Journal of Archaeological Method and Theory (2025) 32:9
https://doi.org/10.1007/s10816-024-09673-6

RESEARCH

All Mixed Up: Investigating Mortuary Practice and Processes of Disarticulation Through Integrated Histotaphonomic Analysis at the Knowe of Rowiegar, Neolithic Chambered Cairn, Orkney, UK

Tierney Tudor[1] · **Rebecca Crozier**[2] · **Richard Madgwick**[1]

Accepted: 11 October 2024

Abstract

The Neolithic site of the Knowe of Rowiegar chambered cairn, Orkney, was excavated in 1937 as part of a campaign that saw the excavation of various chamber cairns on the island of Rousay, Orkney (Davidson & Henshall, 1989). Osteological and isotope research undertaken in recent years has reignited interest in the site. The research presented here focuses on mortuary practices, principally through histotaphonomic analysis. Human remains at Rowiegar were characterised by disarticulation, disorder and fragmentation (Hutchison et al., *Proceedings of the Society of Antiquaries of Scotland*, *145*, 41–86, 2015), as is commonly observed in Neolithic Orkney. In recent years, histological analysis has become more widely used in reconstructing mortuary treatment. This relies on the degree and nature of bacterial attack, often termed bioerosion, and other modifications to bone microstructure as a proxy for early post-mortem treatment. Histological analysis was undertaken on 13 of the 28 individuals from the Rowiegar site. The results presented diverse patterns of bioerosion in the bone microstructure suggesting different mortuary practices. Furthermore, these results suggest that remains were placed in the chambered cairn at different stages of decomposition, with some individuals buried immediately after death and others likely subject to a more complex, multi-stage mortuary rite. There remains uncertainty about the origins of bacterial bioerosion in bone, and future experimental work may necessitate interpretative revision. However, based on current understanding, the research provides a new perspective on mortuary practice at Rowiegar, evidencing diverse, and sometimes complex, pre-depositional mortuary practices.

✉ Richard Madgwick
madgwickrd3@cardiff.ac.uk

[1] School of History, Archaeology and Religion, Cardiff University, Cardiff, UK

[2] Department of Archaeology, University of Aberdeen, Aberdeen, UK

Published online: 02 December 2024

Keywords Histology · Bioerosion · Funerary practice · Taphonomy

Introduction

This paper explores mortuary practices at the Neolithic chambered cairn of the Knowe of Rowiegar, located on the island of Rousay, Orkney, UK, through the lens of histotaphonomic analysis. Histotaphonomic analysis (the taphonomic analysis of bone microstructure) has become an important method in assessing mortuary practice and, whilst more experimental work is required to clarify the aetiology of variation, provides a useful complement to other taphonomic, osteological and archaeological evidence. The human bone from Rowiegar, representing a Minimum Number (MNI) of 28 individuals is, as with many of the Orcadian tombs, characterised by its disarticulated, disordered and fragmented condition (Hutchison et al., 2015). The dispersed remains have raised questions surrounding the mortuary rites enacted on the individuals buried at this site. Analyses presented in this paper provide a new line of evidence for examining the nature of early post-mortem treatment and the mechanisms by which remains became disarticulated. A particular focus is whether this disarticulation is likely to have occurred pre-deposition (*e.g.* through exposure/excarnation) or post-deposition (*e.g.* through exhumation) and the degree to which diverse and/or multi-stage mortuary practices are in evidence.

Background

Neolithic Orkney: Mortuary Rites

Human remains are seen as a key identifier of funerary structures. However, it is worth highlighting that human remains have been identified in various domestic contexts in Orkney, such as two articulated adult females under the walls of House 7 at Skara Brae (Childe, 1931). These discoveries are often overlooked, and it is the presence of large quantities of human remains within some of the chambered 'tombs' of Orkney that has had a significant influence for how we understand the structures themselves: where they lie in the landscape, why they were built and how they were used (Richards, 1996; Jones, 1998; Phillips, 2004). Early work by Chesterman (1979) on human remains from Quanterness (Renfrew, 1979) and Isbister (Chesterman, 1983) envisioned a complex suite of activities, a key aspect of which was excarnation. The acceptance in the academic discourse of the involvement of body exposure generated dramatically imagined funerary rites (Hedges, 1987) and themes around a circulation of bone and ancestral currency (Fowler, 2010; Reilly, 2003; Richards, 1988). However, more recent work (Lawrence, 2007, 2014; Crozier, 2012, 2018) has provided osteological evidence to undermine the excarnation theories. Indeed, Crozier (2018) has argued that bodies were taken into some of the tombs whole and soon after death, with subsequent manipulation restricted to within the structure itself. While this is certainly convincing for sites such as

Isbister (Hedges, 1983), Quanterness (Renfrew, 1979) and Point of Cott (Barber, 1997) with skeletal element representation demonstrated to be consistent with whole bodies, *i.e.* no significant over or under representation of elements (Crozier et al., 2016). The site of Rowiegar is distinct in having an over-representation of crania (Hutchison et al., 2015). Therefore, the question remains, how were bodies treated after death and how did remains become disarticulated at Rowiegar? This research sets out to explore this question using a histotaphonomic approach.

Rowiegar Chambered Cairn

In 1937, the remains of a megalithic structure were excavated on the South-West coast of the island of Rousay, Orkney (Fig. 1). Architecturally consistent with the Orkney-Cromarty type tombs, the Rowiegar chambered cairn is suggested by Davidson and Henshall (1989) to have been of a similar size to the neighbouring and impressive site of Midhowe. However, Rowiegar's chamber and entrance suffered damage with the later insertion of a souterrain, presumably during the Iron Age (Davidson & Henshall, 1989). Prior to this damage, Davidson and Henshall (1989) believe that Rowiegar originally consisted of around 12 stalls, rather than the six that were discovered.

The surviving cells/compartments were numbered from one to six, but the excavators did not specify which end they began from. Typically, numbering by Callander et al. (1934), Callander and Grant (1935) starts at the structure's entrance. However, Hutchison et al. (2015) noted from historical correspondence that the opposite may be true of Rowiegar. Acknowledging a degree of uncertainty, Hutchison et al.'s (2015) plan assigns the cell numbers from the North-West (inner) end (Fig. 2). Although there are detailed records of the site's structure, the contexts and positions

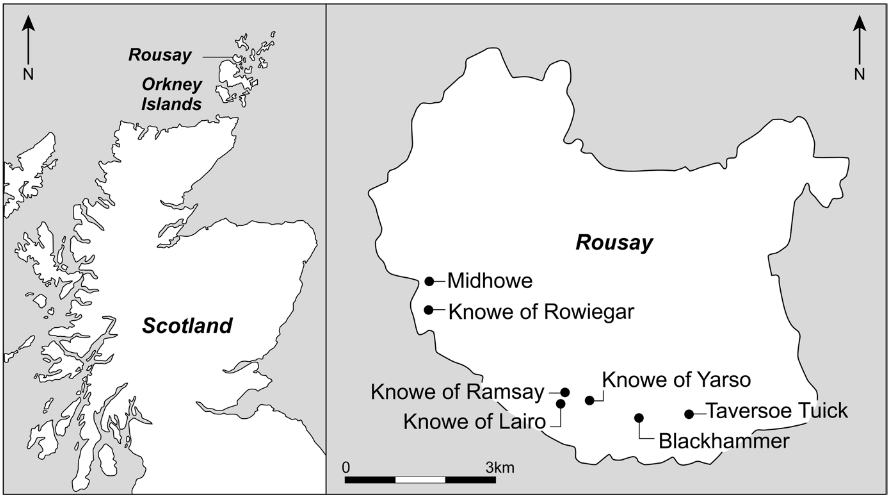

Fig. 1 Location of the Neolithic chambered cairns along the South/South-West coast of the island of Rousay (Hutchison et al., 2015). Figure created by Kirsty Harding

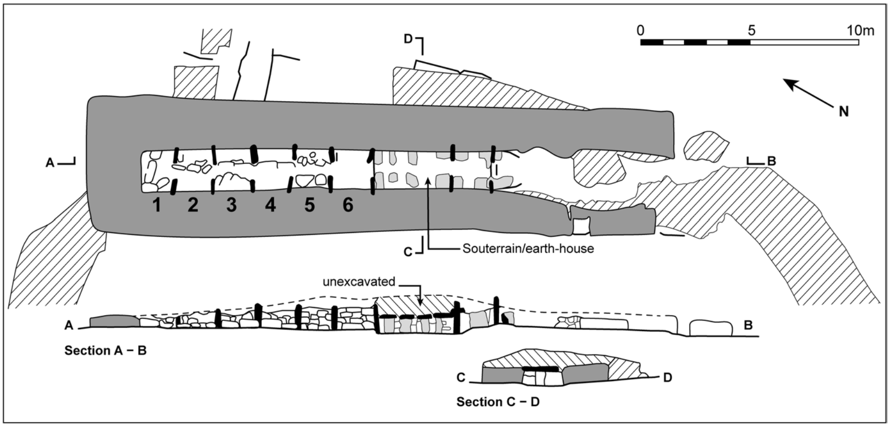

Fig. 2 Site plan with cell numbers and sections of Rowiegar chamber cairn, adapted from Davidson and Henshall (1989)

of excavated finds were poorly recorded (Hutchison et al., 2015); consequently, the original location of the remains is uncertain. During excavation, the human remains were bagged in accordance with their location within the chambered cairn.

The Human Remains

Disarticulated and fragmentary, the recovered human remains have an intriguing profile. Whilst the post-cranial remains are comparatively few, with a bias toward the talus and calcaneus, the assemblage is dominated by fragmented cranial remains. A minimum number of individuals (MNI) of 28 was documented through the identification of at least 28 skulls (mandible and maxilla counts). It is worth noting, however, that previous work by Lawrence (2014) assigned a MNI of 19 individuals based on the mandible. It is not possible to further interrogate Hutchinson et al.'s figure of 28 individuals, as details for siding are not provided in their data (see Hutchison et al., 2015, Table 5). Subsequent attempts at reconstruction and osteological analysis of the assemblage by Hutchison et al. (2015) led the team to suggest several scenarios to explain deposition. It is accepted that the remains within the surviving cells suffered no disturbance, aside from roof collapse, after the Iron Age. However, it is not possible to state if any rearrangement occurred between Neolithic deposition and the area being blocked off in the Iron Age (Hutchison et al., 2015). A range of explanations were suggested to account for the fragmentary condition of the remains, especially the cranial fragments. Explanations include a result of mortuary practices, damage during the Iron Age modifications of the cairn, roof collapse or post-excavation damage. Ultimately, Hutchison et al. (2015) lean towards either the deliberate interment of select body parts (particularly the cranium) following defleshing elsewhere, or removal of body parts from the structure after disaggregation within.

The complex range of osteoarchaeological evidence and the uncertainty over the nature of skeletal disarticulation calls for the addition of histotaphonomic analysis, which has the potential to disentangle issues of equifinality (particularly in terms of multiple potential pathways to disarticulation) in reconstructing mortuary practice (Booth, 2017).

Methodological Background

The principles of histotaphonomic analysis in archaeological bone have been discussed in many publications (Booth, 2015; Booth & Madgwick, 2016; Booth et al., 2022, 2024; Turner-Walkeret al., 2023). Therefore, only a brief summary is provided here.

The approach is concerned with the analysis of taphonomic changes to bone microstructure.

Bacterial bioerosion in the form of micro-focal destruction (MFD) is the most common form of diagenetic change observed within archaeological bone microstructure (Turner-Walker et al., 2002). It appears in different forms described as budded, linear longitudinal and lamellate, principally relating to the pathways of attack (Turner-Walker et al., 2002). Other forms of diagenetic change include Wedl tunnelling, common in wet environments and indicative of fungal action (Bricking et al., 2022; Fernández-Jalvo et al., 2010). Aquatic environments have cyanobacteria present, which cause distinctive forms of microstructural taphonomy (Bricking et al., 2022).

Histotaphonomic analysis is the assessment of preservation and diagenetic change in bone microstructure (Bricking et al., 2022). The preservation of bone microstructure is frequently assessed using the Oxford Histological Index (OHI), as outlined by Millard (2001). The degree of bacterial bioerosion invariably dictates the OHI score. The origin of diagenetic bacteria which causes MFD is currently debated, although experimental studies have shown that bacterial destruction of bone microstructure can begin within the first few days after death and is mostly limited to the first 10 years post-mortem (Bell et al., 1996; Bricking et al., 2022). However, this is not always the case, and bacterial attack can take years to commence under certain conditions (Mavroudas et al., 2023). Evidence suggests that diagenetic bacteria can originate from the gut, infiltrating bone tissue via the vascular network during the putrefactive stages of decay but can also originate from the soil in some circumstances (Booth, 2015; Booth et al., 2024; Turner-Walker et al., 2023). The prevailing cause of this bioerosion has been subject to ongoing discussions as to whether this is endogenous (putrefaction) or exogenous (soil). Brönnimann et al. (2018) found no correlation between the intensity of bacterial attack and sedimentary type and the sedimentation process respectively as part of a study on 208 human and animal skeletal fragments recovered from various feature types and different sediments. This concluded that the bacterial degradation of the bone is mainly caused by endogenous gut bacteria during the putrefaction process (Brönnimann, et al., 2018). By contrast, Turner-Walker et al. (2023) favour an exogenous (soil) origin for bacteria that cause bioerosion, and further research is required to decipher the variables which impact on diagenetic alteration, but the evidence for an exclusive exogenous origin has been rebutted by Booth et al. (2024).

Based on the balance of evidence, particularly in a northern European context, an endogenous model of bioerosion is favoured in this research though the potential impact of soil bacteria is acknowledged. If gut bacteria can be responsible for bioerosion, then histotaphonomic data is useful for exploring mortuary practices. Following this, practices that cause the rapid removal of soft tissue after death, such as excarnation through intentional flesh removal or exposure, will generate well-preserved histology, as collagenolytic bacteria will be unable to access the bone. Intentional preservation of the body (mummification) through deposition in an anaerobic environment such as a bog, or through smoking or drying, would also inhibit bacterial attack leaving well-preserved microstructure (Hess et al., 1998; Parker Pearson et al., 2005; Booth et al., 2015). By contrast, primary burial is thought to cause a slower breakdown of the soft tissue due to a prolonged putrefactive stage, which would be expected to generate poorly preserved histology as bacteria will have ample opportunity to access the bone and destroy its microstructure. Therefore, histotaphonomic analysis can be particularly useful in establishing the cause and timing of disarticulation. As such, we expect that a high prevalence of bioerosion may suggest bodies were inhumed post-mortem and subsequently manipulated after decomposition, as bacteria would have had ample time to transmigrate into the microstructure prior to fragmentation. Conversely, if samples show minimal bioerosion, this may indicate bodies were eviscerated or excarnated in some capacity prior to interment, as putrefactive bacteria would have been removed prior to fragmentation. However, the origin of bacterial bioerosion remains uncertain and interpretations based on an endogenous model may require future revision.

Materials and Methods

A total of 13 samples have been analysed to assess histological preservation (Table 1) using transmitted light microscopy on bone thin sections. This was achieved by cutting transverse sections (c. 10 mm × 20 mm) of bone using a precision drill with a diamond wheel attachment. Bone sections were then embedded in epoxy resin (EpoFix resin mixed with EpoFix hardener, at a ratio of 25:3). These were then left in a desiccator vacuum for at least 24 h to harden. Once hard, transverse sections with a thickness of 70–90 µm were cut from the embedded samples using an annular diamond saw microtome (REHA-Tech). Samples were then mounted onto a glass slide using Entellan mounting medium and then covered with a glass cover slip and left for 24 h before being analysed using a Keyence 4 K digital microscope under varying magnifications. Some samples exhibited marked periosteal cortical bone loss, which complicated analysis and hindered examination of bacterial origin in some instances.

Table 1 Bone samples subject to histotaphonomic analysis from Rowiegar chambered cairn

Skull designator	Bag (number)	Unique ID	Cell No	Age	Sex	Bone	Notes
C1	C(37)	90070S3	4	Adult	Male?	L parietal	Periosteal cortex removed
D1	D(33)	90066S4	4	20–30	Male?	L parietal	
E	E(35)	9006885	6	30+	Male	L parietal	Periosteal cortex removed
FT1	F(38)+T(4)	90071S6	4/6	30+	Male	R parietal	
H1	H(27)	90057S8	4	30+	Male	L parietal	
J	J(28)	90058S9	4	c. 30	Female?	R parietal	Periosteal cortex removed
L	L(23)	90035S10	4	30+	Male	L parietal	
M	M(30)	90063S11	4	30+	Male	L parietal	Periosteal cortex removed
N	N(31)	90064S12	4	30+	Male	R parietal	Periosteal cortex removed
O	O(32)	90065S13	4	c. 30	Male	R parietal	
NN1	NN(2)	14981S14	5	c. 20	Male	R parietal	
P1	P(1)	000×1S15	5	30+	Male	L parietal	Periosteal cortex removed
Bag No	Inner bag	Unique ID	Cell	Age	Sex	Bone	Notes
ZZ(17)	F	16310H7	5	7	N/A	Humerus	Epiphysis complete and intact

Analysis

The thin sections were analysed at 50x, 100x, 150x, 200x, 300x and 1000x magnification under direct transmitted and polarised light (the latter to assess birefringence). Data collected through the histological analysis of these thin sections have been recorded using the Oxford Histological Index (OHI) and Generalised Histological Index (GHI) Birefringence index (indicative of collagen preservation) combined with comments on cracking to provide a broad view of histological preservation (Brönnimann et al., 2018; Jans et al., 2002; Millard, 2001).

Results

The results of the condition of the microstructure are summarised in Table 2 and Fig. 3. The samples can be broadly clustered into two groups in terms of their preservation. Ten samples (77%) score either 0 or 1 in the OHI and are therefore poorly preserved with only limited areas of well-preserved microstructure. Most show no evidence of birefringence, therefore indicating poor collagen preservation, though two samples have partial birefringence. Three samples show mid-ranging OHI scores of 2 and 3. These mixed patterns of preservation are relatively rare

Table 2 Results from the histotaphonomic analysis of all samples

Skull designator	Unique ID	OHI	GHI	Cracking comments	Birefringence	Notes
C1	90070S3	1	1		0	
D1	90066S4	1	1		0	
E	90068S5	0	0		0	
FT1	90071S6	0	0		0	Unknown location of sample
H1	90057S8	2	2		0.5	
J	90058S9	0	0		0	
L	90035S10	1	1		0	
M	90063S11	3	3		0.5	
N	90064S12	1	1		0.5	Stained canalicular network
O	90065S13	1	1	Singular wide crack with staining (infiltration)	0.5	
NN1	14981S13	0	0		0	
P1	000×1S15	0	0		0	
Bag No	Unique ID					
ZZ(17)	16310H7	2	2	Cracking on peri-osteal edge	0.5	

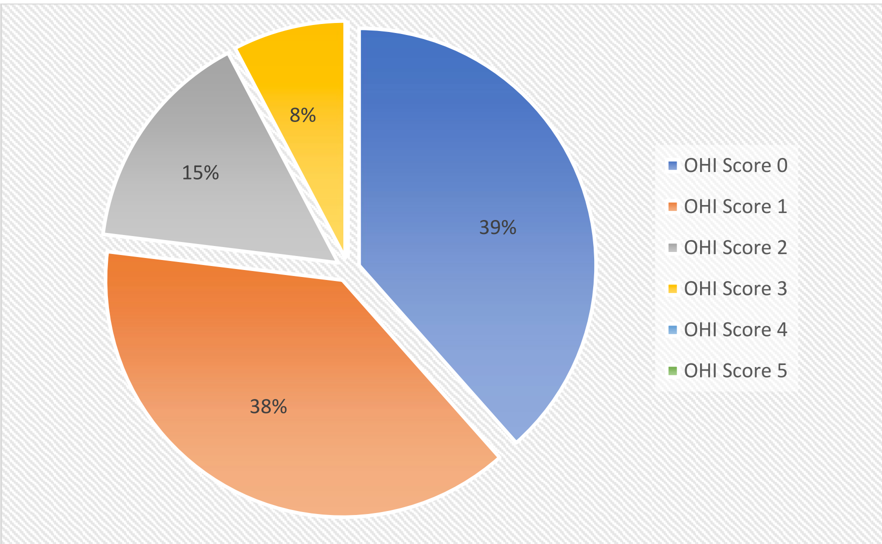

Fig. 3 OHI results from the histotaphonomic analysis of all samples from Knowe of Rowiegar

in histotaphonomic studies. All show partial birefringence. None of the samples showed well-preserved histology, and scores of OHI 4 and 5 were absent from the dataset. The samples within these two groups are described below.

Group 1: Poorly Preserved Samples (OHI 0/1)

The majority of the samples score either 0 or 1 on the OHI and are therefore poorly preserved with only limited areas of well-preserved microstructure. These include samples C1, D1, E, FT1, J, L, N, O, NN1 and P1. All of these samples except N and O showed no evidence of birefringence demonstrating poor collagen preservation. Combined with the extensive evidence for bioerosion, it is likely that bacterial attack is responsible for the degradation of collagen. The other two samples showed only partial birefringence. Cracking was rarely observed in these samples around the cortical surfaces or in the internal bone matrix. There were also no signs of micro-cracking which might be expected to be present in weathered remains or in material deposited in an environment with cycles of wetting and drying, though there is little evidence for hydrological variation or sub-aerial exposure at Rowiegar. However, the degradation of the cortical surface of some specimens may have obscured evidence for micro-cracking.

Sample C1 (Fig. 4) has extensive bioerosion with small areas of well-preserved microstructure surrounded by areas of extensive bacterial attack. This is typical of the ten samples identified as having poor preservation. Figure 4B shows the infiltration of a crack in the bone microstructure, appearing as staining. This infiltration is associated with cracks along the edge of the bone and extends from the periosteal surface. This sample was assigned an OHI score of 1 as the microstructure of the bone has not been entirely destroyed by the microbial attack which can be seen in Fig. 4A and C with approximately 15% still intact across the sample as a whole. No birefringence was observed, as expected in a sample with such extensive bioerosion. The character of the

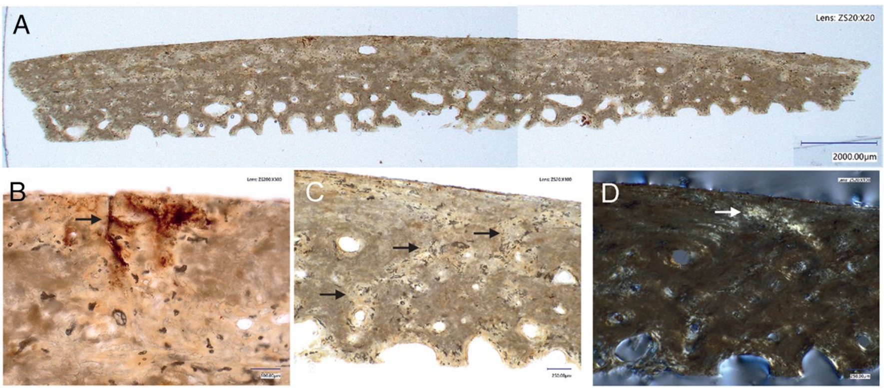

Fig. 4 **A** A scan of the thin section of sample C1 (20 × magnification). **B** Micrograph (300 × magnification) showing cracks with staining along the edge. **C** Micrograph (100 × magnification) showing a small amount of preserved microstructure. **D** Polarised image of the same area (**C**) showing little to no birefringence

bioerosion, which is relatively evenly distributed across the bone matrix, is consistent with an endogenous origin, and there is no evidence of external bacteria penetrating the bone. The degradation of the periosteal periphery makes analysis more challenging for this group of samples.

Group 2: Samples with Mixed Preservation (OHI 2/3)

Three (23%) of the samples demonstrate a mixed pattern of histological preservation (OHI 2–3), showing considerably higher levels of preservation in comparison to the other samples from this site. This mid-ranging pattern of preservation is rare in histological studies of archaeological bone, as bioerosion typically permeates throughout the entirety of the bone matrix or is minimally present rather than intermediate. Samples H1, M and ZZ(17) all show clear signs of bacterial attack, but also have large areas of well-preserved microstructure, suggesting something impacted on the remains to arrest bacterial action. Birefringence was observed in areas of well-preserved microstructure along with isolated areas of low birefringence in other parts of the microstructure, thus providing supporting evidence for mixed preservation. No cracking or micro-cracking was observed in samples in this group.

Sample M shows high levels of preservation similarly to sample H1. However, limited bioerosion can be observed in Fig. 5A, B and C. Due to the bacterial attack being only in small patches in this sample, an OHI score of 3 was assigned. This sample has patches of high birefringence showing excellent collagen preservation in places, as observed in Fig. 5E. Other areas show no birefringence (thus scoring 0.5 on the Birefringence Index overall), generally correlating with the areas of bioerosion. The bioerosion seen in Fig. 5A appears to be concentrated principally on the periosteal surface with some endosteal areas also affected. The peripheral periosteal cortex is absent but the concentration of bioerosion on the edges raises the possibility of an exogenous origin of the bacterial attack.

Sample ZZ(17) (Fig. 6) has visible bioerosion in the central zone of the bone matrix. This suggests endogenous bacterial attack, with clear penetration through the Haversian system (Fig. 6C). Sample ZZ(17) shows signs of cracking along the periosteal edge of the bone. These small cracks, which can be observed in Fig. 6B, only penetrate the periphery of the bone. The mixed pattern of bioerosion results in an OHI score of 2. The cracking does not seem to be linked to the bioerosion observed within the centre of the sample as it does not penetrate past the well-preserved band along the periosteal border (Fig. 6C). Under polarising light, the sample shows partial birefringence, scoring 0.5. The Maltese cross pattern is observable on some osteons, a characteristic sign of excellent preservation of collagen. This mixed pattern of preservation suggests that bacterial attack has been arrested by a change in the situation of the body.

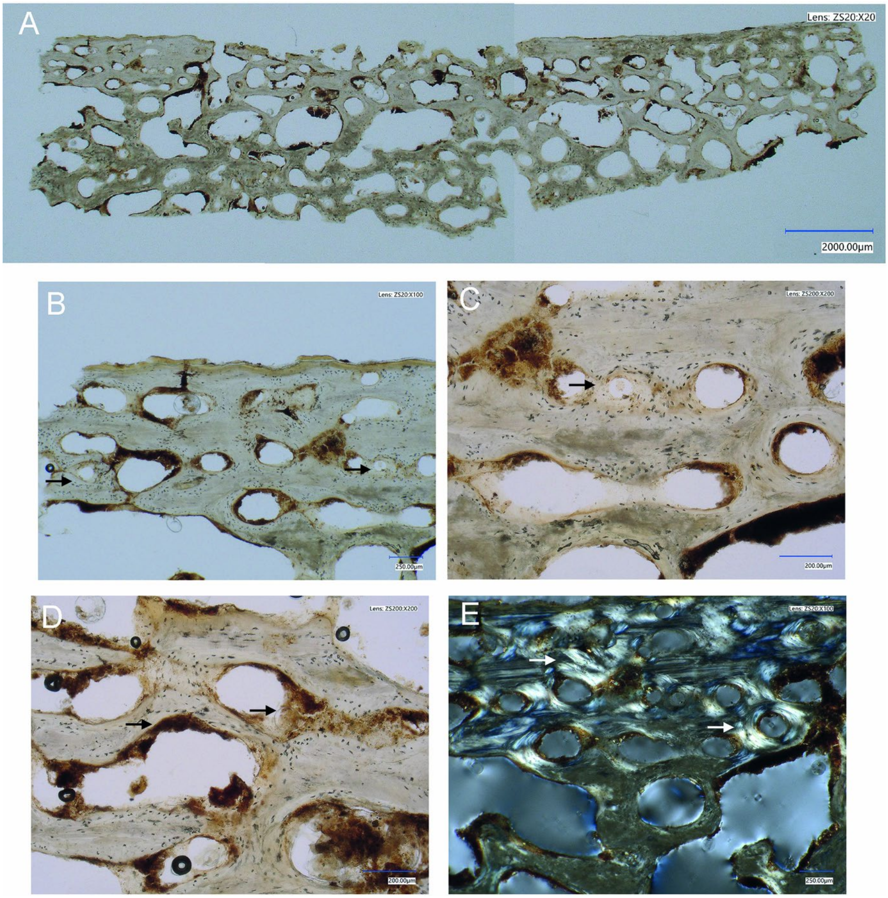

Fig. 5 **A** A scan of the thin section of sample M. **B** Micrograph (100×magnification) showing substantial areas of well-preserved microstructure **C** Micrograph (200×magnification) showing mixed preservation. **D** Micrograph (200×magnification) showing mixed preservation microstructure with limited staining/infiltration in enlarged haversian canals. **E** Polarised image (100×magnification) showing high levels of birefringence

Discussion

The results of the histological analysis contribute important evidence to complement macroscopic taphonomic, anatomical and archaeological data. These findings shed light on mortuary practices at the Knowe of Rowiegar chambered cairn, but interpretations must be made with caution and equifinality remains a challenge in the interpretation of histotaphonomic data. Based on previous research in Britain, this study interprets these data on the basis of a principally endogenous origin of bacterial attack. There is also some support for this at the Knowe of Rowiegar, as more homogeneous patterns of microstructural preservation might be expected if soil bacteria were responsible for the bioerosion.

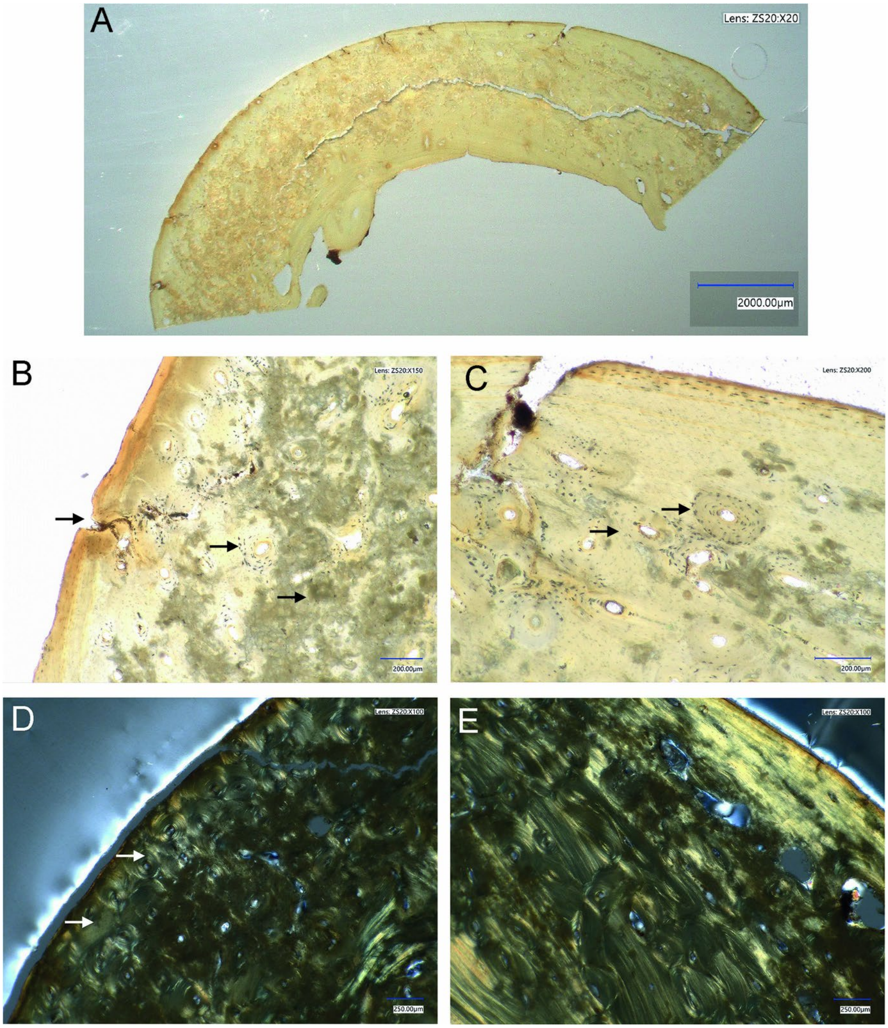

Fig. 6 **A** A scan of the thin section of sample ZZ(17). **B** (150 × magnification) showing bioerosion in the central cortical zone with the outer edges being well preserved and a crack along the periosteal edge of the bone. **C** Well-preserved band along the periosteum edge. **D** Polarised image (100 × magnification) showing mixed levels of birefringence with the Maltese cross visible on osteons on the periosteal edge. **E** Polarised image (20 × magnification) showing partial birefringence

As previously discussed, it is important to note that the association between bioerosion and early post-mortem treatment represents central tendencies rather than absolutes, resulting in the interpretation of the processes of variation in bioerosion being uncertain (Booth & Madgwick, 2016). Although the notion that bioerosion is closely linked to the putrefaction process has strong scientific support (see White & Booth, 2014), there are unquestionably other factors at play. It is clear that putrefaction does not always engender bioerosion. Mavroudas et al. (2023) found limited evidence for modification 24 months post-mortem in modern cadavers, which goes against the putrefaction stage of decay being the origin of bioerosion, though antibiotic medical treatments may go some way to explaining these patterns. Although this is the first study on human cadavers, White and Booth's (2014) study on pig carcasses strongly supports putrefaction being the origin of bioerosion. Climate, environment and the nature of the soil microbiome are all likely to impact on the potential for exogenous bacteria to cause bioerosion, but evidence suggests endogenous bacteria are a more important driver in a British context (Booth et al., 2024). Environmental conditions that inhibit bodily decomposition like waterlogging can influence bacterial bioerosion (Mulville et al., 2012; Turner-Walker & Jans, 2008). However, there is no evidence for variation in soil or environmental conditions, and therefore this is unlikely to account for the variation in bacterial attack that was observed across the Knowe of Rowiegar samples. Whilst precise practices are difficult to reconstruct with confidence (Booth & Madgwick, 2016), possible rites can be identified whilst others can be eliminated, improving the resolution with which funerary practices at the Knowe of Rowiegar are understood.

Subtle variations in the character of preservation were identified across all samples, but the dataset clusters into two broad categories—those individuals with very poorly preserved microstructure, scoring 0–1 (C1, D1, E, FT1, J, L, N, O, NN1, P1) and those with mixed patterns of preservation, scoring 2–3 (H1, M, ZZ(17)). This suggests that two overarching mortuary rites are in evidence, potentially with subtle variations in practice within these groups. The potential for the mortuary rites enacted on the individuals from the Knowe of Rowiegar to include excarnation (through sub-aerial exposure) was one of the, albeit tentative, possibilities put forward in the osteoarchaeological report by Hutchison et al. (2015). Their argument was based on the commingled, disarticulated state of the remains, often considered a hallmark of excarnation. The interpretation was supported by the taphonomic character of the bone, with peri- or early post-mortem cut marks found on one individual bone (Hutchison et al., 2015). However, no weathering was noted, and therefore sub-aerial exposure could not be assigned with confidence. Excarnation through sub-aerial exposure would be expected to produce well-preserved microstructure, with OHI scores of 4–5, due to the rapid degradation of soft tissue, allowing little opportunity for the migration of gut bacteria around the body. The absence of any scores in this range indicates that sub-aerial exposure was not responsible for the disarticulated state of the remains at Rowiegar.

The individuals that exhibited mid-ranging preservation (OHI 2–3, Group 2: H1, ZZ(17) and M) are likely to have decomposed at a faster rate than would have occurred through primary internment in a subterranean context. However, bacterial attack suggests that decomposition was not as quick as would be expected from exposure (White & Booth, 2014). There is a lack of experimental work that produces mid-ranging scores, but cave deposits have commonly produced these patterns (Booth, 2014). It is possible some type of sheltered exposure was practised. Similar patterns in Iron Age pits have been suggested as evidence for sheltered exposure in covered or deep, silting pits (Booth & Madgwick, 2016). In the context of the Knowe of Rowiegar, it is plausible these patterns could result from primary interment in the tomb structure. This is consistent with decomposition that would be quicker than subterranean burial, but slower than full sub-aerial exposure. These findings align with Crozier's (2012, 2018) hypothesis of whole-body interment in other Orcadian tombs. Other explanations are, of course, possible, such as the movement of the body from a context where bacteria could thrive (subterranean burial) to a situation where they could no longer attack the microstructure (*e.g.* through intentional preservation, an anoxic environment or through purposeful defleshing). However, primary interment in the tomb provides the most parsimonious explanation for these individuals. The disarticulated state of the remains is likely to result from later disturbance, perhaps relating to the addition of new burials, though plausibly relating to the deliberate retrieval and circulation of remains. This could explain the underrepresented skeletal elements at the Knowe of Rowiegar.

Multiple taphonomic trajectories are represented by the varying levels of bioerosion in the sample, and not all individuals are consistent with having been interred directly in the chambered cairn. Clearly, there were multiple pathways to the disarticulated state of the remains. Group 1 samples (C1, D1, E, FT1, J, L, N, O, NN1 and P1) presented poorly preserved microstructure (OHI 0–1). These results are consistent with primary inhumation of fully fleshed, articulated remains in a subterranean context (Jans et al., 2004; Booth et al., 2015). This raises the question of how (and in what state) they entered the chambered cairn and how they became disarticulated. Deciphering these details is beyond the potential of histotaphonomic analysis. However, the data provide evidence for a more complex, multi-stage funerary treatment involving secondary burial. In the context of an endogenous model of bacterial bioerosion, these individuals were subject to primary burial where putrefaction took place causing extensive bioerosion. After soft tissue decay, the burials were subsequently exhumed and the remains retrieved. Currently, it is not possible to ascertain how long after soft tissue decay the remains were accessed. Nor is it possible to establish whether all remains were retrieved and deposited in the chambered cairn, or whether selective retrieval of certain elements was undertaken for targeted deposition at the Knowe of Rowiegar. It is also possible that the remains represent the end point of a more protracted funerary practice involving selective retrieval and circulation prior to final deposition. The unbalanced element representation at the site suggests that selective retrieval is likely. However, this must be caveated with the knowledge that a significant portion of the site, and therefore potentially additional remains, was destroyed in the Iron Age. Disentangling these scenarios is beyond the scope of histotaphonomic analysis and these data only provide insights into the early post-mortem period, evidencing primary burial.

As part of a previous report on the remains found at the Knowe of Rowiegar, a programme of radiocarbon dating was undertaken to understand the site's phases of use. Bayesian models for the start and end boundaries of the primary use phases were developed to elucidate the date ranges for the individuals (Table 3) (Hutchison et al., 2015). This demonstrates the deposition of remains over several centuries. It is noteworthy that two of the individuals with mid-ranging scores (H1, ZZ(17)), interpreted as primary interments into the tomb, have closely aligned dates, but this does not mean that this practice was limited to a short period of time, as the other individual (M) has the latest date of all. Overall, evidence suggests that a range of funerary rites were practised throughout the use of the site.

Table 3 Results of radiocarbon dating of the remains undergoing histological analysis from the Knowe of Rowiegar chambered cairn using Bayesian's model (Hutchison et al., 2015) placed in chronological order

Sample (earliest to most recent)	Bayesian model 2 date CAL BC at 95.4% probability	OHI score
NN1	3405–3365	0
E	3375–3350	0
L	3370–3340	1
H1	3365–3330	2
ZZ(17)	3350–3290	2
D1	3345–3270	1
C1	3230–3145	1
O	3215–3130	1
N	3190–3110	1
P1	3180–3100	0
FT1	3170–3065	0
J	3140–3050	0
M	2960–2880	3

Conclusion

In the context of Rousay, Orkney, the Knowe of Rowiegar chambered cairn follows similar patterns of fragmentation, disarticulation and disorder (Crozier, 2016) as other sites along the south of the island. The nature of mortuary practice and how these remains ended up in a disarticulated, commingled state has long been enigmatic. Seven chambered cairns are located along the south coast of Rousay, Orkney. The close proximity of the location of these sites alludes to the idea that they are all part of one funerary complex (Reilly, 2003). All seven sites consist of a mixture of disarticulated, fragmented and disordered remains (Crozier, 2016) which were scattered across the tomb with some unbalanced element representation. These patterns are hallmarks of excarnation (Redfern, 2008), although there are, of course, multiple pathways to skeletal disarticulation. Apart from Midhowe and Taverosoe Tuick, none of the other sites along the south of Rousay have articulated remains; this characteristic led Hutchison et al. (2015) to revisit the potential for excarnation to have had a role in the mortuary rites. However, the histotaphonomic analysis indicates no evidence for excarnation at the Knowe of Rowiegar with primary burial, followed by exhumation and potentially selective retrieval and deposition being the most commonly observed practice.

An over-representation of skull elements in comparison to other skeletal elements, similar to that of Knowe of Yarso, supports the idea of selective retrieval and potentially also circulation and/or curation. The absence of many of the skeletal elements could be attributed to Reilly's (2003) suggestion that all the sites along the south of Rousay were part of a larger complex with remains distributed across multiple sites. Primary interment in the tomb, creating a situation of sheltered exposure, followed by disturbance, likely by later interments, is also in evidence. This implies that Rowiegar chambered cairn was re-entered regularly, similarly to Midhowe, allowing for the interaction with those who are already present within the tomb

(Richards, 1993). These interpretations oversimplify the range of scenarios that could be responsible for the observed patterns of bioerosion and equifinality remains a substantial hurdle to confident interpretation. However, these represent the most parsimonious explanations for the evidence. These findings may require interpretive revision in light of future experimental work on the drivers of variation in histological preservation. However, the variation in patterns of bioerosion points to multiple pathways to disarticulation at the Knowe of Rowiegar and evidences different funerary practices, some of which involve more complex, multi-stage secondary burial. This provides an important contribution to our understanding of early-post-mortem treatment in Neolithic Orkney, and it would be of benefit for more histotaphonomic analysis to be undertaken at comparable sites on Rousay.

Acknowledgements We are grateful to Peter Forward for assistance with microtome thin sectioning and microscope imaging and to Kirsty Harding for producing Fig. 1. Many thanks to the University of Aberdeen Museums and Special Collections for providing access to the Knowe of Rowiegar samples.

Author Contributions RM and RC conceived of the study and designed the research. All sampling, thin sectioning, microscopy and micrograph prodcuction was undertaken by TT, under the supervision of RM. All authors wrote, reviewed and edited the manuscript.

Data Availability Data is provided within the manuscript.

Declarations

Competing Interests The authors declare no competing interests.

References

Barber, J., (1997). *The excavation of a stalled cairn at the Point of Cott, Westray, Orkney*. Scottish Trust for Archaeological Research.

Bell, L., Skinner, M., & Jones, S. (1996). The speed of postmortem change to the human skeleton and its taphonomic significance. *Forensic Science International., 82*, 129–140.

Booth, T. (2014). *An investigation into the relationship between bone diagenesis and funerary treatment*. Unpublished PhD thesis. University of Sheffield.

Booth, T. J. (2015). An investigation into the relationship between funerary treatment and bacterial bioerosion in European archaeological human bone. *Archaeometry, 58*, 484–499.

Booth, T., Chamberlain, A., & Pearson, M. (2015). Mummification in Bronze Age Britain. *Antiquity*, *89*(347), 1155–1173.

Booth, T., Bricking, A., & Madgwick, R. (2024). Comment on "Bacterial bioerosion of bones is a post-skeletonisation phenomenon and appears contingent on soil burial" [Quat. Int. 660 (2023) 75–83]. *Quaternary International., 702*, 61–64.

Booth, T., Bronnimann, D., Madgwick, R., & Portmann, C. (2022). The taphonomic and archaeothanatological potentials of diagenetic alterations of archaeological bone. In C. J. Knusel & E. M. J. Schotsmans (Eds.), *The Routledge handbook of archaeothanatology: Bioarchaeology of mortuary behaviour* (pp. 580–599). Routledge.

Booth, T., & Madgwick, R. (2016). New evidence for diverse secondary burial practices in Iron Age Britain: A histological case study. *Journal of Archaeological Science., 67*, 14–24.

Booth, T. (2017). The rot sets. In: Low-powered microscopic investigation of taphonomic changes to bone microstructure and its application to funerary contexts, In D. Errickson, & T. Thompson (Eds.), *Human Remains: Another Dimension* (pp. 7–28). Academic Press.

Bricking, A., Hayes, A., & Madgwick, R. (2022). An interim report on the histological analysis of human bones from Fishmonger's Swallet, Gloucestershire. *Proceedings of the University of Bristol Speleological Society., 29*(1), 67–86.

Brönnimann, D., Portmann, C., Pichler, S., Booth, T., Röder, B., Schibler, W., & Rentzel, P. (2018). Contextualising the dead – Combining geoarchaeology and osteo-anthropology in a new multi-focus approach in bone histotaphonomy. *Journal of Archaeological Science, 98*, 45–58.

Callander, J. G., & Grant, W. G. (1935). A long, stalled cairn, the Knowe of Yarso, in Rousay, Orkney. *Proceedings of the Society of Antiquaries of Scotland, 69*, 325–351.

Callander, J. G., Grant, W. G., & Low, A. (1934). A long stalled chambered cairn or mausoleum (Rousay type) near Midhowe, Rousay, Orkney. *Proceedings of the Society of Antiquaries of Scotland, 68*, 320–354.

Chesterman, J. T. (1979). Investigation of the human bones from Quanterness. In C. Renfrew (Ed.), *Investigations in Orkney* (pp. 97–111). The Society of Antiquaries of London.

Chesterman, J. T. (1983). The human skeletal remains. In J. W. Hedges (Ed.), *Isbister. A chambered tomb in Orkney*. BAR British Series.

Childe, V. G. (1931). Skara Brae: a 'Stone Age' Village in Orkney. *Antiquity*, *5*(17), 47–59.

Crozier, C. R. (2012). *A taphonomic approach to the re-analysis of the human remains from the Neolithic chamber tomb of Quanterness, Orkney* (Doctoral dissertation, Queen's University Belfast).

Crozier, R. (2018). *A Taphonomic approach to the re-analysis of the human remains from the Neolithic chamber tomb of Quanterness, Orkney*. British Archaeological Reports British Series, Hadrian Books.

Crozier, R. (2016). Fragments of death. A taphonomic study of human remains from Neolithic Orkney. *Journal of Archaeological Science: Reports., 10*, 725–734.

Crozier, R., Richards, C., Robertson, J., & Challands, A. (2016). Reorientating the dead of crossiecrown: Quanterness and ramberry head. In C. Richards & R. Jones (Eds.), *The development of neolithic house societies in Orkney: Investigations in the Bay of Firth, Mainland, Orkney (1994–2014)* (pp. 196–223). Oxbow Books.

Davidson, L., & Henshall, A. (1989). *The chambered cairns of Orkney*. Edinburgh University Press.

Fernández-Jalvo, Y., Andrews, P., Pesquero, D., Smith, C., Marín-Monfort, D., Sánchez, B., Geigl, E., & Alonso, A. (2010). Early bone diagenesis in temperate environments Part I: Surface features and histology. *Palaeogeography, Palaeoclimatology, Palaeoecology, 288*(1–4), 62–81.

Fowler, C. (2010). Pattern and diversity in the Early Neolithic. Mortuary practices of Britain and Ireland: Contextualising the treatment of the dead. *Documenta Praehistorica, 41*, 1–22.

Hedges, J. W. (1983). *Isbister: A chambered tomb in Orkney*. BAR.

Hedges, J. W. (1987). *Tomb of the eagles: Death and life in a Stone Age tribe*. Rowman & Littlefield.

Hess, M. W., Klima, G., Pfaller, K., Künzel, K. H., & Gaber, O. (1998). Histological investigations on the Tyrolean ice man. *American Journal of Physical Anthropology, 106*(4), 521–532.

Hutchison, M., Curtis, N., & Kidd, R. (2015). The Knowe of Rowiegar, Orkney: Description and dating of the human remains and context relative to neighboring cairns. *Proceedings of the Society of Antiquaries of Scotland, 145*, 41–86.

Jans, M., Kars, H., Nielsen-Marsh, C., Smith, C., Nord, A., Arthur, P., & Earl, N. (2002). In situ preservation of archaeological bone: A histological study within a multidisciplinary approach. *Archaeometry, 44*(3), 343–352.

Jans, M., Nielsen-Marsh, C., Smith, C., Collins, M., & Kars, H. (2004). Characterisation of microbial attack on archaeological bone. *Journal of Archaeological Science*, *31*(1), 87–95.

Jones, A. (1998). Where eagles dare: Landscape, animals and the Neolithic of Orkney. *Journal of Material Culture., 3*(3), 301–324.

Lawrence, D. M. (2014). *Orkney's first farmers. Reconstructing biographies from osteological analysis to gain insights into life and society in a Neolithic community on the edge of Atlantic Europe* (Doctoral dissertation, University of Bradford).

Lawrence, D. (2007). Neolithic mortuary practice in Orkney. *Proceedings of the Society of Antiquaries of Scotland, 136*, 47–59.

Mavroudas, S., Alfsdotter, C., Bricking, A., & Madgwick, R. (2023). Experimental investigation of histotaphonomic changes in human bone from whole-body donors demonstrates limited effects of early post-mortem change in bone. *Journal of Archaeological Science*, *154*. https://doi.org/10.1016/j.jas.2023.105789

Millard, A. (2001). Deterioration of bone. In D. Brothwell & A. Pollard (Eds.), *Handbook of archaeological sciences* (pp. 633–643). Wiley.

Mulville, J., Madgwick, R., Powell, A., & Parker Pearson, M. (2012). Flesh on the bones: Animal bodies in Atlantic roundhouses. In A. Pluskowski (Ed.), *The ritual killing and burial of animals: European perspectives* (pp. 208–221). Oxbow Books.

Parker Pearson, M., Chamberlain, A., Craig, O., Marshall, P., Mulville, J., Smith, H., Chenery, C., Collins, M., Cook, G., Craig, G., Evans, J., Hiller, J., Montgomery, J., Schwenninger, J., Taylor, G., & Wess, T. (2005). Evidence of mummification in Bronze Age Britain. *Antiquity*, *79*(305), 529–546.

Phillips, T. (2004). Seascapes and landscapes in Orkney and northern Scotland. *World Archaeology, 35*(3), 371–384.

Redfern, R. (2008). New evidence for Iron Age secondary burial practice and bone modification from Gussage All Saints and Maiden Castle (Dorset, England). *Oxford Journal of Archaeology., 27*, 281–301.

Reilly, S. (2003). Processing the dead in Neolithic Orkney. *Oxford Journal of Archaeology, 22*, 133–154.

Renfrew, C. (1979). *Investigations in Orkney*. The Society of Antiquaries of London.

Richards, C. (1993). *An archaeological study of Neolithic Orkney: Architecture, order and social classification*. Unpublished PhD thesis, University of Glasgow.

Richards, C. (1988). Altered images: A re-examination of Neolithic mortuary practices in Orkney. In J. C. Barrett & I. A. Kinnes (Eds.), *The archaeology of context in the Neolithic and Bronze Age. Recent trends.* Department of Archaeology. University of Sheffield.

Richards, C. (1996). Monuments as landscape: Creating the centre of the world in late Neolithic Orkney. *World Archaeology., 28*(2), 190–208.

Turner-Walker, G., Galiacho, A., Armentano, N., & Hsu, C. (2023). Bacterial bioerosion of bones is a post-skeletonisation phenomenon and appears contingent on soil burial. *Quaternary International., 660*, 75–83.

Turner-Walker, G., & Jans, M. (2008). Reconstructing taphonomic histories using histological analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology., 266*, 227–235.

Turner-Walker, G., Nielsen-arsh, C., Syversen, U., Kars, H., & Collins, M. (2002). Sub-micron spongiform porosity is the major ultra-structural alteration occurring in archaeological bone. *International Journal of Osteoarchaeology., 12*, 407–414.

White, L., & Booth, T. J. (2014). The origin of bacteria responsible for bioerosion to the internal bone microstructure: Results from experimentally deposited pig carcasses. *Forensic Science International., 239*, 92–102.