and 41.0 to 41.4 mm breath [50]. Two extinct species of *Puffinus* inhabited the Canary Islands during the last thousand years: *Puffinus holeae* and *Puffinus olsoni*. *P. holeae* was described based on the remains of Hueso del Caballo site (MIS3, Fuerteventura) [24], and it is described as a bigger species than *P. puffinus*. The analysis of the temporal distribution points to the extinction of this taxon in the Canary Islands during the Holocene, prior to the first entrance of humans in the archipelago [27]. *P. olsoni* was described based on remains from Cueva de las Palomas (Fuerteventura), Los Jameos and Cueva Chica del Mojón (Lanzarote), and it has been described as a smaller species than *P. puffinus*, the remains have been dated as from the Middle Ages [23].

L29 egg size (75 mm  $\times$  45 mm) falls into the egg size range of *Calonectris diomedea*, although the eggshell thickness in *Calonectris* varies around 0.3 mm [51], which is thicker than L29. No data about the egg size of *P. holeae* is available thus it cannot be discarded as the producer of the egg. We tentatively assign the L29 egg to cf. *Calonectris/Puffinus*.

The eggshell thickness of N28 is smaller than the one of the representatives of *Calonectris* and *Puffinus* (0.23–0.34 mm) [52] (Figure 3D). The erosion in the N28 surfaces can explain this difference. Also, there's no available data about the eggshell thickness of *P. olsoni*, which has been described as a small taxon. N28 egg have been tentatively assigned to cf. *Puffinus*.

#### 4.2. Origin of the Accumulation and Seasonality Pattern

Although both L29 and N28 eggs were recovered almost complete (Figure 2) and belong to the same order, the state of development of the embryo and the general state of conservation of the microstructure is different (Figure 3A,B). L29 egg mammillae shows

more signs of reabsorption (Figure 4D), pointing to a more advanced state of development of the embryo than N28 egg (Figure 5C). This could point to a different moment of egg laying, or to a different development speed of each laying taxa.

L29 egg was recovered in the UE08, in contact with UE10, which has been interpreted as a burrow, which affects UE08 occupation level. N28 was recovered in the contact between UE01 and UE08. The presence of complete eggs in the site and the location of L29 in contact with UE10 supports the idea of the seasonal occupation of the site by the Roman dye-makers. Shearwaters nests in burrows, during the spring and summer seasons [50]; furthermore, the human exploitation of the Muricidae for the purple-dye occurs during autumn and winter. Unfortunately, the small amount of remains, and the fact that both eggs are not hatched precludes us from confirming this theory. Also, the high signs of abrasion observed in the N28 eggshell structure contrast with the fact that the egg was recovered complete. This state of conservation, with rounded edges and eroded inner and outer surfaces (Figure 3B) is usually more compatible with highly transported eggshell fragments [53]. The observed damage in the biomineral structure, with a delaminated and partially obliterated mammillary layer, and differential degrees of alteration in the same egg is compatible with the effects of fire-cooking, although this assumption cannot be affirmed, as the egg appear almost complete, and as the authors remark, fire cooking sometimes does not produce changes in the eggshell structure [54]. However, no other signs of egg exploitation have been identified in the site, and the taphonomic signals observed in this egg could be due to sediment abrasion.

## 5. Conclusions

Two complete bird eggs have been recovered in the site of Lobos 3, located in the Isote de Lobos (Canary Islands), a Holocene site identified as purple dye workshop from Early Roman Empire epoch. The characteristics of the eggs structure (CL:ML = 4:1; EZ/SZ = 0.6) allowed their assignation to procellariform birds. The analysis of the eggs size and shape allowed their assignation to cf. *Calonectris/Puffinus* and cf. *Puffinus*. Procellariidae taxa breed during spring and summer, and the Muricidae exploitation occurs during autumn and winter, thus the distribution of the eggs and human occupation signals in the levels of the site could be reflecting a seasonality pattern in the human occupation of the site.

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