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PATTERN AND PROCESS IN BONE MODIFICATION

ABSTRACT: The increase in the recognition of bone modification features has provided the opportunity to examine the relationship of pattern and process in some such features. Trample marks, for example, can be shown to be time and taxon independent. Presently these marks have been reported from fossil vertebrate localities ranging in age from the Cretaceous to the Pleistocene and their occurrence has been attributed to trampling by hooved mammals and dinosaurs.

The occurrence of trample marks at a particular site is dictated by the amount of sand of the substrate, the intensity of trampling activity, or a combination of the two. Other factors which affect the occurrence of these marks include the amount of subaerial exposure prior to trampling and perhaps the size of the animals that are trampling.

KEY WORDS: Scratch marks – Trample marks – Cut marks – Bone modification.

INTRODUCTION

Since at least as long ago as Matthew's study (1901, p. 365) of the Tertiary of northeastern Colorado (U.S.A.), scientists have been aware of the importance of the surface condition of fossil material in interpreting the paleoenvironmental setting of fossil assemblages. This awareness was typically restricted to a qualitative appreciation of bone conditions within a fossil deposit.

The study of the condition of bones has become more formalized as of late, and is now considered by many workers as the study of bone modification processes. These processes can be loosely defined as any post-mortem, prediagenetic process (e. g. trampling, scavenging, weathering) which alters the morphology of a once-living bone. The resulting change in morphology of the bone is referred to as a bone modification feature. Excluded from this definition are patologhical processes (e. g. arthritis) that affect the living animal. Also excluded are those geologic processes which operate independent of those responsible for the formation of a particular site (e. g. compaction of surrounding sediment during lithification which can crush bone, stress due to tectonic forces within the region which can shear bones). Fossilization processes such as the "explosion" of bone cavities due to excessive mineral growth within the bone or bone dissolution are also excluded from this definition.

Interest in bone modification processes has increased substantially in recent years. Indeed this subject has grown to become the subject of entire meetings such as the Bone Modification Conference held at Carson City, Nevada in 1984, or the topic of special interest in certain journals such as *Current Research in the Pleistocene* (v. 5, 1988), and the present journal.

The cause for this renewed interest in bone modification processes is that it is now recognized that a detailed study of the surface condition of a bone can provide clues to those specific processes which acted upon the bone prior to fossilization. Understanding these processes can provide a basis for interpreting how closely a fossil bone assemblage approximates a single faunal community (i. e. a mixed fauna versus a single faunal sample) or it can be determined to what level certain taphonomic processes such as trampling, scavenging or butchering were active within a particular fossil assemblage. A more thorough understanding or surface features of bones can aid in deciphering the puzzles created by the depositional process responsible for a particular site.

Although recent work has shown that many taphonomic processes are capable of leaving modification features on bones, these processes can be subdivided into two groups. One group contains those processes which are active in a fluvial environment (e. g. fluvial abrasion) while a second group contains processes which are active on the land surfaces. Clark et al. (1967) defined the features resulting from this latter group of processes as perthotaxic, and their formative processes as perthotaxic processes. Within this group of processes a further subdivision can be made by considering one subset as the biological processes (e. g. trampling, biting, gnawing) and the second subset as the physical processes (e. g. weathering, wind abrasion). One perthotaxic process, trampling, was overlooked by Clark et al. (1967) but has received considerable attention as of late (e. g. Fiorillo 1984, 1987a, 1987b, in press a, in press b, Behrensmeyer et al. 1986, Oliver 1986, in press). Much is now known about bone modification features (e. g. Binford 1981, Shipman 1981, Fiorillo in press b, and references therein), allowing recognition of the appropriate features which can provide valuable clues to the taphonomic history of the bones at a fossil site.

Arguably identification of the causal factors for particular features may sometimes be in error if the geologic context or corroborating taphonomic data are not also considered. With increased awareness of bone modification pattern and process, it can be shown that such patterns and processes are not necessarily confined to particular intervals of time or limited to unique causes. The following discussion will serve to illustrate this point with an example from one type of bone modification feature, scratch marks, which have been recognized on bones from the Cenozoic and the Upper Cretaceous of North America.

SCRATCH MARKS

Scratch marks are shallow grooves, typically on the order of less than a millimeter deep, which can occur as subparallel sets or as isolated features, and are typically V-shaped in cross section. These features have been in the past largely ignored or overlooked at many paleontological sites, while at archeological sites often these marks were observed, recorded and attributed, almost exclusively, to carcass utilization by hominids implementing stone tools as scraping and cutting instruments (e. g. Bunn 1981, Potts and Shipman 1981). In the last few years it has been shown by both experiment (Fiorillo 1984, 1987a, in press a, Behrensmeyer et al. 1986) and by inference (Fiorillo 1984, 1987a, 1987b, Oliver 1986, in press) that some of these marks can be mimicked by the trampling action of animals on bones exposed on a sandy substrate. Since these data have come to light, I have observed trample marks on bones from numerous fossil vertebrate sites throughout much of the latest Mesozoic and the Cenozoic of the United States as well as several sites in the Miocene Siwaliks of Pakistan. Trample marks have been recorded from the Miocene of Nebraska (Fiorillo 1984, 1987a, in press b), the Miocene of Pakistan (Behrensmeyer et al. 1986), the Pleistocene of Montana (Oliver 1986, in press) and the Cretaceous of Montana (Fiorillo 1987b).

Interpreting butcher or cut marks invokes a need to limit the stratigraphic time interval in which they can occur (i. e. Plio-Pleistocene), since they imply aspects of hominid behavior as the causal factor. Trample marks, however, are clearly not restricted in their stratigraphic range since they have been recorded from the Pleistocene to the Cretaceous. Differentiating between the two types of marks has proven to be extremely difficult in many cases, in which is has been shown that even under microscopic examination the morphology of some stone tool marks and trample marks are identical (Fiorillo in press a, Behrensmayer et al. 1986). In some examples, the separation of the two marks can be based on a stratigraphic occurrence distinctly separate from the stratigraphic intervals containing hominids (e. g. the Upper Cretaceous of North America, Fiorillo 1987b, in prep.). Another example illustrates how trample marks can be differentiated from butcher or cut marks based on the geographic distribution. In the Miocene of Nebraska (U.S.A.), for example, a fossil mammal site contained bones in which 41% exhibited scratch marks, all of which are attributed to trampling (Fiorillo 1984, 1987a, in press a). The earliest unequivocal age for the arrival of hominids to North America is the Pleistocene. Carcass utilization by hominids, therefore, can effectively be ruled out as the cause for the scratch marks at this Miocene mammal site.

Since there is a great deal of morphological overlap between trample marks and cut marks (e. g. Fiorillo in press a, Behrensmeyer et al. 1986), perhaps one method for distinguishing the two types of marks at a Pleistocene site will be found in a statistical study of the position of the scratch marks on bones. For example, trample marks may be dominant on the shaft of bones while butcher marks are found more typically in the areas of muscle and tendon attachment around the "meatier" parts of the skeleton (i. e. near the articulation joints of the shoulder and elbow, and hip and knee).

In addition to a wide stratigraphic range for bones exhibiting trample marks, there also appears to be substantial variation in the general foot morphology needed to create trample marks on bones. Most of the Cenozoic deposits which contain trample marks, for example, are assumed to have been trampled by hooved animals (e. g. Fiorillo 1987a). The trample marks reported from the Cretaceous of Montana (Fiorillo 1987b), however, predate the occurrence of hooved mammals but were almost certainly made by dinosaurs.

The pattern of scratch marks observed on these Cretaceous dinosaur bones are virtually identical to the patterns observed on bones known to have been trampled by large ungulates (i. e. cattle, *Bos taurus*; Fiorillo in press a). In both examples the marks typically appear as shallow, sub-parallel sets of scratches. Although there is a rough similarity in the morphology of the unguals of cattle and those of ornithischian dinosaurs, this similarity in scratch mark morphology is better explained by understanding the actual agent reponsible for the trample marks.

Experiments have indicated that with modern bones the keratin hoof of an ungulate is insufficient for scratching the surface of a bone (Fiorillo 1987a, in press a). Instead, scratch marks are made during contact, and the subsequent movement, of a hard object (e. g. sand grains either on the foot or in the substrate), against the bone surface, much the same way glacial debris operates when leaving striae on exposed bedrock. Indeed this causal mechanism is the reason why trample marks resemble butcher marks, and also the microstriae component of the newly defined percussion marks (Blumenschien and Selvaggio 1988), even at the microscopic scale. The abundance of trample marks at a particular fossil site must be largely dependent on either the amount of trampling activity, the type of substrate, or a combination of the two (Fiorillo 1987a, in press a).

Although further work is needed to test the effect of variations in trampling activity on bones lying on the substrate at a site, the preliminary data for variations of the substrate suggest that the sandier a substrate, the greater the percentage of bones exhibiting trample marks at a site (*Figure 1*). These data were obtained from Hazard Homestead Quary, a mid-Miocene mammal site in Nebraska (Fiorillo 1987a, in press b), an experiment using live cattle and modern bones (Fiorillo 1984, 1984a, in press b), a sample of bones from the White River Group in Nebraska (Fiorillo 1987a, in press a), a Late Cretaceous dinosaur locality in central Montana (Fiorillo 1987b), and a Pliocene mammal locality from Arizona. The geology and general taphonomy of this last site are discussed by Honey (1977), but the examination for trample marks on a sample of bones from this site was performed by the present author.

An additional factor in the occurrence of trample marks is the weathering stage of the bones affected. Behrensmeyer (1978) defined several weathering stages for bones, based on the grease content of bones as well as the condition to the bone cortex. Since trampling affects the outer surface of bones, the occurrence of trample marks on bones is related to the degree of weathering bones have experienced (Fiorillo in press a). The more advanced the weathering has occurred on a bone, the less likely the bone surface will be able to sustain a scratch mark (*Figure 2*). This is presumably due to the bone surface crumbling instead of remaining competent enough to be scratched.

One last aspect of trample marks which may be influential in their occurrence is the size of the animals available for the trampling. Experimental data have shown that the sizes of animals capable of producing trample marks range from domestic cattle (*Bos taurus*, Fiorillo 1984, 1987a, in press a) to humans (Behrensmeyer et al. 1986). The upper limit on this body size is greatly extended by the inference of dinosaurs being responsible for the trample marks observed on bones from the Upper Cretaceous (Fiorillo, 1987b). More precise information on the lower limits of the body size needed to yield trample marks on bones are lacking, but should be obtained since presumably rabbit- and mouse-sized animals are less likely to produce trample marks than are larger animals. The significance of this point is evident in considering if only very small animals were available for trampling at the time a particular site was forming perhaps the site was extensively trampled but the animals were of insufficient body mass to produce trample marks.

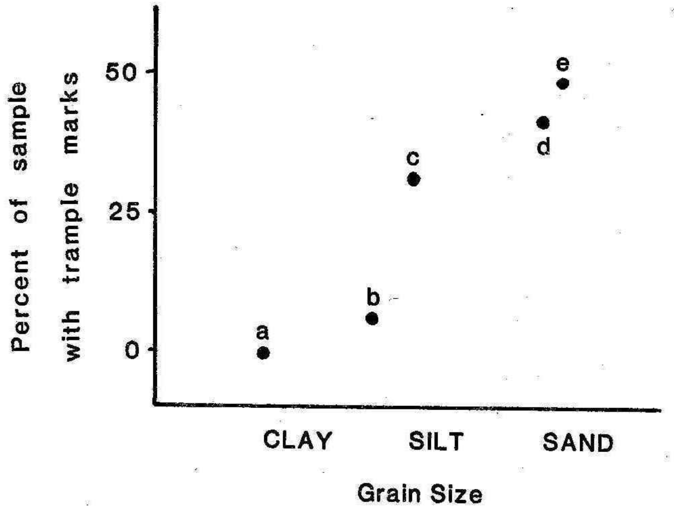

FIGURE 1. *Semi-schematic illustration of the relationship between the number of bones at a site which exhibit trample marks and the grain size of the substrate. The sites are:*
a) a sample of fossil mammal bones (N=70) from the White River Group of Nebraska,
b) a sample of fossil mammal bones (N=170) from the Pliocene of Arizona,
c) a sample of fossil dinosaur bones (N=142) from the Judith River Formation of Montana (Fiorillo, 1987b),
d) a sample of fossil mammal bones (N=196) from the Ogallala Group of Nebraska (Fiorillo, 1987a, in press b),
*e) a sample of modern bones (N=84) which were exposed to trampling by domestic cattle (*Bos taurus*; Fiorillo 1984, 1987a, in press a). Notice that as grain size increases, the percentage of bones at a particular locality which exhibit trample marks also increases. This indicates, then, that the presence of sand in a substrate is a major factor in determining if trample marks are to be formed at a trampled site.*

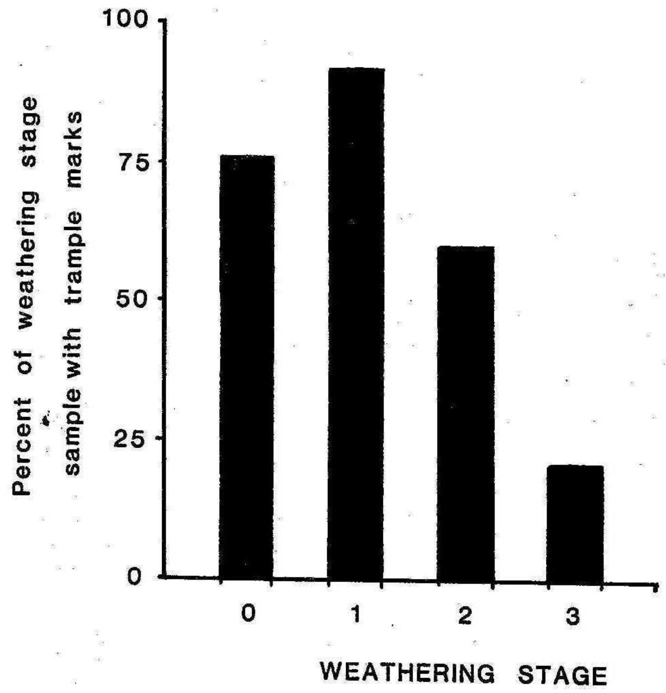

FIGURE 2. *Illustration showing the relationship of the occurrence of trample marks on bones and their respective weathering stage. Data from Fiorillo (1987a, in press a). Notice that as weathering stage increases, the occurrence of trample marks within bones of that stage decreases. This is presumably due to the surface of the bone crumbling rather than remaining competent enough to sustain a scratch.*

DISCUSSION

The above example illustrating the occurrence of trample marks on bones is likely to be tied largely to the amount of sand in the underlying substrate. Since sandy substrates are present throughout the stratigraphic section from the Upper Cretaceous to through the Cenozoic, trample marks have indeed been found on bones within these ages. Similarly, the course of terrestrial vertebrate history extends far back into the Paleozoic, and vertebrate remains have presumably been scattered on the landscape as long. Many of these bones would potentially have been exposed to trampling. Therefore, it is reasonable to predict that with increasing awareness of bone modification phenomena, this lower stratigraphic limit will be extended even further back in time. Given that sand and trampling are the two main factors in producing scratch marks which can be attributed to trampling, and that these factors are independent of time constraints, then this is an example of a bone modification feature whose pattern and process are not constained (in contrast to butcher marks which place constraints on both stratigraphic occurrence and the taxon responsible). Indeed one can predict where further examples of trample marks can be found in deposits still older than those already recorded from the Late Cretaceous of North America (Fiorillo 1987b). The paleoenvironmental reconstruction for the fossiliferous Jurassic Morrison Formation of western North America, for example, includes many sandy fluvial environments (e. g. Dodson et al. 1980). The fauna from the Morrison includes, among other taxa, many large dinosaurs such as sauropods, stegosaurs and allosaurs, each of which would certainly have been capable of leaving trample marks on subaerially exposed bones. The Texas Permian and the Karroo of South Africa provide similar examples of highly fossiliferous terrestrial sequences dominated by sandy fluvial deposits. We can predict that trample marks will be recognized in these deposits also.

Increased recognition of these features throughout the stratigraphic record can provide a source of evidence for subaerial exposure of bones, and will prove to be a valuable tool for paleoenvironmental interpretation. Since the relationship of substrate type with the abundance of trample marks at a site suggests that higher abundances of trample marks are found in areas with coarser substrates, then recognition of this feature provides a means for testing the provenance of the bones at a site. A high percentage of bones with trample marks within a claystone, for example, may be interpreted as an assemblage of bones which were transported in from a sandier depositional environment.

Failure to find trample marks on bones at a fossil site can lead to several alternatives in interpreting the taphonomic history of the site. For example, the site could have been buried before significant trampling could have occurred. It follows from this interpretation that if the substrate was conductive to producing trample marks (i. e. sandy), the site either experienced rapid burial or that high levels of vertebrate activity such as trampling were not occurring when the site was accumulating. The absence of trample marks at a site can also mean that the substrate was not capable of producing marks on bones (i. e. contained no sand), or the bone surface was not capable of sustaining a scratch mark. These latter alternatives can be easily substantiated by corroboration with other taphonomic or sedimentologic aspects of the particular site being studied.

CONCLUSION

Trample marks provide an excellent opportunity to examine pattern and process pertaining to bone modification features. Rather than being a unique occurrence of one type of mark being made by one type of taxon, trample marks seen to have been created by a process which is time and taxon independent. The occurrence of these marks has proven to be related to the relationship between the depositional environment of a particular site, the amount of vertebrate activity at that site (i. e. trampling) and the amount of subaerial exposure that site experienced before final burial.

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