Chapter 12
Bone Weathering of Juvenile-Sized Remains in the North Carolina Piedmont

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Abstract In decomposition studies, soft tissue decay and the effects of the environment on its processes and timing have been the primary focus. Decompositional changes to skeletal material, often called bone weathering, have been observed in far fewer research studies, most notably Behrensmeyer's (Paleobiology 4:150–162, 1978) foundational project that first described the process and time frame for hard tissue decay. While other studies have followed, all have noted that the rate and the process of decay are dependent on the local environmental factors affecting the skeletal material, an issue that is also well known in soft tissue decomposition research. While much of the bone weathering studies are long-term and often use adult elements, this study adds to the literature by focusing on short-term changes occurring within a year to juvenile domestic pigs in the central Piedmont region of North Carolina. In this study, juvenile domestic pigs, *Sus scrofa* ($n = 7$), were used as proxies for human children because of their similarity in size and immaturity of the skeletal elements. Observations took place over an 8-month period; two fleshed pigs ($n = 2$) were placed at the beginning of the observational period, while the other five ($n = 5$) had been in the research field for at least 3 months prior to the beginning of the project. The study found that, while all skeletal elements remained largely intact, specific elements were more affected by different types of weathering. Long, tubular bones, including long bones, metacarpals, metatarsals, and phalanges, were more prone to flaking of the outer layers of cortical bone, while long bones, vertebrae, and ribs were more likely to have loss of bone at the articular facets, leading to exposure of interior trabecular bone. The location of the project, largely underutilized in forensic research, shares similar environmental factors with other large areas of the American South. Consequently, the results could be applied to the broader southeastern United States.

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12.1 Introduction

Forensic research has led to insight into the processes affecting the breakdown of remains after death. The decay of soft tissue has been exhaustively studied, which led to a better understanding of the observable stages and timing of the decay process. While the decomposition process follows a general pattern, researchers have found that the timing of each stage can vary depending on climate and local environmental factors including soil content and acidity, exposure to the elements, and surface versus subsurface deposition [1–4].

Similar to soft tissue decay, skeletal decay occurs in observable stages, but the timing of each stage depends on the local environmental factors acting on the material [5–11]. Skeletal decomposition, or bone weathering, has been defined by one of the original researchers as "... the process by which the original microscopic organic and inorganic components of a bone are separated from each other and destroyed by physical and chemical agents operating on the bone in situ, either on the surface or within the soil zone" [5]. In a study conducted in the diverse local environments of the equatorial climate of Southern Kenya's Amboseli National Park, Behrensmeyer [5] classified the observed decompositional changes into stages (Table 12.1).

The present research study, conducted in the central North Carolina Piedmont, describes the progress of decomposition of both soft and hard tissue remains of juvenile pigs in a semi-wooded environment. Using pigs as proxies for human decomposition has become a common practice due to their availability and similarity to human physiology [12]. Additionally, because of their small size, juvenile pigs have been used as proxies for children in forensic research [13, 14]. This research focus is particularly useful since the many human adult cadaver studies conducted in research fields of the University of Tennessee, Knoxville, and other places may not be appropriate corollaries to child decomposition due to size differences and the immaturity of the skeletal system. The immaturity of the skeletal system, due to the non-fusion of elements during growth, increases the volume of skeletal material present and causes the elements to have an appearance very different from the mature form. Thus, it is necessary to understand how the decompositional processes affect juveniles in an effort to better inform forensic investigators. The purpose of

Table 12.1 Skeletal decomposition according to Behrensmeyer [5]

Stage	Description
0	Fresh, defleshed bone
1	Longitudinal cracking, though some soft tissue may still remain
2 (A)	Topmost layer of bone begins to flake, though some soft tissue may still remain
2 (B)	Topmost layer of bone has almost completely flaked off
3	Topmost layer of bone is gone, compact bone layers (1.0–1.5 mm deep) are fibrous
4	Compact bone continues to appear fibrous and rough, splintering of bone pieces may occur, inner cavity begins to show wear
5	Inner, trabecular bone is exposed, bone itself is falling apart and losing its shape

this project is to establish an approximate timing and description of stages of decay associated with the local environmental factors found in the central Piedmont of North Carolina. This analysis of the effects of the microenvironments is essential if more accurate time-since-death estimations are to be made.

12.2 Background

The North Carolina Piedmont stretches across the state from the Appalachian Mountains in the west to the lowland eastern coastal plain. It is characterized as having a warm temperate climate with fully humid precipitation levels and hot summers [15]. The Lake Wheeler research field is part of land grants connected with North Carolina State University and is located in the center of the Piedmont within the city limits of Raleigh.

The research area is an open agricultural field with partial tree cover bordered by a small stream. Soil samples were collected from two locations where the early fall research subjects were to be placed: one in an open area with no cover and the second located in heavy shade with only minimal sun exposure. Soil analysis was conducted by the North Carolina Department of Agriculture and Consumer Services. The two tests indicate that the research field was composed of mineral class silt or clay loamy soil. While the pH levels varied for the two sampled areas (the shade area measuring at 4.4 and the open area measuring at 5.2), both confirm acidic soil content.

Weather data for the research site was obtained from the State Climate Office of North Carolina and recorded by the Lake Wheeler field lab weather station. The collected data consisted of three environmental measurements: daily average temperature, daily average precipitation, and daily average solar radiation. During the 7 months of field research, spanning the fall through spring season, the average temperature ranged from 77.1°F to 27.5°F, with the lowest temperatures occurring during the winter months (December–February) (Fig. 12.1). Precipitation levels were low during the observation period (7-month average 0.1056 in.), with the

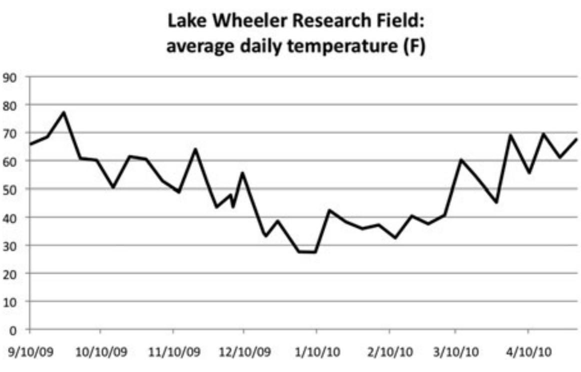

Fig. 12.1 Average Daily Temperature for Lake Wheeler Research Site

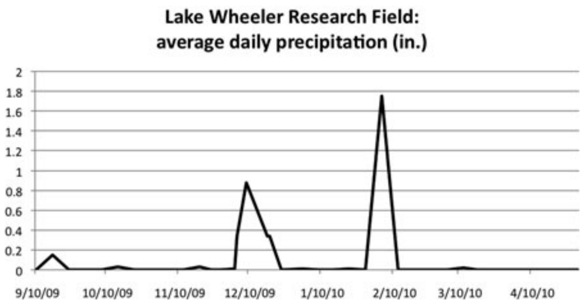

Fig. 12.2 Average Daily Precipitation for Lake Wheeler Research Site

highest levels of accumulation occurring in December (Fig. 12.2). Solar radiation levels were the most variable (averaging 119.467 W/m^2 during the observation period), the lowest occurring between November and early February and the highest occurring from mid-February through the end of April (Fig. 12.3).

Soft tissue decomposition begins to occur soon after death and full skeletonization of remains can be completed within a matter of 2 weeks in a humid, equatorial setting [2]. Skeletal material, however, can remain virtually unchanged long after its initial deposition [7]. Previous decomposition research in warm temperate climate regions, similar to North Carolina, has shown that skeletal remains in warm temperate climate decay at a much slower rate in comparison to equatorial and arid climates [5, 7, 10]. One study, conducted in Somerset, England, found that juvenile cow remains located on the soil surface were largely unchanged for 8 years after death and could be scored only as a 0 on the Behrensmeyer scale [5, 6].

A second study, conducted in Rhulen, Wales, and lasting for approximately 20 years found that after 19 years the surface-deposited large animal remains reached only Behrensmeyer's stage 2 of decomposition. However, after 12 years, remains left in moist, covered environments were found to be more heavily decayed on the epiphyses and articular surfaces [8]. In this same study, small animal bones were found to respond differently to weathering than the large animal remains. While little or no weathering was apparent on large animal bones as late as 12 years after

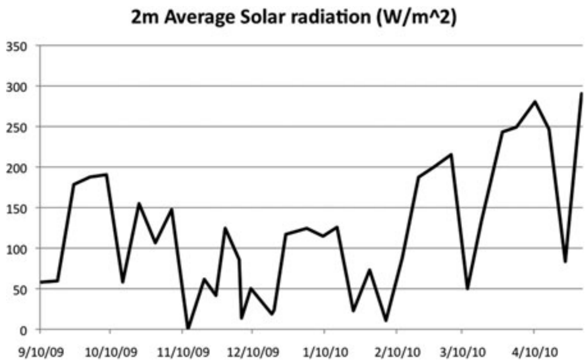

Fig. 12.3 Average Daily Solar Radiation for Lake Wheeler Research Site

death, small animal bones were observed to have more progressive or even complete decay after only 5 years [8]. This differential weathering pattern is likely caused by differences in bone size and density, as it has been found that the greater the density of the bone, the better the preservation [16].

12.3 Methods

Seven juvenile pigs were placed in an open field in staggered phases. Five were placed in early summer, two were placed in early fall, and all, except one, were collected in the late spring/early summer of the following year. The four of the original five pigs were exposed to the elements for 11 months (summer 2009–spring/summer 2010), while the two placed in early fall were exposed for 8 months. One of the pigs placed in late spring/early summer was collected midway through the research period (in early January) and was exposed to the elements for 7 months.

For Behrensmeyer's [5] stages to be applicable, the research subject must be at least 11 lbs (5 kg). Pigs 1 through 5 weighed approximately 35 lbs (15.88 kg), with one reaching 55 lbs (24.95 kg). Pig 6 was 22.5 lbs (11.57 kg) and pig 7 was 23 lbs (10.43 kg). All pigs were juveniles and, based on weight, were approximately between 4 and 10 weeks old. During original placement, all pigs were covered in wired cages to prevent removal by scavengers. Once skeletonized, several of the cages were removed prior to the beginning of the research period (pigs 3 and 5). The subjects were monitored once a week beginning in early September for 34 weeks for a total of 33 observations. One observation was missed in midwinter due to an impassable creek that cut off access to the research field. Pictures taken in the field were with a Nikon Coolpix 4600 point and shoot camera, while those taken during laboratory analysis were with a Canon PowerShot SD750 digital ELPH.

Laboratory analysis included a skeletal inventory of identifiable skeletal elements for a count of bones present. These elements were then analyzed to determine the presence and degree of weathering based on Behrensmeyer's [5] stages.

Because the research subjects were juveniles, no skeletal elements were completely fused, resulting in several components present for each bone. To simplify the count of skeletal material, each whole bone was counted as one element, even if it had several epiphyses present. The epiphyses of long bones were easily identifiable and a special note was made of their condition, but they were not included in the overall bone count. For some major structural elements, the young age of the subjects resulted in some elements remaining in several identifiable pieces. This was especially true for the pelvis. The juvenile pig *os coxae* are made up of three separate bones (the ilium, the ischium, and the pubis) that will later fuse much like the human pelvis. The pubis and ischium were already fused during fetal development. The remaining two elements were easily identified and were each counted as one half of a whole so that each research subject should have two whole innominates (four separate unfused elements from each side) in total.

12.4 Results

During collection, rain, vegetation, and natural soil movement partially buried large portions of several research subjects' skeletal elements. Because of this, collection was performed in two steps: vegetation was cleared and elements that remained on the surface were collected. Then, soil surface was removed and subsurface remains were collected separately. Naturally buried remains were found in proximity to the surface. Roots from surrounding vegetation had grown around and sometimes through many surface and subsurface elements, causing root etching.

The skeletal elements recovered did not show signs of longitudinal cracking or other more advanced weathering forms and were determined to be at stage 0 on the Behrensmeyer [5] scale. However, subtle changes to the bone were present in all study subjects and were categorized as flaking of cortical bone, erosion of articular facets and epiphyseal articulations, pockmarks and erosion of the surface of the elements. Flaking of the cortical bone is characterized by a marbling pattern on the diaphyses of the elements and a series of fine cracks on the outermost layer that had begun to shed parts of itself (Fig. 12.4). This weathering pattern differs from longitudinal cracking in that only the outermost layer is currently affected. Erosion of the articular facets and epiphyseal articulations is characterized as erosion of the outer layer of cortical bone resulting in trabecular bone exposure (Fig. 12.5). Similar to articular facet/epiphyseal erosion, the erosion of the surface of elements, exhibited most often as a circular "pockmark" pattern, due to the wearing away of the cortical bone layer, exposing the underlying trabecular bone (Fig. 12.6). Table 12.2 shows the breakdown of each research pig by the number of elements and weathering percentage. Table 12.3 shows the breakdown of each subject by weathering pattern.

Fig. 12.4 Marbling Pattern on Outer Diaphysis

Fig. 12.5 Erosion of Articular Facets

Fig. 12.6 Circular Pockmark Pattern

12.4.1 Pig 1

Pig 1 was the first placed in the field. Vegetative growth was particularly active even during the winter months, and the skeleton was almost completely obscured for a large part of the research period. During the collection phase, 109 elements were recovered. Root activity minimally affected surface elements; however, it was much more pervasive in the subsurface remains. On effected remains, the area surrounding root attachments showed more wear than other parts of the elements (Fig. 12.7).

Of the recovered surface remains present ($n = 48.5$), 69% ($n = 33.5$) showed some sign of weathering. This was most often seen in the form of erosion of articular facets ($n = 23$), which affected ribs and vertebrae most often. Cortical

Table 12.2 Weathering percentage by proxy and deposition level

Proxy	Total elements collected	Surface/subsurface remains collected	Total weathered
Pig 1	109	48.5	33.5 (69%)
		60.5	34 (56%)
Pig 2	118	69	42.5 (61%)
		49	29 (59%)
Pig 3	88	88 (surface only)	75 (85%)
Pig 4	104	74.5	48.5 (65%)
		29.5	8 (27%)
Pig 5	113	113 (deposition not recorded)	74 (65%)
Pig 6	116	91	26.5 (29%)
		25	6 (24%)
Pig 7	126	105	32 (30%)
		21	2 (9%)

flaking was seen only in the long bones ($n = 3$). Surface erosion ($n = 7.5$) affected several different types of bone, including long bones, but was seen most often in carpals/tarsals. The subsurface remains ($n = 60.5$) followed a similar weathering pattern. Articular/epiphyseal facet erosion affected ribs and vertebrae, as well as metacarpas/tarsals and phalanges ($n = 32$), while surface erosion accounted for a much smaller element weathering ($n = 2$) for a total of 56% ($n = 34$) of the subsurface remains presenting some weathering pattern.

Precipitation accumulation was low, though rainfall was recurrent throughout the study period, encouraging the growth of algae on the exposed surfaces of many of the elements (Fig. 12.8). The presence of green algae on the bone was first noticed on the first observations made for pig 1 on September 24, 2009, which persisted throughout the study period.

12.4.2 Pig 2

As with the other research subjects, persistent rainfall and temperatures above freezing caused continued vegetative growth even during the winter months, which resulted in many elements being covered in green algae from the initial observation, September 24, 2009, and persisting throughout the study. The continued vegetative growth caused the skeleton to be completely covered and obscured from view by December 9, 2009. During the collection phase, 118 elements were recovered. Root activity was moderate, and surface remains were largely free of any fibrous roots, while the subsurface remains were more heavily affected. Many, but not all, elements exhibited some sort of fibrous root activity.

Of the 69 elements recovered from the surface, 62% ($n = 42.5$) showed some sign of weathering. Erosion of the articular/epiphyseal facets was most prevalent ($n = 41.5$) and was found to affect ribs and vertebrae more than other elements. Several elements that were affected by articular facet erosion also presented surface

Table 12.3 Breakdown of weathering by type

Proxy #	Surface/ subsurface elements collected	Total weathered (percentage of total remains)	Weathering type (percentage of total weathered)			
			Cortical bone flaking	Erosion of articular/ epiphyseal facets	Erosion of element surface, "pockmarking"	Multiple patterns in single element (percentage of erosion of articular/ epiphyseal facet count)
Pig 1	48.5	33.5 (69)	3 (9)	23 (69)	7.5 (22)	0 (0.0)
	60.5	34 (56)	0 (0.0)	32 (94)	2 (6)	0 (0.0)
Pig 2	69	42.5 (61)	1 (2)	41.5 (98)	0 (0.0)	5 (12) facet erosion/cortical flaking 5 (12) facet erosion/surface erosion
	49	29 (59)	7 (24)	14 (48)	8 (27)	0 (0.0)
Pig 3	88	75 (85)	3 (4)	70 (93)	2 (3)	9 (13) facet erosion/cortical flaking 3 (4) facet erosion/surface erosion
Pig 4	74.5	48.5 (65)	2 (4)	46.5 (96)	0 (0.0)	2 (4) facet erosion/cortical flaking
	29.5	8 (27)	2 (25)	6 (75)	0 (0.0)	1 (17) facet erosion/cortical flaking
Pig 5	113	74 (65)	0 (0.0)	74 (100)	0 (0.0)	2 (3) facet erosion/surface erosion
Pig 6	91	26.5 (29)	2 (7)	24.5 (92)	0 (0.0)	0 (0.0)
	25	6 (24)	0 (0.0)	6 (100)	0 (0.0)	(0.0)
Pig 7	105	32 (30)	6 (19)	26 (81)	0 (0.0)	5 (19) facet erosion/cortical flaking
	21	2 (9)	0	0	2 (100)	0

Fig. 12.7 Root Activity and Erosion on Epiphysis

Fig. 12.8 Algae Growth on Skull

erosion ($n = 5$), occurring in the carpals/tarsals and sternebrae, and cortical flaking ($n = 5$), which was found more often in long, tubular bones. Only the fibula exhibited just one type of weathering pattern, cortical flaking. Fifty-nine percent ($n = 29$) of the subsurface remains ($n = 49$) were affected by weathering, with articular surface erosion being the most prevalent ($n = 14$). Surface erosion was found only on carpals/tarsals ($n = 8$), and cortical flaking was found on the long bones, phalanges, and the skull ($n = 7$).

12.4.3 Pig 3

Unlike pigs 1 and 2, who were covered by cages for almost the whole observation period, pig 3 was not enclosed. Similarly, while vegetation continued to grow and overtake some of the research subjects, the vegetation from the location of pig 3 only grew enough to partially cover many of the skeletal elements (termed "moderate vegetation growth") by mid-February. This means that pig 3 was completely exposed to environmental factors, particularly the sun, for 4 months. The initial observation (September 10, 2009) found that the bones were bleached white. Rainfall during the week caused many of the bones to become stained with green algae, which slowly faded back to a bleached white/gray color. During the collection phase, 118 elements were recovered. Root interaction was minimal, and fibrous networks attached to elements as seen in pigs 1 and 2 were absent. Pig 3 appears to have been largely unaffected by root activity.

All of the 88 elements were recovered from the surface; no subsurface remains were found. Eighty-five percent ($n = 75$) of the surface remains showed some sign of weathering. Erosion of the articular facets was the most prevalent ($n = 70$) and affected almost every recovered bone. Surface erosion affected 5 elements ($n = 5$), and diaphyseal flaking affected 12 elements ($n = 12$). Several elements that were affected by articular facet erosion also presented surface erosion ($n = 3$) (carpals/tarsals) and cortical flaking ($n = 9$), where long bones were the most represented.

12.4.4 Pig 4

Similar to pigs 1 and 2, pig 4 was enclosed in a cage for the observation period. Root activity was minimal and, similar to pig 3, pig 4 did not have the fibrous root networks attached to elements as seen in pigs 1 and 2. At the beginning of the research period, vegetation was cleared from the cage, revealing elements that were partially buried and several that were green with algae growth. Vegetation within the cage was heavy, though it surrounded the remains, providing some cover from environmental factors, including intensive sunlight, rather than covering the bones. Pig 4 was the closest research subject to the creek that bordered the research field. The creek likely breached its banks in early November as the mid-November observation found sediment deposited in the cage and on the remains, and a cluster of bones had been moved into a pile next to the cage wall. During the collection phase, 104 elements were recovered. No root activity was present.

Sixty-five percent ($n = 48.5$) of the surface remains ($n = 74.5$) presented signs of weathering. Erosion of the articular/epiphyseal facets was most prevalent ($n = 46.5$). Cortical bone flaking was present ($n = 2$) on long, tubular bones such as the femur and metacarpals. Several elements that were affected by articular/epiphyseal facet erosion also presented surface cortical flaking ($n = 2$). Subsurface elements ($n = 29.5$) were affected by weathering patterns at a rate of 27% ($n = 8$). Erosion of articular/epiphyseal facets was the most common type of weathering pattern ($n = 6$), while cortical bone flaking was less prevalent ($n = 2$). One element ($n = 1$), a long bone, was affected by both cortical bone flaking and articular/epiphyseal facet erosion. Surface erosion was notably absent from the remains of pig 4.

12.4.5 Pig 5

Like pig 3, pig 5 was not enclosed in a cage during the observation period. This research subject was collected in early January 2010 (at 7 months exposure) to create a control to understand what weathering patterns took place during longer periods of exposure. Root activity was minimal with only a few elements presenting attached fibrous root networks. During the collection phase, 113 elements were recovered. Depositional levels (surface vs. subsurface), through an oversight on the part of the researcher, were not recorded for this research subject.

Only the erosion of articular/epiphyseal facets and bone surface was present. Sixty-five percent ($n = 74$) of the recovered remains ($n = 113$) presented signs of weathering effects. All of these remains were affected by articular/epiphyseal facet erosion, while several elements ($n = 2$), a carpal/tarsal and ulna, were found to present the additional patterns of surface erosion. No cortical flaking was present.

12.4.6 Pig 6

Set out in the early fall (September 4, 2009), pig 6 was covered by a cage fully exposed to the sun throughout the duration of the research period. Insect activity ceased in mid-October, and the remains appeared to be skeletonized except for the surface-side skin, which persisted. Weather conditions (cool temperatures and sun) caused the remaining skin to mummify. Vegetation growth was slower and root activity was not present. Some elements were stained green with algae.

Of the surface remains collected ($n = 91$), 29% ($n = 26.5$) presented signs of weathering effects. Erosion of the articular/epiphyseal facets was most prevalent ($n = 24.5$). Cortical bone flaking affected two metacarpals/metatarsals ($n = 2$). Subsurface elements ($n = 25$) were affected only by erosion of articular/epiphyseal facets at a rate of 24% ($n = 6$). Surface erosion was notably absent.

12.4.7 Pig 7

Set out at the same time as pig 6, pig 7 was covered by a cage and placed in a corner of the field with complete shade so that only minimal sunlight would reach the subject. Skeletonization and the cessation of insect activity were reached in early October, 2 weeks before the surface skin of pig 6 mummified. Vegetation growth was slower than in other areas, and green plants obscured pig 7 only at the end of March. Leaf litter in the cage due to surrounding trees was more prevalent. Like the other research pigs, the remains were stained green, though not until late November, several weeks after skeletonization was reached. During the collection phase, 126 elements were recovered.

Thirty percent ($n=32$) of the surface remains ($n=105$) presented signs of weathering effects. Erosion of the articular/epiphyseal facets was most prevalent ($n=26$), present in long bones, vertebrae, and ribs, as well as other elements. Cortical bone flaking affected only tubular bones such as long bones and metacarpals ($n=6$). Several elements (humerus, femora, and tibiae) had both types of weathering present ($n=5$). Subsurface elements ($n=21$) were affected only by surface erosion at a rate of 9% ($n=2$) (carpals/tarsals).

12.5 Obstacles

When working with juvenile research subjects in decomposition studies, it is important to remember that the bone was still actively growing and remodeling prior to death. These areas of growth have a coarse and porous appearance that is commonly misidentified as pathological [17]. This problem also occurs in weathering studies where active growth mimics patterns of skeletal decay that expose trabecular bone. One indicator that a roughened, porous area is caused by growth instead of weathering is its location. If the "exposed trabecular bone" is located proximal-posteriorly on the long bones or on the sterno-posterior surface of the ribs, then it is likely growth and not weathering (Fig. 12.9). Another indicator is the timing of these pseudo-weathering marks appear. If the marks have been present since the remains were first skeletonized, it is likely a sign of previous active growth.

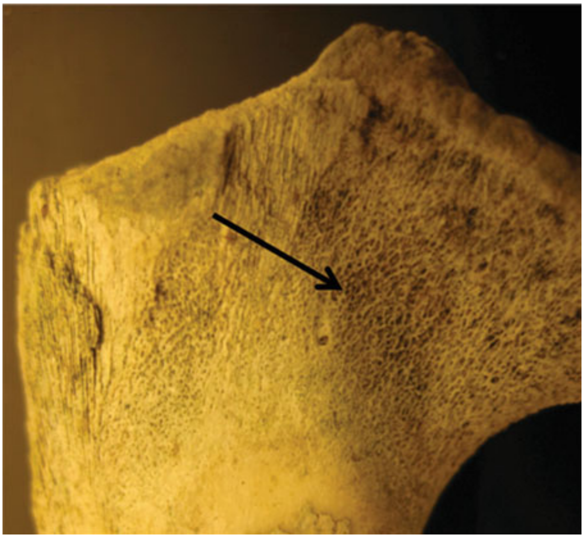

Fig. 12.9 Porosity due to growth in the cut-back zone and not related to weathering (proximal long bone)

Within this project, a small bias may artificially inflate the weathering type count. When documenting the different weathering patterns present, it was not indicated if a few elements contained either one or several weathering types. It was unclear if six skeletal elements recovered from pigs 2, 3, and 6 contained a singular or multiple weathering types. For the analysis used in this study, the elements were counted as if they had only one weathering pattern. This is significant because all elements with multiple weathering types contained erosion of the articular/epiphyseal facets and were counted as part of that type's overall occurrence. The percentages of the mixed types were calculated using the second weathering type count divided into the number of articular/epiphyseal facet erosion instances in the depositional layer of the research proxy.

For instance, one of the pigs may have had 14 instances of articular/epiphyseal facet erosion and 5 instances of cortical flaking. It was later found that two of those five elements with cortical flaking also had articular/epiphyseal facet erosion. For the overall count, these two elements would be included in the baseline count for the erosion type, increasing it to 16 counts and decreasing the cortical flaking to 3 occurrences. The mixed-type percentage then is a part of the articular erosion count. The mixed-type element count of 2 is divided into the articular erosion count of 16, to determine a percentage of mixed-type occurrences.

12.6 Discussion

Skeletonization for the two pigs placed in the research field in the fall occurred within a month. Pig 6, placed in the full sun with no tree cover, was expected to reach full skeletonization before the shade-deposited pig 7; however, a combination of mild temperatures, sun exposure, and maggot activity caused the surface-side skin to mummify (approximately 20–27 days since initial deposition), though the rest of the pig decomposed. Bass [18] described this type of mummification as characteristic of maggots leaving more exposed tissue and burrowing deeper into the body to protect themselves from the sun. Pig 7 reached complete skeletonization within 20 days of deposition (September 24, 2009 observation day) according to Galloway's stages of decomposition [3]. While skeletonization timing for the late spring/early summer pigs was not documented, a similar study conducted in the southern coastal area of North Carolina found that pigs set out in the spring seasons (March–April) and weighing 20–40 lbs (9.07–18.14 kg) were skeletonized within 17–18 days. Pigs weighing between 40 and 50 lbs (18.14–22.68 kg) were skeletonized within 20–21 days [19]. A series of pigs of similar size placed in the Raleigh, North Carolina research field the following summer were found to fully decompose within approximately 1 week. While summer is expected to be the fastest decompositional season due to heat and humidity, this project and previous research show that the spring and fall decompositional season rates are largely comparable.

Due to vegetation cover and the cages that separated the researcher from the pigs, it is difficult to determine the exact observation day when weathering patterns first appeared on each research subject. Photographs taken each week, however, have made it possible to determine the approximate timing of some of the weathering types. For others, laboratory analysis established the research period (7 months, 8 months, or 11 months) as the baseline for the appearance of weathering patterns. This was the case for cortical flaking, while some element diaphyses began to take on a marbled appearance, first noticed on pig 1 during the February 2, 2010 observation day, the small, delicate cortical bone flakes were observable only under laboratory conditions when the bones were able to be handled.

For articular/epiphyseal facet erosion, the pattern was first noted on pig 3. Uncaged some time after skeletonization, but before the start of the research study, pig 3 had the first signs of articular/epiphyseal facet erosion from the first observation day (September 10, 2009) when it had lain exposed for approximately 3 months (Fig. 12.10). It is possible that pig 3 was the first to show any kind of bone wear because vegetation cover surrounding it had remained low, exposing the remains to direct sunlight for a longer period of time.

Surface erosion was first noticed on Pig 7 on a carpal/tarsal on January 9, 2010, 4 months after initial deposition and approximately 3 months since skeletonization. This element would later become buried due to natural soil movement and count as one example of only two surface erosion patterns to occur on pig 7 whether the bone remained on the surface or not.

Overall, when compared to one another, the bone weathering pattern percentages (Table 12.3) indicate that the erosion of articular/epiphyseal facets is the most pervasive weathering pattern in both depositional levels followed by cortical bone flaking and surface erosion. While the weathering patterns can occur in any type of bone, they appear to occur in certain elements more often than in others. The articular/epiphyseal facet erosion tends to occur most often in ribs and vertebrae, likely due to their fragile and less dense structure, particularly in juveniles. Surface

Fig. 12.10 Early Erosion Depicted on Facet and Algae Growth

erosion, or "pockmarking", was most prevalent in carpal/tarsal bones, though it was also seen on long bones, long bone epiphyses, and phalanges, showing a tendency to occur more often in denser element types. Cortical flaking occurred most often on long bone, metacarpal/tarsal, and phalange diaphyses, preferring long, tubular bone elements.

Deposition within the soil layer has been found to drastically slow the decay process [1, 4]; in fact, Rodriguez and Bass [1] found that soft tissue decayed at a rate eight times as slow as surface depositions. This delay does not appear to have been actively at work on the elements found in the soil layer at the time of excavation. This is likely due to the method of burial. Rather than placed immediately at depth, all pigs were deposited on the surface, and some elements were only buried due to natural soil, wind, and water action over time.

12.7 Conclusion

Three types of weathering patterns were noted during the 11-month research period: erosion of articular/epiphyseal facets, surface erosion of elements, and cortical flaking. In her research, Behrensmeyer [5] describes the appearance of cortical flaking on some of her research subjects in Africa, though it was not categorized within the stages of skeletal decomposition and it was unclear when it developed. Other research in colder climates found that pig long bones developed longitudinal cracking between 6 and 9.5 months of exposure, though this was attributed to the freezing and thawing action common in southern Ontario [11].

In the current study, cortical flaking was found in all research proxies, except pig 5, which had been collected at 7 months of exposure. Pig 2 (cumulative 13 elements affected), Pig 3 (12 elements), and Pig 7 (11 elements) had the most amount of cortical flaking. Pigs 2 and 7 maintained a majority of cover for much of the research period, while pig 3 was largely exposed for its duration. Sun exposure, therefore, may not play an intense part in cortical flaking. Articular/epiphyseal erosion was present in all remains and was first noted on pig 3 during the September 10, 2009 observation day, 3 months after deposition. Surface erosion was noted on pig 7 in early January 2010, 4 months after deposition. A preliminary postmortem interval can then be constructed from this information (Table 12.4).

Table 12.4 Postmortem interval (PMI) based on weathering pattern

Weathering pattern	Postmortem interval	Description
Erosion of articular/epiphyseal facets	3–5 months	Erosion facets and bone ends
Surface erosion	4–7 months	Erosion of circular sections of bone; "pockmarking"
Cortical flaking	8–11 months	Marbling of diaphyses, flaking of small pieces of outer layer of cortical bone

In the Piedmont of North Carolina, soft tissue remains can be expected to decompose within approximately 7 days during the summer and within a month during the early fall. While mummification does occur, researchers should be aware that complete decomposition and skeletonization may likely have occurred and only the non-soil side of the remains persisted as a "cover" for maggot activity. While variability is still a possibility, bone weathering patterns will likely appear at approximately 3–5 months with articular/epiphyseal erosion of the less dense bones the first to occur. Between 4 and 7 months, surface erosion will begin to affect more dense elements. Between 8 and 11 months, marbling of diaphyses and cortical flaking will begin to appear on elements, particularly tubular bones.

These weathering patterns are best applied to decomposition cycles that start in the summer and fall. Winter decomposition cycles in the mild temperatures of central North Carolina have not been attempted, but would be expected to have a faster time between deposition and skeletonization in comparison to colder, northern climes. When working with juveniles, the pattern of weathering must be categorized without confusing normal areas of growth. The primary active growth areas are located on the proximal-posterior section of long bones underneath the section of epiphyseal attachment and the posterior portion of the sternal rib ends.

This study provides a baseline for the weathering patterns that investigators will likely encounter. Further, it highlights issues related to bone appearance and growth that are specific to juveniles, whether pig or human. These identified patterns could, with more research, prove to be more variable than they are now understood to be. However, the current patterns are a foundation upon which further knowledge can be expanded and are a reliable basis to estimate the postmortem interval of juvenile remains in central North Carolina and similar environments.

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