Bird eggs in the diet of ancient Pompeii: An SEM analysis of archaeological avian eggshell

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Abstract

The presence of avian eggshell is often interpreted generally as evidence of food consumption. When avian eggshell is identified taxonomically it can be used as a parallel line of evidence to gain a clearer picture of ancient subsistence practices (Beacham and Durand 2007). The Pompeii Archaeological Research Project: Porta Stabia (PARP:PS) conducted excavations in Insula VIII.7 of Pompeii, a non-elite neighborhood located near the so-called entertainment district, between 2005–2012. We predicted that domesticated chicken (*Gallus gallus domesticus*) eggs would play an important role in the non-elite diet, as chickens were frequently mentioned in primary sources, were prevalent in the PARP:PS avian bone assemblage, and are often noted as being cheaper alternatives to other meat sources. We found that while chicken eggs made up the bulk of the eggshell assemblage, partridge (*Perdix perdix*) eggs made up a significant portion as well.

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Highlights

- SEM analysis of archaeological avian eggshell from Pompeii
- *Gallus gallus domesticus* and *Perdix perdix* were the most common identifications
- Examination of SEM images showed high frequency of taphonomic damage
- Embryogenesis was common especially in *Gallus gallus domesticus* and *Perdix perdix*

Keywords

Avian eggshell, chicken, eggs, *Gallus gallus domesticus*, partridge, *Perdix perdix*, Pompeii, scanning electron microscopy, subsistence practices, zooarchaeology

1. Introduction

Romans not only practiced chicken, duck and geese domestication but also raised wood and domestic pigeons and fattened turtle doves and thrushes (Ghigi 1939). The domestic chicken was the most common bird raised in Roman commercial aviaries (Johnson 1986), and they consistently outnumber bones of other avian taxa among the range of sites in Roman Italy (MacKinnon 2004). However, the taxonomic analysis of avian eggshell has rarely been employed at classical archaeological sites, with Maltby et als.'(2018) multi-disciplinary examination of chicken bone and eggshell at a Romano-British site and Sichert et als.' (2019) study of eggshell from a late Roman burial in Germany being notable exceptions. This study identifies avian eggshell using a scanning electron microscope (SEM), a technique that has been applied somewhat more frequently in the past decade (Beacham and Durand 2007; Lamzik 2013). Avian eggshell can also be identified using DNA analysis, a technique that is becoming more common (Oskam and Bunce 2012; Oskam et al. 2011; Presslee et al. 2017; Stewart et al. 2013; Stewart et al. 2014).

Identifying avian eggshell to more specific taxonomic categories and interpreting it in context with the rest of a site's faunal assemblage allows zooarchaeologists to use avian eggshell as a parallel line of evidence to gain a more detailed understanding of economic strategies (Beacham and Durand 2007; Lapham et al. 2016; Medina et al. 2011). The present study uses scanning electron microscopy to identify and interpret avian eggshell recovered from a non-elite neighborhood of pre-Roman and Roman Pompeii (c. 300 BCE–79 CE) by the Pompeii Archaeological Research Project: Porta Stabia (PARP:PS, 2005–2012).

1.1 Dietary role of eggs

Eggs are a nutrient powerhouse. All nine essential amino acids for human nutrition are found in an egg, and eggs are composed largely of proteins and fats (Romanoff and Romanoff 1949), making them a valuable source of energy. Although wild eggs are considered to be a seasonal resource, eggs are easily portable and it is possible to store them for several months during which time they are still edible (Serjeantson 2009). Domestic birds can produce eggs throughout the year and egg production even on a small scale can provide a less costly protein alternative to meat (Serjeantson 2009).

The potential contribution of eggs to ancient Mediterranean diets is likely to have increased with greater emphasis on raising birds in domestic contexts. By the latest period covered by our study, raising chickens as well as other birds was much discussed in Latin agricultural writing (most notably within the works of Columella), and archaeological evidence shows increased prevalence of chicken bones at sites in Italy and beyond (Brothwell 1997; Lauwerier 1986; Maltby et al. 2018). Additionally, the Roman idiom “from eggs to nuts” meaning “from beginning to end” as well as the presence of several recipes for eggs in the collected recipes attributed to Apicius indicates that eggs were a common part of at least some Roman diets (Grainger 2007a).

1.2 The Pompeii Archaeological Research Project: Porta Stabia

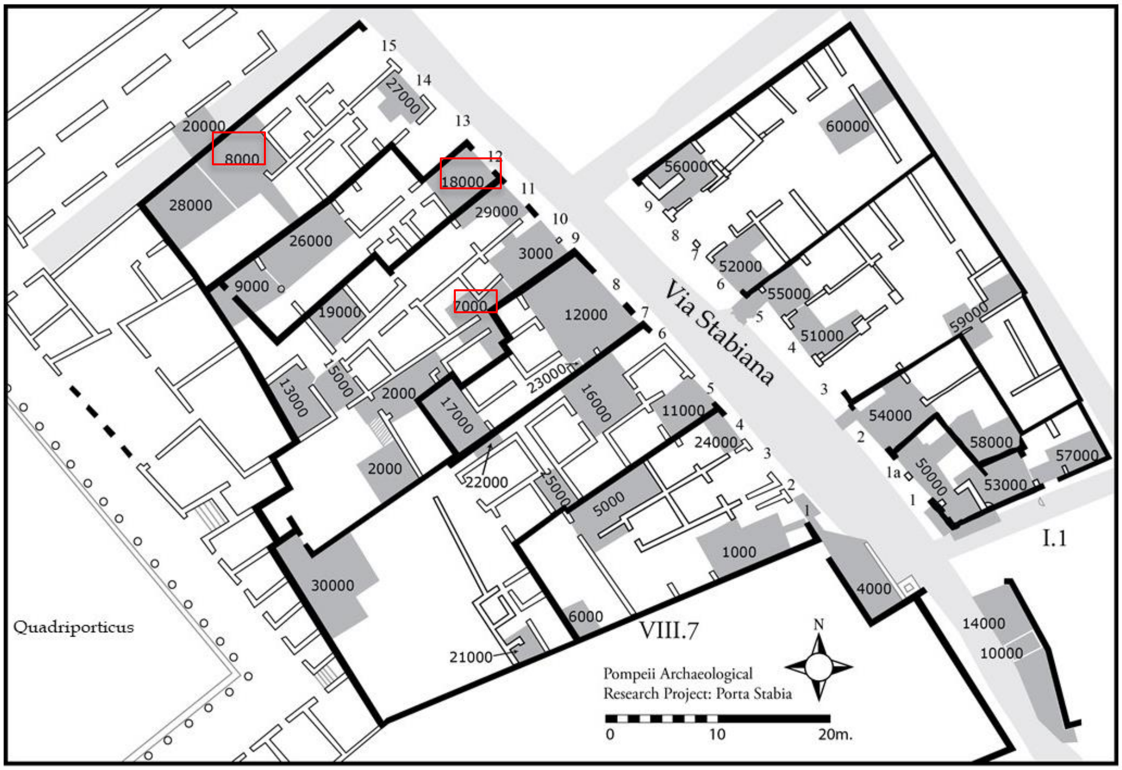


Figure 1 Map showing areas excavated by the Pompeii Archaeological Research Project: Porta Stabia; contexts discussed in this article are outlined in red.

The faunal assemblages of the Pompeii Archaeological Research Project: Porta Stabia (PARP:PS, 2005–2012: University of Cincinnati, Director Steven Ellis) present an opportunity to evaluate the contribution of eggs of different avian species to an ancient diet. PARP:PS excavated in two city blocks, Insula VIII.7 and I.1, located in the southern corner of the city.(Figure 1). PARP:PS excavated trenches in all of the structures in Insula VIII.7, which have their entrances on the via Stabiana and their rears adjacent to the rooms on the east side of the quadriporticus but without access to them. The faunal remains discussed in detail in this paper come from three excavated trenches in Insula VIII.7: 7000, 8000, and 1800 (Figure 1). These excavated areas were identified as industrial/manufacturing or commercial contexts. Phasing from the site indicates that these areas were in use from 600 BCE until the eruption of Vesuvius in 79 CE.

Larger faunal remains, including bird bones, were recovered by dry sieving excavated sediments through mesh with 1 cm^2 openings. Eggshell fragments were recovered by wet-sieving samples of excavated sediment using mesh with 1 mm^2 openings, mainly focusing on closed contexts such as deposits inside domestic drains and intact vessels. This allows us to be reasonably sure that the eggshells discussed here can be used to examine subsistence practices, as it is unlikely that there are ecological factors involved in their deposition. In total, 660 bird bones were recovered from the excavations in Insula VIII.7, with 561 identified as chicken (*Gallus gallus domesticus*) and 99 as "other bird". The majority of the recovered bird bones dated to 125 BCE–34 CE (site phases 3–5). The eggshell samples discussed here date to 80 BCE–79 CE (site phases 4-7), though they come primarily from phases 4–5.

2. Theory

2.1 Using avian eggshell to examine socio-economics

Zooarchaeologists have examined the utility of bone assemblages to developing socioeconomic models. This has often been accomplished through the examination of different butchery practices (Landon 2005; Lyman 1987; Trusler 2017), though there are a number of ways in which socioeconomic status can be expressed (Ashby 2002). In spite of this, the role that birds have played within the consumption practices of a site, both as a meat product and as a producer of eggs, has long been understudied. Due to the low cost of many bird products, including both meat and eggs, the exclusion of these products ultimately serves to undervalue the role that non-elites played within the consumption practices of a site.

Examination of food remains from classical sites, and in particular commercial or retail buildings, can reveal socio-economic differences that may not be revealed by its monumental architecture or location within a city (Ellis 2018). The diversity of food consumption that existed within Roman cities, and even between neighboring establishments in the same neighborhood, has already been demonstrated through examination of faunal bone assemblages within the Pompeian Porta Stabia neighborhood and at its neighboring city Herculaneum, both of which were buried by the eruption of Vesuvius in 79 CE (Ellis 2018; Rowan 2017).

Reconstructing the consumption practices of this Pompeian neighborhood can allow us to understand very simply what the Pompeian non-elite were both purchasing and selling to other non-elites. While this case study represents a small glimpse into the egg consumption of this neighborhood, covering a subsample of the eggshell excavated from three trenches in Insula VIII.7, it provides a framework for incorporating eggshell analyses into excavations at classical archaeological sites.

In the future a comparison between these non-elite commercial contexts and non-elite domestic contexts, as well as the addition of analyses of larger numbers of archaeological avian eggshell, could help to further develop the understanding of the non-elite consumption of birds. For instance, were the foods that were consumed within this commercial context a luxury for non-elites or did they form the same proportion in the everyday diet (essentially domestic contexts)? Though we did not examine the impact of food choices on maintaining identity in this study, the data generated would be a useful addition to a broad approach to understanding ancient identity.

The following model for avian egg prevalence at Roman archaeological sites can aid in the goal of examining the ways in which food choice, preparation and consumption all serve as a means to create and maintain identities (as suggested by Landon 2005: 21).

The examination of egg consumption will add information about an understudied aspect of the ancient socioeconomic foodscape.

2.2 Prior uses of SEM technology to examine avian eggshell

SEM identification of avian eggshell was pioneered several decades ago but has been slow to be widely applied. While some research has been done in the interpretive potential of using the presence and frequency of eggshell to examine subsistence practices (Windes 1987), few studies have attempted to taxonomically identify eggshell (Sidell 1993). Tyler (1970) attempted to identify the eggshell from Salamis using methods which included examination of the mammillary layer. Tyler (1970) also documented the eggshell features and typical variations. Keepax (1981) expanded on this research when she conducted a pioneering study into the structure of eggshell and the development of different methodologies to aid in the taxonomic identification of archaeological eggshell fragments. This methodology was not fully investigated and documented until Sidell’s core guide on the use of the SEM to identify archaeological eggshell (1993). Since then, few studies have been conducted using eggshell: so far, they include studies of turkey domestication in the American southwest (Beacham and Durand 2007; Conrad et al. 2016) and Mexico (Lapham et al. 2016), an analysis of the avian bone and eggshell assemblage from a historic American plantation (Lamzik 2013), a comparison of the eggshell assemblage from three occupations of a site in Leicester, England (Boyer 1999), and a comparison of the avian bone assemblage with the eggshell assemblage from a site in Orkney (Eastham 1997). Avian eggshell can also be identified using DNA analysis, more specifically using Zooarchaeology by Mass Spectrometry (ZooMS), and this technique is becoming more common (Oskam and Bunce 2012; Oskam et al. 2011; Presslee et al. 2017; Stewart et al. 2013; Stewart et al. 2014). The current study employs SEM methodology which allows for not only taxonomic identification of the eggshell but also examination of embryogenic and taphonomic damage.

3. Methodology

3.1 Creating a model for avian prevalence at Roman archaeological sites

We began by developing a model for the prevalence of bird eggs at Roman sites based on previous zooarchaeological research and the discussions of bird species and avian resources in Roman primary sources. Cato the Elder's *De Agricultura*, Varro's *Rerum Rusticarum* Columella's *De Re Rustica* are each a series of instructions for different agricultural matters intended for the elite Roman landowner (ancient references were drawn from translations in the Loeb Classical Library Series). Pliny the Elder's *Naturalis Historia* is an encyclopedia of the natural world covering matters from agriculture to astronomy (ancient references were drawn from translations in the Loeb Classical Library Series). The book of recipes known by modern convention as *De Re Coquinaria* (Lindsay 1997: 145) and attributed to Apicius was also used, though the nature of its authorship is much discussed and the language indicates that it dates to the 4th century CE (Grainger 2007b, Lindsay 1997). The majority of the primary sources we consulted for our study date to the same chronological range as the deposits at Pompeii where the eggshells were recovered, with the exception being Apicius, which is much later.

Birds were prevalent in the primary sources (Table 1) and were low cost, widely available birds within the Roman Empire. Based on analysis of the primary sources, we predicted that chicken (*Gallus gallus domesticus*) eggs would comprise most of the avian eggshell assemblage as chickens were the most discussed avian species in each of the primary sources studied (Table 1). We predicted that pigeon would also likely make up a significant portion of our eggshell assemblage as they are described in the primary sources as good breeders (Columella 8.8.10). Geese, which do not a large profit for farmers but were easy to care for according to Columella (8.8.3), were expected to have significant representation within our assemblage. However, the emphasis placed by the primary source authors on the excellent taste of goose meat (Pliny 10.27.52-53) and the two recipes for goose meat and six for duck meat provided by Apicius made it seem likely that goose/duck meat rather than goose/duck eggs would be the product targeted by farmers. We did not expect to find a significant amount, if any, of wild or exotic species within our assemblage due to the high energetic cost of obtaining them compared to the relative ease of access of domesticated eggs in an urban society. We did not expect that the residents of a non-elite area of Pompeii would have the wealth or personal leisure to pay such high energetic costs when domesticated eggs were a cheap alternative.

Table 1Table showing mentions of birds in the primary sources examined across ancient sources (specifically the volumes of Cato, Varro, Columella, Pliny, Apicius) counted by number of lines discussing each species.

Species	***De Agricultura*, Cato *(c. 160 BCE)***	***De Rerum Rusticarum III*, Varro *(116–27 BCE)***	***De Re Rustica*, Columella (4–70 CE)**	***Naturalis Historia*, Pliny (23–79 CE)**	*De Re Coquinaria*, **"Apicius" (4th century CE)**
Chicken	12	123	618	107	15 Recipes for Chicken: 4 Recipes for Eggs
Guinea Fowl	N/A	6	7	1	N/A
Jungle Fowl	N/A	10	N/A	N/A	N/A
Peafowl	N/A	37	200	44	N/A
Partridge	N/A	6	N/A	56	3 Recipes
Quail	N/A	2	N/A	40	N/A
Swan	N/A	N/A	N/A	15	N/A
Geese	9	48	151	90	2 Recipes
Duck	N/A	20	79	2	6 Recipes
Teal	N/A	7	N/A	N/A	N/A
Coot	N/A	6	N/A	N/A	N/A

Pigeon	11	79 (1 mention is of a wood pigeon)	136	125	2 Recipes
Turtle Dove	N/A	17	38	4	3 Recipes
Eagle	N/A	3	N/A	150	N/A
Bearded Eagle	N/A	N/A	N/A	3	N/A
Francolin	N/A	N/A	N/A	N/A	2 recipes
Kestrel	N/A	N/A	9	N/A	N/A
Hawk	N/A	2	2	45	N/A
Vulture	N/A	N/A	N/A	15	N/A
Kite	N/A	N/A	N/A	20	N/A
Kingfishers	N/A	N/A	N/A	25	N/A
Heron	N/A	N/A	N/A	5	N/A
Storks	N/A	N/A	N/A	62	N/A
Crow	N/A	1	N/A	27	N/A
Raven	N/A	N/A	N/A	83	N/A
Chough	N/A	N/A	N/A	13	N/A
Cuckoo	N/A	N/A	N/A	38	N/A
Crane	N/A	2	N/A	61	6 Recipes
Swallows	N/A	1	N/A	29	N/A
Beeeater	N/A	N/A	N/A	8	N/A
Pelicans	N/A	N/A	N/A	10	N/A
Flamingo	N/A	N/A	N/A	1	2 Recipes
Woodpecker	N/A	N/A	N/A	29	N/A
Parrot	N/A	1	N/A	11	1 Recipe
Owl	N/A	N/A	N/A	70	N/A
Ostrich	N/A	N/A	N/A	18	2 Recipe
Starling	N/A	N/A	N/A	10	N/A
Ibis	N/A	N/A	N/A	7	N/A
Thrush	N/A	10	N/A	N/A	N/A
Blackbird	N/A	4 (1 mention is of white blackbirds as a rarity)	N/A	10	N/A
Nightingale	N/A	1	N/A	42	N/A
Robin	N/A	N/A	N/A	2	N/A
Wheatear	N/A	N/A	N/A	4	N/A
Ortolan	N/A	1	N/A	N/A	N/A
Pegasus bird and Griffin	N/A	N/A	N/A	5	N/A
Phoenix	N/A	N/A	N/A	36	N/A
Sanqualis and immulsus	N/A	N/A	N/A	11	N/A
Seleucis	N/A	N/A	N/A	6	N/A

In sum, this model posits that within an avian eggshell assemblage at a non-elite

Roman site:

1. A majority of domesticated bird eggs will be present, with very few from non-domesticated birds.
2. The predominant species will be chicken (*Gallus domesticus*).
3. Pigeon (*Columba* sp.) will be the second most prevalent species in the eggshell assemblage.
4. Geese and ducks will have a significant representation, though not as prevalent as pigeons, within the eggshell assemblage.
5. There is expected to be a very small number of eggshell fragments that do not belong to these four species (chicken, pigeon, goose, or duck).
6. These species frequencies are reflective of the cost and availability of these birds within the Roman market. Only birds with a low relative cost and a wide availability should be frequent at a non-elite site. It is possible for 'other' species with a high relative cost and/or small availability to be present, but only in very low quantities.

After developing this model, we tested it through the use of an SEM to identify the avian eggshell fragments from PARP:PS to species.

3.2 Methodological background

There is a large diversity of eggshell types, which makes the identification of eggshell to species possible (Sidell 1993). There is also a great deal of variation within species, which complicates taxonomic identification (Sidell 1993). This is especially apparent with pigmentation, which may vary even within the same brood (Sidell 1993). Pigmentation also tends to be eliminated after burial, so species identification for archaeological samples based on this factor is largely impossible. Due to fluctuations within other variables such as size and shape, measurements are generally given as a range or average (Sidell 1993). It is important to make taxonomic identifications based on a number of characteristics, since there is so much variation within eggshell features (Sidell 1993). Firstly, a pore count and measurement of shell thickness can be used to taxonomically identify the eggshell. Secondly, microscopic examination of the eggshells' mammillary layer will help with identification to species.

Eggshell is composed of inner membranes, a mammillary layer made up of cones, a palisade or 'spongy' layer, and often a crystalline surface layer that produces a pitted outer appearance (Beacham and Durand 2007; Keepax 1981). Calcified mammillary knobs form on the core of the mammillary layer. These knobs are made up of crystalline calcium carbonate, and the morphology of these knobs varies according to species (Beacham and Durand 2007). The calcite crystals form from the cores or organic centers within the inner membrane, which results in the production of rounded tips (the mammillary cones) (Keepax 1981). The variation within species can be observed in both the mammillary cone shape and the distance and depth of the fissures between the cones (Sidell 1993).

The embryo obtains about 80% of its calcium requirement from these mammillary cones (Beacham and Durand 2007). The cones become increasingly pitted during embryogenesis (Beacham and Durand 2007), which is a result of the partial demineralization of the mammillary cones (Bellairs and Boyde 1969). Visible changes to the mammillary layer of the egg due to embryonic development occur about 16 days after the egg is fertilized (Lapham et al. 2016). Resorption occurs in a patterned progression starting from day 18 until the egg is hatched (Beacham and Durand 2007). A slight hole will form in the center of the mammillary cone by day 18 which becomes a broader and deeper crater as incubation progresses (Beacham and Durand 2007).

Complicating matters is that the mammillary layer is the portion of eggshell that is most susceptible to erosional processes (Beacham 2006). Decaying plant material produces acids that can destroy eggshell (Carpenter 1982). Drier and more alkaline environments resulted in higher chances of eggshell preservation in one study of naturally weathered eggshell (Clayburn et al. 2004). Low Eh, high pH soils with high levels of calcium carbonate have been shown to have the least impact on preservation potential of calcareous structures such as eggshell (Retallack 1984).

3.3 Statistical methods

We tested 121 archaeological samples out of our total 3,503 eggshell fragments (Table 2). First, we sorted the eggshell into fragment size categories: <3mm, 3-5mm, >5mm. Most of the eggshell fell within the <3mm category, with 273 3–5mm fragments, and only 38 >5mm fragments. In order to ensure that there was no bias in our sample if eggshells should fragment differently dependent on species, we chose ten fragments each from the 3–5mm, and >5mm categories. We then determined ‘priority’ for each excavated context based on several factors, including the security of the context, the time period, and the available avian bones from the context. Security was determined by whether there was determined to be any disturbance to the context, as well as whether the remains came from a ‘closed’ context such as inside an amphora. Contexts with higher numbers of avian bones were privileged over those with fewer. Based on this priority, we had a pre-determined number of fragments from each size category within a context to select for scanning electron microscopy.

Table 2 List of PARP:PS contexts with tested eggshell

					Tested eggshell		
SU	**Phase**	**Time Period**	**Short Description**	**Type**	**<3mm**	**3-5 mm**	**>5mm**
7022	7a	62-79 CE	Fill in drain under capstones SU 7010, 7013	Drain fill (primary)	4	2	1
7032	7a	62-79 CE	Fill in drain, under modern fill SU 7022	Drain fill (primary)	4	2	0
7034	7a	62-79 CE	Fill in drain, under fill SU 7032	Drain fill (primary)	4	2	3
7036	7a	62-79 CE	Fill in drain SU 7035, over SU 7037	Drain fill (primary)	4	2	2
7037	7a	62-79 CE	Fill in drain SU 7035, under SU 7036 (=SU 7034, 7038?)	Drain fill (primary)	4	2	4
7055	5a	1-34 CE	Amphora and its fill in SU 7049	Amphora fill (primary)	10	0	0
7056	5a	1-34 CE	Amphora and its fill in SU 7049 Occupation/Use	Amphora fill (primary)	10	0	0
8024	4a	80-1 BCE	Three whole amphorae and amphora fragments in fill SU 8020	Cesspit	20	0	0
18025	5a	1-34 CE	Fill in tank SU 18024	Vat/Tank Fill	21	0	0
18071	6	35-61 CE	Fill in cesspit SU 18070	Cesspit fill (primary)	20	0	0

In order to select the fragments to be identified using the SEM, we laid out all fragments from each size category in each context individually on a tray and numbered them. Next, we used a random number generator (www.random.org) to select the fragments to be tested. This process was repeated across all stratigraphic units that had been selected for identification using the SEM.

3.4 Visual identification methods

We used the standard visual identification methods described by Sidell (1993). Shell thickness was measured using an eyepiece graticule in a light microscope calibrated to mm. We took several readings from different edges of each fragment to ensure accuracy. We then took three pore counts from within the same 1 mm^2 of each eggshell fragment and calculated the average to minimize errors in counting.

3.5 Preparing avian eggshell for SEM analysis

After selecting the eggshell fragments which would be identified, we cleaned the eggshell fragments to remove any remaining dirt following flotation. We placed the samples in distilled water in an ultrasonic tank (cf. Beacham and Durand 2007 and Sidell 1993). We then removed the eggshells from the tank and placed them on paper towels to dry.

3.6 SEM identification methods

We followed the methodology suggested by Goldstein et al. (1981) for biological specimens. We used a carbon conducting double-sided sticker to mount each specimen, internal surface side up, on an aluminum stub. These stickers act as a conducting pathway between the coated eggshell fragment and the aluminum stub. The creation of this conducting pathway is crucial, as it prevents the sample from becoming electrically charged, as it would be if isolated from the microscopes stage (Goldstein et al. 1981).

We then placed the stubs with mounted specimens in a gold sputter coater for a six-minute cycle. This step was to increase the conductivity of the sample as biological materials have a high electrical resistivity and will rapidly accrue an electrical charge from the electron beam (Golstein et al. 1981). After each fragment was coated, we used a Hitachi S3200N scanning electron microscope to take images of each fragment. We used a standard working distance of 50 micrometers and took image captures at 100X, 300X and 800X magnification (cf. Sidell 1993).

We examined each SEM image and looked at several factors to determine taxonomic identification: pore count per mm^2, mammillae definition, mammillae shape, mammillae spacing, and the depth of the fissures between the cones (Table 3). Mammillae shape, size, and spacing was defined as regular (R), fairly regular (F), slightly irregular (S), or irregular (I) (Figure 2). Regular is defined as having the same general shape, size or spacing across ≥90% of the SEM image. Fairly regular shape, size, or spacing is consistent across ≥75% of the SEM image. Slightly irregular shape, size, or spacing has a non-uniform appearance to one of these characteristics across ≤25% of the SEM image. Irregular shape, size or spacing indicates that there is inconsistency in the appearance of one of these characteristics across ≥90% of the SEM image.

The mammillae definition was judged to be either well, fair, or poor; well-defined mamillae are distinct, compact shapes, fair mammillae have distinct shapes but appear less compact then well-defined mammillae, poor defined mammillae have little to no definition to the individual mammillae (Figure 3).   The fissure depth was defined as shallow, moderate, or deep (Figure 3). In avian eggshell, sutures join individual mamillary cones; with shallow fissures these sutures between cones are visible, sometimes giving the appearance that there is little to no space between the cones. Moderate fissures may have some sutures visible but the mammillary cones sit visibly apart from each other. Deep fissures appear as distinct black spaces between the mamillary cones with no sutures visible. In some instances, the fissure depth was given as a range. Sidell (1993) used these distinctions when describing the characteristics of the mammillary layer but did not explicitly define them.

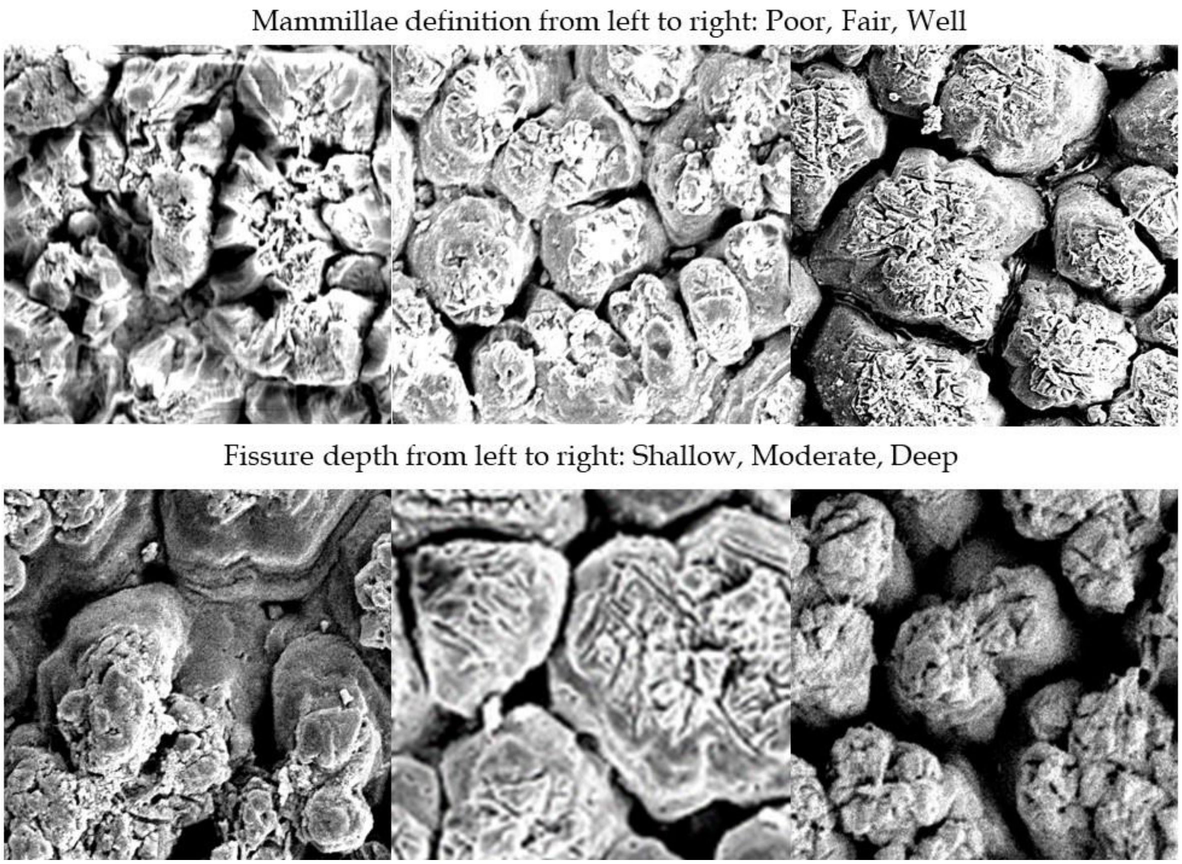


Table 3 Factors considered when determining eggshell speciation

Characteristic	Mammillae Definition	Mammillae Shape	Mammillae Size	Mammillae Spacing	Depth
Descriptions	Poor	Irregular (I)	Irregular (I)	Irregular (I)	Deep
	Well	Slightly Irregular (S)	Slightly Irregular (S)	Slightly Irregular (S)	Moderate
	Fair	Fairly Regular (F)	Fairly Regular (F)	Fairly Regular (F)	Shallow
		Regular (R)	Regular (R)	Regular (R)	

To make these assignments, Taivalkoski and Holt assessed each criterion independently and then compared assessments. In the instances when our assessments did not initially match, we discussed our reasons for making our assessments until a consensus was reached. We also assigned a confidence level for each assessment (low, medium, high).

Using these assessments, together with the quantitative assessments we had obtained using a light microscope (number of pores and thickness), we were able to determine what species each eggshell likely belonged to. We used Sidell (1993) as a reference for both measurements/counts and images of mammillary cone characteristics.

Lastly, each image was assessed for evidence of embryogenesis and/or taphonomic damage. Both of these processes result in obfuscation of the mammillary cones and thus it can be difficult to reliably distinguish taphonomic damage from incubation (Sichert et al. 2019). Beacham and Durand (2007) describe three categories for eggshell resorption: (i) 'No Resorption' is shown in eggs from day zero to 16 of incubation; (ii) 'Minimal Resorption' (MR), shown by days 18–22; and (iii) 'Significant Resorption' (SR), shown from day 24 to hatching. Embryonic resorption occurs in uniform patterns (Beacham and Durand 2007). Taivalkoski assigned each eggshell fragment to one of these categories by visually examining the SEM images; resorption was only noted where it occurred uniformly across the fragment surface. Taphonomic damage was noted when there was non-uniform patterning of mammillary cone obliteration (cf. Clayburn et al. 2004; Morel 1990). Taphonomic damage was assessed on a 1–5 scale based on categorizations defined by Sichert et al. (2019): 1) not assessible 2) uncorroded 3) surface mostly uncorroded with corroded zone(s) 4) surface mostly corroded with uncorroded zone(s) 5) surface uniformly corroded.

4. Results

*Table 4 Identifications and characteristics of PARP:PS eggshell fragments. Thickeness, pore/mm2, depth of fissures, and mammillae characteristics are all used to identify taxon. Resorption is used to identify embryogenesis stage. *I=Irregular, R=Regular, F=Fairly Regular, S=Slightly Irregular **MR=Minimal Resorption, SR=Significant*

*Resorption ***1=not assessible, 2=uncorroded, 3=surface mostly uncorroded with corroded zone(s), 4=surface mostly corroded with uncorroded zone(s), 5=surface uniformly corroded.*

Eggshell ID	Species	Thickness	Pore/mm2	Mammillae Characteristics*				Depth of Fissures	Resorption**	Corrosion***
				Definition	Shape	Size	Spacing			
SU 7022A	*unidentifiable*	0.45	3						n/a	5
SU 7022B	*unidentifiable*	0.4	2						n/a	5
SU 7022C	*unidentifiable*	0.2	2						n/a	5
SU 7022D	*unidentifiable*	0.15	1						n/a	5
SU 7032A	*Gallus gallus domesticus*	0.2	2	Well	I	I	R	Moderate	SR	3
SU 7032B	*Gallus gallus domesticus*	0.25	2	Well	I	I	R	Deep	MR	3
SU 7032C	*Gallus gallus domesticus*	0.3	3	Well	I	I	R	Deep	No	2
SU 7032D	*Gallus gallus domesticus*	0.25	3	Well	I	I	I	Moderate	No	3
SU 7034A	*Gallus gallus domesticus*	0.3	2	Well	I	I	I	Moderate	No	3
SU 7034B	Not chicken	0.2	2	Well	I	I	R	Moderate	No	2
SU 7034C	*Gallus gallus domesticus*	0.15	1	Well	I	I	R	Deep	No	2
SU 7034D	*Gallus gallus domesticus*	0.2	2	Well	I	I	F	Deep/Moderate	No	2
SU 7036A	*Perdix perdix*	0.2	4	Well	R	I	I	Deep-Shallow	No	2
SU 7036B	*Perdix perdix or Anas sp. Domestic*	0.2	2	Well	I	I	I	Shallow-Deep	MR	2
SU 7036C	*Most similar to cormorant*	0.2	2	Poor	I	I	I	Shallow-Deep	SR	3
SU 7036D	*Columba sp.*	0.3	2	Well	I	I	I	Shallow-Deep	No	2
SU 7037A	*Perdix perdix*	0.4	2	Well	I	I	I	Deep	No	2
SU 7037B	*Perdix perdix*	0.4	2	Well	I	I	F	Moderate	No	2
SU 7037C	*Gallus gallus domesticus*	0.35	2	Well	I	I	F	Shallow-Deep	No	2
SU 7037D	*Perdix perdix*	0.35	2	Fair	I	I	I	Shallow-moderate	No	2
SU 7055A	*Gallus gallus domesticus*	0.3	2	Well	I	I	F	Deep	No	2
SU 7055B	*Perdix perdix*	0.3	2	Well	I	I	R	Deep	No	2
SU 7055C	*Perdix perdix*	0.25	1	Well	I	I	R	Deep	No	2
SU 7055D	*Gallus gallus domesticus*	0.2	2	Well	I	I	R	Moderate-Deep	MR	2
SU 7055E	*Gallus gallus domesticus*	0.2	1	Well	I	I	F	Moderate-Deep	No	2
SU 7055F	*Perdix perdix*	0.15	1	Well	I	I	F	Moderate-Deep	MR	2

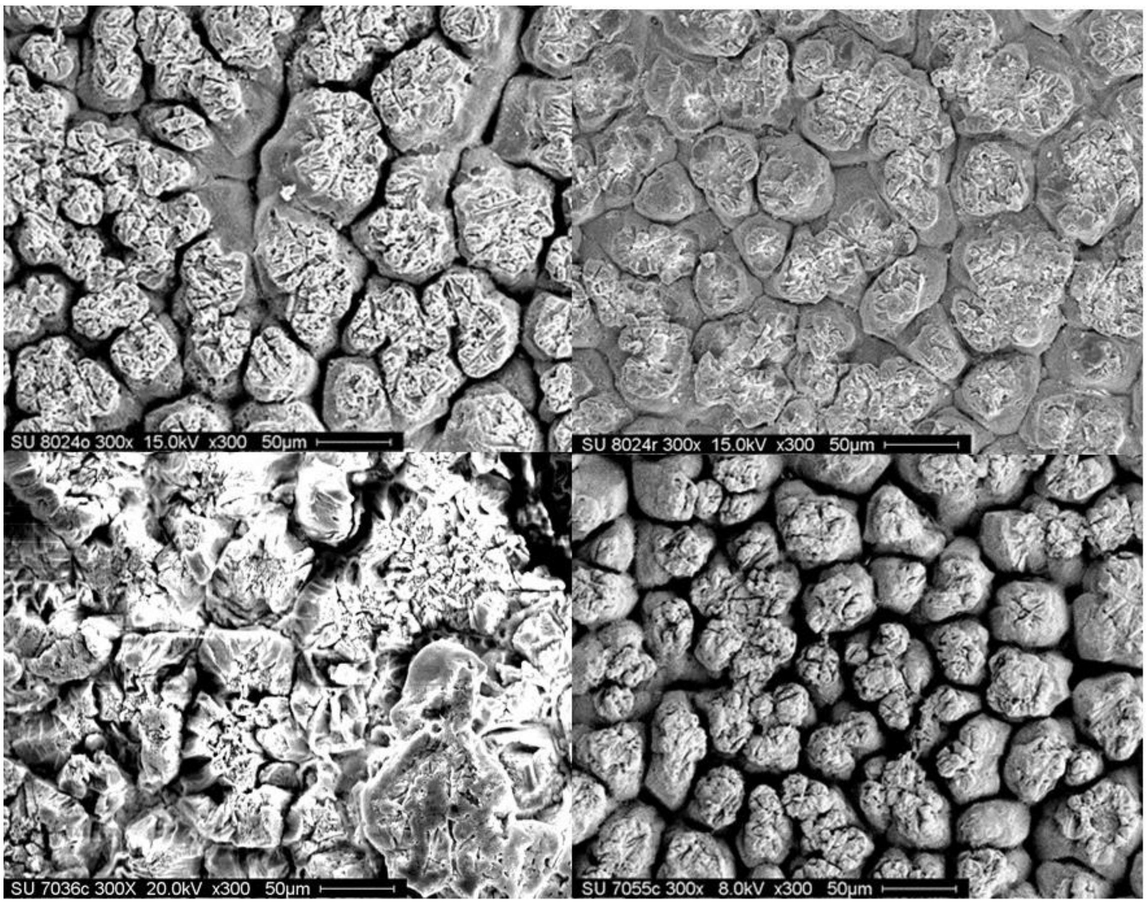
SU 7055G	*Perdix perdix*	0.2	3	Fair	I	I	F	Deep	No	3
SU 7055H	*Gallus gallus domesticus*	0.25	2	Well	I	F	R	Deep	MR	2
SU 7055I	*Gallus gallus domesticus*	0.2	2	Well	I	I	R	Moderate	MR	2
Su 7055J	*Gallus gallus domesticus*	0.3	2	Fair	I	I	I	Deep	No	2
SU 7056A	*Gallus gallus domesticus*	0.2	2	Well	I	I	F	Moderate-Deep	MR	2
SU 7056B	*Gallus gallus domesticus*	0.2	3	Fair	I	I	I	Deep	MR	2
SU 7056C	*Gallus gallus domesticus*	0.2	2	Well	I	I	I	Moderate-Deep	No	2
SU 7056D	*Perdix perdix*	0.2	5	Well	I	I	I	Moderate-Deep	No	2
SU 7056E	*Gallus gallus domesticus*	0.2	1	Well	I	I	I	Moderate-deep	No	2
SU 7056F	*Gallus gallus domesticus*	0.2	2	Well	I	I	I	Moderate-deep	No	2
SU 7056G	*Gallus gallus domesticus*	0.25	2	Well	I	I	I	Moderate-deep	No	2
SU 7056H	*Gallus gallus domesticus*	0.15	1	Well	I	I	I	Moderate-deep	No	2
SU 7056I	*Gallus gallus domesticus*	0.25	2	Well	I	I	I	Moderate-deep	MR	2
SU 7056J	*Perdix perdix*	0.2	3	Well	F	I	I	Moderate-deep	No	2
SU 8024A	*Gallus gallus domesticus*	0.15	2	Well	I	I	I	Moderate-deep	No	2
SU 8024B	*Gallus gallus domesticus*	0.25	1	Well	I	I	I	Moderate	MR	2
SU 8024C	*Gallus gallus domesticus*	0.25	1	Well	I	I	I	Moderate	MR	2
SU 8024D	*Perdix perdix*	0.25	3	Well	I	I	I	Moderate-Deep	MR	3
SU 8024E	*Gallus gallus domesticus*	0.3	1	Fair	I	I	I	Moderate	No	3
SU 8024F	*Gallus gallus domesticus*	0.25	1	Well	I	I	I	Moderate-Deep	No	2
SU 8024G	*Gallus gallus domesticus*	0.3	2	Well	I	I	I	Moderate-Deep	MR	2
SU 8024H	*Gallus gallus domesticus*	0.2	1	Well	I	I	I	Deep	No	4
SU 8024I	*Gallus gallus domesticus*	0.2	3	Well	I	I	I	Moderate	No	2
SU 8024J	*Gallus gallus domesticus*	0.2	2	Fair	I	I	I	Moderate	No	2
SU 8024K	*Gallus gallus domesticus*	0.3	2	Fair	I	I	I	Moderate-Deep	No	3
SU 8024L	*Gallus gallus domesticus*	0.3	1	Well	I	I	I	Moderate-Deep	No	2
SU 8024M	*Gallus gallus domesticus*	0.3	2	Well	I	I	I	Moderate-Deep	No	2
SU 8024N	*Gallus gallus domesticus*	0.25	3	Well	I	I	I	Moderate-Deep	No	2
SU 8024O	*Gallus gallus domesticus*	0.3	1	Well	I	I	I	Moderate-Deep	No	2
SU 8024P	*Gallus gallus domesticus*	0.3	3	Well	I	I	I	Moderate-Deep	No	2
SU 8024Q	*Gallus gallus domesticus*	0.3	3	Well	I	I	I	Moderate-Deep	No	2
SU 8024R	*Columba sp.*	0.3	3	Well	I	I	I	Moderate-Deep	No	2
SU 8024S	*Gallus gallus domesticus*	0.3	2	Well	I	I	I	Shallow-Moderate	No	3

SU 8024T	*Perdix perdix*	0.3	2	Well	I	I	I	Shallow-Moderate	MR	3
SU 18025A	*Gallus gallus domesticus*	0.25	2	Well	I	I	I	Deep	No	2
SU 18025B	*Gallus gallus domesticus*	0.3	3	Well	I	I	I	Moderate	No	2
SU 18025C	*Gallus gallus domesticus*	0.2	2	Well	I	I	I	Moderate	No	2
SU 18025D	*Gallus gallus domesticus*	0.3	4	Well	I	I	I	Deep	No	2
SU 18025D	*Gallus gallus domesticus*	0.25	3	Fair	I	I	I	Moderate	MR	2
SU 18025E	*Gallus gallus domesticus*	0.2	1	Well	I	I	I	Moderate-Deep	MR	2
SU 18025F	*Gallus gallus domesticus*	0.3	2	Well	I	I	I	Deep	No	2
SU 18025G	*Gallus gallus domesticus*	0.25	3	Well	I	I	I	Moderate-Deep	No	2
SU 18025H	*Gallus gallus domesticus*	0.3	4	Fair	I	I	I	Moderate-Deep	No	2
SU 18025I	*Gallus gallus domesticus*	0.25	2	Well	I	I	I	Moderate	No	2
SU 18025J	*Perdix perdix*	0.3	2	Well	I	I	I	Deep	MR	2
SU 18025K	*Gallus gallus domesticus*	0.3	3	Fair	I	I	I	Shallow	No	3
SU 18025L	*Gallus gallus domesticus*	0.25	2	Fair	I	I	I	Moderate-Deep	No	2
SU 18025M	*Gallus gallus domesticus*	0.25	2	Fair	I	I	I	Moderate	No	2
SU 18025N	*Gallus gallus domesticus*	0.25	3	Well	I	I	I	Shallow	No	2
SU 18025O	*Gallus gallus domesticus*	0.3	2	Well	I	I	I	Deep	No	2
SU 18025P	*Phasianidae or Anseridae*	0.3	3	Well	I	I	I	Deep	No	2
SU 18025Q	*Perdix perdix*	0.25	2	Fair	I	I	I	Moderate-Deep	No	3
SU 18025R	*Gallus gallus domesticus*	0.25	3	Well	I	I	I	Moderate	No	2
SU 18025S	*Gallus gallus domesticus*	0.25	2	Well	I	I	I	Moderate-Deep	No	3
SU 18025T	*Gallus gallus domesticus*	0.25	2	Well	I	I	I	Shallow-Moderate	No	2
SU 18071A	*Gallus gallus domesticus*	0.3	2	Well	I	I	I	Moderate-Deep	No	2
SU 18071B	unidentifiable	0.3	1	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 18071C	unidentifiable	0.2	1	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 18071D	unidentifiable	0.3	2	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 18071E	*Gallus gallus domesticus*	0.25	2	Well	I	I	I	Moderate	n/a	4
SU 18071F	unidentifiable	0.2	2	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 18071G	unidentifiable	0.3	1	n/a	n/a	n/a	n/a	n/a	No	5
SU 18071H	*Gallus gallus domesticus*	0.2	1	Fair	I	I	I	Moderate	n/a	3
SU 18071I	unidentifiable	0.3	2	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 18071J	unidentifiable	0.3	2	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 18071K	unidentifiable	0.2	2	n/a	n/a	n/a	n/a	n/a	n/a	5

SU 18071L	unidentifiable	0.3	?	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 18071M	unidentifiable	0.2	2	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 18071N	unidentifiable	0.3	2	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 18071O	unidentifiable	0.2	3	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 18071P	unidentifiable	0.3	3	Fair	I	I	I	Deep	MR	2
SU 18071Q	unidentifiable	0.3	?	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 18071R	unidentifiable	0.2	?	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 18071S	unidentifiable	0.25	2?	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 18071T	*Gallus gallus domesticus*	0.3	2?	Fair	I	I	I	Shallow	No	3
SU 7022(3-5)A	*Perdix perdix*	0.3	3	Poor	I	I	I	Shallow-Moderate	No	3
SU 7022(3-5)B	unidentifiable	0.2	3	n/a	n/a	n/a	n/a	n/a	MR	4
SU 7022(5)	*Gallus gallus domesticus*	0.3	2	Well	I	I	I	Deep	MR	2
SU 7032(3-5)A	*Gallus gallus domesticus*	0.2	3	Well	I	I	I	Moderate	No	2
SU 7032(3-5)B	unidentifiable	0.3	2	Poor	I	I	I	Shallow-Moderate	MR	2
SU 7034(3-5)A	*Perdix perdix*	0.2	2	Fair	I	I	I	Shallow	No	2
SU 7034(3-5)B	*Gallus gallus domesticus*	0.2	2	Well	I	I	I	Moderate-Deep	No	2
SU 7034(5)A	unidentifiable	0.3	3	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 7034(5)B	unidentifiable	0.3	3	n/a	n/a	n/a	n/a	n/a	MR	4
SU 7034(5)C	unidentifiable	0.2	3	n/a	n/a	n/a	n/a	n/a	n/a	5
SU 7036(3-5)A	unidentifiable	0.2	2	Poor	I	I	I	n/a	MR	2
SU 7036(3-5)B	unidentifiable	0.25	2	n/a	n/a	n/a	n/a	n/a	No	2
SU 7036(5)A	unidentifiable	0.25	3	n/a	n/a	n/a	n/a	n/a	MR	3
SU 7036(5)B	unidentifiable	0.2	3	n/a	n/a	n/a	n/a	n/a	SR	2
SU 7037(3-5)A	*Gallus gallus domesticus*	0.2	3	Well	I	I	I	Moderate	MR	2
SU 7037(3-5)B	*Gallus gallus domesticus*	0.2	2	Well	I	I	I	Moderate-Deep	No	3
SU 7037(5)A	unidentifiable	0.25	3	n/a	n/a	n/a	n/a	n/a	No	4
SU 7037(5)B	unidentifiable	0.2	2	Poor	I	I	I	Deep	No	4
SU 7037(5)C	unidentifiable	0.2	3	n/a	n/a	n/a	n/a	n/a	No	5
SU 7037(5)D	unidentifiable	0.25	3	n/a	n/a	n/a	n/a	n/a	No	5

4.1 Taxonomic Identifications

We were able to positively identify 87 of the 121 total specimens to some taxonomic level: 67 chicken (*Gallus gallus domesticus)*, 16 partridge (*Perdix perdix*), 2 pigeon (*Columba* sp.), and 1 possible seabird most similar to a cormorant (*Phalacrocorax corbo* (Table 4).



Representative images for the four species identified: Top left Gallus gallus (SU 8024O), Top Right Columba sp. (SU8024R), Bottom Left seabird most similar to cormorant (SU 7036C), Bottom Right Phasianidae (SU 7055C).

Chicken eggs were present in every context with identifiable fragments, and partridge eggs were present in all but two; one of these contexts contained the possible seabird. The identification of the seabird was based on the irregular appearance of the fissures, which were almost obliterated in some areas, due to a combination of embryogenesis and taphonomic damage. This fragment was similar to the cormorant; however, the mammillary cones did not match completely with the cormorant image from Sidell's guide (1993). This fragment could also potentially come from a Passerine, or songbird, based on the shape and spacing of the mammillary cones, but we were unable to identify the fragment further because the rest of the variables that could be used to identify it to species were ambiguous. Partridge eggshells were absent from 2/3 of the examined drain contexts, though it is unclear whether this is significant at this time.

4.2 Taphonomic Damage

Forty-eight fragments showed some level of taphonomic degradation; 23 of these were unable to be identified due to the degree of taphonomic degradation. These types of damage are consistent with expected taphonomic processes such as abrasion and erosion from slightly acidic soils (Clayburn et al. 2004; see Figure 2). In addition, there was one stratigraphic unit (SU 18071) which had 12 eggshell fragments which were not able to be identified due to degradation.

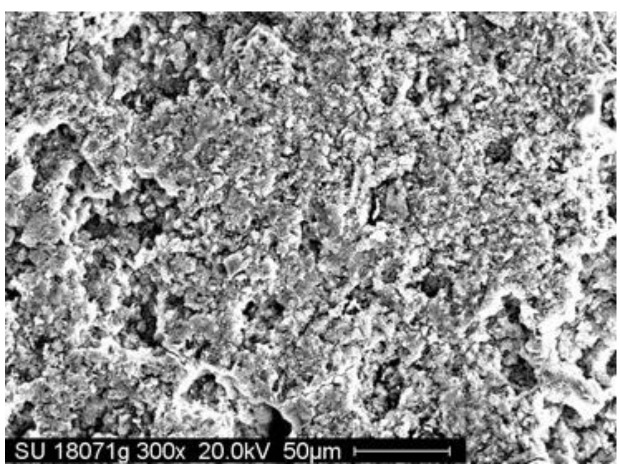


Figure 2 Image showing probably weathered eggshell from SU 18071(Eggshell ID 18071G)

The majority of the >5mm samples were unidentifiable due to taphonomic damage (7 of 10 samples). In addition, one of the >5mm samples could not be identified due to a combination of erosion of the mammillae due to embryogenesis and corrosion due to taphonomic damage. In contrast, only one of ten 3–5mm samples and 15 of 101 <3mm samples were not able to be identified due to taphonomic damage. Initially we thought that this could have been due to preparation error. For example, large surface cracks may be caused by movement of the coated layer, the appearance of large particulate matter may be caused by dust and dirt, and obscured surface detail may be caused by too much coating (Goldstein et al. 1981). These errors seem unlikely, however, as these samples were the ones put through the scanning electron microscope last, when our ability to execute our methodology was at its best. In addition, all samples were put into the agitation tank on the same day, so the fact that this degradation was limited to such a specific portion of the samples makes it improbable that the damage occurred during cleaning. The counting of pores and measurements of the eggshell fragments were done on different days in the order in which they were put through the SEM.

4.3 Embryogenesis

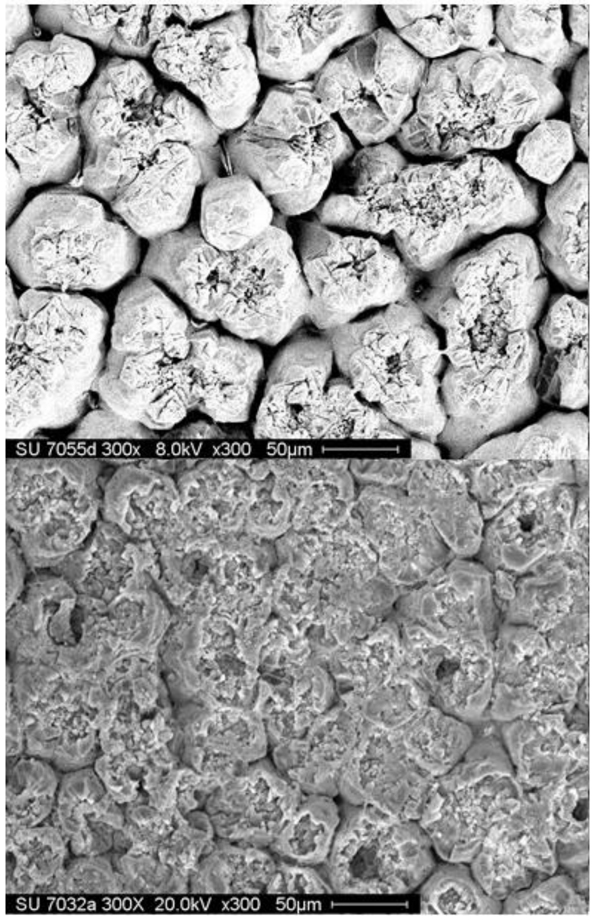


Figure 3 PARP:PS eggshell fragments (left: Eggshell ID 7055D top, Eggshell ID 7032A bottom) showing eggshell resorption . Top image shows minimal resorption, bottom image shows significant resorption.

Twenty-eight fragments exhibited evidence for embryogenesis (Figure 3). Fifteen chicken, four partridge, and six unidentified fragments showed minimal resorption. Two of the non-identifiable fragments with minimal resorption also showed signs of taphonomic damage. One chicken, the possible seabird, and one unidentified fragment showed significant resorption (See Table 4). In sum, about 23% of chicken and 27.7% of partridge showed evidence of embryogenesis.

5. Discussion

Chicken fragments made up the majority of our avian eggshell assemblage, as we predicted. We did not expect partridge to make up such a large percentage of our sample.

The prevalence of partridge eggshell in our assemblage is interesting as there are no references to partridge in Cato or Columella and only six references in Varro. This is surprising since the presence of so many eggs, many showing significant evidence of embryogenesis, indicates the possibility of partridge being raised for food. Pliny has a chapter on partridge in his *Natural History* (10.51) and though he does not expound on the keeping of tame partridge he does make a distinction between wild and tame partridge (10.51). The brief references to partridge in Varro and Pliny indicate that at least some Roman farmers raised partridge for meat, though perhaps not as commonly as they raised chicken or pigeon, which are frequently referenced in Cato, Varro, and Columella.

According to Grainger (2006), Apicius lists three recipes for partridge meat but makes no mention of partridge eggs, which could suggest that the residents of this non-elite neighborhood were consuming partridge eggs but not the higher status partridge meat. This is further supported by the relative absence of partridge bones in the archaeological assemblage. It is also possible that some of the birds were hatched and kept as breeding birds as the presence of significantly resorbed partridge eggshell would indicate. This could underscore the elite status of partridge meat and indicate that partridge farmers sometimes also sold excess eggs to poorer Pompeians. Perhaps raising partridges for meat was a strategy of poorer Pompeians, which could explain the prevalence of embryogenesis in the partridge eggshells, who consumed only the eggs but occasionally sold the meat for higher prices. It is also possible that non-elite Pompeians were collecting wild partridge eggs to sell in the restaurants and shops of insula VIII.7, but it is more likely that partridges were being raised mainly for eggs, or that the partridge meat was sold to elites while the eggs were kept for the non-elites. Regardless, these findings lead further credence to the idea that we should not be so quick to draw direct associations about social status from food remains (Ellis 2018).

We expected to find a large percentage of pigeon eggshell, but this was not the case. In contrast to partridge, there are several references to raising or fattening pigeons in the primary sources (Cato, *Agr*. 90.91; Columella 8.8.1–2; Ghigi 1939). In addition, according to Grainger (2006), Apicius mentions two recipes for pigeon. It should be noted that both partridge and pigeon eggs are quite small, averaging about half the size of a chicken egg.

This case study represented a small sample of the eggshell assemblage from three trenches in Insula VIII.7 of the Porta Stabian neighborhood of Pompeii. Examination of larger samples, and from larger areas of ancient cities, can add valuable information on the diversity of food resources and potential associated socio-economic differences. Combining taxonomic eggshell identification with broader zooarchaeological studies can provide a more holistic view of ancient foodscapes.

In future studies, it would be beneficial to attempt to distinguish between wild and domestic eggs, especially in the case of partridge. The exploitation of wild eggs was likely an important interaction between the culture and the ecosystem (Stewart et al. 2013). Since we suspect there is some inclusion of wild eggs in this sample, the additional information which could be gained by distinguishing between wild and domesticated eggs would add greatly to our understanding of Roman subsistence practices.

Further, more concrete methodologies to distinguish the corrosion caused by incubation and that of taphonomic damage will allow archaeologists to clearly identify eggs that have undergone embryogenesis. As both processes can cause corrosion to the inner eggshell surface it can be difficult to accurately identify incubated eggs (Sichert et al. 2019), although the corrosion caused by taphonomic damage tends to be irregular (Clayburn et al. 2004; Morel 1990) while incubated eggs tend to show uniform patterns of corrosion (Beacham and Durand 2007).

Another area where this methodology can be expanded upon is through an examination of what causes the observed types of taphonomic degradation in eggshells. It is likely that the degradation derives as a result of being in acidic environments; Clayburn (2004) showed that low pH and weathering can have a detrimental effect on eggshell mammillary structure. Using this information, researchers would be able to select context priority if the context's soil is known to be acidic or not.

6. Conclusions

This study produced interesting results concerning the role of eggs within the Roman non-elite diet. We expected chicken eggs to make up the majority of the eggs found at this Pompeian site; we found that while chickens do make up a significant portion of the eggshell assemblage (55% of the tested sample), partridge made up 13% of our tested sample. The presence of partridge in our assemblage was unexpected due to the relatively low importance ascribed to partridges by primary source authors.

This type of study can be beneficial in understanding the role that birds played within ancient diets. Taxonomic eggshell identification has rarely been employed at classical archaeological sites. As this study shows, the use of this technique has the potential to reveal information about bird exploitation in antiquity that is not evidenced by primary source materials or archaeological avian bone analyses. We would expect the model we have developed here to be applicable to most Roman sites in similar environmental settings with the addendum that further emphasis should be placed on the importance of partridge eggs to the non-elite diet. This case study demonstrates that taxonomic identification of avian eggshell can reveal egg consumption patterns that are not predicted by examination of classical primary sources alone. Combining taxonomic analyses of avian eggshell with broader zooarchaeological studies can provide a more holistic interpretation of the foodscape in ancient cities.

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