Corroded, Thinned and Polished Bones Created by Golden Eagles (*Aquila chrysaetos*): Taphonomic Implications for Archaeological Interpretations

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In a recent paper, Schmitt and Juell argued that corroded, thinned, and polished bones may be diagnostic of carnivore scatological bone. This paper examines leporid and bird bones recovered from 20 golden eagle (*Aquila chrysaetos*) pellets, and concludes that these same taphonomic traces are commonly present on bones regurgitated by this diurnal raptor. As a result, much additional research will be required before carnivore scatological bone can be uneqivocally distinguished from bones cast by golden eagles.   © 1996 Academic Press Limited

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Introduction

Schmitt and Juell (1994) recently argued that corroded, thinned, and polished bones together may be diagnostic of carnivore scatological bone. In this paper I demonstrate that bones in golden eagle (*Aquila chrysaetos*) pellets closely resemble those commonly found in mammalian carnivore scats.

It is well known that raptors may deposit thousands of bones in cave and rockshelter settings by regurgitating (or casting) pellets full of bones or by dropping unswallowed portions of animal carcasses below feeding or roosting sites (Miller, 1929; Guilday & Parmalee, 1965; Brain, 1981; Andrews, 1990; Kusmer, 1990; Hockett, 1991, 1994; Schmitt, in press). Experimental research on captive raptors (Duke *et al.*, 1975; Dodson & Wexlar, 1979; Hoffman, 1988) and studies of raptor pellets collected in natural settings (Hockett, 1989, 1991; Andrews, 1990) have clearly shown that the pellets of diurnal birds of prey such as harriers, hawks, kestrels, and eagles contain fewer bones and bones that exhibit greater corrosive damage than those found in owl pellets (Mayhew, 1977: 25; Korth, 1979: 240; Andrews, 1990: 26). The fewer bones in diurnal raptor pellets, however, can only partially be attributed to stronger gastric fluids because diurnal raptors often swallow fewer bones during feeding than do owls (Andrews, 1990: 28). Owls typically swallow their prey whole or in two or three large chunks (Dodson & Wexlar, 1979: 282), whereas diurnal raptors more often strip and consume flesh off of the bones (Hockett, 1989: 127–128).

Andrews (1990: 38) recently noted that the potential significance of diurnal raptors as accumulators of bone has received little attention compared to the amount of data collected on owls. Mayhew (1977), however, examined bones extracted from kestrel (*Falco tinnunculus*) and buzzard (*Buteo buteo*) pellets. Mayhew (1977: 26) concluded that bones from diurnal raptor pellets are occasionally well preserved, but overall extensively corroded rodent teeth is the most salient feature of prey remains in diurnal raptor pellets. Andrews (1990: 75) similarly found that on a relative scale of 1–5 (1 representing absent to minimal digestion; 5 representing extreme digestion), molar digestion in diurnal raptors scores a 5. Bramwell, Yalden and Yalden (1987) examined remains of black grouse (*Lyrurus tetrix*) recovered from a cave in England. They concluded that these bones had been deposited in the cave by golden eagles, and that both human and eagle behaviour may lead to the differential deposition of upper leg and wing bones in some cave sites. Hockett (1991) compared cottontail (*Sylvilagus* sp.) bones found in Northern harrier (*Circus cyaneus*) pellets to those found in owl pellets. The most significant interpretations were that both data sets contained significantly more subadult than adult bones and significantly more forelimb than hindlimb bones (Hockett, 1991: 673). Hockett (1993, 1995) later found the reverse patterning in an assemblage of unswallowed cottontail and hare (*Lepus* sp.) bones collected from a golden eagle nest. The nest assemblage contained more adult than subadult bones, and more hindlimb than forelimb bones. Schmitt (in press) recently argued that these patterns are characteristic of golden eagle nest assemblages.

This study reports the first detailed taphonomic examination of bones in eagle pellets. Although the sample size is modest, the data indicate that relatively large numbers of bones may accumulate in cave and

rockshelter settings as a result of eagles casting pellets. Further, bones in eagle pellets may be large and well preserved, but they are typically broken and extensively corroded and thinned, and jagged ends may be polished.

The Study Nests

The golden eagle pellets were recovered from two separate nests located in northwestern Nevada. One nest is located in Dry Valley near the western edge of the hydrographic Great Basin. The nest (Matrac Roost) was built approximately 10 m above present ground surface on a small rock ledge. The ledge protrudes out of the steep-walled face of a rock outcropping that overlooks the valley floor.

Matrac Roost was first visited in 1990. During this visit, 18 golden eagle pellets and over 900 leporid (cottontail and hare) bones were collected from the nest (Hockett, 1993, 1995). I returned to the nest in April, 1991, and noted two golden eaglets and three skinned and decapitated leporid carcasses lying in the nest.

Two additional golden eagle pellets were collected in 1991 near a nest located in the Black Rock Desert, northwestern Nevada. This nest was also located about 10m above present ground surface on a small rock ledge. At the time of discovery, this nest also contained two golden eaglets and one skinned and decapitated leporid carcass. No bones were collected from this nest, but two golden eagle pellets were collected from the top of the rock outcropping directly above the nest, and were included in the sample described below.

Expected Taphonomic Traces on the Pellet Bones Based on Relevant Golden Eagle Behaviour

Golden eagles frequently build nests in cave and rockshelter settings such as on ledges that protrude from rock outcroppings. In Nevada, over 95% of inventoried golden eagle nests are located along rock outcroppings (Herron, Mortimore & Rawlings, 1985: 45).

The largest concentrations of bones produced by golden eagles are likely to occur at eyries (nests where eaglets are hatched and raised). The reproductive cycle of golden eagles begins in January or February with mate and nest site selections (Herron *et al.*, 1985: 45). Eaglets generally hatch between late April and early May (Ellis, 1979: 7). Eaglets fledge at approximately 10 weeks of age, although they remain in the nesting territory, and are dependent on parents for food until they become proficient hunters (Herron *et al.*, 1985: 46).

Leporids (particularly hares) constitute up to 85% of golden eagle diets in Nevada (Herron *et al.*, 1985: 46). It is no coincidence that the reproductive success of golden eagles often corresponds to the reproductive success of leporids (Phillips & Beske, 1990: 16; Phillips *et al.*, 1990: 9). Because a large number of young leporids are available to predators such as eagles during the spring breeding season, both adult and subadult leporid bones are expected to be deposited at many golden eagle eyries.

Several researchers have noted that eagles often decapitate their prey before bringing carcasses to eyries or to other nesting or feeding sites (Mayhew, 1977: 25; Brain, 1981: 106; Hockett, 1993: 106–107). Many diurnal raptors, however, break open the occipital region of leporid skulls in order to consume the brain (Hockett, 1989: 127). As a result, leporid mandibles overall are expected to occur in low numbers in eaglet pellets that are cast at eyries. This patterning would be in contrast to the relatively large number of mandibles and teeth documented in other diurnal raptor pellets and in owl pellets (Mayhew, 1977; Hockett, 1989, 1991; Andrews, 1990). Because eagles may consume the brain, however, skull fragments may be present in pellets if these bones are not destroyed by digestive enzymes.

The digestive enzymes of diurnal raptors are generally stronger than those of owls, and the digestive enzymes of subadult raptors are stronger than those of adults (Duke *et al.*, 1975; Andrews, 1990). Eaglets tend to cast pellets at eyries much more frequently than do adults, and they may cast as many as three pellets in a 40 min time span (Ellis, 1979: 29). Thus, the majority of bones cast at eyries are expected to be extensively corroded.

Animals as large as leporids are too large for eagles to swallow whole (discounting very young animals), so leporid bones must often be broken before they are swallowed (Hockett, 1991: 671). Nevertheless, eagles are capable of casting very large items. For example, Brain (1981: 107) reported that an African black eagle (*Aquila verreauxi*) cast part of a tortoise (*Kinyxis belliana*) carcass that measured 8·5 cm in length by 7·5 cm in width. Ellis (1979: 63) reported that a golden eagle pellet from Montana measured 8·0 cm in length.

Based on behavioural observations, the majority of bones in golden eagle pellets are expected to be broken and extensively corroded hare bones, but large, relatively unbroken items may also be cast by golden eagles.

Leporid Bones in Eagle Pellets

As mentioned above, a total of 20 golden eagle pellets was recovered from within or near two active golden eagle nests. A total of 19 of the 20 pellets contained exclusively leporid bones. One pellet contained three bird bones that were not identified (Table 1).

A total of 48 bones was recovered from the 20 golden eagle pellets (Table 1). Of these, 45 bones (94%) were leporid or leporid-sized. Of these, 33 (73%) were identifiable to element and genus. A total of 32 of the

Table 1. Bones recovered from 20 golden eagle pellets

Element & portion	Leporid	Bird
Distal mandible	1	
Skull fragments	7	
Complete tibia	1	
Complete femur		1
Distal femur	1	
Calcaneus	4	
Innominate	3	
Complete humerus	1	
Complete ulna		1
Vertebra	15	
Unidentified	12	1
Totals	45	3

Figure 1. Complete subadult hare tibia, complete bird ulna, and complete bird femur extracted from golden eagle pellets. Note minimal degree of corrosive damage.

33 (97%) identifiable leporid bones were from hares. The only cottontail bone in the sample was a complete humerus.

Skeletal element, portion, breakage and age

Vertebrae, skull fragments, calcanei, and innominates were the most common leporid elements identified in the golden eagle pellets (Table 1). Interestingly, vertebrae were the most common leporid element identified; not a single rib fragment was present in any of the pellets. It is likely that some rib fragments were swallowed along with the vertebrae, but they probably were destroyed by digestive enzymes.

The presence of only one distal mandible fragment supports behavioural observations that eagles often bring decapitated carcasses to their nests, and that eaglets are more likely to cast pellets in and under nests than adults. Seven skull fragments were present in the pellet bone assemblage, however, so it is possible that both adult and eaglet pellets were collected from the nests. It is also possible that eaglets are occasionally fed portions of the skull.

Only six long bones were recovered from the eagle pellet bone assemblage (Table 1). Three long bones were from leporids, and three were from a bird. Of the three leporid long bones recovered, only the distal femur fragment is from an adult animal. The complete tibia is from a subadult hare, and the complete humerus is from a very young cottontail. The three bird bones consisted of a complete femur, a complete ulna, and one broken and corroded long bone fragment that was not identified to element.

The subadult hare tibia and the complete bird ulna and femur are remarkable for their size and excellent state of preservation (Figure 1). The hare tibia measures 8·0 cm in length, and although the bone shows signs of digestive corrosion, it still retains the proximal, unfused epiphysis. The bird bones were recovered from a single pellet that measured 13·0 cm in length by 4·0 cm in width. The bird ulna measures

10·4 cm in length. The femur measures 6·2 cm in length. These data corroborate behavioural observations that eagles are capable of casting very large items.

The presence of a complete subadult cottontail humerus, the large number of vertebrae present, and the excellent state of preservation of the leporid and bird limb bones are remarkable considering that dense bones such as the calcaneus were subjected to extreme digestive attrition (see discussion below). Nevertheless, these seemingly contradictory data, or the presence of minimally corroded "soft" bones with extensively corroded "hard" bones, has been noted in other raptor pellet bone assemblages (Dodson & Wexlar, 1979: 282).

Digestive corrosion, polishing, and staining

Damage to bones caused by the digestive enzymes of mammalian, marsupial, avian, and reptilian predators has not been shown to be replicated by any other natural or cultural process (Andrews, 1990: 64). Digestive enzymes may cause corrosion (scouring, pitting, and thinning), polishing, and staining to bone (Mayhew, 1977; Fisher, 1981; Andrews & Evans, 1983; Andrews, 1990; Marshall & Cosgrove, 1990; Schmitt & Juell, 1994). Digestive enzymes can also cause exfoliation similar to mechanical weathering (Andrews, 1990: 82–87).

The majority of identifiable leporid bones recovered from the golden eagle pellets are extensively corroded and thinned (Figures 2, 3 & 4). Jagged ends of fractured bone specimens are often polished. All innominates, calcanei, and most of the vertebrae exhibit moderate to extensive corrosive damage. The innominates and calcanei are extensively thinned (Figures 2 & 3).

Andrews (1990) previously noted that bones in diurnal raptor pellets may be similar to those found in mammalian carnivore scats, although bones in eagle pellets were not part of the samples he analysed. The data presented here corroborate Andrews' (1990)

Figure 2. Hare innominates extracted from coyote scats (left) and golden eagle pellets (right). Note differential staining on bones from both samples, and the high degree of thinning on the eagle pellet bones.

Figure 4. Leporid vertebrae extracted from coyote scats (top) and golden eagle pellets (bottom). Note similarities of corrosive damage on bones from both samples.

Figure 3. Hare calcanei extracted from coyote scats (left) and golden eagle pellets (right). Note the high degree of corrosion and thinning on bones from both samples.

observations. Bones in golden eagle pellets and in mammalian carnivore scats may contain relatively large numbers of vertebrae (Schmitt & Juell, 1994: 255), the majority of bones will exhibit corrosive damage, and some bones may be extensively thinned and pitted, and broken and jagged ends of bones may be polished.

In contrast to bones in coyote (*Canis latrans*) scats, however, the majority of leporid bones from the eagle pellets do not exhibit differential staining (see Figure 2; also see Schmitt & Juell, 1994: 252, figure 3). Additionally, coyote scats on average contain greater numbers of bones than golden eagle pellets. Schmitt & Juell (1994: 251) recovered 3397 bones from 40 scats, or an average of 85 bones per scat. The 20 golden eagle pellets contained an average of 2·4 bones per pellet. The low numbers of bones in the eagle pellets is probably partially due to strong digestive enzymes, but these data probably also corroborate behavioural observations that eagles swallow relatively few bones during feeding (Brain, 1981: 107; Hockett, 1989: 127–128; Andrews, 1990: 28).

Golden eagle pellets, however, appear to contain proportionately more identifiable bones per pellet than do coyote scats. Seventy-five percent of the bones in the golden eagle pellets were identifiable to element and genus. In contrast, a maximum of 40% of the bones extracted from the coyote scats reported in Schmitt & Juell (1994) were identifiable. This patterning is most likely due to mammalian carnivore mastication of carcasses before swallowing.

Finally, golden eagles may cast large, minimally corroded bones. For example, one complete subadult hare tibia was recovered from an eagle pellet, and the proximal and distal ends of the bone exhibited relatively minor corrosive damage. In contrast, mammalian carnivores are not known to pass bones as complete as this specimen through their digestive tracts.

Discussion and Archaeological Implications

Schmitt & Juell (1994) recently analysed a large assemblage of leporid bones extracted from coyote scats. Among other interpretations, Schmitt & Juell (1994: 259) concluded that "Overall, we find the digestive thinning and rounding of broken surfaces to be an unequivocal attribute in the identification of Class III [leporid-sized] scatological bone". Data presented here indicate that leporid bones in golden eagle pellets show most of the attributes commonly attributed to scatological bone, namely corrosive pitting, thinning, and rounding of broken surfaces. Bones that are differentially stained or discoloured, however, may be more common in coyote scats than in golden eagle pellets.

Our ability to infer accurate prehistoric subsistence patterns partially rests with our ability to distinguish bones accumulated and deposited at a site by humans from those accumulated and deposited by non-human agents. In many cases both raptors and mammalian carnivores are likely to have contributed bones

to cave and rockshelter deposits. It is imperative that archaeologists look beyond the deposition of mammalian carnivore scats and owl pellets, and more fully consider the role that diurnal raptors such as eagles may have played in the formation of these bone deposits. While it is true that regardless of the predator, the presence of partially digested bone in an archaeological site will largely represent bones accumulated by non-human taphonomic agents (Schmitt & Juell, 1994: 259), it may be important to distinguish bones deposited in diurnal raptor pellets from those deposited in mammalian carnivore scats or in owl pellets. These types of data prove crucial in paleoecological research (Andrews, 1990), and in research that attempts to bridge the gap between paleoecology and archaeology (Stiner, 1990). Much additional research is required before carnivore scat bones are reliably distinguished from bones cast by eagles based on qualitative attributes such as corrosion, thinning, and polishing. Additionally, larger samples are needed to determine if skeletal part frequencies and/or fragmentation patterns (e.g. Andrews 1990) distinguish carnivore scat bones from bones cast by eagles and owls.

Acknowledgements

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