

ZOOARCHAEOLOGY AND TAPHONOMY: A GENERAL CONSIDERATION

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ABSTRACT.—Challenges to increase our understanding of how taphonomic processes potentially affect quantitative and distributional properties of the archaeofaunal record have been responded to by development of an unwieldy terminology and a plethora of control studies on taphonomic processes. A preliminary effort towards integration of concepts and data here involves specification of zooarchaeological analytic goals and a field of study, and alignment of six general taphonomic processes with four general taphonomic effects. The alignment indicates data requisite to taphonomic analyses, and can serve as a reference framework to facilitate construction of a holistic theory of taphonomy from esoteric control study data.

INTRODUCTION

Understanding how taphonomic processes affect quantitative faunal measures is a major challenge facing zooarchaeological research today (Gilbert and Singer 1982; Holtzman 1979; Turner 1983). Quantitative measures such as taxonomic abundances, meat weights, and frequencies of particular skeletal elements are all affected by taphonomic processes (Badgley 1986a; Gifford 1981; Grayson 1979, 1984; Klein and Cruz-Uribe 1984; Lyman 1984a). Not only are quantitative data important in many analyses, but so are the distributions of bones and taxa within a site (Grayson 1983; Lyman 1980; Wheat 1972). Taphonomic processes may obscure distributional contexts; unrelated elements may become spatially associated, or related elements may lose their spatial association (Hill 1979b). The second major challenge in zooarchaeological research is, then, ascertaining the meaning of distributional patterns of bones.

These two challenges have been met in two ways. First, a rather pedantic terminology has been developed in discussions of taphonomy (see Appendix). Many of the words in this unwieldy jargon are only infrequently used by zooarchaeologists and paleontologists involved in taphonomic research. In this paper I avoid this terminology in order to present a general, readily comprehensible and jargon-free discussion of taphonomy.

The second response to the challenges has resulted in a plethora of papers that describe control studies of the decomposition and subsequent dispersal, modification, destruction and burial of one or more animal carcasses and/or their parts (e.g., Abler 1985; Andrews and Cook 1985; Bickart 1984; D'Andrea and Gotthardt 1984; Hill and Behrensmeyer 1984, 1985; Johnson and Haynes 1985; Walters 1984, 1985). Many of these papers discuss some cautionary implications of the control observations. Integration of the data derived from these studies into a coherent whole in paleobiology (Behrensmeyer 1984; Behrensmeyer and Kidwell 1985) and zooarchaeology (e.g., Maltby 1985) has only just begun.

The two responses are rather disparate while the two challenges are interrelated. Here I take steps towards building a general model of taphonomy within which the jargon and control studies might be subsumed to make a more coherent whole. My discussion is specifically directed towards elucidating how quantitative and distributional

characteristics of the faunal record might be conditioned by taphonomic factors. Although I focus on analysis and interpretation of archaeological faunal remains, the discussion is equally applicable to paleontological faunas and more general site formational studies (e.g., Schiffer 1983).

ON THE ANALYSIS OF ARCHAEOFAUNAS

Analyses of archaeological faunal remains have been undertaken at least since the late nineteenth century in North America (Robison 1978). While once scarcely more than a subsidiary endeavor, archaeological site reports now regularly contain a section on recovered faunal remains, often by a specialist, and many more independently published and in-depth studies of faunal remains are being prepared by specialists in zoology and archaeologists with zoological training (Bogan and Robison 1978; Lyman 1979a). This reflects the holistic approach of archaeologists trying to understand and explain the totality of human history.

There are two basic goals to analyzing prehistoric faunal remains: reconstruction of hominid subsistence patterns and reconstructing paleoecological conditions. The former has been characterized as an attempt "to explain, in the form of predictive models, the interface that existed between prehistoric human populations and the faunal section of the biotic community" (Smith 1976:284). This goal is anthropological in orientation as it addresses topics such as human diet, procurement strategies, and predator-prey relationships (e.g., Hildebrandt 1984). Analytic goals are attained using anthropological and ecological principles in analysis and interpretation (Lyman 1982; Rackham 1983). Analyses of paleoecological conditions use zoological and ecological data, methods, and theory (Dodd and Stanton 1981; King and Graham 1981) to reconstruct faunal turnover and succession, paleoenvironmental history, and zoogeographic history (e.g., Grayson 1985).

The two distinguished goals are not mutually exclusive. Both require taxonomic identification of faunal remains, a requirement necessitating adherence to zoological method and theory. Data interpretation requires use of ecological principles whether those concern habitat preferences of taxa or determining available biomass (meat). Interpretation of a single archaeofauna may accomplish either or both goals (King and Graham 1981) because, in part, analytic techniques overlap. Distinction of the two goals is useful to my discussion, but is not mandatory to actual analysis.

BASIC CONCEPTS AND TERMINOLOGY

In the following I focus on animal remains, particularly mammal bones, but hasten to note my remarks are applicable to remains of other animal taxa and plant remains as well. That is, while the field of taphonomic study includes the remains of any organism and its geological context, I restrict my discussion and examples largely to mammal remains.

Taphonomy is generally construed as focusing on the post-mortem, pre- and post-burial histories of faunal remains. Burial is considered to be a stage intermediate to pre- and post-burial histories due to the potentially destructive and disruptive nature of burial processes (e.g., Dixon 1984; Kranz 1974a, 1974b). Various arrangements of taphonomic factors have been posited in the form of models depicting a general taphonomic history (e.g., Gifford 1981; Meadow 1981). Generally, a bone may be buried, exposed, reburied, re-exposed, transported, and reburied prior to recovery. Realistic sequences of taphonomic factors may therefore require the inclusion of loops (Fig. 1). For purposes of this paper, chronologies of taphonomic agents and processes are called *taphonomic histories*.

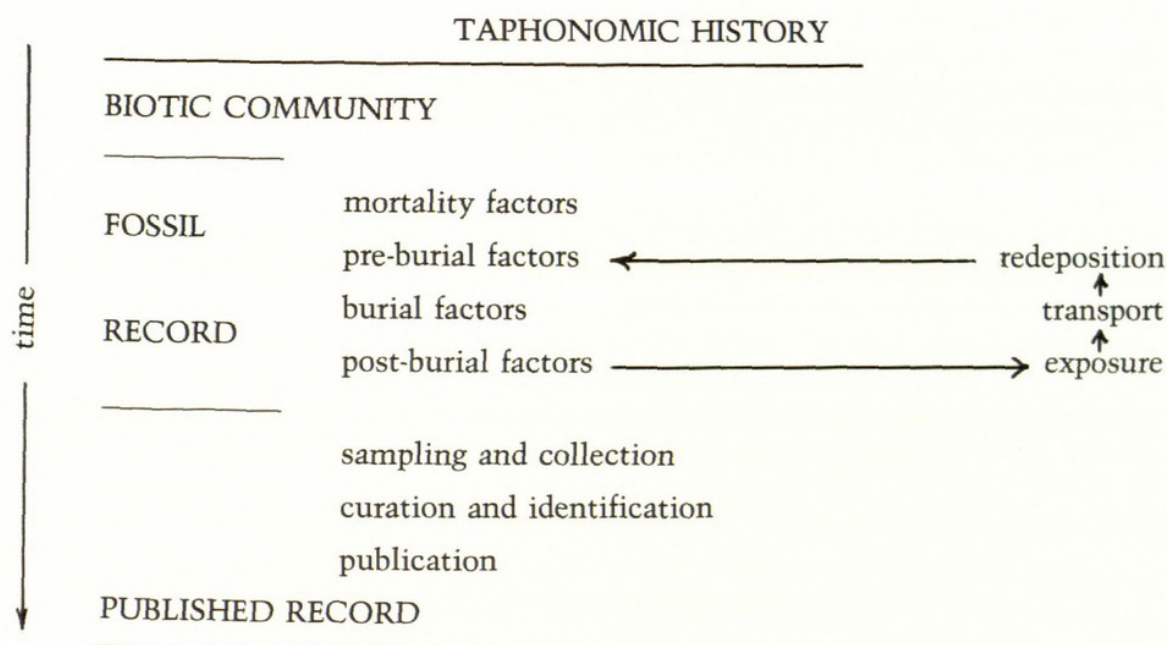


FIG. 1.—Generalized taphonomic history.

A taphonomic history begins when one or more members of a biotic community die. Post-mortem events may include any fraction or the total of any of the processes listed or implied in Fig. 1. It is important to realize that recovery is a potentially biasing factor because it affects the collected assemblage through differentially moving and dispersing it. What the collector perceives as pertinent observations may significantly affect which data are recovered and recorded, consequently affecting final analytic results. A large literature already exists on this crucial topic (Gamble 1978 and references therein). Paleontologists have become much more aware of the stratigraphic and sedimentary contexts of fossils and the potential taphonomic significance of such geological data (Badgley 1986b; Dodson 1980; Krumbein 1965). As a result, more care is taken in the recovery of fossils today than in the past. Archaeologists display equivalent increases in awareness of these issues (Bonnichsen and Sorg 1988).

A *fauna* is some specified set of animal taxa found in a geographic area of some specified size, kind, and location at some specified time (Odum 1971:366-367). For example, one can specify a modern intertidal fauna of the Pacific Rim, a prehistoric terrestrial fauna of Europe, and a Pleistocene mammalian fauna of Colorado. Zoologists study faunas by observing living animals. Paleontologists and archaeological faunal analysts study faunas by analyzing fossils. I have had several other zooarchaeologists tell me "fossils are mineralized animal remains" and/or "fossils are older than 10,000 years." I find neither of these criteria in definitions published by paleontologists (see Appendix). I thus use the term *fossil* here to denote any trace or remain of an animal that died at some time in the past (ascertaining the age of animal death is a separate problem).

A *fossil record* is a set of fossils in some defined geographic space and geologic context. That is, a fossil record consists of those observable phenomena such as the particular bones in a particular stratum. A *fossil fauna* consists of those taxa represented

by the fossil record at a specific locality. The term *fossil fauna* serves to emphasize the taphonomic distinction between a living fauna and a fauna represented by fossils. While the term *fossil fauna* as defined here is virtually synonymous with the term *local fauna* and perhaps *faunule* (Tedford 1970), the first term emanates from the taphonomic perspective of this paper while the latter two terms emanate from a paleoecological perspective.

The fossil record may be in a purely geological context, or in an archaeological context. In the former case, there are no undisputed cultural materials associated with the fossils, while in the latter case there are associated cultural materials. I therefore distinguish two kinds of fossil faunas: those without and those with spatially associated cultural materials, or *paleontological faunas* and *archaeofaunas*, respectively. While the distinction tends to imply whether or not humans had a role in the taphonomic history of a particular fossil assemblage, analytically categorizing a particular fossil record as constituting a naturally or culturally deposited set of faunal remains is a major hurdle (Avery 1984; Potts 1984; Turner 1984). I return to this issue below.

TAPHONOMIC HISTORIES

The paleontological fossil record has been formed totally by natural processes including geological (degradation, aggradation, pedogenesis, etc.) and biological processes (natural senile deaths, predator caused deaths, carnivore attrition, etc.). These natural processes act upon the available organisms (which are in turn conditioned by such natural factors as topography, substrate, vegetation, and climate) and affect the addition to, maintenance in, and subtraction from the paleontological fossil record of organisms and their remains.

The archaeological fossil record is formed not only by the same natural processes as the paleontological fossil record, but also by human processes. An archaeological site, for example, consists of cultural and natural objects that are added, spatially arranged, and preserved and/or destroyed by various human and natural processes. Human processes that affect potential additions to the fossil record include selective hunting (Smith 1979; Wilkinson 1976) and butchery practices (Binford 1978; Noe-Nygaard 1977). Human behaviors that result in the formation of a fossil record have been labeled the "cultural filter" (Daly 1969). Variation in both archaeological and paleontological fossil records is created by varying the additions, the means of addition, and the means of maintenance and subtraction of animal remains from the fossil record.

The distinction between paleontological faunas and archaeofaunas is based on characterizations of their respective taphonomic histories outlined above. It must be emphasized, however, that the characterizations are simplistic. Some fossil records may have no undisputed and spatially associated cultural materials even though humans had an active role in the formation of these records. In the absence of undisputed, associated artifacts, attributes of bone modification attributable to human activities such as butchering and bone tool manufacture are cited as evidence of human intervention. One major example of this involves mastodon (*Mammuth* sp.) bones in North America (Fisher 1984a, 1984b; Gilbow 1981; Gustafson *et al.* 1979). In these cases, modifications to bones which are inexplicable given natural processes are cited as evidence of human taphonomic agents even though no artifacts are associated with the faunal remains (see Haynes and Stanford [1984] for similar arguments regarding North American late Pleistocene *Camelops* sp.). However, it is not at all clear as yet whether any of these cases actually represent humanly modified carcasses (e.g., Graham *et al.* 1983).

The literature on attributes of bone modification is expanding rapidly (Bonnichsen and Sorg 1988 and references therein) yet debate abounds over the precise meaning of many attributes (e.g., Johnson 1982, 1985 *versus* Lyman 1984b; and Shipman 1981a; Shipman and Rose 1983 *versus* Eickhoff and Herrmann 1985; Behrensmeyer *et al.* 1986). At present, then, attributes of bone modification used to distinguish archaeofaunas and paleontological faunas are equivocal. Many other kinds of data are necessarily used regularly to help analytically distinguish the two types of fossil records (see TWO EXAMPLES below).

Taphonomic histories are often reconstructed from the abundance and distribution of fossils in a fossil record. For example, in paleontological endeavors a common argument is that the geological context of fossils will provide clues to pertinent taphonomic factors (Behrensmeyer 1975, 1979; Hill and Walker 1972). Features of fossils, such as rounding of fracture edges, abrasion, or surficial modification are also examined (Voorhies 1969). Archaeofaunal analysts have also depended largely on the kinds and distributions of fossils in archaeological sites to infer taphonomic histories (Binford 1978, 1981; Lyman 1985). The objects in a site, their frequencies, spatial loci and associations, and geological and cultural association are all that are observable in the fossil record. A scientific approach to taphonomy must realize what the empirical phenomena of the fossil record are, and produce a model that permits expectations to be phrased concerning fossil assemblage content and distribution; i.e., the archaeologically visible fossil record. Such a model would ideally be universally applicable and yet specific enough to grant insights to particular taphonomic pathways.

A first step to model building involves understanding the basic structure of taphonomic processes and effects. Processes that form the fossil record can be arranged on two dimensions (Fig. 2). The OBJECT dimension consists of addition, subtraction, or maintenance of an object. The SPATIAL dimension consists of movement, and non-movement. Combining these two dimensions results in six categories of taphonomic processes. All taphonomic processes can be included in this framework whether the taphonomic agent is human or natural. The processes, and their attendant empirical effects, create variability between and within particular fossil records. Because the major expressions of taphonomic effects in archaeological contexts are assumed to be largely attributable to human processes, random variation in fossil assemblage content and distribution is not anticipated, an anticipation borne out by studies of archaeological

		SPATIAL	
		movement	nonmovement
OBJECT	subtract	I	II
	maintain	III	IV
	add	V	VI

FIG. 2.—Intersection of two taphonomic dimensions to form six categories of taphonomic processes.

faunas (e.g., Lyman 1978; Meadow 1978; Noe-Nygaard 1977; Pozorski 1979). However, natural processes also create non-random patterns in the archaeological record (Binford 1981, 1983; Brain 1969; Haynes 1980; Hill 1979a, 1979b). The first step in analysis then, is to recognize patterns associated with natural processes. This may be accomplished by first comparing the fossil record under study to random models of the variable(s) under scrutiny, such as skeletal element frequencies or locations. Subsequent to this first comparison, the analyst can begin to assess the meaning of any detected non-random patterns by comparing the fossil record to models of fossil records created by various taphonomic processes. Brain's (1967, 1969) comparison of bone part frequencies in ethnoarchaeological contexts with frequencies of bone parts from South African caves is a classic example of this latter comparative approach.

Taphonomic histories, in general, are initiated when an animal dies. Soft tissues may then be removed, bones may become disarticulated, scattered, buried, fossilized, rot away, and may eventually be recovered by the archaeologist or paleontologist. Of course, various processes may or may not be simultaneous and may or may not affect particular carcasses or bones. The general set of potential effects of taphonomic processes may be arranged into four categories: disarticulation, scattering or dispersal, fossilization, and mechanical modification.

Disarticulation refers to the anatomical disassociation of skeletal elements. Disarticulation is related to soft tissue that functions to hold joints together (Dodson 1973; Hill 1980; Schafer 1972; Toots 1965). Chemical or mechanical breakdown and/or removal of soft tissues ultimately results in disarticulation (e.g., Coe 1978; Micozzi 1986; Payne 1965). Because soft tissue anatomy varies from joint to joint, the process of disarticulation is extremely complex under natural conditions (Hill 1979a), but is not so complex as to preclude construction of models of natural disarticulation (Hill 1979a, 1980; Hill and Behrensmeyer 1984, 1985).

Dispersal or transport of skeletal elements may precede, or be simultaneous with or subsequent to disarticulation, and is related to disarticulation because it concerns the spatial location of fossils. While disarticulation requires only a few centimeters of spatial disassociation of parts to destroy anatomical integrity, dispersal entails centimeters to kilometers (Hill 1979a). *Dispersal* of skeletal parts means the increase or decrease of distance between bones. Models of dispersal have been constructed for fluvial transport (Behrensmeyer 1975; Boaz and Behrensmeyer 1976; Hanson 1980; Korth 1979; Voorhies 1969), human transport (Binford 1978), raptor transport (Plug 1978), transport by porcupines (Brain 1980), carnivore transport (Binford 1981), and random processes (Hill 1979a).

Fossilization is here meant to denote the alteration of bone chemistry (Cook 1951; Cook *et al.* 1961; Cook and Heizer 1952; Hare 1980; Rolfe and Brett 1969; Schopf 1975; Shipman *et al.* 1984; White and Hannus 1983). Research suggests that the type of sedimentary matrix in which the bone is deposited largely determines the particular types of fossilization processes that bones may undergo. Secondary determinants of fossilization processes include environmental conditions such as soil moisture regimes as determined by precipitation and temperature. Some fossilization processes, especially weathering (Behrensmeyer 1978), may result in fragmentation of bones.

The final readily discernible category of taphonomic effect is *mechanical alteration*. Mechanical alteration denotes the structural and/or morphological alteration of the original living bone by mechanical or physical processes. Common examples of mechanical alteration include fragmentation and abrasion. For instance, each bone in an animal is a complete, discrete object. The cause of the animal's death and/or post-mortem factors may result in broken bone (Lyman 1988). Fragmentation, then, is the destruction of original discreteness of a bone by generating multiple discrete objects from the original discrete object by mechanical or physical means, in this case by the physical

loading of force on the bone. Abrasion is the modification of original bone morphology by the application of frictional forces to the bone surface. Models of bone fragmentation are still in developmental stages (Bonnichsen 1979; Evans 1976; Johnson 1985), and abrasional forces are still poorly understood (Behrensmeyer *et al.* 1986; Brain 1967; Morlan 1980; Shipman and Rose 1983).

To date most analyses of fossil assemblages that consider taphonomic issues assess whether or not the fossil assemblage has been transported to its recovery location. Shotwell (1955) was one of the first analysts to develop a sophisticated and objective analytic technique to assess whether or not a fossil assemblage had been transported, and to assess which taxa in the assemblage were locally derived and which were probably intrusive or non-local. While Shotwell's (1955) technique was later adapted to distinguishing naturally from culturally deposited taxa in archaeofaunas (Thomas 1971), it has since been shown to contain serious flaws (Grayson 1978b; Wolff 1973). Analysts still address this issue, using techniques such as assessing the degree of abrasion of bones (Behrensmeyer 1975) to determine whether the assemblage or portions thereof have been fluvially transported to the collection locality, and use of experimental data to allow inferring the agent of transport (Binford 1981; Lyman 1985). Paleoeological interpretation may only be considered realistic when this distinction of transported and nontransported taxa has been made. Inferences regarding human subsistence practices generally consider the transport issue under the larger realm of the "schlepp effect" (Binford 1978; Daly 1969; Lyman 1985; Perkins and Daly 1968) and differential storage of foodstuffs (Binford 1978).

Many ways exist for members of a biotic community to die, and many ways exist for dead organisms to become a fossil assemblage. Different taphonomic histories may result in similar fossil records regardless of the initial biotic community or set of dead organisms (Gifford 1981), the phenomenon of *equifinality*. This is the ultimate analytic challenge of taphonomic research: to determine which of several possible taphonomic histories is actually responsible for a bone assemblage.

GOALS OF TAPHONOMIC ANALYSIS IN ZOOARCHAEOLOGY

Subsistence studies, by the nature of their research questions, require knowledge of the formation of the archaeofaunal record (Lyman 1982; Maltby 1985; Medlock 1975; Rackham 1983). Similar knowledge is important to paleoeological research but for different reasons (Behrensmeyer and Hill 1980; Gifford 1981). Subsistence studies require that the fossils constituting the archaeofauna be sorted into at least two categories: those fossils deposited as a result of human (subsistence and other) behaviors, and those naturally deposited (Binford 1981; Thomas 1971). Culturally deposited fossils must be qualitatively and quantitatively representative of the fauna exploited, and quantification techniques must produce accurate relative abundances of economically important taxa (Grayson 1979, 1984; Lyman 1979b). Paleoeological studies, because of their different goals, need not have representative samples of exploited fauna, but do require representative samples of the prehistorically extant fauna. Exploited and extant faunas need not be similar because human populations may not have randomly exploited extant faunas. Sample requirements are flexible in the sense that they have certain tolerance limits. For example, a bison kill site probably does not include all taxa exploited by a group of people, and a zooarchaeologist may focus only on the microfauna and ignore larger taxa in an archaeofauna, depending on the research questions being asked. Sample representativeness is relative to some population which in turn is dictated by the research goal and is controlled by the formation, recovery and analysis of the fossil record (Fig. 1).

Gifford (1981) distinguishes two basic goals of taphonomic research: (1) "stripping away" the taphonomic overprint from the fossil record to obtain accurate resolution of the prehistoric biotic community, and (2) determining the nature of the taphonomic overprint in order to be able to list the precise taphonomic mechanisms responsible for a given fossil assemblage, enabling the writing of taphonomic histories. The latter goal is analogous to studying formation of the archaeological record (e.g., Schiffer 1983). The former goal is seen as a necessary step towards paleoecological analysis because the target of analysis requires knowledge of the prehistoric biotic community.

Determination of the exact taphonomic history of a particular fossil assemblage is frequently attempted by archaeologists who wish to know which taxa were exploited and the relative proportions in which those taxa were exploited. Many interpretations therefore involve outlines of the suspected human (taphonomic) behaviors that resulted in the fossil record under scrutiny. For example, Wheat's (1972) description of the butchery process evidenced at the Olsen-Chubbuck bison kill site is simply a narrative model of the suspected taphonomic history of that site's fossil record. Other examples include the recent discussions of Plio-Pleistocene sites at Olduvai Gorge (Binford 1981; Bunn 1982; Bunn and Kroll 1986; Potts 1982, 1986) and the Pleistocene site of Zhoukoudian (Binford and Ho 1985; Binford and Stone 1986).

The two goals of taphonomic research are not mutually exclusive. Stripping away the taphonomic overprint requires that the overprint be known. Once the taphonomic overprint is known, the prehistoric biotic community can be determined by analytically reversing the effects of the taphonomic processes. Of course, this procedure requires the assumption that the sample of fossils is representative of the biotic community. This assumption has been analytically controlled in cases where an archaeofauna is directly compared with a paleontological fauna in geographic and temporal proximity to one another (e.g., Briuer 1977), and in cases where two or more geographically and temporally adjacent archaeofaunas are compared (e.g., Grayson 1983; Guilday *et al.* 1978). The covert assumption to such comparative analyses is that because each fossil assemblage has undergone a more or less unique taphonomic history, similar, independent interpretive results derived from the assemblages are thought to represent prehistoric reality. That is, taphonomic processes have not totally obscured all indications of a prehistoric biotic community as all examined fossil assemblages indicate the same community.

A third goal of taphonomic analysis involves explaining the variability in frequencies of fossil categories. Any number of fossil categories can be defined, but the two most common ones are taxonomically defined and anatomically defined categories. In the former case, each fossil is identified as representing a particular taxon; in the latter case, each fossil is identified as representing a particular skeletal element. Both categories are important in quantification techniques such as NISP and MNI. The most frequently occurring anatomical category within a taxonomic unit determines the MNI value for that taxon. Variability in taxonomic frequencies is often interpreted as signifying paleoecological conditions (Grayson 1981). Frequencies of taxa measured by counts of anatomical and taxonomic fossil categories are, however, a function of taphonomic processes. Capabilities to explain variability in frequencies of anatomical parts in taphonomic terms will provide understanding of what frequencies of fossil categories are actually measuring, be it paleoecological conditions or something else (Lyman 1984a).

DISCUSSION

Taphonomy is concerned with differences and similarities within the fossil record and the link between a fossil record and the prehistoric fauna from which it derived. Concerning the latter, obvious differences include the presence of living organisms

versus post-mortem remains of organisms. Ecological and ethological studies of extinct taxa are, of course, impossible to do in the detail that living taxa are studied. Even those taxa with modern, living counterparts are not so easily dealt with when represented by fossils because studying living taxa presents certain difficulties (Coe 1980). Differences and similarities between living and fossil faunas present taphonomic challenges to paleoecological research because the ecological principles used to study living faunas are commonly used in paleoecological research (Western 1980; Van Couvering 1980). Consequently, the fossil record must be analytically reconstituted into a fossil fauna or the original biotic community to answer many research questions. Subsistence studies using archaeofaunas face similar analytic challenges (King and Graham 1981; Smith 1979).

Techniques for meeting these analytic challenges can be derived by considering the four categories of taphonomic effects (disarticulation, dispersal, fossilization, mechanical alteration). Each of these effect categories is visible in the fossil record and can be incorporated in an operational model of taphonomy. Comparing taphonomic effects with taphonomic processes (Fig. 2) suggests several points (Table 1). First, process category VI is largely a data recovery factor and not strictly taphonomic. New or additional fossils cannot be added to an assemblage that is in situ without movement of the "new" fossils. The only conceivable way this may happen is if the assemblage moves to a new location and is deposited around the "new" fossils without the latter's movement, as in some fluvial settings (Boaz 1982). A common and readily conceivable way for new fossils to be added to an assemblage without movement of the former is for the sampling universe to be enlarged such that additional fossils are collected.

TABLE 1.—*Comparison of taphonomic processes and taphonomic effects.*

TAPHONOMIC PROCESS CATEGORY	TAPHONOMIC EFFECT CATEGORY
I. move and subtract	A. disarticulation
II. non-move and subtract	B. dispersal
III. move and maintain	C. fossilization
IV. non-move and maintain	D. mechanical alteration
V. move and add	
VI. non-move and add	
PROCESSES ALIGNED WITH PROBABLE EFFECTS	
I — A, B, D	
II — C	
III — A, B, D	
IV — C	
V — A, B, D	
VI — sampling	

The second important point deriving from comparison of processes and effects is that different processes can have similar effects; equifinality is a very real problem. Disarticulation, dispersal, and mechanical alteration all involve movement of the fossils while fossilization effects do not require movement. Finally, all effect and process

categories concern frequencies (add, maintain, subtract) and distributions (move, non-move) of fossil categories. It is therefore pertinent to discuss techniques for measuring each taphonomic effect in the fossil record.

Disarticulation seems to correlate with soft tissue anatomy. Hill (1979b:744) for instance, concludes that "the determining controls of the [disarticulation] pattern are inherent in the anatomy of the dead animal itself and thus independent of the agents whereby it is realized." Disarticulation might be modeled by a rank ordering of the cross-sectional area of soft tissue surrounding joints. The basic analytic assumption might be phrased as "the greater the cross-sectional area of soft tissue associated with a joint the longer the joint will remain intact subsequent to the animal's death." This assumption of course presumes that soft tissues associated with each joint are qualitatively identical, which is highly unlikely (Hildebrand 1974; Romer and Parsons 1977). Study of disarticulation in the fossil record requires detailed data on bone location and spatial association.

Dispersal is a complex process minimally controlled by disarticulation, type and strength of dispersal mechanism, substrate, topography, and bone density, size and morphology. Hill (1979a:269-270) begins his discussion of dispersal by hypothesizing that scattering is caused by processes that act randomly. When observed, departures from the random pattern suggest non-randomly acting processes whose identity must be determined. Hill's (1979a) hypothesis could be used as the first null hypothesis to be tested with fossil data. Then, intrinsic properties of bones can be used to generate expectations regarding distributional patterns of fossils (e.g., Frostick and Reid 1983; Korth 1979). Clearly, data on bone location, orientation and angle of dip (e.g., Butzer 1982:100-104) should be recorded during field recovery, as well as sedimentological data indicating mode of deposition and turbation processes (Wood and Johnson 1978).

Fossilization mechanisms are minimally dependent on climate, depositional matrix, and bone porosity. There apparently is no detailed model of fossilization comparable to Hill's (1979b) models of disarticulation and dispersal. Documented processes of fossilization (e.g., Rolfe and Brett 1969; Schopf 1975) indicate, however, that in order to study fossilization, data required include matrix chemistry and mineralogy, chemistry of the fossils and original chemistry of the bones, climatic (past and present) information such as temperature, precipitation, and ground water regimes, and a knowledge of geologic and pedogenic processes forming particular strata.

Mechanical alteration seems to be largely controlled by bone structure and morphology, at both microscopic and macroscopic levels, and bone porosity and density. In order to measure mechanical alteration in the fossil record, the minimal requisite data are frequencies of fragment types (Watson 1979) and whether or not fragments of a bone are associated in situ, polish and abrasion, and other features. For example, Klein and Cruz-Urbe (1984) suggest sediment overburden may crush more deeply buried bones; all else being equal, the analyst could measure fragment sizes to determine if fragments decreased in size with increasing depth. Shipman (1981b:129) also suggests differences in fragment sizes are indicative of differences in taphonomic histories (see Binford [1978] and Schmitt [1986] for ethnoarchaeological and archaeological studies of the taphonomic meaning of differences in fragment sizes, respectively).

Despite the pleas of several authors over a decade ago (Hill 1978; Hill and Walker 1972; Munthe and McLeod 1975), the kinds of data mentioned above are seldom recorded by field crews and/or published by analysts. Because fossil category abundances are important to many traditional analyses and interpretations, frequency data are nearly always published, and more is known about the taphonomy of fossil category frequencies than virtually any other variable of the fossil record. In fact, several recent taphonomic analyses of Plio-Pleistocene sites in Olduvai Gorge, Tanzania, focus

heavily on such frequencies yet fail to adequately consider the range of processes that may have affected those frequencies and also fail to describe data concerning other taphonomically relevant variables (Bunn and Kroll 1986; Potts 1986). The relevance of all variables to complex taphonomic problems is made abundantly clear by considering two examples of taphonomic analysis.

TWO EXAMPLES

I have thus far suggested that taphonomic histories are usually complex, and that taphonomic processes may be arranged in six general categories while taphonomic effects may be arranged in four general categories. Alignment of process and effect categories reveals the types of data required for taphonomic analyses. I also have distinguished two basic goals of zooarchaeological faunal analysis (determination of human subsistence patterns and prehistoric ecological conditions) and two types of fossil records (archaeofaunas and paleontological faunas). All of these issues I have discussed are found in one form or another in taphonomic studies. In this section I review two published taphonomic studies, one I consider to be a good example of careful taphonomic analysis and one I consider to be not so good, to illustrate points raised in preceding sections of this paper.

The not so good.—In the 1960s and 1970s, C. V. Haynes (1969, 1976) argued that indisputable proof of the earliest people in the Americas should consist minimally of unquestionable stone artifacts, multiple and/or demonstrably uncontaminated radio-carbon dates, and a clear, tight, undisturbed stratigraphic association of the artifacts and dates. Stanford (1979) updated these criteria in light of the potential that the earliest Americans may have used non-lithic tools. He suggested that in addition to Haynes' mandatory criteria, archaeologists must learn to recognize bone and antler artifacts, and to distinguish faunal accumulations attributable to human activities from those attributable to non-human agents and processes.

McGuire (1980:263) wished to "document the results of natural faunal activity at a cave site" as part of the larger pursuit of unequivocal indicators of late Pleistocene humans in the Americas. McGuire's arguments rest on the *inference* that deposits at Mineral Hill Cave, Nevada, are natural. As evidence for this inference he suggests that "indicators of aboriginal occupation such as smoke blackening, artifactual material, lithic debris, and burnt bone were not found" (McGuire 1980:264). This is all negative evidence, which would not be so crucial were it not for the fact that only a "2.3% sample was excavated" (McGuire 1982:241). Here lies the first of two basic problems with McGuire's taphonomic analyses.

McGuire sampled 2.3% of the horizontal area of the cave interior. It cannot be ascertained what fraction of the deposit volume was sampled. This plus the fact that artifacts are not generally randomly distributed while McGuire's sample is restricted to one horizontal location makes for a sample that no doubt is not representative of the deposit as a whole. As made quite clear by, for instance, Gamble (1978), archaeologists sample space, not the artifacts or bones that may occur in that space. Hopefully, if appropriate sample techniques are used, a representative sample not only of space will be derived, but a sample of artifacts and faunal remains representative of the complete population of bones and artifacts in the sampled space will be recovered.

Hole (1980) has noted that often a complex sampling technique is chosen with little regard for the purpose (desired data) of sampling (see also Nance 1983). In the case of Mineral Hill Cave, no reasons are given for the sampling design used. Therefore, one

can only wonder why a test pit was not placed near the entrance to Mineral Hill Cave instead of placing both test pits 8 m away from the cave entrance in a dark recess of the cave. Several Great Basin caves which were occupied by prehistoric peoples tend to have the greatest amount of culturally deposited debris in the half of the cave nearest the cave entrance (e.g., Aikens 1970; Jennings 1957). Not only does McGuire's sample appear to be much too small (see also Gruhn and Bryan 1981), but it seems inappropriately located for the purposes of the research. This indicates the importance of sampling and data recovery in taphonomic analyses.

The second major problem is that McGuire (1980, 1982) *infers* that the Mineral Hill Cave deposit is natural. Binford (1981:26-27) notes that "diagnostic signature patterns that discriminate one deposit forming agent or set of agents from another" must be established. "We must see a bear make a footprint to know what a *bear* footprint looks like" (Binford 1981:27). Then, a uniformitarian assumption is made in order to allow identification of animal tracks encountered in the future as having been made by bears or some other animal when the animal itself is not visible. The problem at Mineral Hill Cave is that McGuire did not see the bear, and simply because he did not find any evidence of tracks, he infers the bear was not there. This problem is not McGuire's alone as other archaeologists working with faunal remains have made the same error (e.g., Briuer 1977; Gilbow 1981). Simply comparing a bone assemblage from a site with no artifacts to a bone assemblage from a site with associated artifacts proves little, particularly when the sites are of comparable age and the possibility exists that people were present in the area. This is, in fact, the problem rather than the solution; we simply do not know what a fossil assemblage deposited by people but without associated artifacts should look like. This illustrates that my distinction of archaeofaunas and paleontological faunas, while useful for discussion purposes, is not meant to connote that every bone in the former was deposited by humans while all bones in the latter type of fauna were not deposited by humans.

McGuire (1980) uses several equivocal lines of evidence to infer people were not responsible for the Mineral Hill Cave deposit. First, McGuire (1980:265) argues that the ratio of stone artifacts to bones at two Great Basin cave sites suggests "even an infrequent occupation of Mineral Hill Cave would have resulted in at least some artifactual evidence." We simply do not know enough about how the deposition rates of site sediments, bones, and artifacts may vary and/or covary to make such assertions. The two caves McGuire chose for comparison may or may not be representative of the total range of variation in these rates.

Further, the ratio of stone tools to bones is a fallacious indication of human presence when the concept of expedient bone tools is introduced (Gruhn and Bryan 1981). Expedient bone tools were made from the bones of animals being butchered and were discarded after use with the rest of the faunal debris (Johnson 1982, 1985). Only knowledge of tool production need be brought to a butchering locality. If stone tools were curated, only expedient bone tools may be recovered by the archaeologist. We are far, however, from having established criteria for the identification of expedient bone tools (Lyman 1984b).

The second line of evidence McGuire (1980) employs is the absence of burnt bone. By implication, the presence of burnt bone would signify the presence of people. Balme (1980), however, argues that burnt bone with no associated artifacts deposited in an Australian cave was not deposited by people. The presence or absence of burned bone is at best a highly ambiguous criterion for assessing the presence or absence of people.

The third line of evidence is that the ceiling of the cave was not smoke-blackened. To get smoke-blackening, a fire which produces smoke must be present. Either no fires or smokeless fires were built in Mineral Hill Cave. Alternatively, the history of the cave

subsequent to smokey fires in the cave may have included roof fall events, water seepage over the ceiling, or some other process which effectively removed any evidence of a smoke-blackened ceiling. Clearly, the geological history of the site must be considered in taphonomic analyses.

The fourth line of evidence McGuire (1980:260) refers to is "split long bones of large mammals." Because such broken bones are present in the Mineral Hill Cave deposit, McGuire argues that citation of the presence of such broken bones in sites is an equivocal indicator of human presence. He has, however, failed to (1) convincingly demonstrate humans did not break the Mineral Hill Cave bones (cf. Morlan 1984), and (2) describe the fractured bones from Mineral Hill Cave in such a fashion as to allow comparison with known naturally and culturally broken bones (see Biddick and Tomenchuk [1975] for a clever but seldom used descriptive technique conducive to such comparative studies). This illustrates how critical data are often not recorded and/or reported in many taphonomic studies.

I am unconvinced that prehistoric people never entered Mineral Hill Cave. This is not to say that I believe people did enter the cave, but only that on the basis of the published evidence, it is impossible to determine whether or not people did actually utilize Mineral Hill Cave and contribute to the formation of the deposit. McGuire's sample is inappropriate for the taphonomic question he asks, his analyses fail to consider all relevant comparative data and theory, and he fails to present sufficiently detailed data for other taphonomists to perform comparative analyses. These problems plague many published taphonomic studies; this is not good. Fortunately, not all taphonomic studies are plagued by these problems; some are good.

The good.—Extinction of the large-antlered Irish elk (*Megaloceros giganteus*) has often been explained as resulting from their having become mired down in bog mud and/or being drowned in part because their antlers were so cumbersome. Barnosky's (1985, 1986) analyses of remains of this large cervine are truly examples of taphonomic research at its best.

Barnosky (1985) begins by listing six test implications of the miring-drowning due to large antlers hypothesis. Only one of these is met with available data: all individuals in the bog he sampled were males, as predicted by the model, female Irish elk not carrying antlers. But the other five hypotheses are not met: antlers are smaller than normal on average in Barnosky's sample, skeletons are not articulated nor complete, the bones are embedded in clay deposits too thin for the animals to have become mired down in, the deposits are not disturbed by trampling or struggling of these animals as they should have been by mired down animals, and the bog waters were apparently shallow enough (as inferred from geologic data) to preclude drowning of upright animals. These six test implications required detailed morphometric, contextual, associational, and stratigraphic data, all prerequisites I have noted in previous sections of this paper.

Failing to confirm the miring-drowning hypothesis, Barnosky (1985, 1986) proposes and tests two alternative hypotheses. The Pleistocene overkill by human hunters hypothesis (Martin and Klein 1984) is quickly discarded because no artifacts have been found associated with remains of Irish elk, and "the few examples of modification to Irish elk bones reputed to have been inflicted by humans cannot be distinguished from other naturally created kinds of breaks, abrasions, gnaw-marks, or scratches" (Barnosky 1986:132). Further, the oldest archaeological evidence of humans in Ireland dates between 9000 and 8500 B.P., while the Irish elk was extinct there ca. 10,600 B.P. In contrast to McGuire's (1980, 1982) undated but probable latest Pleistocene Mineral Hill Cave materials, tight chronological and stratigraphic control of Irish elk remains described by Barnosky makes the argument for absence of a human taphonomic agent much more convincing.

The second alternative hypothesis is that "male Irish elk visited bogs more often than females did during winters, when unfit animals died and decomposed near the water's edge, in some cases on the ice, and were scavenged and trampled" (Barnosky 1985:340). Evidence bearing on the six test implications for the miring-drowning hypothesis are consistent with the winterkill hypothesis, as are four other test implications specific to it. All elk died with antlers attached, suggesting an autumn-winter death season. Elk mortality was demographically attritional. Barnosky's sample of Irish elk tended to be small in body and antler size, suggesting "some combination of limited resources, malnutrition, or disease during fetal or postnatal growth" (Barnosky 1985:341). Finally, in modern cervines, "male mortality is greater than female mortality during winter, apparently because males, unlike females, eat little during the fall rut and enter the winter in poor condition," males more often seek winter shelter in valley bottoms (near bogs), and thus may die near lake (bog) shores "because they need water and because they are easy prey on ice" (Barnosky 1985:343), thereby explaining the overabundance of males relative to females in collections of Irish elk fossils. The test implications for the winterkill hypothesis underscore the necessity of age-sex demographic data, morphometric data, and the use of modern analogs as comparative bases in taphonomic analyses.

While Barnosky's (1985, 1986) study deals with paleontological faunas, his careful and detailed analyses should be emulated by those studying archaeofaunas. In fact, Fisher (1984a, 1984b) has made just such an attempt with North American mastodon remains, concluding like Barnosky that winterkill (and malnutrition) was a major mortality factor but that humans exploited (hunted? scavenged?) this large mammal. While not without weaknesses, Fisher's analyses and conclusions warrant careful study.

In summary, Barnosky not only provides many (but not all; e.g., the "scratches" on Irish elk bones are not described) relevant data, he considers three separate hypotheses. The winterkill hypothesis clearly succeeds because its test implications are met and test implications of the other hypotheses are not met. Further, while McGuire (1980, 1982) only considered four test implications, all with negative evidence confirming his hypothesis that people did not use Mineral Hill Cave, Barnosky (1985, 1986) considered a dozen implications, some with negative evidence and some with positive evidence to confirm his hypothesis. All taphonomists should emulate and seek to improve Barnosky's methods: they are good.

CONCLUSION

A taphonomic history results in a fossil assemblage which may poorly reflect the quantitative properties of the biotic community from which the fossils derived. Taphonomic processes sometimes mimic and other times obfuscate their respective effects, thereby rendering the writing of taphonomic histories difficult. While a terminology has been developed to characterize the complexities of taphonomy (Appendix), that terminology has become unwieldy and as a result is not regularly utilized in its entirety. I have attempted here to reduce the complexities of taphonomic processes to a small set of general processes and to align these general processes with their respective general effects. This simple framework guides us towards recognition of data requisite to taphonomic analyses. Perhaps the esoteric results of control studies can eventually be integrated into this framework and ultimately lead to a more holistic theory of taphonomy.

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APPENDIX

Taphonomy Terminology

actualism: "the methodology of inferring the nature of past events by analogy with processes observable and in action at the present" (Rudwick 1976:110)

actuopaleontology: (1) the study of modern organisms and environments for application to paleontological problems (Kranz 1974b) (see also Schafer 1962; Richter 1928); (2) emphasizes the idea that understanding the post-mortem history of one fossil group often requires knowledge of the life histories of associated and interacting organisms (Lawrence 1968); (3) "the application of the uniformitarian principle to

paleontological problems" (Warne and Hantzschel 1979); (4) see "neotaphonomy" and "neontology"

allochthonous: a fossil assemblage which has been transported from the area where the represented animals died and presumably lived

anastrophe: a catastrophe of limited scope and area, generally producing mass mortality in the affected area (Kranz 1974b)

anataxic: factors operating on buried bones, including: re-exposure or disinterment, weathering, mineralization, transport after re-exposure

archaeofauna: faunas recovered from archaeological sites (Grayson 1979); see also "paleontological fauna" and "local fauna"

attrition: loss of fossil information by non-preservation (after Lawrence 1968)

attritional mortality: diachronic death assemblage; the deaths of different aged animals over a prolonged period, that indirectly reflects the age-specific survivorship of a population (Voorhies 1969; Gifford 1981)

autochthonous: (1) a fossil assemblage which is found where the represented animals died and presumably lived; (2) fossils which experienced life, death and burial within the same place or locale

biocoenose: (1) the life assemblage of organisms; (2) consists of a living population; (3) "a biocoenose encompasses a biotope and a community of all organisms living in it" (Schafer 1972); (4) an ecological unit (or living community) consisting of an integrated living congregation of diverse organisms with both biotic and abiotic characteristics

biostratinomy: (originally biostratonomy) (1) the study of preburial taphonomic factors, e.g., those processes affecting an organism between death and final burial (Lawrence 1979a); (2) the study of pre- and syn-burial interrelations between dead organisms and their external environment (Lawrence 1968); (3) see "perthotaxic"

catastrophic mortality: (1) synchronic death assemblage; (2) a representative sample of all living age classes killed more or less instantaneously, forming a "snapshot" of a living population structure (Voorhies 1969; Gifford 1981)

chrisocoenosis: post-mortem use of bones by humans (A. S. Gilbert 1979); i.e., the fossil assemblage created by post-mortem use of bones by humans

coprocoenosis: a fossil assemblage derived from scats and owl pellets (Mellet 1974)

diagenesis: (1) the study of post-burial taphonomic factors, i.e., between burial and recovery (Lawrence 1979b); (2) study of the post-entombment histories of organic remains (Lawrence 1968); (3) "fossildiagenese" (Muller 1953); (4) see also "anataxic" and "taphic"

disarticulation: the generic process and result of loss of anatomical integrity (Hill 1979b); see also "dispersal" and "scattering"

- dispersal: the generic process and result of spatial movement of individual skeletal elements from a single organism (note that two elements may become more, or less, spatially contiguous) (Hill 1979b); see also "disarticulation" and "scattering"
- equifinality: the property of allowing or having the same effect or result from different events (Webster's Third International Unabridged Dictionary)
- ethnoarchaeology: study of living peoples with the aim of elucidating archaeological problems; i.e., a discipline with the goal of establishing and clarifying the relationships between material vestiges of human behavior and the living systems which generate them (Gifford 1977)
- fauna: some specified set of animal taxa in close spatial and temporal association; usually qualified by some geographic, temporal and/or taxonomic criterion (after Odum 1971:366-367) (see also Tedford 1970)
- fossil: (1) any specimen demonstrating physical evidence of the occurrence of ancient life; generally distinguished from Recent or non-/sub-fossil remains on the basis of its (the fossil's) geologic mode of occurrence (Schopf 1975); (2) the identifiable remains of (once) living organisms or of their activities preserved in the sediments by natural processes (Finks 1979); (3) any contemporary trace or remain of an organism that died at some time in the past (Matthews 1962)
- fossil assemblage: an aggregate of individual elements (that interact with various modification agents in statistical fashion, with considerable potential for variation in traces they ultimately may bear) (Gifford 1981)
- fossilization: the maintenance or alteration of chemical properties of organic materials by natural processes (Finks 1979)
- fossil record: that contemporary set of fossils in some specified geographic space and geologic context (Lyman 1982); see also "local fauna"
- fragmentation: mechanical disassociation of skeletal parts
- liptocenosis: remnant (fossil) assemblage (Rolfe and Brett 1969)
- local fauna: the fauna represented by one or several geographically, geologically and taxonomically similar fossil samples; i.e., may be represented by fossil samples from a single site or several sites in close geographic and stratigraphic association (not necessarily representative of a biocoenose, and not necessarily implying any paleoecological reality) (Tedford 1970); see also "fossil record"
- mineralization: see "fossilization"
- neontology: the "paleontology" of living animals including the "paleoecology" of modern environments (Warne and Häntzschel 1979); see also "neotaphonomy" and "actuopaleontology"
- neotaphonomy: involves relevant experimentation or observations of the condition of modern vertebrate remains in closely defined environments, designed to test taphonomic conjectures and to suggest consequences for paleoecological interpretation

tation not visible in the fossil record such as the absence of a taxon or the structure and composition of a paleocommunity from certain kinds of fossil remains (Hill 1978)

oryctocoenose: remains that were found together in an outcrop (Lawrence 1979c)

paleoecology: (1) the study of environmental relations of fossil organisms between their birth and death (Lawrence 1968); (2) a discipline focusing on interrelationships which occurred in the geologic past between living organisms and their surroundings (Lawrence 1971)

paleontological fauna: (1) "the maximum geographic and temporal limits of a group of organisms sharing a suite of common species" (as evidenced by the fossil record) (Tedford 1970); (2) faunas recovered from paleontological sites; (3) see also "archaeofauna" and "local fauna"

paleotaphonomy: observations on fossil assemblages (Hill 1978); see also "neotaphonomy" and "taphonomy"

pedoturbation: various processes of homogenization (or haploidization), which impede soil horizon formation; soil mixing (Wood and Johnson 1978); may be mechanical or chemical (faunal-turbation; floral-turbation; cryoturbation; graviturbation; argilliturbation; aeroturbation; aquaturbation; crstalturbation; seismiturbation)

perthotaxic: taphonomic factors which operate between the time of an organism's death and the time of its burial, including but not limited to scavenging and weathering; see also "biostratinomy"

perthotaxis: a death assemblage with corpses in various stages of decomposition (Clark and Guensburg 1970)

petrification: (1) "cellular permineralization": permeation of cells and interstices (not replacement) by mineral matrix at or very soon after deposition (Schopf 1975)

preservation: (1) "duripatric (hard part) preservation"; original hard parts are preserved due to resistance to oxidation and physical damage (Schopf 1975); (2) "authigenic preservation"; fossil is encased by cementing minerals which preserve surface configuration of organic parts while internal organization is lost or degraded (Schopf 1975)

proximal community: the species of a community which lived in close spatial proximity to the site of the deposition of their remains (Shotwell 1955); see also "autochthonous"

quarry site: localized concentrations of fossil bones; vary greatly in density of materials and total volume; vary in degree of representation of biocoenose (Shotwell 1955)

scattering: the increase in dispersion of skeletal parts (Hill 1979b); see also "dispersal" and "disarticulation"

signature criterion/pattern: "a criterion that is constant and unique and that discriminates one modifying agent or set of agents from another" (Binford 1981; Gould 1980)

- sullegic: factors influencing collection; i.e., whether or not a particular fossil is collected; includes: area of site or site chosen, sampling design (where you collect), collection procedures (e.g., hand-pick versus screening (mesh size) versus flotation) (Meadow 1981)
- taphic: factors determining whether or not a bone will be buried; the when, where, how and why of burial
- taphocoenosis: (taphocoenose) assemblage of organic materials which are buried together (Lawrence 1979c)
- taphonomy: (1) the science of the laws of embedding or burial; the study of the transition, in all details, of organics from the biosphere into the lithosphere (Efremov 1940); (2) the study of differences between a fossil assemblage and the community(ies) from which it derived; the nebulous region of conjecture constituting hypothetical assertions about the causes of the observed bias in fossil assemblages (Hill 1978)
- thanatic: (1) factors or variables pertaining to the death of an organism; (2) causes of death; (3) circumstances inducing death among individuals of a biocoenose (Clark and Kietzke 1967)
- thanatocoenose: (1) the death assemblage derived from a biocoenose (biocoenose = thanatocoenose = fossil assemblage); (2) may not be from one but several communities (Shotwell 1955); (3) organisms that died together (Lawrence 1979c)
- transport: loss of fossil information by physical movement of fossils away from the site of the original biocoenose (adapted from Lawrence 1968)
- trephic: (1) factors incident to curating and identifying a specimen which determine whether a particular fossil becomes available for analytic use (i.e., becomes or provides data) (Clark and Guensburg 1970); (2) includes determining which bones that were recovered are identified/recorded (skill of analyst), analytic procedures (sampling), to publication format (NISP or MNI or both) (Meadow 1981)
- weathering: chemical and mechanical alteration of bone microstructure prior to burial (Behrensmeyer 1978)



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