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Full name of the paper (= suggested running title)

Where the snags are: looking into bird bones

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This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/oa.2976

Keywords

Taphonomy; bird bones; intratendinous ossification; zooarchaeology; cave archaeology; scientific inquiry

ABSTRACT

A study of bird remains from Koziarnia Cave (Poland) revealed the presence of nearly a dozen bony shreds (*snags*) projecting from the natural canals in bones; the *snags* were made of a material that accumulated during the Late Pleistocene. This paper describes this phenomenon and determines the most probable agent responsible for its occurrence by utilising observations of *snag* microstructure, taphonomic analysis of bird assemblages from Koziarnia Cave, and surveys of collected bird remains (modern and fossilised). The presence of *snag* may be a good qualitative indicator of an agent responsible for the accumulation of bird bones at archaeological sites and could be useful in future taphonomic studies.

1. INTRODUCTION

During a re-examination of bird bones from Koziarnia Cave for a different project (Kot et al., 2019), we noticed needle-like structures projecting from bone canals of birds, mainly from tendinous canals (details in the results section, Figures 1–3). To the best of our knowledge, this phenomenon (hereafter referred to as *snags*) has not yet been described. From visual analysis alone, the *snags* appear to be bony shreds jammed into the bone canals; to some scholars, this may suggest intentional human activity.

Humans worldwide have used animal bones for millennia–including producing needles (e.g., d'Errico et al., 2018) and splinters from bird remains (Laroulandie, 2014; Serjeantson, 2009). Such needles and splinters could have had varied uses, including making clothes. Shreds of bone jammed in the tendinous canals of other bones could suggest use for either ornamental intentions or for extracting tendons. The tendons could have been used as substitutes for fibrous plants for making threads, considering that plants do not thrive in harsh cold climates. However, because tendons are poorly preserved at archaeological sites, it is difficult to confirm their presence and thus evaluate their significance.

Other hypotheses concerning the presence of *snags* include sheer coincidence, recurring activity of an animal predator, and humans processing birds with their bare hands. In these cases the *snags* would be intra-tendinous ossifications, which are a distinct structural feature of the musculoskeletal systems of various birds such as galliforms, owls, passerines, hummingbirds, or penguins (Vanden Berge & Storer, 1995). Validating the hypotheses regarding the involvement of animal or human agents for the presence of *snags* could provide a qualitative indicator useful in future taphonomic studies of bone assemblages from archaeological sites.

2. MATERIAL AND METHODS

The main material of our study consists of 17 bird bones with bony shreds (*snags*) jammed into their canals such that they project from natural openings in the bones (details in the results section, Figures 1–3). The bones were found at Koziarnia Cave (Poland) during archaeological fieldwork conducted from 1958 to 1963 (Chmielewski et al., 1967) and were analysed along with the other bird remains found there (Bocheński, 1974).

The *snags* were noticed only recently during a re-examination of the collection of bird remains for a new project that aimed to determine and re-evaluate the stratigraphy and chronology of the cave and track human and animal activity therein (Kot et al., 2019; 2020).

Twelve bones with *snags* were found in the entrance zone of the cave in a loess layer VIII-3 (Figure 1b, c), dating from the Late Pleistocene (MIS 3/2) (Berto et al., 2021; Kot et al., 2020). Single flint artefacts found in this layer, which can be attributed to the Gravettian technocomplex, indicated human occupation in the Upper Palaeolithic (Kot et al., 2020). One bone with a *snag* came from layer 2 in trench IV inside the cave; a cave bear's bone from the same layer was radiocarbon dated to 31–29 ky cal (Kot et al., 2020). Both layers VIII-3 and IV-2 were regarded as a single chronostratigraphic unit (layer 11) by Chmielewski et al. (1967) but new results did not confirm the previous correlation of the layers from the inner and outer part of the cave (Kot et al., 2020). For this reason, in the paper, we use a unified layer numbering for the inner part of the cave, whereas the layers found in the entrance zone (trench VIII) are enumerated separately. The remaining four bones with *snags* were recovered from sediments with mixed or undeterminable stratigraphy.

Anatomical terminology used to describe the bones and their structures follows Baumel and Witmer (1993). The osteological collection at the Institute of Systematics and Evolution of Animals, Polish Academy of Sciences was used. All bird bones from Koziarnia Cave were subjected to taphonomic analysis to establish the most probable depositor of bird bones in the cave. Bones covered with cave sediments were cleaned with a brush and water. The surfaces of the bones were observed under a low-power microscope (Leica MZ-6, 6.3–400× magnification) and several optical-stereoscopic microscopes (Olympus SZX9, metallographic Nikon Eclipse LV 100, and digital Nikon Shuttlepix microscopes; each with a 6.3–200× magnification). Possible traces of human activity such as cut marks, burn marks, peeling, joint overextension (Fernández-Jalvo & Andrews, 2016; Laroulandie, 2005); animal activity such as marks showing gnawing, trampling, or traces of digestion; and post-depositional environmental modifications such as root etchings, weathering, and abrasions (Fernández-Jalvo & Andrews, 2016), were recorded. Bone frequencies were presented in terms of minimum number of elements (MNE) values (Lyman, 1994; Serjeantson, 2009). Select bones were observed using field emission scanning electron microscopy (SEM-FE), which enabled the use of energy dispersive X-ray spectroscopy (SEM-EDS) for quantitative elemental analysis. A standard acceleration voltage of 20 kV was used for the latter. Two EDS spectrometers placed on opposite sides of the SEM specimen chamber enabled the acquisition of sufficient SEM-EDS spectra, regardless of the orientation and morphology of the sample.

To determine the contribution of animal activity to the features observed in the bird bones from Koziarnia Cave, the bones discarded by birds of prey were examined. The criteria for choosing the samples were (i) the availability of the material, (ii) their origin being in a region where the relevant birds (*Lagopus* spp.) occur, and (iii) their inclusion in material discarded by a raptor that preys on *Lagopus* spp. As a result, the bones studied were those discarded by *Accipiter gentilis* and those from *Bubo bubo* pellets collected in northern Finland in the second half of the 20th century; the majority of the material had already been analysed as part of other studies (Tornberg, 1997; 2001; Tornberg et al., 2006; 2012; Wertz et al., 2020). The collected remains had previously been stored at the Natural History Museum of the University of Oulu; however, since the closure of its collection, they had been stored by one of the authors (R. Tornberg).

As the aim of the survey was purely qualitative (answering the question '*Is there any*?'), the samples were chosen to increase the chance of a positive outcome rather to obtain a reliable frequency of occurrence. Rough estimates suggest that *ca*. 170 bones with natural bone canals (i.e., carpometacarpus, tibiotarsus, and tarsometatarsus), that were discarded by *A. gentilis*, were examined. The number of bones regurgitated by *B. bubo* and analysed was impossible to establish due to high fragmentation of the material.

Another qualitative survey of the presence of *snags* was conducted on bird bones from archaeological sites in Poland such as Obłazowa Cave, Mamutowa Cave, Rockshelter in Żytnia Skała, and Rockshelter in Krucza Skała (Figure 1a). The material is stored at the ISEA PAS and has been studied previously (Bocheński, 1974; Bocheński & Tomek, 2004; Lemanik et al., 2020).

3. RESULTS AND DISCUSSION

3.1. Description of the *snags*

Snags were found in three types of *Lagopus* spp. bones: carpometacarpus (CMC), tibiotarsus (TBT), and tarsometatarsus (TMT) (Figures 1–3). All *snags*, with one exception, projected from tendinous canals; the exception was a *snag* projecting from a vascular foramen in the

TMT (Figure 2d). The *snags* had a bone-like colour and the general appearance of bony shreds. At least one *snag* was hollow in the middle; under a low-powered microscope this may have resembled a medullary cavity, but SEM observations revealed the fibrous structure of the *snag*, implying that it may have been an intra-tendinous ossification (IO) (Figure 2b, 3b). The other *snags* appeared to have the same structure (Figure 3a). EDS revealed that a *snag* consisted of a bony substance, calcium phosphate (most likely hydroxylapatite), soiled with various aluminium phyllosilicates (i.e., clay minerals) from cave sediments (Figure 2). As Vanden Berge and Storer (1995) noted, the ossifications within tendons develop in 'bare' or unsheathed segments of tendons at some distance from the skeletal attachment. The possible hypotheses to explain the formation of ossified tendons that get stuck in canals as *snags* are: (1) natural post-depositional processes, such as fluvial transport or soil movement, that occur in caves; (2) pathological physiological processes; (3) predator/scavenger activity; or (4) human activity.

Hypotheses (1) and (2) imply sheer coincidence and are confuted by the non-trivial number of *snags* found. Bone pathologies are rare among remains of wild-living birds (Waldron, 2009). In addition, no bone with a *snag* is affected by a pathognomonic sign such as an eburnation (see: Waldron, 2009). Hypothesis (2) also fails to explain the presence of *snags* in the vascular foramen.

The more plausible hypothesis is hypothesis (3), according to which a *snag* may be a tendinous ossification that was stuck in the bone canal after a raptor/scavenger tugged or severed the tendon. The most likely raptor would be an animal that preys on *Lagopus* spp., such as a carnivorous mammal, an owl, or a diurnal bird of prey. Hypothesis (4), which suggests human activity implies, as mentioned in the introduction, the purposeful use of bird bones (e.g. for ornamentation or to extract tendons) or processing of the bird body with bare hands and teeth (Laroulandie, 2005; Steadman et al., 2002).

3.2. Tracking bone depositors (deposited taxa, bone modifications, skeletal composition) at the site

No clear traces of human or animal activity were observed on bones with *snags*. Analysis of whole bird bone assemblage from Koziarnia Cave may reveal the main depositor of the birds in the cave; however, such an analysis can only reveal a probable reason for the *snags*. Grouse, including *Lagopus* spp., do not inhabit caves (Voous, 1960); therefore, it is clear that those birds were deposited therein by a raptor or scavenger. The animal depositor of the *Lagopus* can also have preyed on the rodents that were abundant at the site but not on small passerines (Berto et al., 2021). Although the remains of a few potential depositors like *Falco columbarius*, *Haliaeetus albicilla*, *Canis lupus*, and *Vulpes lagopus* have been identified at the site (Berto et al., 2021), this alone does not make them the probable depositors. As Andrews (1990) concluded, the remains of a given raptor in an assemblage suggests that it itself was also preyed upon; paradoxically, this makes this raptor the least likely depositor.

Overall, the bird bone assemblage at Koziarnia Cave was heavily affected by post-depositional processes such as root etching and abrasion (Table S1). These may have obscured subtle traces of animal activity and may be why so few firm animal traces have been detected (Table S2). Singular tooth marks observed on *Lagopus* bones from the relevant layers (layers VIII-3 and 11) demonstrate that at least some of the birds had been discarded by carnivorous mammals. Nevertheless, this proportion was probably rather small because bones accumulated by carnivorous mammals tend to be heavily modified either by gnawing or gastric juices (Andrews, 1990; Krajcarz & Krajcarz, 2014; Lloveras et al., 2012), and these modifications are difficult to conceal. For this reason, owls or diurnal birds of prey seem to be the more probable culprits (e.g., Andrews, 1990).

No clear traces of human activity have been discovered on bird bones from the relevant layers, although there are five cut marks on bones identified as chicken bones or galliform bones that come from mixed or uncorrelated layers; however, as mentioned before, humans can process a bird without leaving such traces. The evidence against human-created deposition is the frequency of the *Lagopus* bones deposited in the relevant layers (Figure 4). A large share of TMTs and CMCs corresponds well to bones discarded by owls, particularly Snowy Owls (*Bubo scandiacus*) and Eagle Owls (*Bubo bubo*) (Baales, 1992; Bochenski, 2005; Laroulandie, 2002); human-created assemblages usually contain a much larger share of humeri and femora (Bochenski, 2005; Mourer-Chauviré, 1983). Notably, both Snowy Owls and Eagle Owls leave the bones of their prey digested to a less-than-moderate degree (Andrews, 1990).

3.3. Surveys on collections of: (1) non-ingested bones discarded by *Accipiter gentilis*, (2) *Bubo bubo* pellets, and (3) fossil bones of *Lagopus*-sized tetraonids from various cave sites

Among the bones that were discarded by both *A. gentilis* and *B. bubo*, we discovered some with confined IOs (Figure 5a–c). Six were in the canals of *Lagopus* bones discarded by *A. gentilis* (three in CMCs and three in TBTs; Figure 5a, b) and one was in the TBT of a *Tetrao urogallus* regurgitated by *B. bubo* (Figure 5c). Both assemblages could not be compared in terms of their 'IO-holding' potential, as reflected by the composition of taxa, anatomical representation, and bone fragmentation. Many bones discarded by *A. gentilis* can still be articulated and are often surrounded by entanglement of dried or ossified tendons projecting in various directions. The occurrence of such may arguably enhance the probability that an ossified tendon could reach the vascular foramen in the TMT and become stuck therein. The TBT extracted from the *B. bubo* pellet showed obvious traces of digestion (Figure 4c).

If raptors, particularly owls, are indeed responsible for the presence of *snags*, the occurrence of *snags* should not be limited to Koziarnia Cave. A survey conducted of bird bones from available cave sites has proven this correct, and similar assemblages were found at other sites (Table S3, Figure 5d). Notably, the four assemblages in which *snags* were discovered are believed to have been deposited mainly by owls (Table S3). No bone with a jammed *snag* showed distinctive indications of predation such as tooth marks or digestion traces.

4. SUMMARY AND CONCLUDING REMARKS

This paper described the phenomenon of *snags*: bony shreds jammed in the remains of birds recovered at some cave sites, including Koziarnia Cave. The *snags* are built of threads that resemble the structure of bird IOs. The taphonomic study of bird bones from Koziarnia Cave suggested that an owl was the most likely depositor of the *Lagopus* bones; they were also indicated as the most likely depositors of bones with *snags* at other sites where these were found.

Surveys of modern material discarded by a large diurnal bird of prey (*A. gentilis*) and a large owl (*B. bubo*) revealed the presence of IOs stuck in the natural canals of the bones of their prey. Large diurnal birds of prey and owls consume their prey in different ways; the former tend to strip the flesh off them and eat only part of the bones, while the latter are more prone to swallow the prey whole or in large pieces (Andrews, 1990; Serjeantson, 2009). It is obvious that the *T. urogallus* eaten by the *B. bubo* was consumed in pieces. We can only hypothesise how the *snags* became jammed in the canals; it seems clear that this might have occurred due to tugging on a tendon while the flesh was being stripped off the carcass, or as the carcass was being divided, although this could also have happened as the bones were squeezed during pellet formation. We do not know whether *snags* may occur in assemblages accumulated by carnivorous mammals, although their different methods of processing food (crushing and shredding) may result in a negative outcome. It is even less probable, that a *snag* could be found among bones discarded by humans. Humans can obtain meat without tugging the tendons in bird carcasses; they may use sharp tools to divide these, and/or they may cook them–thereby reducing firmness and cohesion of the flesh–before portioning the food.

The presence of *snags* may therefore be a good qualitative indicator of bird of prey depositions at archaeological sites.

ACKNOWLEDGMENTS

We would like to thank the Ojców National Park and the Institute of Geophysics, PAS for their kind permission for conducting the fieldworks; Claudio Berto for generous sharing his artwork, and Piotr Wojtal for his selfless encouragement and support. The project was partially financed by the National Science Centre, Poland, within the framework of project no. 2016/22/E/HS3/00486. We are very grateful to the three anonymous reviewers whose comments definitely improved the paper.

SUPPORTING INFORMATION

Table S1. Post-depositional modifications observed on the bird bone assemblage.

Table S2. Raptor/scavenger modifications on the *Lagopus* bones.

Table S3. *Snags* discovered in the fossil material stored at ISEA PAS

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on reasonable request from the corresponding author. Pertinent additional data can be found in the Supporting Information of this article.

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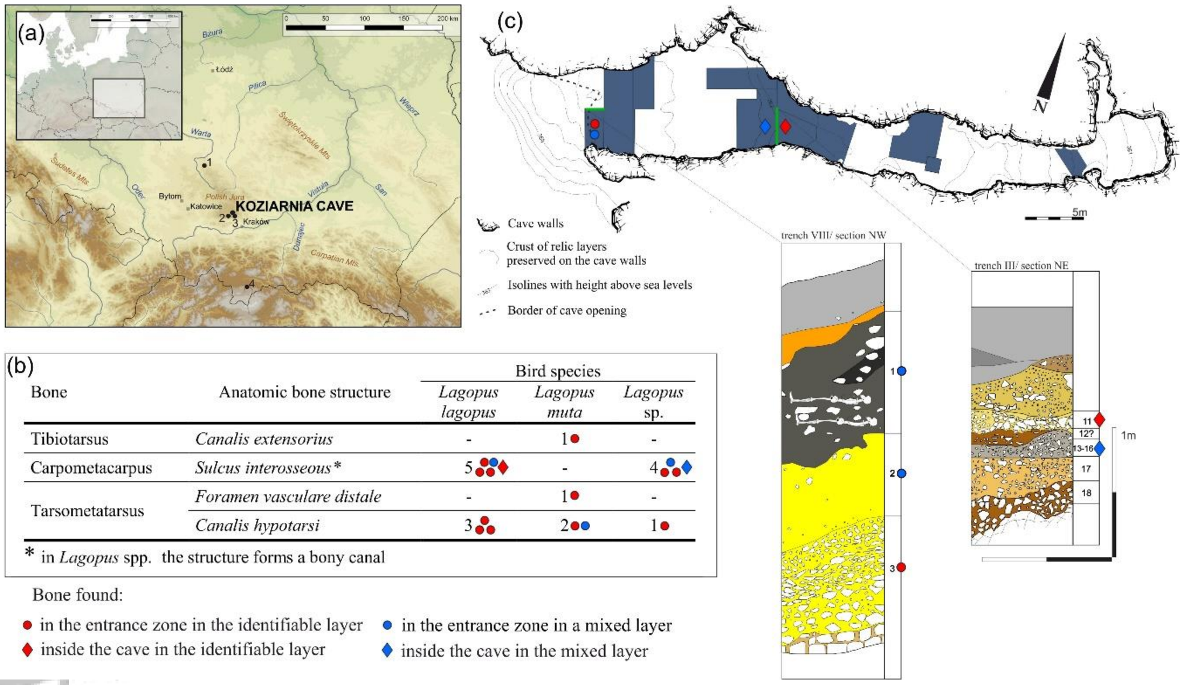

Figure 1.

(a) – Locations of Koziarnia Cave and other sites mentioned in the text: 1, Rockshelter in Krucza Skała; 2, Rockshelter in Żytnia Skała; 3, Mamutowa Cave; 4, Obłazowa Cave. (b) and (c) – the number and placement of the *snags* found within bones and cave trenches (steel-blue polygons) and layers in Koziarnia Cave. The map template is courtesy of Claudio Berto.

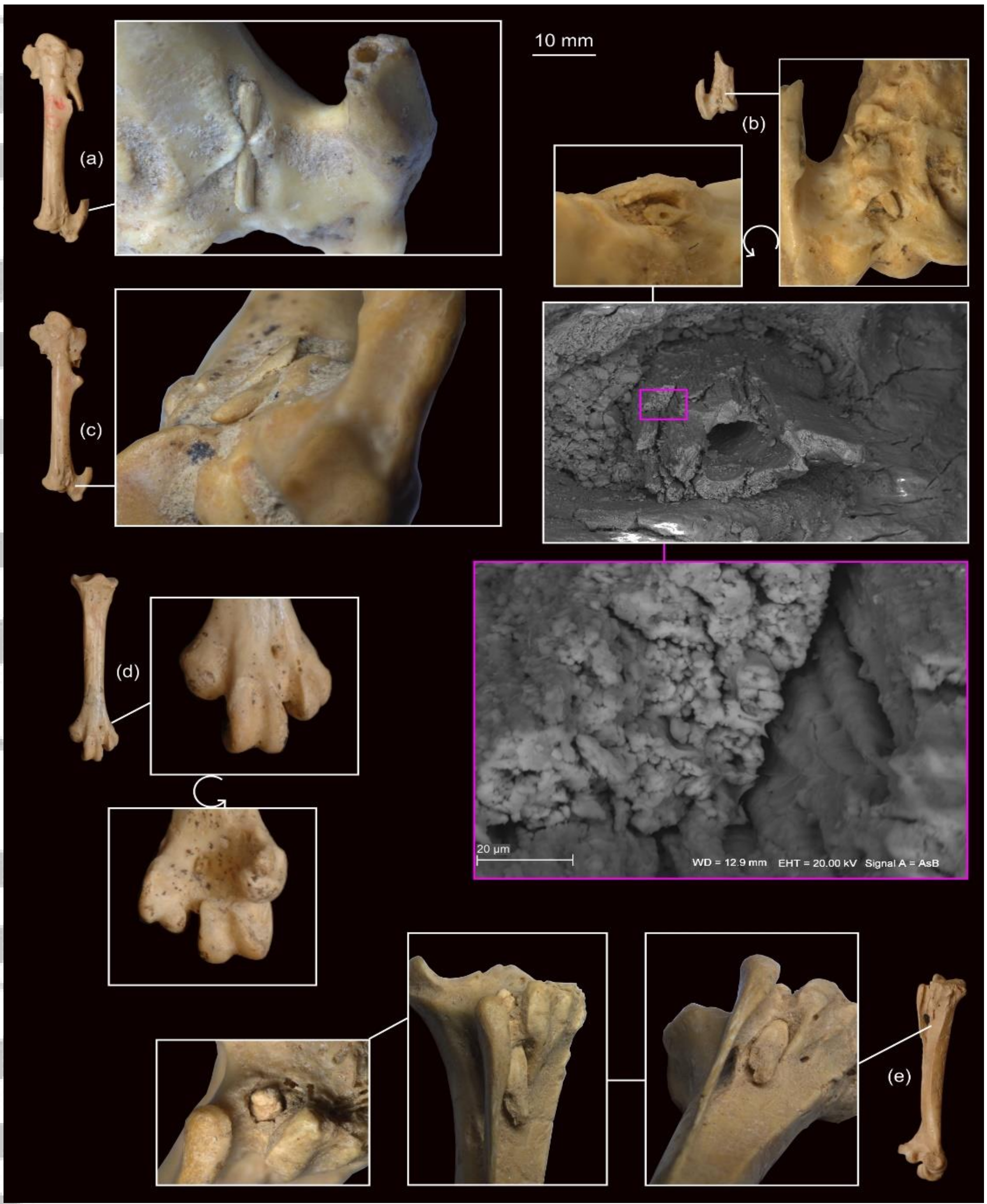

Figure 2.

Snags stuck in *Lagopus* bones recovered from Koziarnia Cave; *snags* projecting from (a-c) tendinous canals in carpometacarpus samples, (d) vascular foramen in tarsometatarsus sample, and (e) a tendinous canal in tarsometatarsus sample.

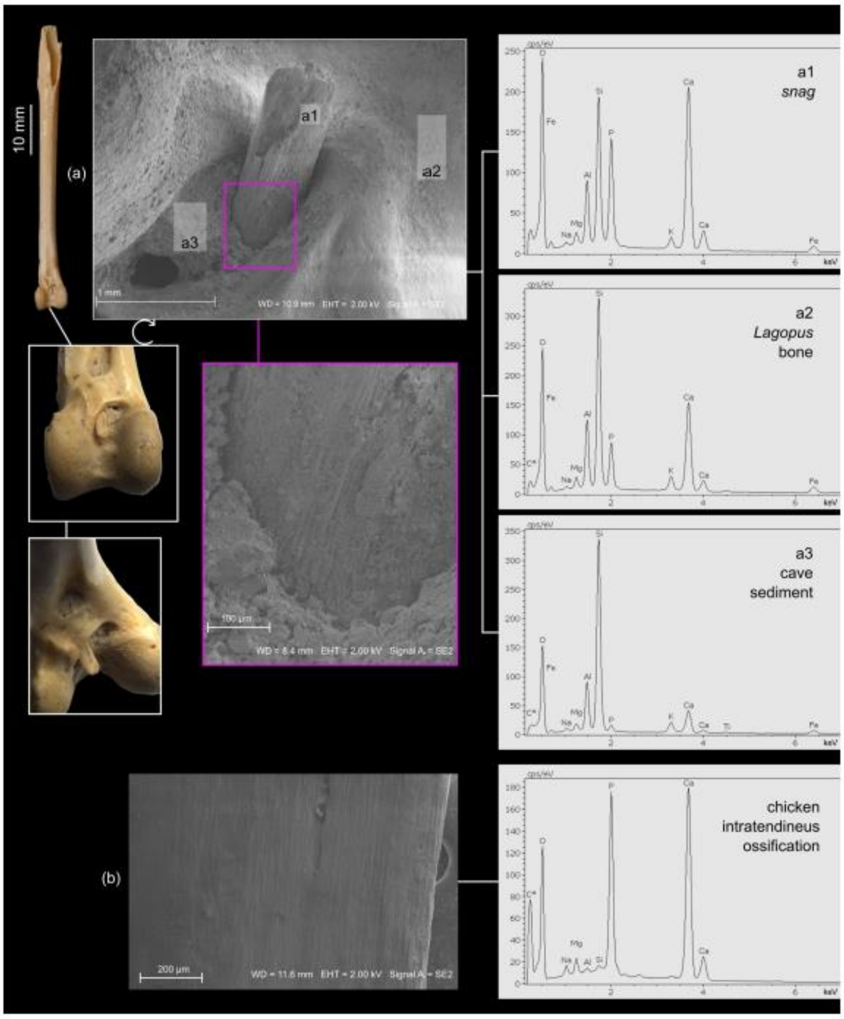

Figure 3.
Microstructure and energy dispersive X-ray spectroscopy (EDS) spectra of (a) a snag projecting from a tendinous canal in a tibiotarsus sample and (b) an intra-tendinous ossification in a modern chicken. The white rectangles numbered a1–3 show areas subjected to EDS analysis; the charts on the right present the corresponding EDS results.

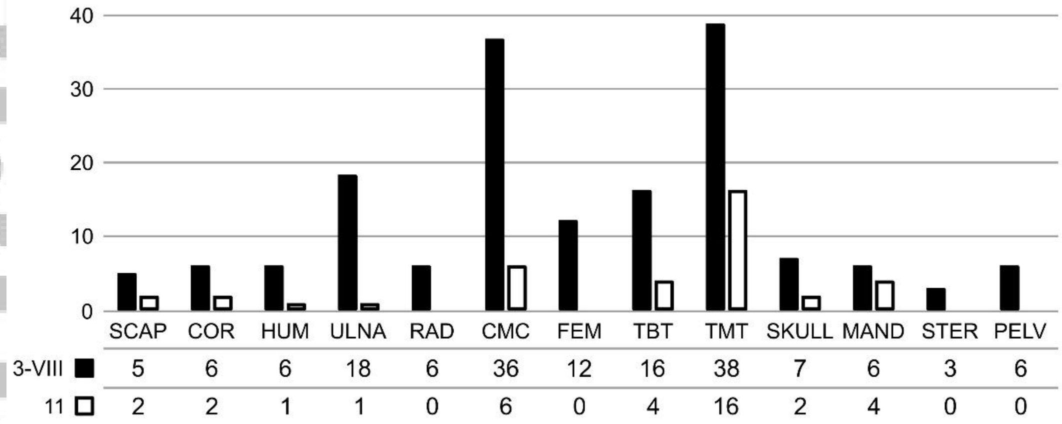

Figure 4.

Frequency of the *Lagopus* bones in Koziarnia Cave from the layers in which the *snags* were discovered (Layer VIII-3 and Layer 11), presented in minimum number of element (MNE) values. cmc, carpometacarpus; cor, coracoid; fem, femur; hum, humerus; mand, mandibula; pelv; pelvis; rad, radius; scap, scapula; ster, sternum; tbt, tibiotarsus; tmt, tarsometatarsus.

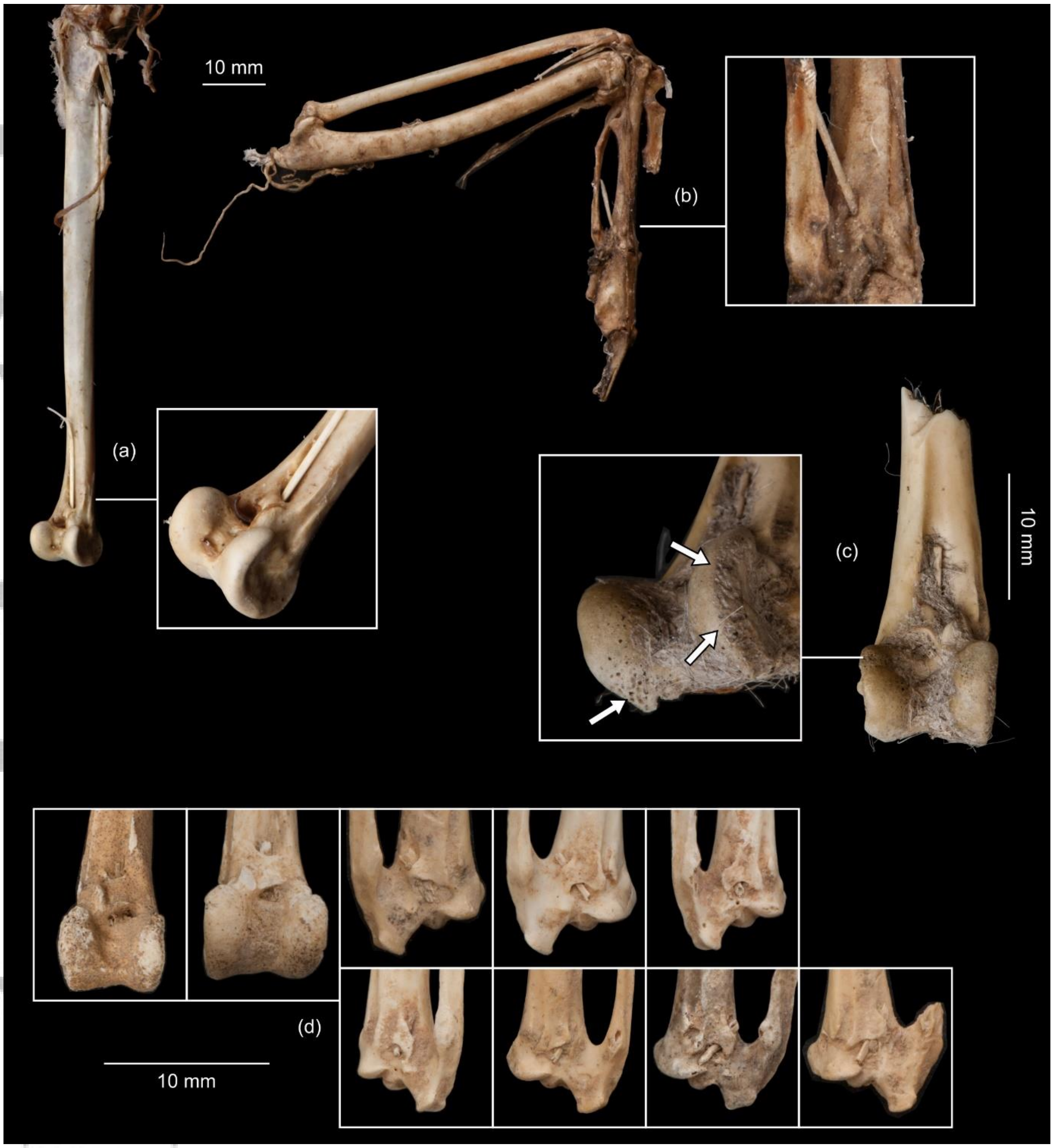

Figure 5.

Bones with *snags* discovered during the surveys conducted as part of this study. (a, b) *Lagopus* bones discarded by *Accipiter gentilis*, (c) *Tetrao urogallus* bone regurgitated by *Bubo bubo*; the arrows show the clear traces of digestion, (d) *Lagopus* spp. or *Lagopus*-sized galliform bones recovered from various cave sites.