MICROVERTEBRATE TAPHONOMY IN ARCHAEOLOGICAL SITES: AN EXAMINATION OF OWL DEPOSITION AND THE TAPHONOMY OF SMALL MAMMALS FROM SENTINEL CAVE, OREGON

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ABSTRACT

Analysis of microvertebrate remains from archaeological sites can yield important information concerning human utilization of small animals and the environment within which cultures functioned. Knowledge of the depositional and postdepositional history of the microvertebrate remains is necessary for both these areas of research. Methods for recognizing deposition by owls, a major source of small animal remains in archaeological sites, are examined in this study.

Characteristic patterns of bone fragmentation and skeletal element representation are derived, and their variability examined, through the actualistic investigation of remains accumulated by three species of wild owls. This provides useful baseline information concerning initial characteristics of owl deposited assemblages and allows more educated hypotheses concerning the taphonomic history of small animal remains. However, it is shown that these characteristics are not truly diagnostic criteria because they overlap with attributes produced by other processes and do not satisfy "if and only if" statements.

The application of this actualistic research to taphonomic problems encountered in archaeological sites is assessed through the analysis of 18,500 small mammal bones and teeth from Sentinel Cave, a northern Great Basin archaeological site in southeastern Oregon. Fifteen descriptive attributes were

recorded for each bone in the assemblage. These data were analyzed with the aid of an information storage and retrieval computer program to derive characteristics comparable to the actualistic data.

The analysis demonstrates that element frequency criteria are obscured by sampling loss, postdepositional modification, and multiple depositional agents. It is suggested that characteristics of individual bones, such as type of break, digestive erosion, tooth marks, and burn patterns are more important, but that all information, including context, must be utilized in conjunction to satisfactorily investigate taphonomic processes. Deposition of the rodent and lagomorph remains in Sentinel Cave is ascribed primarily to owls, with a limited carnivore contribution. Woodrat activity appears to have had little effect on the assemblage other than the possible relocation of some lagomorph bones.

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CHAPTER I

INTRODUCTION

Small animal remains are encountered in most archaeological sites and in some site contexts they may make up a significant proportion of the recovered faunal material. Analysis of these remains can yield important information concerning human behavior. Research involving small animal remains is generally conducted to answer questions in two areas: cultural utilization of small animals and paleoenvironmental reconstruction. The foundation for both areas of research is the correct assessment of the depositional and postdepositional history of the small animal (microvertebrate) remains. However, many of the processes involved in small animal taphonomy are not well understood.

The present research was initiated to increase our understanding of a major source of microvertebrate remains in archaeological sites: owl pellet deposition. Owl pellets have become widely recognized by archaeologists as potential sources of microvertebrate skeletal remains in caves and rockshelters. Yet there has been little explicit theoretical or methodological consideration of how owl pellet deposition can be accurately identified as a contributor of microvertebrate remains in archaeological sites.

The present study was formulated to address this problem in a research design consisting of two major parts. The first part of the research consists of an actualistic investigation of

processes involved in accumulation of owl pellet bone. Objectives of this part of the research are to 1) systematically examine mechanisms involved in owl pellet deposition, and 2) attempt to develop methods to distinguish owl deposition of microvertebrate remains from cultural and other forms of natural deposition. The second part of the research consists of the analysis of microvertebrate remains recovered from Sentinel Cave, an archaeological site in southeastern Oregon. Objectives of this part of the study are to 1) apply owl deposition identification criteria developed in the actualistic study to determine their usefulness, and 2) attempt to identify agencies responsible for the bone accumulation. A corollary part of the research is an examination of the valid use of owl pellet remains for paleoecological analyses, using Sentinel Cave data as an example.

Theoretical Background

This study concentrates on small mammal remains which are defined as hare-sized or smaller. Although small birds, reptiles, amphibians, and even fish may be preyed upon by owls, they generally make up a small portion of owls' diets (Bent 1938; Mikkola 1983). Also, remains of these animal classes are relatively uncommon in many archaeological deposits (e.g. Bickart 1984). The taphonomic history of non-mammalian remains may yield important cultural and/or environmental information, but constraints of this study do not allow for their in-depth

analysis.

Small mammals as potential subsistence items

Small mammals may have been an important part of some prehistoric cultures' subsistence strategies (Brothwell and Jones 1978; Stahl 1982; Jones 1984). Early ethnographic accounts document small mammal consumption in many areas (e.g. Waugh 1916; Beals 1945; Swanton 1946; Forde 1961). In particular, Great Basin cultures utilized rabbits and rodents (e.g. Lowie 1909; Egan 1917; Kroeber 1925; Kelly 1932; Steward 1938). As Great Basin ethnography and archaeology indicates, larger, rabbit-sized prey were probably more significant subsistence items than small rodents. Prey of this size may also make up a considerable portion of the diet of some of the larger owls (Burton 1973; Mikkola 1983). Analyses of human coprolites also indicate that some prehistoric humans ingested small mammals. For example, small mammal bones were found in coprolites from a 2800 year old rockshelter in Texas (Bryant and Williams-Dean 1975), and in coprolites from the early Woodland period from Salts Cave, Kentucky (Watson 1969).

Modern studies in sub-saharan Africa and South America suggest that small mammals are commonly utilized in areas where large game is scarce or has been depleted (den Hartog and de Vos 1974; Jones 1984). For example, rodents comprise a large portion of the diet of many South American tropical forest populations (Ross 1978; Hill and Hawkes 1983). In tropical forests, large

animals are generally rare, solitary, nocturnal, and inhabit areas with difficult access, making availability to hunters low (Ross 1978).

The biology of small mammals enables them to be utilized efficiently as sources of protein under circumstances where large animals are difficult to procure. In many areas, small mammals are the most abundant mammals in terms of both species and number of individuals. Two small mammal orders, Rodentia and Insectivora, comprise the first and third largest orders, respectively, of mammals (Vaughan 1972). Most small mammals are relatively r-selected, when compared to larger mammals, although there is a wide range of variability in reproductive strategies within the group (see Table 1) (Golley et al. 1975). The most extreme r-strategists have short life spans, high, often cyclical, reproductive rates, and high population numbers. These characteristics permit them to adapt to changing and/or harsh environments. The high reproductive rate of Type 1 in Table 1, and the stable populations of Types 2 and 3, along with relatively high numbers of individuals for all types with respect to large mammals, make small mammals relatively reliable potential food sources under certain conditions. Methods of distinguishing natural from cultural deposition of small mammal remains are necessary if we are to gain an understanding of the conditions under which small mammal utilization was included, and the part it played, in prehistoric subsistence strategies (e.g. Hayden 1981; Styles 1982).

Table 1. Small mammal demography. From Golley, F. et al. 1975.

Microtinae, Muridae	High reproductive rate, low survival rate, population volatile.
Cricetinae, Soricidae	Moderate reproductive rate, medium survival rate, moderate population density, more stable than above, seldom at high densities.
Sciuridae, Zapodidae	Low reproductive rate, high survival rate, rather low population density, often seasonally dormant, populations generally stable.

Small mammals as past environmental indicators

Paleoenvironmental studies in archaeology are not concerned with simply reconstructing past environments, but are implemented for the purpose of gaining an understanding of the relationship between humans and their environment. Knowledge of the biotic and physical environment in which a prehistoric culture functioned, including spatial and seasonal distribution of resources, is critical to an understanding of the culture and development of explanations of culture change. Culture ecology has become an important conceptual framework in archaeology since the work of Julian Steward (1938, 1955) and need not be discussed further here.

Information concerning past environments can often be obtained from small mammal remains. However, paleoecological interpretations based on these remains (as well as those based on other data) are not straightforward. It is generally recognized today that taphonomic investigations must precede

paleoecological reconstruction (e.g. Lawrence 1971; Munthe and McLeod 1975; Shipman 1981a; Behrensmeyer and Kidwell 1985). A variety of processes act on organisms between time of death and final deposition of their remains. The result is that observed assemblages normally provide a distorted picture of original living communities. Information contained in the living ecological communities is altered by these biasing processes and taphonomic studies are necessary to identify these biases (Behrensmeyer and Kidwell 1985).

Small mammal skeletal remains can be deposited in caves and rockshelters through a variety of means such as fluvial transport, natural death, mammalian carnivores, avian predators and human activity. Each depositional agent involves a unique set of processes. This results in assemblages from different agents being biased in different ways. For example, each agent accumulates bones from a different combination of microenvironments and varies in differential selection of species and skeletal elements. Thus, identification of possible mechanisms responsible for an accumulation of bones in a cave or rockshelter is a necessary first step in paleoecological research.

Taphonomy

Taphonomy is the study of processes that act on an organism between time of death and discovery of its remains. Although earlier work by German paleontologists laid the groundwork for

development of the field, taphonomy was first defined by I. A. Efremov (1940: 85): "the study of the transition (in all its details) of animal remains from the biosphere into the lithosphere, i.e. the study of a process in the upshot of which organisms pass out of the different parts of the biosphere and, being fossilized, become part of the lithosphere".

Paleontologists divide the taphonomic history of an organism into phases delineating the sequence of processes that may act on the organism. Clark and Kietzke (1967) were one of the first to describe this sequence in detail. In more general terms, taphonomy can be divided into two subareas: biostratinomy and diagenesis (Lawrence 1971). Biostratinomy is the study of processes occurring between death of an organism and its burial. Diagenesis is concerned with processes occurring between initial burial and discovery. Much archaeological taphonomic work to date has focused on biostratinomy. Diagenesis, or postdepositional processes, has not as yet received as much systematic attention.

Discussions of taphonomy have traditionally focused on bias (Gifford 1981) and loss of information (Behrensmeyer and Kidwell 1985). This leads to an emphasis on what we cannot do, rather than what we can do with organic remains and neglects the fact that information is not only lost, but is also added and altered during the taphonomic history of organisms (Behrensmeyer and Kidwell 1985). The definition of taphonomy recently suggested by Behrensmeyer and Kidwell (1985:105) is a useful working

definition for taphonomic research and is used in this project: "the study of processes of preservation and how they affect information in the fossil record".

Uniformitarianism

The science of taphonomy is based on the principle of uniformitarianism. Taphonomy is a retrodictive or historical science by which indirect attempts are made to reconstruct past conditions, events, and behaviors which cannot be directly viewed (Simpson 1970; Shipman 1981a). Assumptions provided by uniformitarianism ("the present is the key to the past") allow past phenomena to be scientifically studied (Gould 1965).

Uniformitarianism has a controversial history and has encompassed many tenets since it was first fully developed by Charles Lyell (1830-1833) (Simpson 1970). Simpson's (1970) review of these principles indicates that some of these have been shown to be false or of only historical value while others are as important and necessary today as they were historically. The uniformitarianism concept called actualism by some (e.g. Simpson 1970) and methodological uniformitarianism by Gould (1965) covers assumptions necessary for taphonomic inferences. Actualism, as a principle, refers to present laws of nature and the assumption that these laws have been present and unchanging through time (Simpson 1970). Thus, one studies present day causes and effects and assumes these same causal mechanisms acted in the past. Specifically in taphonomy, one assumes that

physical, chemical, and mechanical properties which effect organic remains do not change through time (Shipman 1981b). However, taphonomic and paleoecological inferences require further assumptions concerning biological phenomena which may not be as immutable as physical laws (Shipman 1981a). Thus researchers attempt to understand how and why processes produce effects in an effort to delineate past events (Shipman 1981a).

Taphonomy and archaeology

Taphonomy was first applied to archaeological problems in the late 1960's and 1970's in a series of important papers concerned with early human versus natural bone modification (Brain 1969, 1976; Behrensmeyer 1975; Hill 1975, 1978). Following this lead, much archaeological taphonomic research has focused on the important problem of distinguishing human modification of large mammal bone from carnivore modification (e.g. Binford and Bertram 1977; Binford 1981; Haynes 1980, 1981, 1983; Hill 1983; McKinney 1974; Shipman and Rose 1983; Sutcliffe 1970). In the 1980's taphonomy has become an integral part of many faunal studies and a number of reviews concerning taphonomy in archaeology have been written (e.g. Gifford 1981; Shipman 1981b; Johnson 1985).

Middle-range theory

Taphonomic research in archaeology can be placed under the domain of middle-range theory, as "defined" by Binford (1981). Middle-range theory, a concept borrowed from sociology, has

taken its place in archaeological thought largely through the influence of Binford, although Raab and Goodyear first introduced the term to archaeologists (Schiffer 1980). As developed in sociology, middle-range theorizing was meant to generate theories that would link empirical data to higher level abstractions (Raab and Goodyear 1984). As such, Binford's and other archaeologists' use of the concept has generated criticism (e.g. Schiffer 1980; Raab and Goodyear 1984).

Raab and Goodyear (1984) feel that use of middle-range theory in archaeology has for the most part become synonymous with the investigation of site formation processes. They appear to believe that the term middle-range theory should be confined to explanations of culture behavior. While explanations of variability in cultural behavior can indeed be middle-range theories, I see no problem with including *the process of explaining* site formation under the same rubric. This stage of theory-building, of which taphonomy is a part, is concerned with developing methodology to identify processes that formed the archaeological record, and thereby aid in explanations of why and how it was formed. Binford's middle-range theory (Binford 1981) and taphonomic theory central to this project are concerned with providing a scientific framework within which the static archaeological record can be linked to past dynamic processes.

Actualism as method

Determination of processes responsible for deposition of a bone assemblage requires knowledge of processes and their effects acquired through actualistic research, the direct observation of present causes and effects (Gifford 1981). This is step two of Simpson's (1970:85) (see also Shipman 1981a) three step approach to historical research. Knowledge gained through actualistic research is then used to make inferences about the history of an assemblage through analysis of assemblage attributes and comparison of these attributes with known phenomena (Simpson's steps one and three).

Chapter II of this thesis describes actualistic research conducted to gain an understanding of processes involved in owl pellet deposition and their effects on resultant assemblages. An attempt was made at this stage to develop diagnostic criteria for identifying owl deposition in an assemblage.

Proper application of actualistic methods to produce diagnostic criteria (Binford's (1981) signature criteria) involves examining the possibility of equifinality, or chances of obtaining the same results from different processes (Gifford 1981, Shipman 1981a). Diagnostic criteria are valid only when "if and only if" statements have been postulated, tested, and all other possible causes eliminated (Lyman 1982). In Chapter III, criteria proposed for identifying owl pellet deposition are compared to effects of other known small mammal bone

depositional mechanisms.

There are problems associated with the search for criteria diagnostic of cultural or various natural forms of bone deposition. First, arguments from elimination can never be totally proven because one can never be sure that all causes have been considered. Second, it is becoming increasingly clear from analysis of both large mammal and microvertebrate remains that many different processes have similar effects on bones. Probability of postdepositional modification and assemblages consisting of bones from a variety of sources further complicate the search for truly diagnostic criteria. Actualistic investigation of depositional agents provides a foundation upon which research concerned with postdepositional modification and analysis of complex assemblages must then be conducted. Many lines of evidence are brought into play when determining the depositional history of a site (e.g. Lyman 1982; Payne 1983). Although the formulation of truly diagnostic criteria may not always be possible, we may be able to postulate which agents most likely produced certain assemblage characteristics (Shipman 1981b) and will at least be made more aware of complicating factors through this type of research. These problems are further addressed and methods for dealing with them suggested in Chapters IV to VI, in which the depositional history of a microvertebrate assemblage from Sentinel Cave, Oregon, is discussed.

CHAPTER II

CHARACTERISTICS OF BONE DEPOSITED BY OWLS

Pellet Production

More than sixty families and 330 species of birds produce pellets regularly (Glue 1970). This diverse group includes not only birds of prey, but also species in families such as Laridae, Corvidae, and Laniidae. However, species with pellets most useful for ecological analysis, and which may contribute bones to an archaeological site, are largely confined to the owl families (Tytonidae, the barn owls, and Strigidae, other owls) and, to a lesser extent, to the Falconiformes (falcons, hawks, and eagles). Other species generally produce pellets with very little or no bone in them.

Owls swallow their prey whole, or in a few large chunks (Mikkola 1983). A number of hours after ingestion, a pellet, composed of matted fur, feathers, and bone, is regurgitated. Pellets are formed by muscle action in the ventriculus or gizzard during digestion (Smith and Richmond 1972). Owls generally produce at least two pellets per day (Guerin 1928). For example, barn owls commonly eject a small pellet during the night while hunting and a larger pellet during the day while at their roost or nest (Burton 1973). Piles of pellets accumulate rapidly under long-used roosts and, given proper preservation conditions, large deposits of bone may develop. Amount of prey

per pellet varies from one individual to many individuals per pellet (Doerksen, 1969, records 10 items in one barn owl pellet) depending on prey size and time between captures (Smith and Richmond 1972). The amount and quality of bone found in owl pellets is extraordinary. Generally, relatively complete prey skeletons with very little breakage or corrosion are found.

Most pellet skeletal material that survives in archaeological sites will be found in caves and rockshelters. Although large numbers of remains are deposited by owls in open areas, these pellets are usually subject to diverse environmental processes and few bones survive. Levinson (1982) discusses the stages of decomposition and processes affecting owl pellets from ejection to burial. In the majority of cases, fur and feathers decompose rapidly. Marti (1974) placed owl pellets in natural situations in Colorado and found that some were totally disintegrated after two months and that by ten months only a few bones were left. Korth (1979) feels that most microvertebrate assemblages are the result of water activity rather than either owl pellets or carnivore scats because scats and pellets easily disintegrate in streams and rain and surface runoff is sufficient to sort and transport most small bones. However, most microvertebrate assemblages survive in caves and rockshelters, used as roosts and dens, where preservation conditions are good and disturbance may be relatively minimal.

Previous Research

Recent research by paleontologists (Raczynski and Ruprecht 1974; Korth 1979; Dodson and Wexlar 1979) has led to the discovery of potentially diagnostic criteria which may help distinguish owl pellet deposition in archaeological sites. These investigations focus on two types of data: those describing relative percentages of skeletal elements found in pellets and data describing breakage characteristics of individual elements.

Raczynski and Ruprecht's (1974) research documents amount of bone loss observed in long eared *(Asio otus)*, tawny *(Strix aluco)*, and barn *(Tyto alba)* owl pellets. The greatest contribution of this paper is the consideration of processes, and their variability, leading to bone loss. Korth (1979) calculates percentage representation of various skeletal elements in 40-60 barn owl and great horned owl *(Bubo virginianus)* pellets and briefly describes condition of the bone. Dodson and Wexlar (1979) tabulated element percentages and breakage characteristics of bone from captive great horned owl, barn owl, and screech owl *(Otus asio)* pellets. They found apparently characteristic breakage patterns in a sample of 40 pellets from the three species.

Archaeological discussions of owl pellet bone characteristics are limited. Brain (1981) discusses the accumulation of microvertebrate remains by owls in southern Africa and mentions breakage characteristics of hare *(Pronolagus*

randensis) crania. Andrews (1983) provides some information on patterns of element completeness in bone from African owl pellets.

Some discrepancy between Korth's (1979) and Dodson and Wexlar's (1979) findings indicate that the total range of variation in owl pellet bone breakage characteristics is not documented in either study. None of the bones from barn owl pellets, nor bones of small prey from great horned owl pellets, were broken in Korth, while bones from Dodson and Wexlar's barn owl pellets averaged 28% broken and great horned owl bones 66% broken. This type of taphonomic work will only be of practical use to archaeology if we are aware of the range of variation possible in owl pellet bone characteristics. Additional investigation of owl pellets is one way of increasing our knowledge of variation, but perhaps more importantly, explicit consideration of the processes leading to the bone accumulation, and their variations, is necessary. The present study is designed to add to the small body of data concerning owl pellet breakage patterns by investigating pellets deposited by three species of wild owls. Processes that lead to owl pellet formation and deposition are then examined in an effort to explain the development of the breakage patterns and account for variation in these patterns.

Methods

Five samples of pellets from three species of owls, barn *(Tyto alba)*, great horned *(Bubo virginianus)*, and short-eared *(Asio flammeus)*, were analyzed. Pellets were obtained as follows: Thirty barn owl pellets were collected from a barn in Surrey, British Columbia during June to August, 1983. Ten barn owl pellets were collected in June, 1984 from a barn in Crescent Beach, British Columbia. Each barn was inhabited at the time of the study by a single, adult, barn owl. Ten great horned owl pellets were collected from under each of two trees in the Reifle Wildlife Reserve, Delta, British Columbia during May, 1984. According to a reserve ranger, great horned owls were seen roosting in the trees. Twelve short-eared owl pellets, collected by Michael Wilson during spring, 1971, in the Snake River Canyon, near Asotin, southeastern Washington, were also analyzed. Only whole, undamaged pellets were used in the analysis.

All bone from each pellet was carefully extracted manually using fingers and tweezers to separate bone fragments from the fur. Chemical extraction has been used successfully by other researchers (e.g. Dodson and Wexlar 1979), but manual extraction was felt to be most expedient in this case since freshness of the pellets allowed easy separation with no breakage and near complete bone extraction. Bone recovery was checked by myself or my assistant by searching through the fur a second time. Any

pellets that did become hardened before dissection were soaked in water for a few minutes.

Following Dodson and Wexlar's (1979) procedure, bones of each pellet were sorted according to anatomical element. The following elements were analyzed: skull, mandible, scapula, humerus, radius, ulna, innominate, femur, and tibia. For each element the following information was recorded: species, state of epiphyseal fusion, portion of element represented, sites of breakage, and evidence of digestive erosion. Elements were identified to genus or species by direct comparison with osteological specimens in the Simon Fraser University Zooarchaeological Collection and The Museum of Natural History, University of Puget Sound.

To determine if breakage patterns were present, breakage data recorded for individual pellets were combined for each sample by totalling the number of element types exhibiting each particular breakage state found. For example, the total number of humeri in each of four breakage categories (whole, distal end missing, proximal end missing, both ends missing) was determined. This was done for each element type used in the analysis.

Minimum number of individuals (MNI) present in each pellet was calculated by siding and then counting the most frequent element portion for each prey species represented. MNI for each sample was then obtained by adding the MNI's for each individual

pellet.

Analysis and Results

Table 2 lists species composition and number of prey items per pellet for each of the five samples. The high proportion of voles (*Microtus* sp.) agrees with other North American owl dietary studies. *Microtus* appears to be a favored food of many owl species including barn and short-eared owls when available (Bent 1938; Craighead 1969). These results and ecological investigations of wild owl diet (e.g. Clark 1975; Dexter 1978; Herrera and Jaksic 1980; Brown 1981) support Dodson and Wexlar's (1979) contention that owl pellets usually produce large quantities of bone from a restricted number of species in a restricted size range. The facts that owls selectively exploit prey species and that diet may vary seasonally, according to location, and from year to year (Graber 1962; Herrera and Hiraldo 1976; Dawe et al 1978) have implications for paleoenvironmental analyses (see Chapter 6).

The analysis involves bones of 195 prey individuals recovered from 72 pellets (Table 2). Ninety-four individuals were recovered from 30 pellets in the first barn owl sample (B1), 34 from 10 pellets in the second barn owl sample (B2), 22 from 10 pellets in the first horned owl sample (G1), 27 from 10 pellets in the second horned owl sample (G2), and 18 individuals were collected from 12 pellets in the short-eared owl sample

(S1).

Relative skeletal completeness: percentage present

The number of skeletal elements present in each sample of pellets is listed in Table 3. Percentage present (PP) is the proportion of elements present (NISP) relative to the expected number, given MNI. This measure is widely used to quantify relative element abundances (or relative skeletal completeness) within assemblages (e.g. Dodson and Wexlar 1979; Korth 1979; Shipman and Walker 1980; Andrews and Nesbit Evans 1983). Attempts to characterize microvertebrate assemblages by a measure of relative percentage of skeletal elements are based on the assumptions that certain depositional agents will yield assemblages with more complete individuals than other agents, that the proportion of skeletal elements will be different in assemblages deposited by different agents, and that these differences are consistent and unique enough to be used to distinguish depositional agents.

The data in Table 3 indicate a relatively high average percentage present for all element types in each sample: 79% and 83% for the barn owls, 82% and 87% for the horned owls, and 92% for the short-eared owl. All other skeletal elements (e.g. ribs, vertebrae, phalanges) were also present in each pellet, but were not tabulated. Korth (1979) and Dodson and Wexlar (1979) also obtained high average PP's from their pellet samples: 85.2%, 81.7%, 72.1% (Dodson and Wexlar 1979); 73.9%, 78.6% (Korth

Table 2. Species composition from five owl pellet samples. See text for collection locations.

Sample	Prey Species	MNI	Number of Pellets	Number of Prey/Pellet
B1	Microtus	77	30	3.1
	Peromyscus	4		
	Sorex	9		
	Zapus	4		
B2	Microtus	13	10	3.4
	Lagomorpha	3		
	Peromyscus	11		
	Sorex	7		
G1	Microtus	20	10	2.2
	Sorex	2		
G2	Microtus	22	10	2.7
	Sorex	5		
S1	Microtus	18	12	1.5

1979). This suggests a relatively high average percentage of the element types considered here can be expected in an assemblage formed from owl pellets (provided differential degredation or removal does not occur after deposition).

There are a few potential problems with PP that should be recognized by those using it to distinguish depositional agent. One problem that can be readily overcome is differential fragmentation. Differential breakage has been recognized as a quantitative problem in faunal studies for some time (Chaplin 1971). Quantification founded on NISP is based on the assumption that all elements of all species have an equal chance of breaking. However, cultural and natural processes can affect bones of different species differentially and lead to erroneous estimates of relative species abundance. This criticism of NISP

Table 3. Representation of skeletal elements in five owl pellet samples.

	Barn Owl MNI=94			Barn Owl MNI=34		
ELEMENT	# PRESENT	PP	WHOLE(%)	# PRESENT	PP	WHOLE(%)
MAXILLA	176	.94	.48	50	.74	.40
MANDIBLE	177	.94	.46	61	.90	.46
SCAPULA	115	.61	.05	44	.65	.22
HUMERUS	155	.82	.87	59	.87	.83
RADIUS	128	.68	.90	52	.76	.85
ULNA	149	.79	.79	55	.81	.83
INNOMINATE	123	.65	.52	60	.88	.45
FEMUR	153	.81	.88	62	.91	.82
TIBIA	157	.83	.41	66	.97	.50
TOTAL	1333	.79	.59	509	.83	.60

	Great Horned Owl MNI=22			Great Horned Owl MNI=27		
ELEMENT	# PRESENT	PP	WHOLE(%)	# PRESENT	PP	WHOLE(%)
MAXILLA	38	.86	.84	54	1.00	.96
MANDIBLE	36	.82	.72	53	.98	.47
SCAPULA	33	.75	.15	33	.61	.06
HUMERUS	37	.84	1.00	46	.85	.98
RADIUS	36	.82	.97	45	.83	1.00
ULNA	38	.86	.92	47	.91	.96
INNOMINATE	36	.82	.67	49	.91	.73
FEMUR	35	.80	1.00	47	.87	1.00
TIBIA	37	.84	.78	48	.89	.50
TOTAL	326	.82	.78	422	.87	.74

	SHORT-EARED OWL MNI=18		
ELEMENT	# PRESENT	PP	WHOLE(%)
MAXILLA	36	1.00	.89
MANDIBLE	35	.97	.37
SCAPULA	25	.69	.16
HUMERUS	31	.86	1.00
RADIUS	34	.94	.97
ULNA	35	.97	.89
INNOMINATE	35	.97	.43
FEMUR	34	.94	.97
TIBIA	31	.86	.93
TOTAL	296	.91	.75

is most recently examined by Grayson (1984) and Klein and Cruz-Uribe (1984).

Cultural and natural processes can also differentially break elements within an individual and can potentially cause problems with any measure of relative skeletal completeness. If all fragments are tabulated, bones which break more frequently will be overrepresented relative to bones that are less prone to breakage, and MNI calcualtions based on these artifically high counts will be skewed. As an example, differences in amount of fragmentation between my samples and Dodson and Wexlar's (1979) samples could account for some of the differences in PP. In my sample B1, 52% of the innominates are whole, while 30.8% are whole in their barn owl sample. If all innominate fragments were counted, the more fragmentary nature of the second sample could result in a higher number of innominates present. The high percentage of tibias present in Dodson and Wexlar's horned owl data (105.4%) could also be partly a function of fragmented elements (only 5.1% of the tibias are whole).

This is easy to rectify by counting only one diagnostic area of a bone (the most common area of an element) (Watson 1979). At present it is not clear whether differential breakage has been corrected for in most small animal taphonomic studies. Researchers should indicate how element counts are computed, and how MNI is calculated, so that results from different assemblages may be compared. In this study the number of elements present for each sample (column 2 of Table 3) was

obtained by counting the most common diagnostic zone for each element type. The zones counted are presented in Table 5. For example, in sample B1 the distal end of the humerus, which is the most common area of the humerus found in the sample, was counted: 141 whole humeri plus 14 distal humeri equals 155 humeri.

Grayson (1984: 45-49) discusses another potential problem with PP. Because PP is determined from MNI, factors that affect MNI estimation will also affect PP. MNI is dependent on how faunal assemblages are aggregated for analysis. Consequently, different aggregation decisions will produce varying most abundant elements, MNI's, and PP's. Thus PP values should be interpreted in light of how material from a site is lumped together for analysis.

Percentage present and sample size

Another potential problem is the relation between PP and sample size. Percentage present can be expressed as follows:

(1.) PP = NISP observed/NISP expected, given MNI

This expression is actually a form of NISP/MNI:

(2.) NISP expected = MNI x constant (c)

where c = number of element types in sample (lefts and rights counted separately). Therefore,

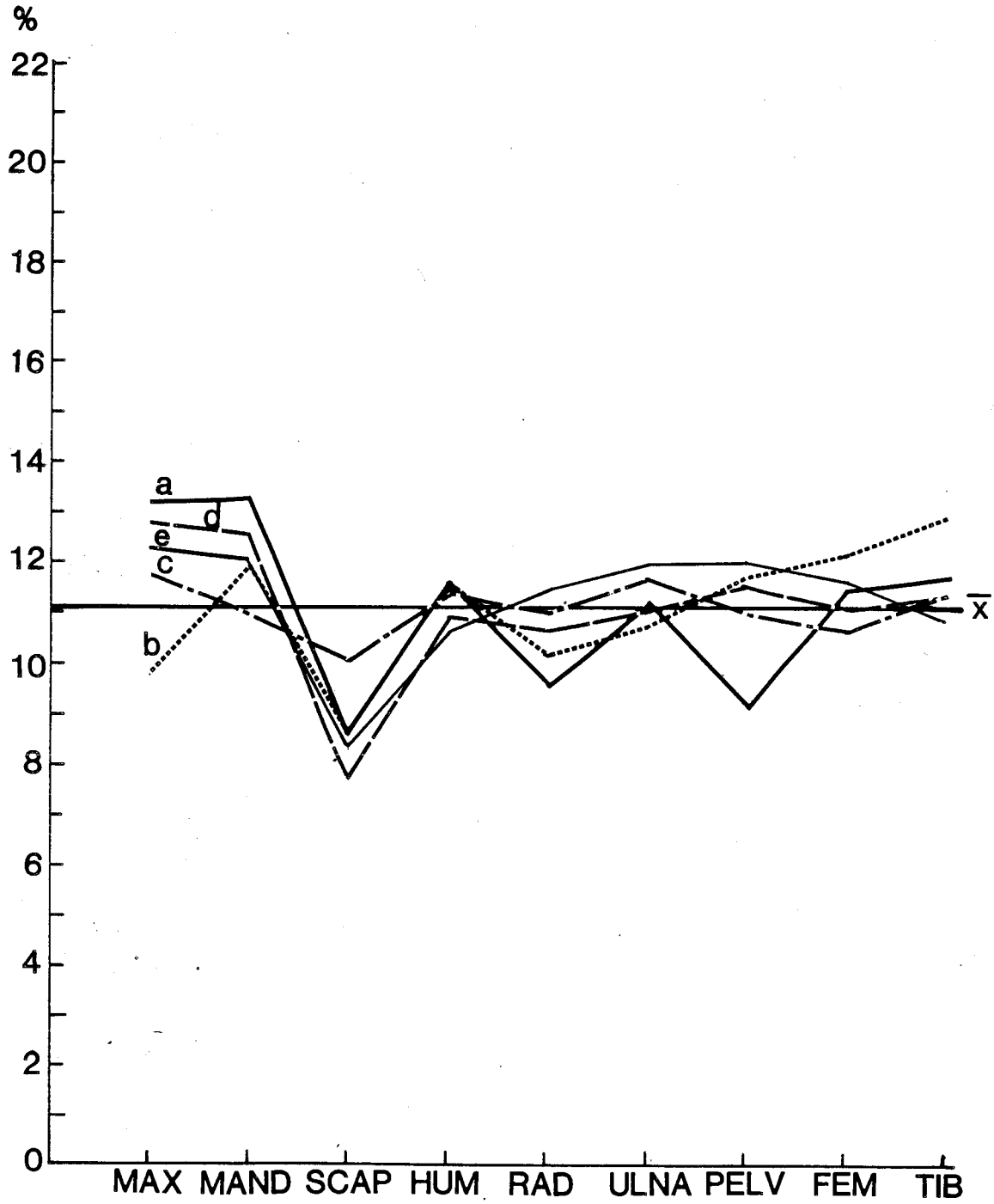
(3.) PP = NISP/MNI x c.

The relationship between sample size (NISP) and indices in the form MNI/NISP, or its reciprocal, has been discussed by Casteel (1977a, 1977b) and Grayson (1978a, 1978b, 1981, 1984) and, for most assemblages, can be described by hyperbolic and parabolic curves. Grayson has shown that these indices measure sample size, yet PP has been widely employed without acknowledgement of this by its users.

A measure that reflects completeness of individuals while avoiding most sample size problems is relative frequency of element types. The use of frequency of occurrence of elements has also been suggested by others as a method of examining taphonomic biases (e.g. Voorhies 1969; Dodson 1973). One would expect the frequency of element types in owl deposited assemblages to be roughly similar assuming one is counting elements with the same natural frequency, such as paired limb bones. In other words, there should be little variance between frequency of elements. Figure 1 illustrates relative frequency of elements for the five owl pellet samples analyzed in this study. These data suggest variability around the average percent is relatively small for element frequencies in owl assemblages (Table 4).

Owl pellet remains also have a distinctive "matched-element profile". That is, if various skeletal elements could be matched (e.g. Morlan 1983), one would find a high occurrence of matches. This could be useful in distinguishing owl deposition from depositional agents that randomly collect skeletal elements

Figure 1. Relative frequency of skeletal elements in five owl pellet samples. a and b) barn owls, c and d) great horned owls, e) short-eared owl.


%
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20
18
16
14
12
10
8
6
4
2
0
a
d
e
c
b
x̄
MAX MAND SCAP HUM RAD ULNA PELV FEM TIB

Table 4. Skeletal part relative frequency variances and standard deviations. Owls a and b are barn owls, c and d are great horned owls, e is a short-eared owl. Carnivore a is a mongoose, b is a bat-eared fox, c is a coyote. Carnivore data from Andrews and Nesbit Evans (1983). Assemblages with largest NISP were used.

	OWL ASSEMBLAGES					CARNIVORE ASSEMBLAGES		
	a	b	c	d	e	a	b	c
NISP	1333	509	326	422	296	106	135	88
VARIANCE	2.40	1.60	0.21	1.82	1.20	30.12	45.87	18.59
STANDARD DEVIATION	1.60	1.40	0.48	1.43	1.20	5.80	7.18	4.57

(such as packrats and ants). Unfortunately, logistics involved in quantitatively matching elements precludes the use of this method for most analyses.

Breakage patterns

If different agents fragment bones in different ways, the proportion of whole bones in an assemblage may be useful for determining depositional agent. The proportion of whole elements relative to the total number of elements is listed in the last column of Table 3. The relatively smaller percentage of complete skulls, mandibles, scapulae, and tibiae as compared to Dodson and Wexlar (1979) is probably due to the high percentage of immature animals, with less robust bones, in the wild owls' diets. (Almost 100% of the femora and humeri in my samples had unfused epiphyses.) Juveniles often make up a large proportion of owls' diets during certain times of the year (e.g. Boonstra 1977) both because of relatively great abundance of immature age classes, and juveniles' relative inexperience.

My data and that of Dodson and Wexlar (1979) and Racyznski and Ruprecht (1974) indicate differences in amount of breakage between owl species. Patterns of relative completeness of different element types are suggested however (Figure 2). The least complete elements are consistently the scapula and innominate. The femur is generally the most complete, along with the radius, mandible, and humerus. The skull, ulna, and tibia generally are intermediate. Bone structure and robusticity may account for much of this pattern (Evans 1973; Johnson 1985); owl consumption behavior probably accounts for some also.

The data also indicate that characteristic types of damage are inflicted on elements and that characteristic element fragments result (Table 5 and Figure 3) (see also Korth 1979, Dodson and Wexlar 1979). Breakage patterns for each element are summarized below. Skull: When fragmentary, skulls usually fragment into separate bones. These bones, such as the occipital, jugal, nasals and premaxillaries, are common in pellets. In general, skulls sustain a relatively large amount of damage to the occiput but may otherwise be whole. (In Table 5, "whole" skulls includes those missing occiputs.) Mandible: Very few mandibles are heavily fragmented (about 5%), but about half suffer damage of some sort to the ascending ramus. Digestive erosion, exposing tooth rows, is seen in about 18%. Scapula: The spine is commonly broken (80-90%). The articular portion survives about 2 to 4 times as well as the dorsal portion. Dorsal borders are feathery in about 50% of the scapulae.

Humerus: In general, about twice as many distal ends survive as proximal ends. Radius: Distal and proximal ends survive about equally well, contrary to Dodson and Wexlar (1979). Radii survive as about as well as humeri and consistently better than ulnae. Ulna: Proximal ends are much more common than distal ends. Innominate: Innominates range from about 45 to 73% whole; the rest break into separate ilia, ischia, and pubes. Ilia appear to survive about twice as well as ischia and pubes. Digestive erosion is common on the end (tip) of ilia (about 30%). Femur: The proximal end is more likely to survive than the distal end by about 2 to 1. Tibia/fibula: Most intact tibiae have broken fibulae (50-80%). Distal ends were about twice as common as proximal in my data, but not in that of Dodson and Wexlar (1979).

Digestive erosion

Most bone from owl pellets appears to incur little or no surfact pitting or corrosion while passing through the owl's digestive system. However, digestive erosion can occur, although it is rarely mentioned in the literature (Errington 1938; Moon 1940), and is probably a cause of some bone loss (Racyznski and Ruprecht 1974). Results of this study indicate that digestive erosion occurs at typical sites. These are the tip of the ilium, the mandibular tooth row, and proximal epiphyses of long bones. Some digestive erosion is visible by eye or with a light microscope (Figure 4 illustrates typical erosion).

TABLE 5. BREAKAGE PATTERNS OF SKELETAL ELEMENTS FROM FIVE OWL PELLET SAMPLES.

ELEMENT		BARN OWL #	BARN OWL #	GREAT HORNED OWL #	GREAT HORNED OWL #	SHORT-EARED OWL #
HUMERUS:	WHOLE	141	53	37	45	31
	DISTAL	14	6	0	0	0
	PROXIMAL	7	4	0	0	0
ULNA:	WHOLE	119	48	35	45	31
	DISTAL	1	2	0	0	0
	PROXIMAL	30	7	3	2	4
RADIUS:	WHOLE	120	47	35	45	33
	DISTAL	6	3	0	0	0
	PROXIMAL	8	5	1	0	1
FEMUR:	WHOLE	138	54	35	47	33
	DISTAL	4	4	0	0	1
	PROXIMAL	15	8	0	0	1
TIBIA:	WHOLE	138	60	37	46	29
	DISTAL	19	6	0	2	2
	PROXIMAL	10	2	0	2	2
SCAPULA:	WHOLE W/SPINE	6	10	5	2	0
	WHOLE, NO SPINE	17	11	2	4	4
	ARTICULAR END	36	8	8	9	6
	DORSAL END	13	2	6	2	6
	DORSAL FEATHERY	56	15	12	18	14

TABLE 5 (contin.)

ELEMENT		BARN OWL	BARN OWL	GREAT HORNED OWL	GREAT HORNED OWL	SHORT-EARED OWL
SKULL:	WHOLE	8	1	4	6	2
	OCCIPUT MISSING	34	9	12	20	14
	FRAGMENTED	46	15	3	1	2
MANDIBLE:	WHOLE	81	28	26	25	13
	ASCENDING RAMUS GONE	24	10	0	0	0
	CORONOID PROCESS BROKEN	27	10	6	24	15
	ANGULAR PROCESS BROKEN	13	2	3	0	1
	COR & ANG PROCESSES	17	7	1	4	4
	ANG & MAND PROCESSES	6	1	0	0	0
	FRAGMENTED	7	3	0	0	2
INNOMINATE:	WHOLE	64	34	32	46	25
	ILIUM	59	21	3	1	5
	ISCHIUM	34	17	4	0	1
	PUBIS	29	8	2	0	1
	ISCH & PUB	11	1	0	1	0

Figure 2. Percentage of whole skeletal elements in three owl pellet samples. a) barn owl, b) great horned owl, c) short-eared owl.

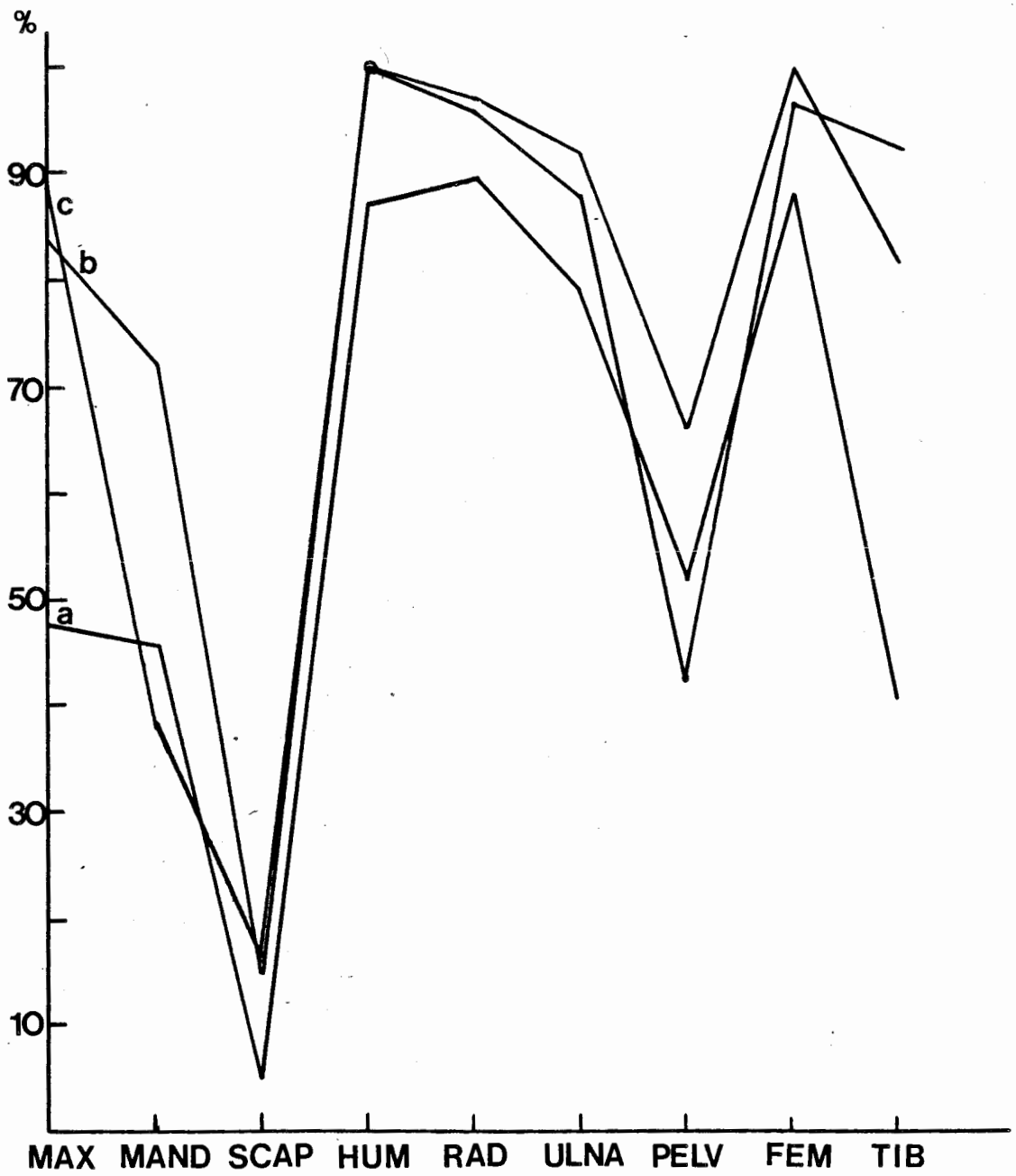
%
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Figure 3. Characteristic breakage damage observed on Microtus bones from barn owl pellets.

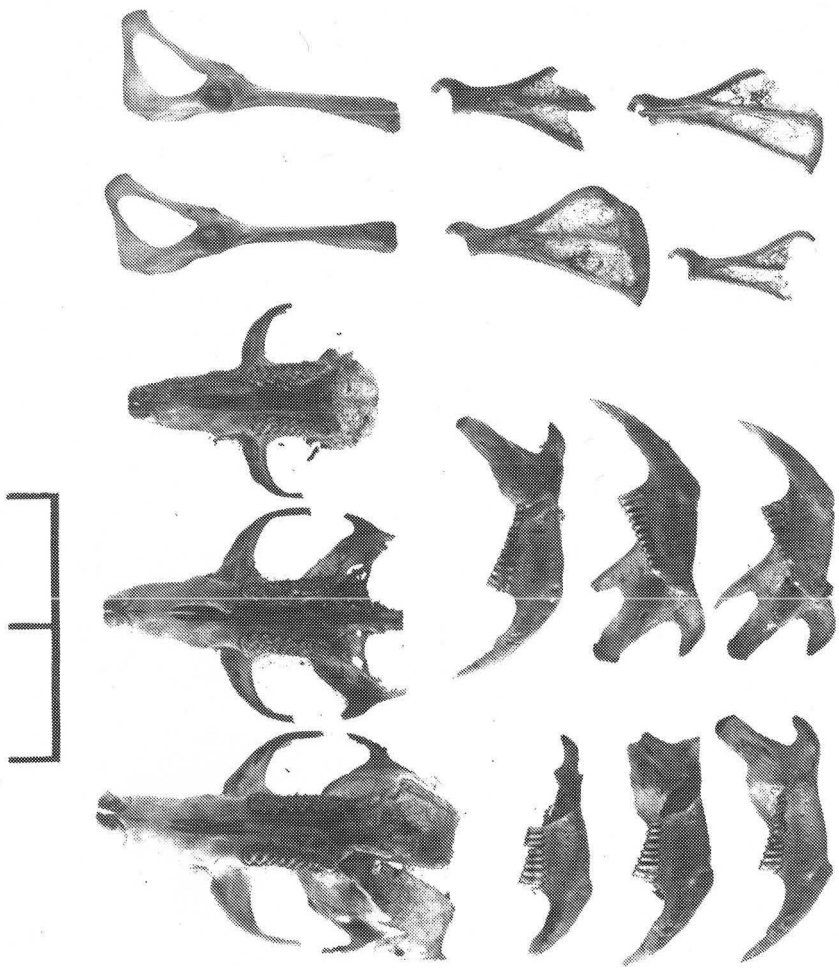
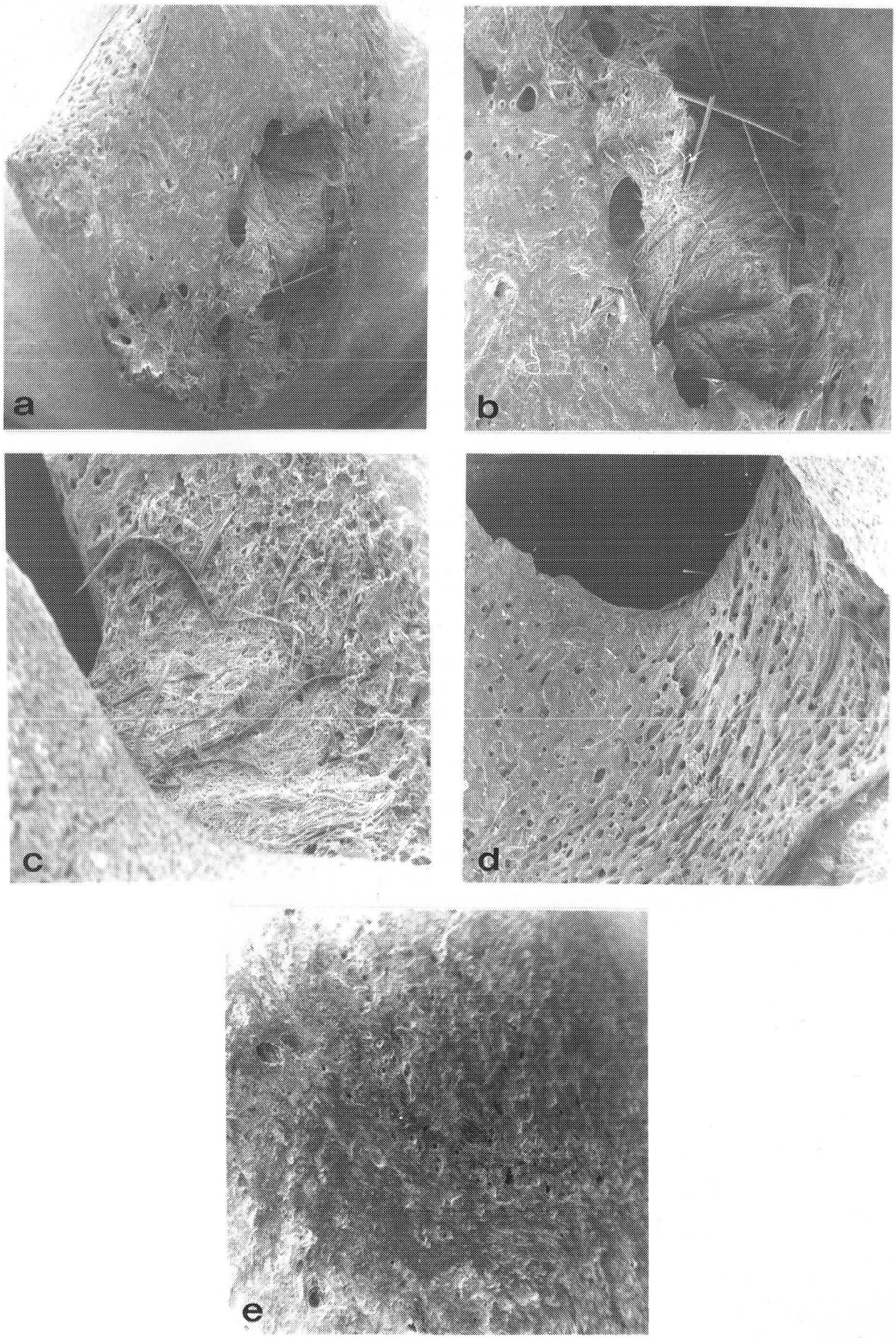


Figure 4. Typical sites of digestive erosion observed on Microtus bones from owl pellets. a) mandibular toothrow, b) proximal ulna, c) tip of ilium, d) posterior edge of pelvis.

b
d
a
c

Figure 5. Scanning electron microscope photographs of digestive erosion on Sylvilagus bones from great horned owl pellets. a) proximal ulna (x10), b) proximal ulna (x20), c) proximal humerus (x40), d) proximal humerus (x30), e) control (x30).


a
b
c
d
e

The scanning electron microscope (SEM) can detect erosion not otherwise visible (Shipman, personal communication) and has been used to distinguish between erosion caused by different avian and mammalian predators. Extent of erosion correlates with gastric juice pH of the predator (Shipman 1981a). Figure 5 illustrates damage caused by digestive erosion to a rabbit (*Sylvilagus* sp.) distal humerus and proximal ulna from a great horned owl pellet.

Summary of owl pellet bone characteristics

When these results are added to what is already known about owl pellet assemblages, some general and potenially useful patterns emerge. These generalizations about owl pellet assemblages are:

1. Large quantities of bone from a restricted number of species, consisting of a restricted size range. Possible high percentage of nocturnal and crepuscular animals.
2. Possible high percentage of immature animals.
3. High frequency representation of all skeletal elements and little variance among frequency of paired skeletal elements.
4. High relative frequency of complete femora, radii, mandibles, and humeri. Low relative frequency of complete scapulae and innominates.
5. Fragmentary skulls with separate skull bones commonly present, or whole skulls with damaged occiput. A large proportion of mandibles with damage to ascending ramus and scapulae with spine broken and dorsal edge feathery.

Relative loss of proximal humeri, distal ulnae, and distal femora.

6. Bone in good condition, but may show evidence of digestive erosion, especially on ilial tips, mandible tooth rows, and epiphyses of long bones.

In order to assess the usefulness of these generalizations for aiding in the identification of owl pellet assemblages, a few questions need to be addressed. These are: (1.) How representative are these characteristics of all owl deposition? (2.) Are there other agents that produce similar characteristics? i.e. what is the probability of equifinality? (3.) What effect may postdepositional modification have on our ability to use these criteria?

Variation In Owl Deposited Bone

If it can be explained how and why these characteristics occur through an understanding of processes leading to them, it may be possible to delineate the range of variability to be expected in these characteristics and to judge their representativeness. To that end, processes leading to owl pellet bone accumulations are explicitly considered below.

Mechanical breakage of bones occurs during prey procurement and consumption. Most breakage observed in bone from pellets probably occurs during these stages. Although bone breakage is generally minimal, amount of breakage can vary widely due to a

number of factors.

Prey capture

Owls capture prey with their talons. Usually prey is killed by the piercing and grasping action of the talons, along with bites to the occipital region (Burton 1973; Everett 1977; Mikkola 1983). Some bone breakage occurs at this stage, particularly at the occipital area. Different owl species and individuals may inflict different amounts of damage on bones at this stage, depending on how the animal is grasped. Barn owls apparently inflict minimal damage on bones (Dodson and Wexlar 1979; Kusmer 1983). Duke et al (1976) observed that snowy owls *(Nyctea scandiaca)* and great horned owls crushed prey skulls; and that great horned owls in particular often crushed other bones as well. They feel the crushed bone would not survive digestion well.

Small prey consumption

Damage to the bones of prey during consumption is partly a function of size of the prey in relation to size of the owl. Small prey is usually eaten at once or carried only a short distance, unless it is taken to the nest to feed young (Burton 1973; Mikkola 1983). Most owls swallow their prey whole (Burton 1973; Everett 1977; Mikkola 1983). Little or no bone damage would occur during this process. However, a few owl species, such as tawny *(Strix aluco)* and short-eared *(Asio flammeus)* owls, and some smaller species, often tear their prey apart and

swallow it in a few large chunks starting at the head (Short and Drew 1962; Clark 1975; Mikkola 1983). This should cause more bone breakage, as Dodson and Wexlar (1979) found when they analyzed screech owl *(Otus asio)* pellets. About 80% of the bone was broken, compared to about 65% and 20% of the bone from great horned owl and barn owl pellets, respectively. (The short-eared owl pellets analyzed in this study did not yield highly fragmented bones however.)

Researchers have also noted that young owls may tear up their prey more finely than do adults (Clark 1975; Mikkola 1983). Parents may eat the head and forequarters of prey items before bringing them to their young. The prey is then torn into pieces at the nest for the young (Glading 1943; Watson 1957; Clark 1975; Mikkola 1983).

Small animals and birds are sometimes decapitated (Bent 1938; Burton 1973). On the other hand, Raczynski and Ruprecht (1974) note that owls may eat only the heads of rodents, especially during periods of prey abundance. Thus in some pellets number of cranial elements may be either over or under represented relative to postcranial elements.

Pellet formation and ejection

A number of hours after prey ingestion, a pellet, composed of matted fur, feathers, and bone is ejected. The pellet is formed by muscle action in the ventriculus or gizzard during digestion (Smith and Richmond 1972). During this process,

digestive enzymes such as pepsin, amylase, and trypsin, are secreted into the ventriculus from various glands (Leprince et al 1979). Some time after digestion is complete, the pellet, made up of undigestible substances, passes to the proventriculus or glandular stomach where it remains until ejection (Smith and Richmond 1972). The pellet is ejected by contractions of the ventriculus, proventriculus, and abdominal wall, which force the pellet up in a series of steps (Mikkola 1983).

Owls' gastric juice is significantly less acidic than that of Falconiformes. Duke et al (1975) found the basal pH of Strigiformes to be about 2.35 (range of means 2.2-2.5) and that of Falconiformes to be about 1.6 (range of means 1.3-1.8). The difference in gastric juice pH appears to account for the greater amount of, and less corroded condition of, bone in owl pellets as opposed to Falconiform pellets (Duke et al 1975). Cummings et al (1976) found that bones were corroded significantly more by solutions of pH 1.66 than by solutions of pH 2.35. Proteolytic activity was also found to corrode bone slightly (Cummings et al 1976).

Although bone loss due to digestion is not as extensive for Strigiformes as it is for Falconiformes, some loss does occur at this stage (Raczynski and Ruprecht 1974). Raczynski and Ruprecht (1974) found loss due to digestion to vary slightly among different owl species. Also, juvenile owls apparently have a lower basal gastric juice pH than do adults, which results in more bone loss (Errington 1932; Grimm and Whitehouse 1963; Clark

1975; Lowe 1980). Bones of prey with more robust skeletons, and adult prey survive both mechanical breakage and digestion better than bones of relatively gracile species and juveniles (Short and Drew 1962; Southern 1970; Clark 1975; Lowe 1980).

Investigations of owl pellet ejection have revealed variability in the time period between prey ingestion and pellet ejection, or meal to pellet interval (MPI). Smith and Richmond (1972) found that a minimum of 6.5 hours elapses before a pellet is ejected. After that period, pellet ejection can be induced by presenting another prey item to the owl (Smith and Richmond 1972; Lowe 1980; Boxall and Lein 1982). If more prey is given within the 6.5 hour period, ejection time is delayed and a larger pellet is formed (Smith and Richmond 1972). Fuller and Duke (1979) found that this caused gastric digestion to be less efficient. MPI increases directly with increasing size of a meal (Chitty 1938; Short and Drew 1962; Duke et al 1976). It is also influenced by time of day, nutrient composition, and size of the owl (MPI is shortest for the smallest owls) (Chitty 1938; Smith and Richmond 1972; Duke and Rhoades 1977).

This variability in the length of time prey bone is retained by owls has important taphonomic implications. Lowe (1980) found that within a species (in this case the tawny owl *(Strix aluco)*), bone digestion, breakage, and loss varied in relation to seasonal changes in feeding behavior. During his research, tawny owls consumed more prey and ejected more pellets in autumn and early winter. Efficiency of bone digestion was less during

this period, resulting in less skull bone loss in the pellets than during spring and summer. Thus intrinsic changes in feeding behavior can result in pellets with intraspecific variability in bone composition and condition. Owl feeding behavior is influenced by factors such as relative prey abundance, weather conditions, and breeding (Craighead and Craighead 1969; Mikkola 1983).

Summary

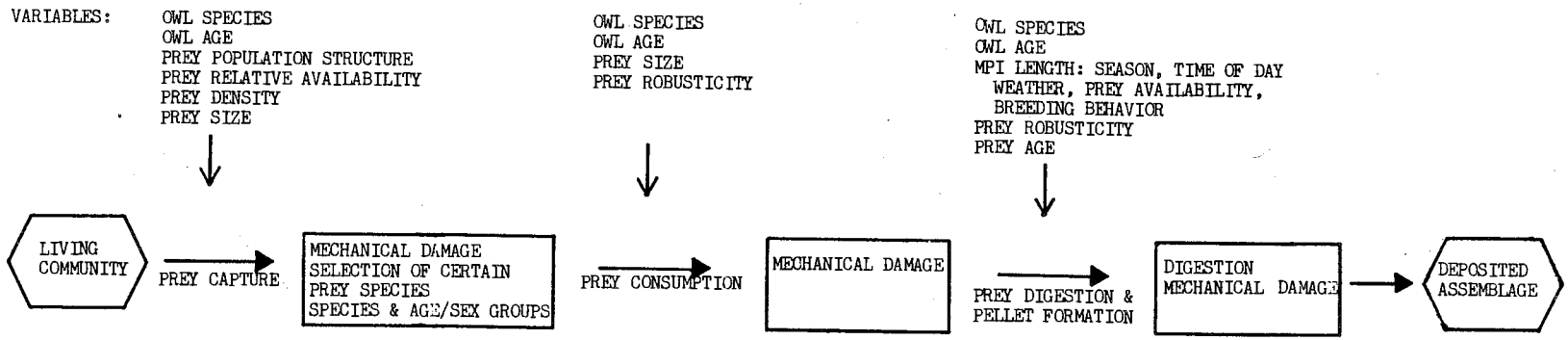
The processes that appear to result in the characteristics of bone found in pellets can be summarized as follows: Mechanical damage occurs during prey capture. This behavior varies with species and ranges from minimal damage to occiput (e.g. barn owls) to more extensive damage (e.g. great horned owls). Mechanical damage also occurs during prey consumption and again this varies with owl species. Most prey is swallowed whole, incurring little breakage. However a few species, and juvenile owls, tear up prey, resulting in more breakage. A number of factors cause variability in digestion and breakage within an owl's stomach. These include age of owl, age of prey, robusticity of prey skeleton (prey species), and seasonal or daily changes in owl feeding behavior (and thus changes in consumption to ejection period and digestion efficiency) caused by prey behavior (relative availability), weather conditions, and intrinsic behavioral modifications such as those during breeding season.

Discussion

Prey species composition and age structure characteristics 1 and 2 (page 35) of the pellet assemblages can be explained by owl hunting behavior and relative prey abundance. The extensive literature on owl diet reveals that although specific composition varies, owls' prey mainly on nocturnal and crepuscular species and concentrate on one or a few species.

Characteristics 3 through 6, which describe amount of and condition of the bones in the pellets, can be explained by owl capture and consumption behavior and digestion physiology. These processes usually result in little bone loss and breakage. Prey species with less robust skeletons and young prey may sustain more damage. Also, juvenile owls and owl species that tear prey apart may produce pellets with more fragmented bones and higher bone loss. However, even pellets with fragmented remains (e.g. sceech owl pellets, Dodson and Wexlar, 1979) contain large amounts of recognizable bone and relatively high element representation (see also Short and Drew 1962; Southern 1969; Clark 1972). Because prey is swallowed whole or in large chunks, bone is generally not fragmented into small unrecognizable fragments but elements may snap in half or break according to strength properties of the elements. Even bones from pellets of the great horned owl, which has been observed cracking bones during consumption (e.g. Duke et al 1976; Dodson and Wexlar 1979), often do not sustain heavy damage or loss (e.g. Korth 1979; this study).

Figure 6. Taphonomy of owl pellet bone.


VARIABLES:
OWL SPECIES
OWL AGE
PREY POPULATION STRUCTURE
PREY RELATIVE AVAILABILITY
PREY DENSITY
PREY SIZE
OWL SPECIES
OWL AGE
PREY SIZE
PREY ROBUSTICITY
OWL SPECIES
OWL AGE
MPI LENGTH: SEASON, TIME OF DAY
WEATHER, PREY AVAILABILITY,
BREEDING BEHAVIOR
PREY ROBUSTICITY
PREY AGE
LIVING COMMUNITY
PREY CAPTURE
MECHANICAL DAMAGE
SELECTION OF CERTAIN
PREY SPECIES
SPECIES & AGE/SEX GROUPS
PREY CONSUMPTION
MECHANICAL DAMAGE
PREY DIGESTION &
PELLET FORMATION
DIGESTION
MECHANICAL DAMAGE
DEPOSITED ASSEMBLAGE

Thus, although many factors may cause some variability in pellet bone characteristics (Figure 6), this variability will be negligible in most cases and patterns of fragmentation and element representation are characteristic although it is not possible to compose a list of specific diagnostic criteria.

The diagnostic potential of these characteristics must be further assessed by examining the possibility that other sources of microvertebrate remains may yield assemblages with similar characteristics. Other mechanisms of microvertebrate deposition are discussed in Chapter III.

Large Prey

Remains of larger, rabbit-sized prey, which are probably more significant from a cultural point of view, are an even more difficult and neglected topic. Prey of this size, such as squirrels and waterfowl, may make up a large portion of the diet of eagle owls, of which there are at least 12 species worldwide (Burton 1973; Mikkola 1983). The New World representative of this group, the great horned owl, is found throughout most of North and South American. In areas where rabbits and hares are common they often make up a large percentage of great horned owls' diets (e.g. Errington 1940; Moon 1940; Craighead and Craighead 1969; Maser et al 1970; Korschgen and Stuart 1972; Woffinden and Murphy 1982). For example, during a ten year study in north central Alberta, snowshoe hare *(Lepus americanus)* were

found to compose up to 81% of the prey remains under roosts (Rusch et al 1972; McInvaille and Keith 1974; Adamcik et al 1978). Other large owls, such as barn and snowy owls, may also, though less commonly, take large prey (Craighead and Craighead 1969, Mikkola 1983).

Since rabbits and other medium-sized animals were probably important human subsistence items in some areas, such as the Great Basin, these facts deserve some attention.

Feeding behavior and quantity eaten is related to many variables including hunger, abundance of prey, and whether young are being fed. Large prey (other than small juveniles) is typically torn into chunks and swallowed. A prey item usually makes up more than one meal and may be fed upon by more than one owl (Errington 1938). The head is usually torn off and swallowed first. This may be a reflexive action associated with killing processes (Errington 1938). In some cases only the head is eaten (Keith pers. com.; Todd pers. com.). Bent (1938) found a large number (about 113) of rats under a great horned owl nest with only the brains picked out of open skulls.

Skulls found in pellets are usually highly fragmented (Marti pers. com.; Todd pers. com.). Most elements appear in pellets, but there is a lot of breakage (Marti pers. com.). However, the bones are not crushed into small pieces as they are when chewed by mammalian carnivores (Forsman pers. com.). Leg bones are almost never whole (Marti pers. com.), and may not be swallowed

at all if they are too difficult to break (Errington 1938). Hind feet are often not swallowed (Keith pers. com.; Todd pers. com.).

Prey may also be stripped of flesh, leaving most bones. Snowy owls have been observed picking rabbit, hare, and large bird bones clean (Watson 1957). Cleaned skeletal remains of birds and mammals are sometimes found beneath great horned owl roosts (Bent 1938). These remains, although not consumed and expelled in pellets, would be incorporated into the deposited mass of bones.

One might imagine that the majority of large prey taken by owls are juveniles. This appears to be the case for most owls. For example, Morris (1970) found that barn owls generally take the youngest and smallest size class of large prey. Great horned owls, which take large prey more commonly than other owl species, do not always follow this pattern. Rusch et al (1972) found that 97% of the snowshoe hares *(Lepus americanus)* recovered from horned owl pellets in central Alberta were adult, although they estimated 60% of the hares were immature at that time of year.

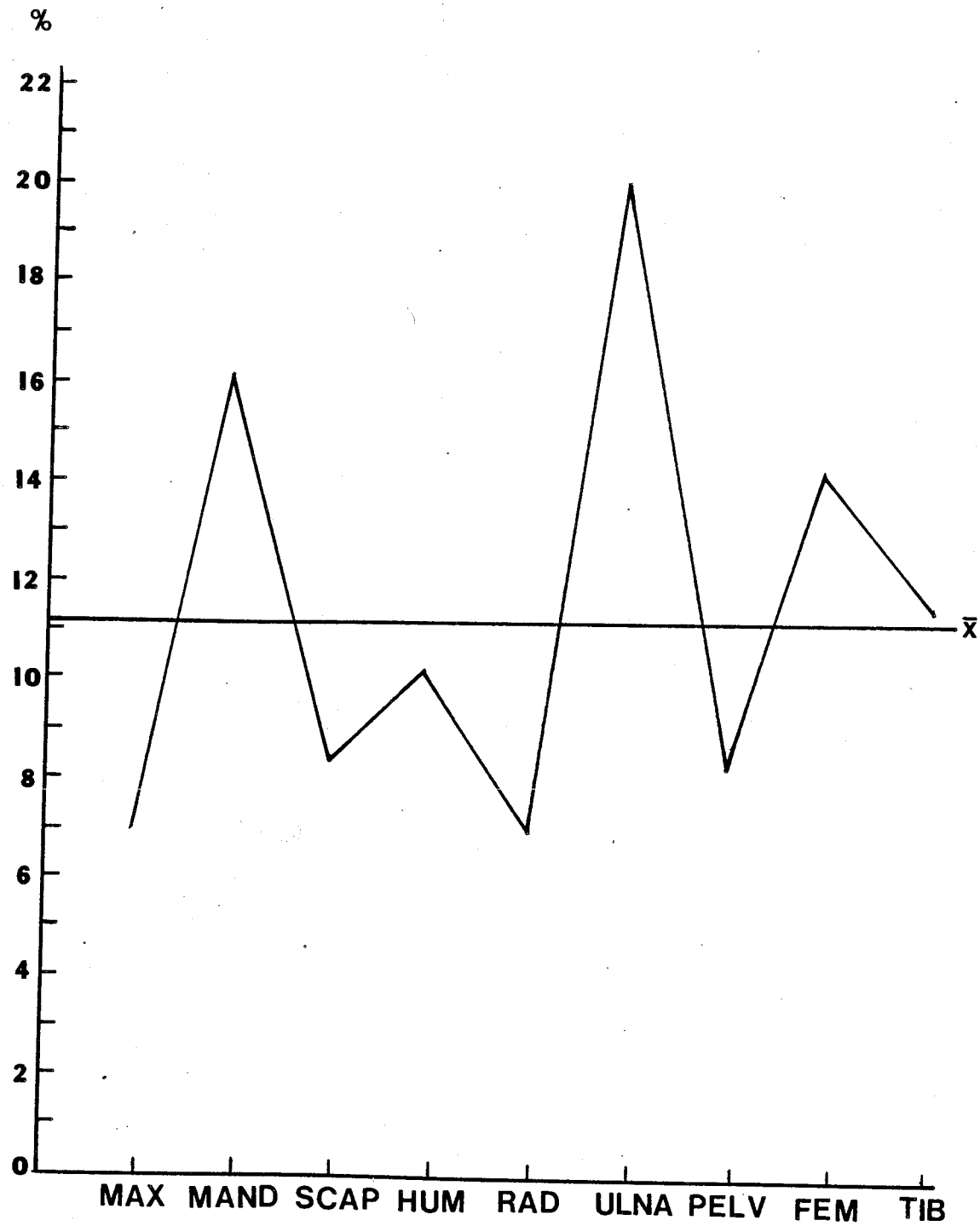
Since feeding behavior of owls consuming large prey and elements swallowed varies, element frequency representation in bone accumulations will also vary. It would therefore be difficult to define patterns of element representation that could be used to identify owl deposition of rabbit-sized

remains. A factor that contributes to this variation is the addition of remains carried to the nest or roost that are not ingested. This process would add relatively whole, and relatively unbroken, skeletons to the deposit. Definition of characteristics of individual bones may be a more useful avenue to pursue when searching for evidence of owl deposition of large animal remains.

The most obvious difference between pellets containing small prey remains and pellets containing large prey is the amount of unidentifiable bone fragments. In this study, less than 1% of the bone from small prey could not be identified to skeletal element. However, in a small sample of bone (43.5 grams) from great horned owl pellets with identifed rabbit remains *(Sylvilagus nuttallii)*, 27.9% (12 grams) could not be identified to skeletal element. Most of these fragments appear to be rib fragments, and fragments of thin, flat bones such as pelves, scapulae, and crania. This exemplifies the greater amount of breakage large prey elements undergo during owl consumption.

The rabbits (MNI=5) in this sample were immature which probably accounts for the high frequency of elements (Table 6 and Figure 7). These small rabbits seem to have been relatively completely eaten at one meal. However a large amount of damage was sustained by the bones (Table 7). Also, vertebrae and foot bones are largely underrepresented (Table 6). Vertebrae were probably extensively crushed. The feet may not have been swallowed.

Figure 7. Relative frequency of lagomorph skeletal elements from a great horned owl pellet sample. % = $NISP_{element}/NISP_{total}$.


%
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18
16
14
12
10
8
6
4
2
0
$\bar{x}$
MAX
MAND
SCAP
HUM
RAD
ULNA
PELV
FEM
TIB

Table 6. Representation of lagomorph skeletal elements in a great horned owl pellet sample.
MNI-minimum number of individuals based on each skeletal element.
present-total number of elements based on most common element portion present.
PP-proportion of individuals present relative to expected, given MNI.

ELEMENT	# PRESENT	PP	MNI
Maxillae	3	.3	2
Mandible	8	.8	5
Scapula	4	.4	3
Humerus	5	.5	3
Radius	3	.3	2
Ulna	10	1.0	5
Innominate	4	.4	2
Femur	7	.7	4
Tibia	6	.6	3
Vertebrae	49		
Calcanea	4		
Astragali	4		
Phalanges	22		
Carpals/Tarsals	8		
Metapodials	11		

Table 7. Breakage patterns of lagomorph skeletal elements from a great horned owl pellet sample.

MANDIBLE	SKULL
whole-0	maxillary-3
asc. ramus gone-5	premax-5
asc. ramus-6	frontal-4
frag. horiz. ramus-2	temporals-7
	occiput-6
	other frags-25
HUMERUS	SCAPULA
proximal-5	articular end-4
distal-4	fragments-14
RADIUS	ULNA
proximal-3	proximal-10
distal-1	shaft-2
FEMUR	TIBIA
proximal-2	proximal-6
distal-7	distal-1
INNOMINATE	
pubis-2	
ilium-4	
acetabulum-2	

CHAPTER III

OTHER SOURCES OF MICROVERTEBRATE REMAINS: THE POSSIBILITY OF EQUIFINALITY

Many different processes may be responsible for deposition of microvertebrate remains. The most commonly postulated origins of microvertebrate assemblages are fluvial transport (e.g. Shotwell 1955, 1958; Voorhies 1969) and predator deposition through feces or pellets (e.g. Mellet 1974; Mayhew 1979). Microvertebrate remains have also been shown to have accumulated through packrat and ant activity (Mead 1980; Shipman and Walker 1980) and in natural geologic traps (e.g. Guilday 1971). In archaeological sites, the possibility of human deposition must also be considered.

Fluvial transport, predator deposition, and cultural deposition are discussed in some detail below. Deposition by ants (see Shipman and Walker 1980) and crocodiles (see Fisher 1981) occur in limited ecological circumstances and are not discussed further here. Packrat microvertebrate collections occur in Sentinel Cave and are discussed in conjunction with the analysis of those remains in Chapter V.

Fluvial Transport

Dodson (1973) and Korth (1979) show experimentally that small animal bones are greatly susceptible to water transport

and that bone size, shape, orientation, and density affect bone transport potential. The hydraulic behavior of bones, based on the above variables, results in selective sorting and dispersal. This leads to assemblages with: 1.) a low percentage representation of skeletal elements (e.g. the mean PP for a fluvial deposit examined by Wolff (1973) is 0.12) and 2.) low frequency representation of most skeletal elements with only a few, similarly hydraulically structured elements in abundance. These elements should be hydraulically equivalent to associated sediments (Korth 1979).

These characteristics clearly differ from owl deposited assemblages and, with sedimentological data, provide good evidence of fluvial origins. Korth (1979) also provides experimental evidence of abrasion patterns, especially rounded edges, which he feel differ from owl pellet breakage patterns. However, he acknowledges that some characters seem similar to what appear in owl pellet bone (i.e. skull bone breakage along sutures).

Predator Accumulations

Predators of small mammals may accumulate skeletal remains through regurgitation of pellets (owls and diurnal raptors), deposition of feces (mammalian carnivores), and by carrying animals back to the den or nest.

Diurnal raptors

Pellets of Falconiformes contain considerably less bone than owl pellets and the bones do not reflect number of prey items consumed (Errington 1933; Glading 1943). This is the result of differences in both feeding behavior and digestive physiology. Most diurnal raptors break up bones of prey while feeding (Bent 1938; Craighead and Craighead 1969; Clark 1972; Mikkola 1983) and may pick flesh off, leaving bone of both large and small prey (Moon 1940; Einarsen 1956). The higher acidity of Falconiformes gastric juice results in more complete digestion of bone and greater corrosion of incompletely digested remains (Duke et al 1975; Cummings et al 1976). Digestive corrosion also extends to tooth enamel, leaving teeth with an eroded shape and a powdery matte appearance (Mayhew 1977).

These factors produce pellets with either no bone, or small amounts of highly fragmented and corroded bones and teeth. In an experimental study, the average proportion of bone in Falconiformes pellets was found to be only 6.5% compared to 45% in Strigiformes pellets (Duke et al 1975). Andrews (1983) examined bone breakage in African kestrel pellets and discovered that there were relatively fewer complete postcranial bones and a higher proportion of isolated teeth compared with barn owl and great horned owl pellets. However, some owl species may produce patterns of postcranial element completeness similar to the kestrel pattern in Table 3 (Andrews 1983:81) (see above discussion on variability in owl deposited bone). While degree

of fragmentation may distinguish owl and diurnal raptor assemblages, the best criteria seem to be amount of digestive erosion on the bones (Shipman 1981)and especially condition of the teeth (owls do not erode tooth enamel).

Mammalian carnivores

Small animal remains deposited in carnivore feces reflect the generally great amount of damage produced by consumption and digestion processes, although amount and condition of bone recovered from feces vary with predator species and size of prey. Teeth and bones are often absent or too fragmentary to be used to identify prey species in feces of small mustelids such as *Mustela vison, Mustela erminea,* and *Mustela nivalis* (Day 1966; Akande 1972). Small mammal bones often appear in scats of larger carnivores such as *Martes martes, Vulpes vulpes,* and *Canis latrans*, but the amount of bone found in scats varies widely (Errington 1935; Murie 1946; Lockie 1959; Day 1966). Canids seem to swallow small rodents whole without crushing many bones with their teeth (Errington 1935; Lockie 1959; Goszcznski 1974). However, tiny, sharp fragments of bone may be found in coyote scats (Johnson and Hansen 1979; Korth 1979). These fragments may result from the mastication necessary to consume larger prey (Andrews and Nesbit Evans 1983). Bones and teeth appear to be rare in wolf scats (Floyd et al. 1978).

Bones recovered from carnivore scats are generally highly fragmented and exhibit extensive signs of digestive erosion,

prompting usage of the term "scat bone" (Binford 1981; Gifford 1981; Dansie 1982). Partial digestion may produce surface polishing, pitting, and sharpened edges (Sutcliffe 1970; Johnson 1985) or corrosion of the surface, exposing internal structure and rounding edges (Shipman 1981b; Andrews and Nesbit Evans 1983).

Andrews and Nesbit Evans (1983) examined remains from scats of six carnivores: white-tailed mongoose *(Ichneumia albicauda)*, genet *(Genetta genetta)*, bat-eated fox *(Otocyon megalotis)*, coyote *(Canis latrans)*, fox *(Vulpes vulpes)*, and pine marten *(Martes martes)*. Although there was some variation according to species, degree of bone breakage was found to be high and large amounts of unidentifiable bone fragments were recovered. Loss of skeletal elements (especially skulls) was also relatively high and degree of digestive erosion was extensive and included enamel and dentine erosion in Canid and Mustelid scat remains. Tooth marks were common on *Canis latrans* and *Vulpes vulpes* remains but were not found on remains from the other species. Mean relative percentage of skeletal elements was low (28.0-49.3%), reflecting the high degree of bone loss and fragmentation. Korth (1979) obtained a higher PP value (64.8%) from coyote scat remains.

At this point I would like to return to an issue I raised earlier concerning the relationship between PP and sample size. In Chapter II I indicated that PP is related to NISP due to the nature of the measure itself, which is a form of NISP/MNI. PP

values for the above carnivore and owl deposited assemblages appear to distinguish between depositional agent. However, the following discussion shows that for these data PP is also measuring sample size.

The data consist of seven owl pellet samples from this project (B1 was divided into 3 samples of 10 pellets each), three owl pellet samples from Dodson and Wexlar (1979), an ant deposited sample (Shipman and Walker 1980), and six carnivore samples (Andrews and Nesbit Evans 1983) (Table 8). NISP is the total number of maxillae, mandibles, scapulae, humeri, radii, ulnae, pelves, femora, and tibiae present in each assemblage. MNI is calculated from the most common element present (that for which the authors list a PP of 100%). Because none of the elements in the genet assemblage described by Andrews and Nesbit Evans (1983) has a PP of 100%, that assemblage is omitted.

Application of Model I least squares regression to the data, transformed to natural logarithms, results in a highly significant relationship (Figure 8) described by the equation:

$$\ln PP = -1.63 + .24\ (\ln Nisp)$$

$$(r = .93,\ p<0.001)$$

Although cursory examination may convince one that differences in PP for carnivore and owl deposited assemblages are related to expected differential treatment of bones by the depositional agents, the PP values of these data are also reflecting sample size.

Figure 8. The relationship of lnPP to lnNISP.
($y = -1.63 + .239(x)$)

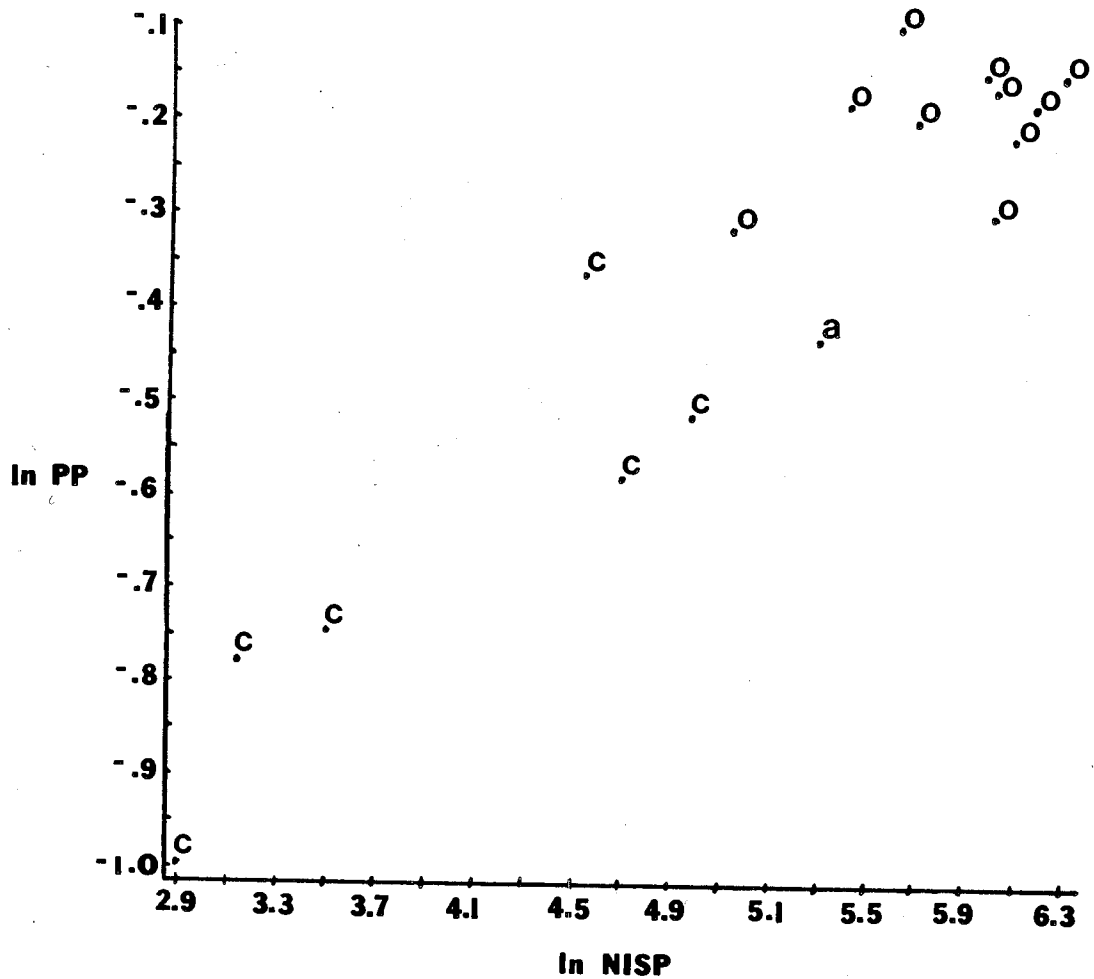
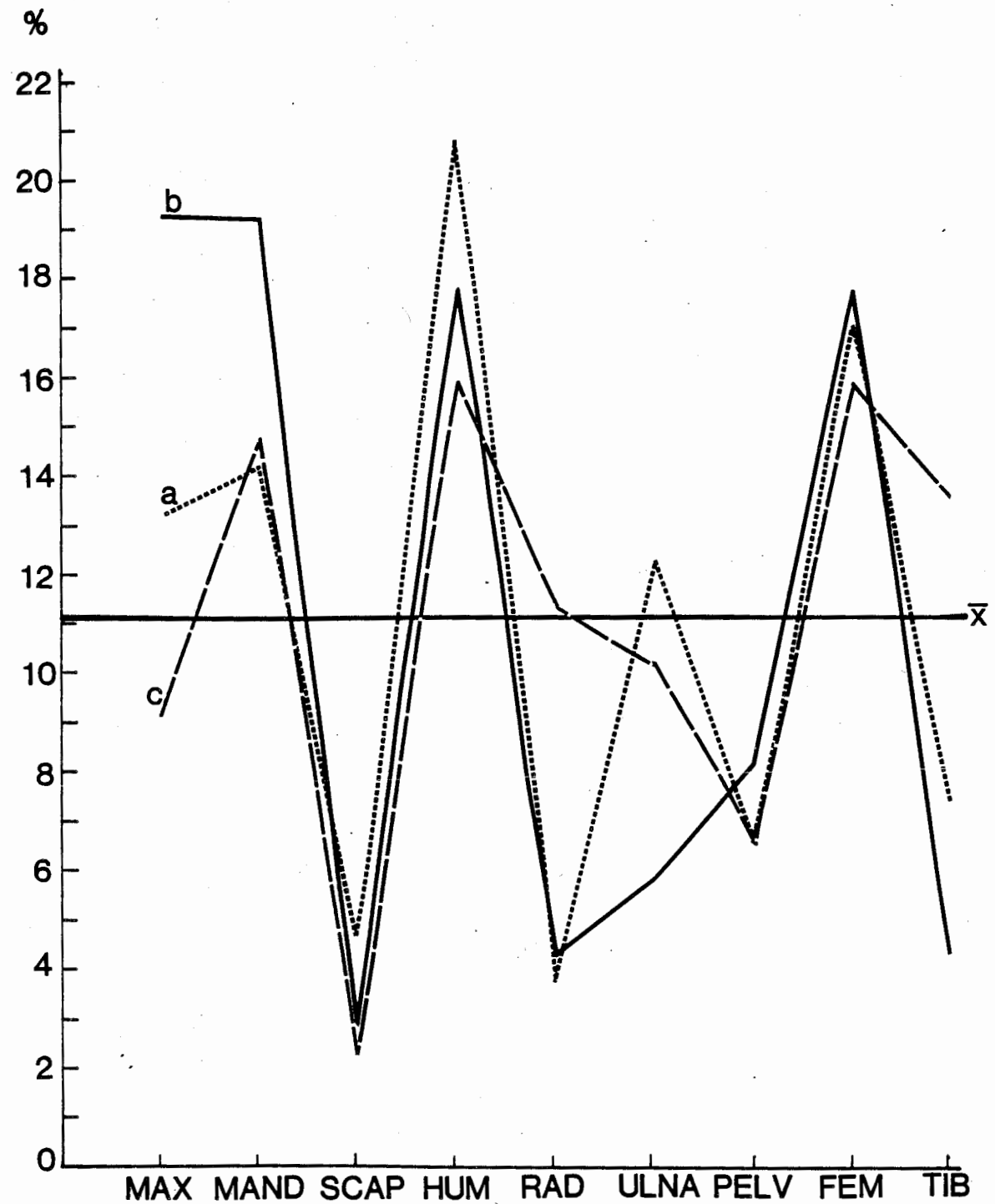

-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
-.9
-1.0
ln PP
2.9
3.3
3.7
4.1
4.5
4.9
5.1
5.5
5.9
6.3
ln NISP

Figure 9. Relative frequency of skeletal elements in three carnivore assemblages (from Andrews and Nesbit Evans, 1983). a) mongoose, b) bat-eared fox, c) coyote.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MAX MAND SCAP HUM RAD ULNA PELV FEM TIB

Table 8. NISP and relative percentage present (PP) of skeletal elements from owl pellets, carnivore scats,and an ant deposited assemblage. Samples 1-7 from this study, 8-10 from Dodson and Wexlar (1979), 11-16 from Andrews and Nesbit Evans (1983), 17 from Shipman and Walker (1980).

SAMPLE	NISP	PP
1. Barn owl	433	.73
2. Barn owl	445	.85
3. Barn owl	464	.81
4. Barn owl	509	.83
5. Great horned owl	326	.82
6. Great horned owl	422	.87
7. Short-eared owl	296	.91
8. Great horned owl	571	.86
9. Barn owl	253	.83
10. Screech owl	155	.72
11. Mongoose	106	.54
12. Bat-eared fox	135	.58
13. Coyote	88	.69
14. Fox	33	.46
15. Arctic fox	19	.35
16. Pine marten	24	.44
17. Ant	220	.64

Unfortunately the magnitude of the problem is not clear from these data because of the small number of samples analyzed and because NISP values for the owl and carnivore samples do not overlap. Because NISP values are all relatively low, we do not know if the relationship would be as significant if larger samples were included. However most actualistic data consist of relatively small samples as do many archaeological faunal assemblages, especially if the remains are divided and analyzed according to taxon.

The effect of sample size can be removed by examining the residuals, which reflect the variance not explained by sample size (Grayson 1984). Alternatively, relative frequency distributions can be constructed and compared, as suggested in

Chapter II. One would expect carnivore assemblages to exhibit greater variance among frequencies of element types than owl assemblages. The pattern of element frequency for an assemblage may therefore yield information concerning depositional agent.

Figures 1 and 9 demonstrate clear differences in element frequency distribution between the owl and carnivore samples. Variance around the average percent is much greater for element frequencies in carnivore assemblages than for element frequencies in owl assemblages (Table 4). Although relative frequencies of elements can be used to distinguish these assemblages, it should be noted that the pattern of element representation is similar in both (Figures 1 and 9). This is because robusticity and shape of the elements affect which elements survive actions of the depositional agents. Element density and structure also play an important part in modification of assemblages after deposition.

In most cases, carvivore assemblages should be distinguishable from owl pellet assemblages. Relatively highly fragmented remains, with a high incidence of unidentifiable fragments and digestive erosion, a high variance in element frequency distribution, and possible tooth marks should identify carnivore activity. Andrews and Nesbit Evans (1983) also feel that the fragmentary and eroded condition of carnivore scat bone would result in fewer remains being preserved than owl pellet remains. However, as I discussed earlier, it is possible that highly fragmented remains may result from owl deposition.

A factor that further complicates predator deposited assemblages is the occurrence of skeletal remains that were brought to the site, but did not pass through pellets or scats. Both avian and mammalian predators may bring large numbers of remains to a den or nest, especially to feed young. These remains would not reflect consumption and digestive processes, and accumulating agent may be difficult or impossible to discern. Characteristics such as size of prey (larger carnivores may be indicated by the presence of some large prey remains) and presence of tooth puncture and gnaw marks may be useful in some cases. Certain predators may damage remains in characteristic ways. For example, Brain (1981: 108) found that African black eagles *(Aquila verreauxi)* accumulate large numbers of hyrax skulls with characteristic damage to calvaria. Cape eagle owls *(Bubo lacteus)*, on the other hand, inflict a different type of damage (both calvaria and nasals are broken) on skulls of hares which are not swallowed (Brain 1981: 125).

Animals may also die naturally in a cave or rockshelter, or accumulate in natural traps. The geological formation of the cave should suggest possibility of the second occurrence (e.g. Guilday 1971). Animals that die naturally may be difficult to distinguish from remains left by accumulators that leave no direct evidence on the bones. As a whole, these remains, with their high frequency of all skeletal elements, would be difficult to distinguish from owl deposition. The species composition may give some indication as one would expect only

those species which frequent caves to die there naturally. Also, a large accumulation of remains would probably indicate some sort of collector action rather than random death.

Cultural Deposition

It is difficult to determine traits of small mammal remains deposited as a result of human processing and consumption activities because of the wide range of ways in which humans may handle small mammals and because few accounts of these activities have been documented.

Small mammals may be consumed whole; with little or no processing other than possible roasting. It is likely that little evidence would be left of animals cooked and consumed relatively whole. Cut marks appear to be less common on small animal bones than on large bones (Jones 1984) and many of the small bones may be consumed. Consumption patterns would probably result in certain elements being underrepresented and element frequency patterns that differ from the high relative frequency representation of skeletal elements found in owl deposited remains. Also, one might expect different breakage patterns and more breakage due to mastication. Brain (1981) suggests that hyrax *(Procavia capensis)* and *(Heterohyrax brucei)* bones believed to have been deposited by Stone Age humans were chewed by people after being roasted and that parts that could not be chewed were discarded, some becoming burned in the process. The

parts most commonly discarded were distal humeri, mandibles, and maxillae.

Evidence of burning may indicate human consumption, particularly if the burning is patterned. Vigne and Marnival-Vigne (1983) found distinctive burned zones on prehistoric pika *(Prolagus sardus)* remains. They attribute the pattern (broken ends of long bones, the nasal end of mandibles and maxillae, and distal radii, ulnae and tibiae were consistently burned) to the burning of bones not protected by flesh during roasting. Dansie (1984) also suggests charred distal ends of long bones result from roasting of whole animals.

Jones (1984) has suggested that people may produce distinctive bone tubes during marrow extraction. The Ache, a hunter-gatherer group in Paraguay, bite or chop the ends off of small animal long bones and push or suck the marrow out. These bone tubes comprised about 90% of the small animal long bones in an Ache assemblage (Jones 1984).

At the other extreme, small mammal bones may be pulverized in mortars for soup and bone meal (e.g. Kroeber 1925: 814). Dansie (1984) has found that a high frequency of "tiny unidentifiable impact fractured fragments" results from human consumption of pulverized small mammal bones and suggests these remains may be recovered in flotation samples.

Species composition may also give some clues, depending on the situation, but cannot be generalized about. In most cases,

one would not expect a high frequency of nocturnal and low frequency of diurnal animals, as is typical of owl assemblages, to be deposited by humans.

Further Considerations

Actualistic research, such as that conducted in this study, is clearly only a first step within the broader research goal of attempting to understand the taphonomic history of a microvertebrate assemblage. Through this type of research we attempt to develop a body of knowledge concerning how various depositional mechanisms alter bone and what the resultant bone attributes are. These attributes, for the most part, consist of physical characteristics of recently deposited individual bones and bone assemblages. Actualistic studies of modern depositional agents produce useful baseline information concerning initial characteristics of assemblages and we need to learn more about individual fragment and quantitative characteristics produced by different mechanisms before possible diagnostic criteria can be established with confidence.

When this information is applied during the investigation of a microvertebrate assemblage, a number of complicating factors emerge. These include: 1) information concerning effects of most depositional agents on small bones is limited at present, 2) some depositional agents yield similar characteristics, 3) in most cases it can be assumed a variety of mechanisms added bone

to the deposit, and 4) postdepositional processes may obscure indicators of depositional processes.

Previous sections of this paper explicate attributes of owl deposited bone and their range of variability; and a discussion of other depositional agents reveals that some of these attributes can also be caused by other processes. Some breakage characteristics of individual bones may reflect physical properties of the bone rather than depositional (or postdepositional) mechanisms. As West (1983: 378) states, concerning what he calls "equifacts", one "...must acknowledge the fact that there are objects, archaeological, geological, or biological, that are ambiguous-defy ready explanations". Assemblages are therefore analyzed as a whole and are examined for the occurrence of a number of characteristics which may delineate the most probable depositional agent(s). Depending on the characteristics of an assemblage one should be able to produce a "short-list" of possible agents and investigate these. For example, if an assemblage consists of a large number of all skeletal elements, with little fragmentation, one may consider owl or packrat activity or natural death. On the other hand, if the assemblage is relatively highly fragmented (the proportion of identifiable to unidentifiable fragments is a useful measure to calculate) one may look for evidence of owl deposition (different owl species, juvenile owls), carnivore activity, or postdepositional modification.

The complexity of most sites, caused by a varied depositional history, means that quantitative indicators of any one agent based on numbers and type of elements present may be obscured. One must also be aware of the fact that excellent recovery techniques are necessary for quantification characteristics of small bones to be valid. Even when a 3.18 mm screen in used, some material may be lost (see Chapter V). Bulk samples for finer screening should also be collected to test for amount of loss and ensure a representative sample. Postdepositional modification (including differential preservation of elements both inter- and intra-specifically) (Klein and Cruz-Uribe 1984; Grayson 1984), can also alter quantitative indicators. In such cases, it may be more worthwhile to approach the analysis from the angle of diagnostic marks (such as digestive erosion) on individual bones. Also, Klein and Cruz-Uribe (1984) suggest examining NISP/MNI values for each skeletal element of each taxon to obtain information concerning differential depositional and postdepositional histories. Of course, investigation of other sources of data,such as contextual (e.g. Maas 1985) and geological information, coincide with examination of bone attributes. Examination of context, including distribution of microvertebrate remains in relation to natural and cultural features in the cave (e.g. Payne 1983), is highly important.

The application of research concerning microvertebrate taphonomy is investigated in Chapters IV and V of this thesis,

in which microvertebrate remains from a northern Great Basin site are examined.

CHAPTER IV

SENTINEL CAVE: DESCRIPTION, EXCAVATION, AND METHODS OF ANALYSIS

Description and Setting

Sentinel Cave (35Ha312) was excavated during 1979 as part of the long-term, multidisciplinary, Steens Mountain Prehistory Project. Principal Investigators of the project were C. Melvin Aikens (University of Oregon), Donald K. Grayson (University of Washington), and Peter J. Mehringer, Jr. (Washington State University). Sentinel Cave was excavated under the direction of James D. Wilde (University of Oregon). The major research goals of the Steens Mountain Prehistory Project were to:

> "1) locate and study sites representative of the full range of archaeologically recorded human activities during the complete span of aboriginal occupation within a restricted geographic area; 2) document a sequence of Holocene paleoenvironments within the study area, and to firmly establish that sequence on the basis of independent mutually cross-checking data; and, 3) compare the history of cultural adaptation with the paleoenvironmental history in a search for correlations between these records, seeking ecologically based explanatory hypotheses for any cultural shifts which are correlated with environmental changes, and offering supplementary hypotheses for any cultural phenomena which cannot be explained in this fashion " (Aikens et al 1982: 10).

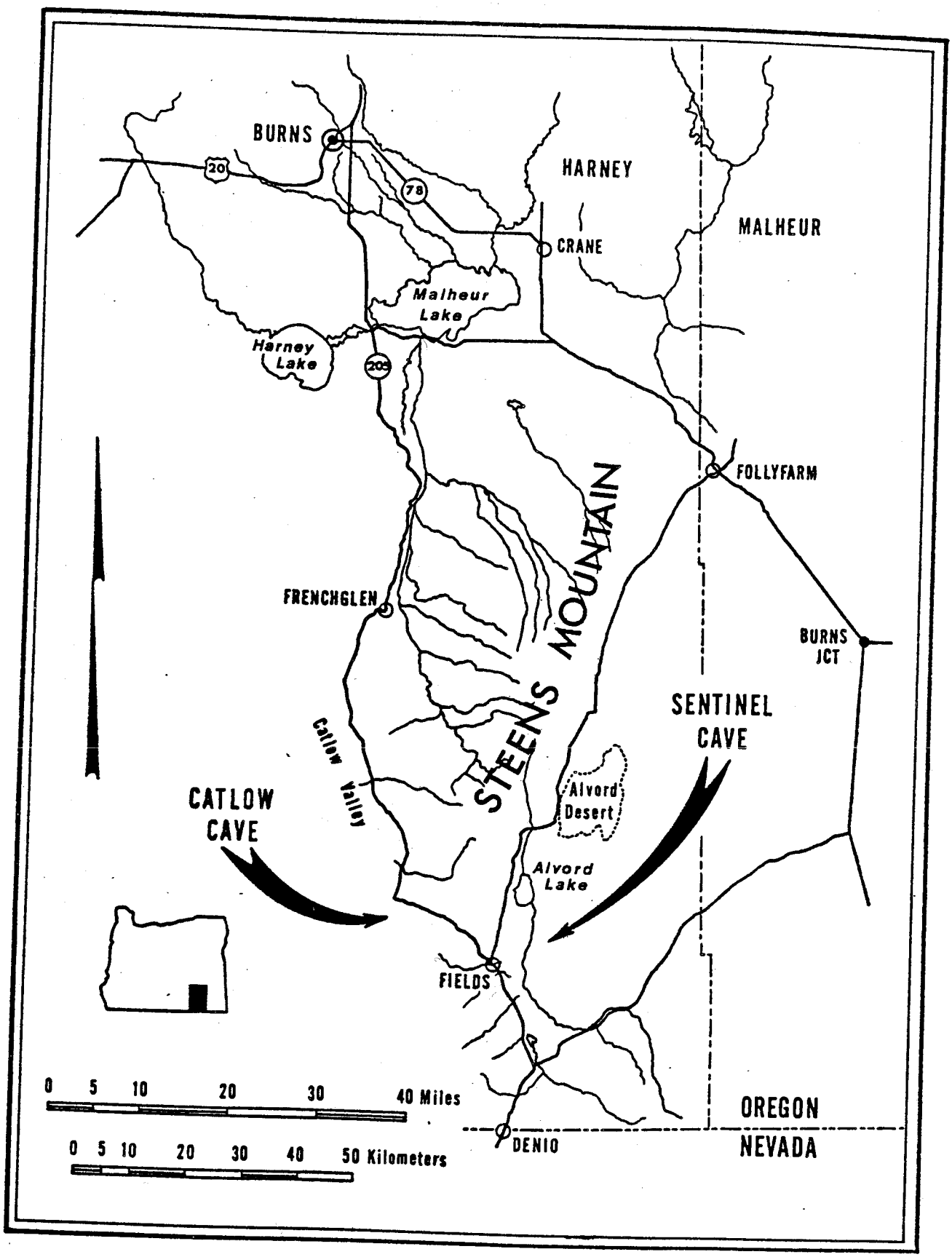
It was hoped that excavation at Sentinel Cave would yield: 1) artifact assemblages in stratigraphically controlled, datable contexts spanning the period of prehistoric occupation of the area, and 2) faunal and floral remains in association with the artifacts to be used in reconstruction of the environmental history during aboriginal occupation (Wilde 1981; Aikens et al

1982).

Sentinel Cave is located in the Alvord Basin east of Steens Mountain in Harney County, about 10 km east of Fields, in southeastern Oregon (Figure 10). It is situated at the base of an ignimbrite tuffaceous rim on the uppermost beach line (approximately 1280 m above sea level) on the eastern edge of Pleistocene Lake Alvord (Aikens et al 1982). The cave faces west and is 13-17 meters deep, 15 meters wide at its mouth, and about 7 meters high at its maximum (Wilde 1981). Its deposits were formed by roof spalls, windblown dust from the Alvord lakebed, and woodrat *(Neotoma)* nesting materials (Aikens et al 1982).

Sagebrush and grasses dominate the vegetation surrounding Sentinel Cave; coniferous trees were apparently never an important part of Steens Mountain vegetation during the Holocene (Aikens et al 1982). Shadscale-greasewood *(Atriplex confertifolia-Sarcobatus vermiculatus)* associations characterize this desert shrub or salt desert shrub community of the Basin and Range saline soil regime (Franklin and Dyrness 1973). Sentinel Cave is located at the transition between the desert shrub zone and the big sage *(Artemesia tridentata)* belt which occurs on the lower slopes of Steens Mountain at elevations of about 1280 to 1676 meters (Hansen 1956). The shadscale-greasewood community of the desert shrub zone includes white bottlebush *(Sitanion hystrix)*, Indian ricegrass *(Oryzopsis hyemoides)*, alkali salt-grass *(Distichlis stricm)*, creeping wildrye *(Elmyus triticoides)*, and Sandberg's bluegrass *(Poa*

Figure 10. Map of Steens Mountain region, southeastern Oregon, showing location of Sentinel Cave.
From Aikens et al. 1982.


BURNS
20
78
HARNEY
MALHEUR
CRANE
Malheur Lake
Harney Lake
205
FOLLYFARM
STEENS MOUNTAIN
FRENCHGLEN
BURNS JCT
SENTINEL CAVE
Catlow Valley
CATLOW CAVE
Alvord Desert
Alvord Lake
FIELDS
0 5 10 20 30 40 Miles
0 5 10 20 30 40 50 Kilometers
OREGON
NEVADA
DENIO

sandbergii) (Wilde 1981). Vegetation growth is richer immediately surrounding the cave because of a slight increase in available moisture at the base of the precipitous rim into which Sentinel Cave was cut (Wilde 1981). Greasewood *(Sarcobatus vermiculatus)*, historically introduced cheatgrass *(Bromus tectorum)*, and Indian ricegrass growth is denser and individual plants are larger along this strip (Wilde 1981).

Artemesia tridentata is the predominate vegetation of the big sage belt in the uplands above the east rim of the cave and to the north. Big sage is found in association with green rabbitbrush *(Chrysothamnus viscidiflorus)*, grey rabbitbrush *(C. nauseosus)*, and native grasses such as *Poa* spp., *Agropyron* spp., and *Stipa* spp. (Hansen 1956; Wilde 1981). The desert shrub community gives way to more mesic floral associations, including buffaloeberry *(Sheperdia argenta)*, along channels of Trout Creek, near the center of Alvord Basin (Wilde 1981). In the desert shrub communities to the south and west of the cave, various microhabitats exist among ancient lake bar and spit formations and relatively stabilized sand dunes and small playas (Wilde 1981).

Pollen records obtained from lake cores as part of the Steens Mountain Prehistory Project suggest terrestrial vegetation has been dominated by sagebrush and grasses for the past 11,700 years (Aikens et al 1982). Changing relative abundances of sagebrush and grass pollen indicate three major climatic periods during the Holocene. Timing of these events

varies with elevation, but in general, sagebrush dominance from about 8700-7200 B.P. suggests this was a drier and warmer period than those immediately before or after (Aikens et al 1982). Evidence of increased juniper grassland from pollen cores and woodrat middens also indicate a return to more mesic conditions after this period (Aikens et al 1982).

The Steens Mountain and Alvord Basin region is classified as a high desert. Mean daily maximum temperature for July is 29-32° C; mean daily minimum temperatures range from 10-15° C (Wilde 1981). For January, mean daily maximum temperatures range from 3-6° C and mean daily minimum temperatures are -5 to -6° C (Wilde 1981). Mean annual precipitation is about 280 mm, most of this falls as snow on the mountain during the winter (Wilde 1981). The Alvord Basin is in the rainshadow of Steens Mountain and most available moisture is provided by ephemeral snow fed streams and a few springs (Wilde 1981).

Excavation Methods

(from Wilde 1981)

A grid of four two by two meter units was laid out along the rear of the cave where roof-fall rocks were less abundant (Figure 11). Surface faunal material, accumulated by owls and packrats, was collected from this area in 25 x 25 cm. units. Excavation proceeded according to natural stratigraphic levels aided by the exposure and cleaning of a stratigraphic profile in

a pothunters pit in the southeastern corner of the cave. Beginning at this profile, strata were removed in three 50 cm. blocks: (0-0.5 N, 0-2 W), (0.5-1.0 N), and (1.0-1.5 N). New profiles were drawn at 0.5 N and 1.0 N. All visible disturbances (e.g. rodent burrows and nests) were excavated and collected separately. All excavated material was screened through 3.18 mm. mesh.

The tight control over horizontal and vertical proveniences and the attempt to maximize recovery with a small screen mesh resulted in a collection of microvertebrate remains which is suitable for investigations of depositional history.

Stratigraphy

Four major strata were delineated by excavation (Figure 12). The microfaunal remains from Stratum III (about 19,000 bones) were analyzed for this study. Stratum III, the zone above a Mazama tephra lens (about 6900 B.P.) to the base of a *Neotoma* sp. midden, is composed of levels of fine dust, abundant roof spalls,and evidence of *Neotoma* activity. A radiocarbon date of 3460± 75 B.P. (SI 4297) was obtained from a hearth near the top of the stratum . Stratigraphic features in Stratum III are described as follows by Wilde (1981) (Figure 13):

* Feature 6: The uppermost level of Stratum III. It contained few organic remains and many fine spalls and was associated with Feature 7. This level generally extended from

99.60-99.50 meters.

* Feature 7: A hearth consisting of a charcoal and dust lens, overlying a thin lens of gray ash. A date of 3460± 75 B.P. (SI-4297) was obtained from this feature and several flakes were found in association.
* Feature 8: This unit underlay Feature 6 and extended from 99.50-99.35 meters. It consisted of fine roof spalls and dust and contained only scant vegetal and faunal remains. Several flakes were found in this unit. The level was divided into subunits A-D to achieve greater stratigraphic control.
* Feature 9: A heavily rat-urine-stained and consolidated level which was associated with a large roof-rock fall that supplied homes for several generations of woodrats. This unit was rather sinuous along the west wall and extended generally from 99.75-99.25 meters.
* Feature 13: The base of the heavily rat-urine-stained level beneath Feature 9. This unit was also associated with the rockfall events and apparently was composed almost totally of rat nest remains; it was found upon excavation, to have been reworked to a very large extent by burrowing rodents. Faunal remains which were considered to have been *in situ* were collected in finer divisions A and B. Those within disturbed areas or with unclear provenience were collected separately as mixed data. This level extended generally from 99.52-99.11 meters.
* Feature 10: Another roof-spall and dust level at the base of

Unit II. This stratum contained a large pocket of relatively heavy roof spall. This unit was divided into three levels, A-C.

* Feature 11: The uppermost layer of the lower dust level in Stratum III. This layer contained relatively few spalls and was characterized by the inclusion of particles of tephra within the sediment. It extended generally from 99.25 to 99.01 meters.
* Feature 12: A heavy spall lens in the eastern portion of the excavation area.

Artifacts

Evidence for human artifacts in Sentinel Cave is limited. A total of 1 biface fragment, 1 drill fragment, 4 scrapers, and 124 flakes were recovered and 90% of these were found beneath the Mazama tephra lens (Aikens et al 1982). Fourteen artifacts were found in Stratum III (Wilde 1981). Tools make up 40% of the total assemblage and 34% consist of cutting edges (Wilde 1981). Functional analysis of the artifacts suggest human activities, including short term camping, hide preparation,and some lithic modification, changed little throughout occupation of the site (Wilde 1981). The cave appears to have been utilized less after the circa 6900 B.P. eruption of Mt. Mazama. Increased roof spall activity after this time accumulated large piles of rocks on the cave floor and opened up the ceiling, resulting in more exposure to the elements (Aikens et al 1982).

Figure 11. Plan of Sentinel Cave showing collection grid and excavation units.

From Aikens et al. 1982.

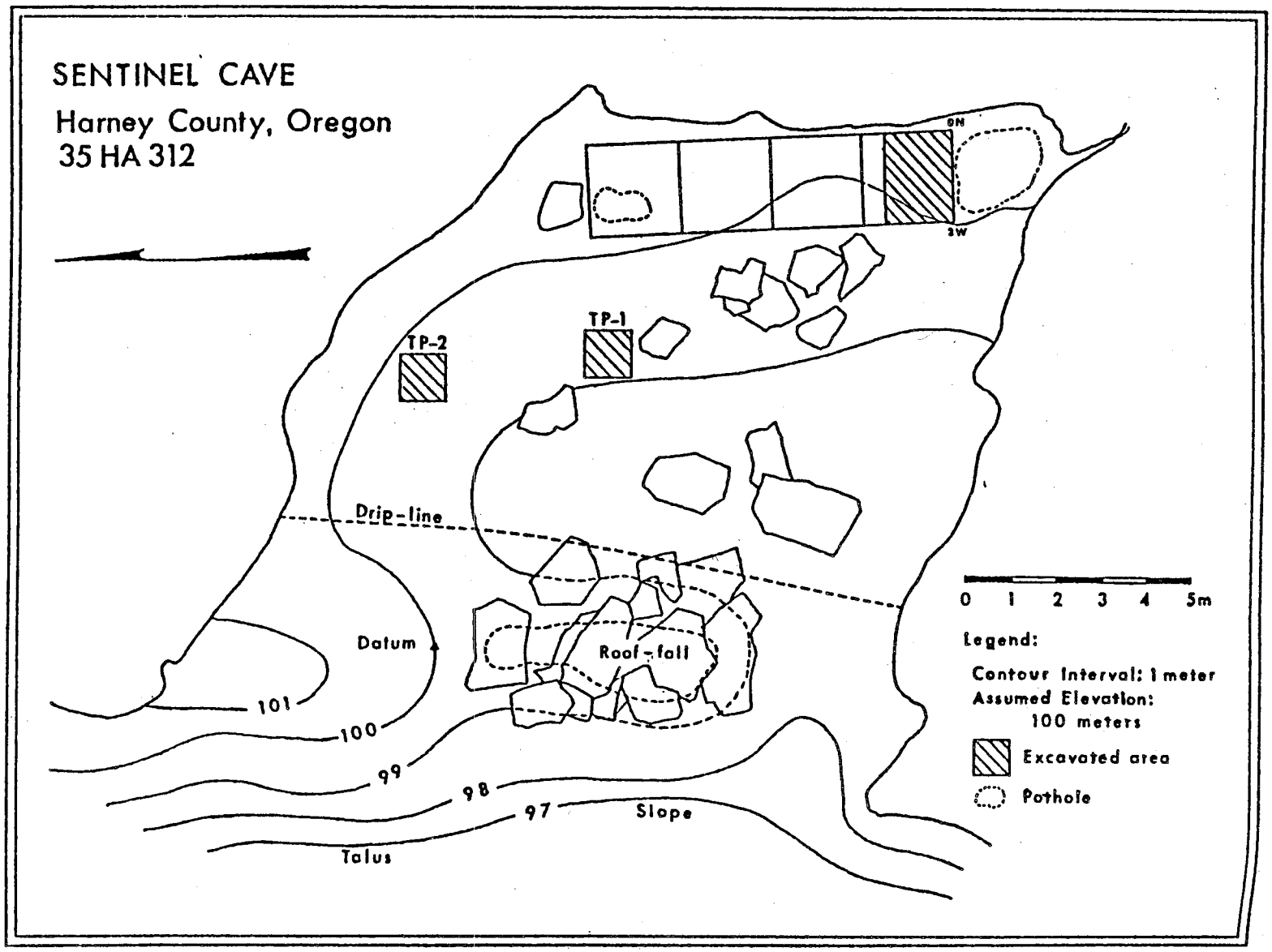

SENTINEL CAVE
Harney County, Oregon
35 HA 312
0N
3W
TP-1
TP-2
Drip-line
Datum
Roof-fall
101
100
99
98
97
Talus
Slope
0 1 2 3 4 5m
Legend:
Contour Interval: 1 meter
Assumed Elevation:
100 meters
Excavated area
Pothole

Figure 12. Schematic profile at 0.5 north, 0-2 west in Sentinel Cave, showing the major strata. The hearth in Stratum III and Mazama tephra lens in Stratum II are also shown. From Aikens et al. 1982.

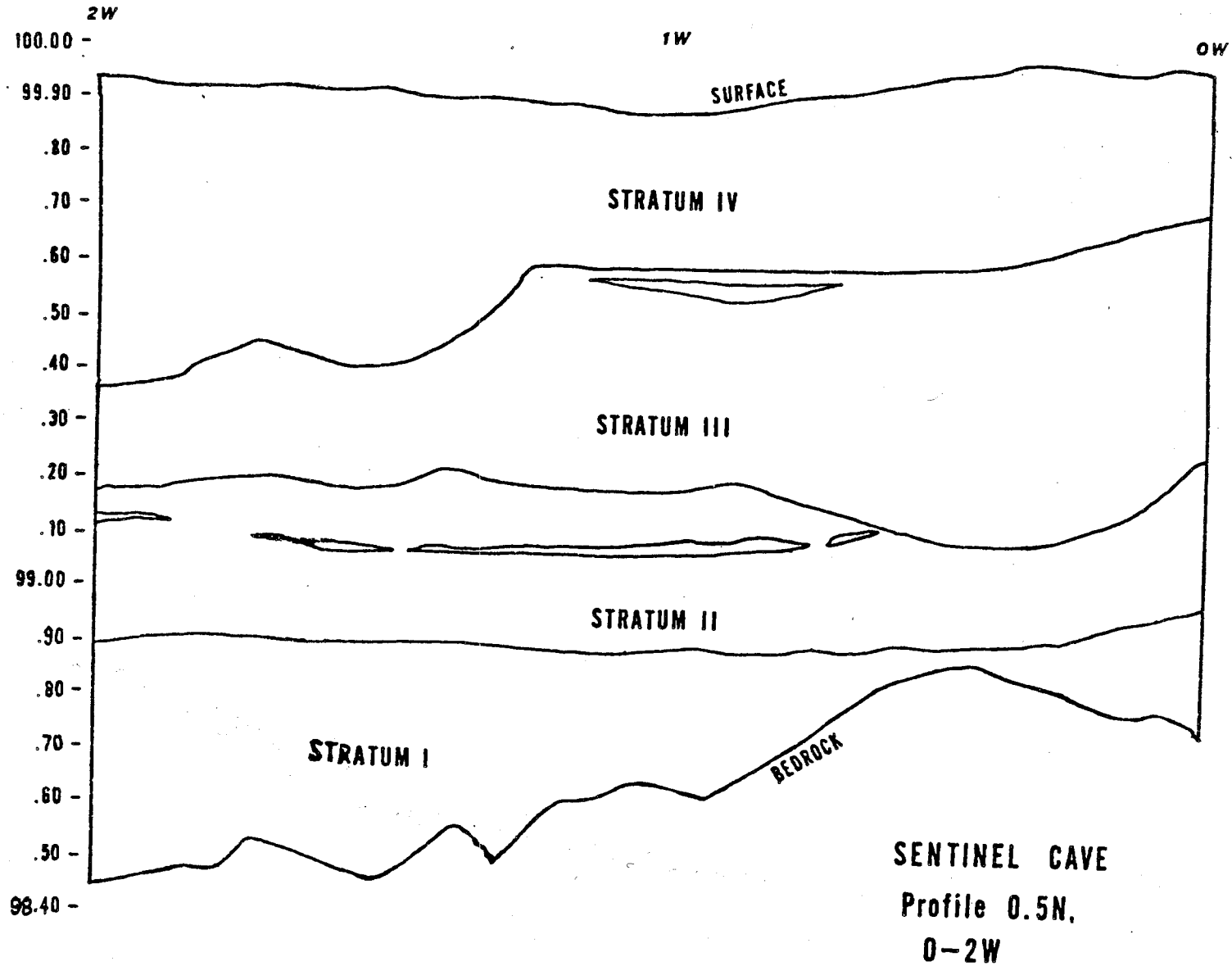
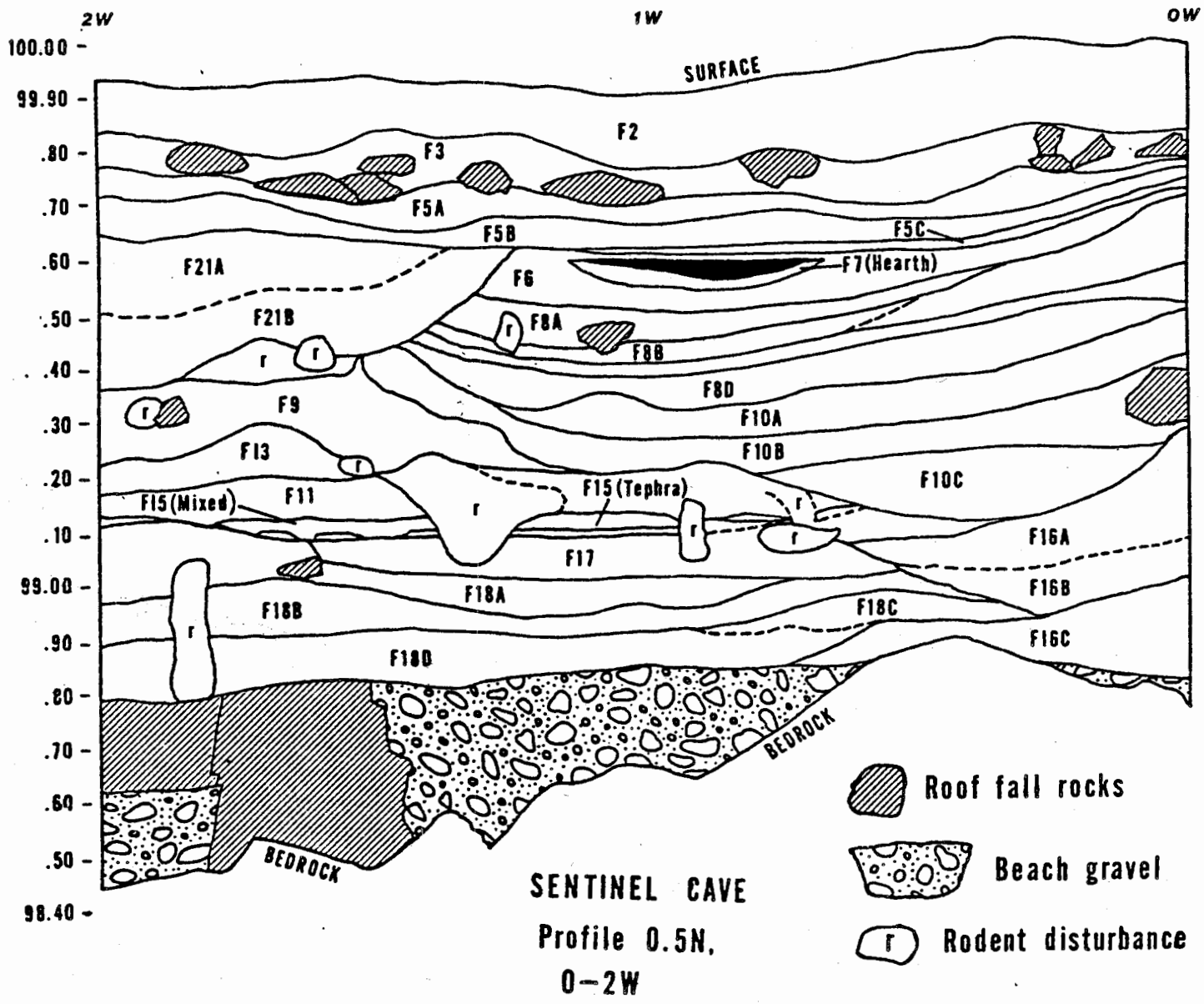

2W
1W
0W
100.00
99.90
.80
.70
.60
.50
.40
.30
.20
.10
99.00
.90
.80
.70
.60
.50
98.40
SURFACE
STRATUM IV
STRATUM III
STRATUM II
STRATUM I
BEDROCK
SENTINEL CAVE
Profile 0.5N,
0–2W

Figure 13. Profile of Sentinel Cave at 0.5 north, 0-2 west. From Aikens et al. 1982.


2W
1W
0W
100.00
99.90
.80
.70
.60
.50
.40
.30
.20
.10
99.00
.90
.80
.70
.60
.50
98.40
SURFACE
F2
F3
F5A
F5B
F5C
F21A
F6
F7(Hearth)
F21B
F8A
F8B
F8D
F9
F10A
F10B
F13
F10C
F15(Mixed)
F11
F15(Tephra)
F16A
F17
F16B
F18A
F18B
F18C
F16C
F18D
BEDROCK
BEDROCK
r
Roof fall rocks
Beach gravel
Rodent disturbance
SENTINEL CAVE
Profile 0.5N,
0–2W

Methods of Analysis: Sentinel Cave Microfauna

This analysis was undertaken to investigate the ability of various actualistic data and methods to discern taphonomic processes in archaeological and paleontological sites. The first step in the analysis involved compiling a list of information needed to answer questions concerning the taphonomic history of the assemblage, while taking into consideration that the information had to be in a form comparable to the actualistic data presented in Chapter II. A list of fifteen attributes that would satisfactorily obtain this information from the bone fragments was then developed. Because of the large number of bones to be analyzed and the large number of attributes recorded for each specimen, data was entered into the TAXIR computer program for further analysis. TAXIR is a Michigan Terminal System (MTS) information storage and retrieval program which allows data to be stored efficiently and selectively retrieved. The TAXIR system enabled me to obtain quantified information concerning any group of specimens and combination of the fifteen attributes I desired. The attributes (descriptors) recorded for each specimen and values (descriptor states) assigned to each attribute are listed in Appendix A.

Before data were recorded for each provenience, specimens were divided into "indeterminate" and "identifiable" groups, counted, and weighed. For the purposes of this study, I defined as identifiable all those specimens which could be identified to

skeletal element. Exceptions to this were all rib, vertebrae, and unfused epiphyseal fragments; and all skull fragments other than mandibles and maxillae. These are included in the indeterminate portion of the sample, along with fragments unidentifiable to skeletal element. Indeterminate specimens are futher described (see Appendix A under Portion and Segment) so that the number of each type of specimen is available.

Identifiable specimens are placed into general size categories corresponding to the size of the animal they came from (see Appendix A) so that it is possible to see if similarly sized animals had similar taphonomic histories, even if specific taxonomic identifications could not be made for all specimens. By treating groups of similarly sized specimens (and thus species) as analytical units I was able to include all specimens in the analysis, increase my sample sizes, obtain a more accurate picture of the number of each skeletal type present and overcome some differential identification biases.

As discussed earlier, taphonomic information is potentially contained in quantitative element representation data, characteristics of the individual specimens, such as breakage, burning, and tooth marks, and contextual data. Each of these types of data are utilized in the next chapter in an attempt to assess their usefulness for taphonomic interpretations.

CHAPTER V

RESULTS: TAPHONOMY OF STRATUM III

A total of 18550 mammal bones were analyzed (997 grams). 12641 bones were indeterminate (458 grams) and 5909 (539 grams) were identifiable. Table 9 presents the numbers of identified specimens (NISP) and minimum number of individuals (MNI) for taxa identified in each stratigraphic feature of Stratum III. For purposes of MNI calculations, each feature was treated as a single stratigraphic unit. MNI was calculated by siding and counting the most common element portion present in each feature. The identifiable faunal assemblage consists primarily of small rodents and lagomorphs. About 50% of the assemblage consists of small, primarily nocturnal heteromyid and cricetid rodents (size categories a and b). Another 30% consists mainly of packrats (*Neotoma* sp.) and a few Sciuridae and *Thomomys* sp. (size categories c and d); and about 23% are lagomorphs (size category e). Only two carnivore specimens were recovered (spotted skunk, *Spilogale putorius*, from Feature 9). Bat remains were sparsely scattered throughout the stratum. Appendix B, The Systematic Accounts, further describes the identified remains, discusses identification criteria, and provides some local habitat and distribution information.

To maintain contextual control, faunal remains in each feature are discussed separately and the features compared to each other. Features with a small number of remains (Features 7,

Table 9. Numbers of Identified Mammalian Specimens and Minimum Number of Individuals from Stratum III, Sentinel Cave.

TAXON	Feature 6		Feature 7		Feature 8		Feature 9		Feature 10		Feature 11		Feature 12		Feature 13		Feature 15	
	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI
Mammalia	2798	-	128	-	5371	-	2052	-	1591	-	150	-	80	-	451	-	20	-
Chiroptera	1	1	1	1			1	1	3	2			1	1				
Antrozous pallidus	3	1			4	4	3	1	1	1	1	1						
Sorex sp.	1	1			1	1												
Sorex preblei							1	1										
Lagomorpha	197				359		307		147						7			
Lepus sp.	46	8			128	12	43	8	42	5	1	1			27	4		
Sylvilagus sp.	13	3					6	2	3	2	1	1						
Sylvilagus cf. nuttalli	10	5			21	5	14	4	6	3	1	1						
Rodentia	385	38	18	4	1250	121	321	36	453	53	20	5	12	3	56	10		
Sciuridae	6	2			11	2	4	3	5	1								
Amnospermophilus leucurus	1	1																
Spermophilus sp.					2	2	7	1	2	1								
S. cf. townsendii	2	2			2	2	1	1	3	2								
Thomomys sp.	18	3	1	1	31	12	14	4	16	3					3	2		
Thomomys umbrinus	1	1																
Heteromyidae	7	3	1	1	20	11	7	3	10	5								
Perognathus cf. parvus					2	2	4	2	2	2								
Microdipodops megacephalus	5	4			1	1												

Table 9 (contin.)

TAXON	Feature 6		Feature 7		Feature 8		Feature 9		Feature 10		Feature 11		Feature 12		Feature 13		Feature 15	
	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI
Dipodomys sp.	102	18	4	2	220	44	104	21	67	15	1	1	2	1	18	5		
Cricetinae	42	20			99	43	43	16	23	11			1	1	2	1		
Reithrodontomys megalotis	6	2			3	3			2	2								
Peromyscus sp.	12	7	1	1	38	20	11	7	15	2					8	4		
Onchomys leucogaster	1	1			3	2												
Neotoma cinerea	9	3			4	3	16	5	3	1	2	1						
Neotoma lepida	153	20	1	1	363	41	157	19	96	14			8	1	15	3		
Microtinae	16	7			35	19	15	6	23	10					3	1		
Mircotus sp.	5	3			19	5	10	5	6	3					5	2		
Microtus montanus	1	1					1	1										
Lagurus curtatus	5	2			1	1	1	1							1	1		
Spilogale putorius							2	1										
TOTAL	3846	164	155	11	7988	356	3145	149	2519	138	177	11	104	7	596	35	20	-

11, 12, and 15) are discussed first.

Feature 7

The hearth near the top of Stratum III contained only a few fragments of bone, most of which were indeterminate. Twelve unidentifiable fragments were burned. The few identified small rodent and bat bones probably do not represent human activity.

Features 11 and 15

The dust and tephra levels at the bottom of Stratum III contained only a few bones, most of which were indeterminate.

Feature 12

This heavy spall feature also contained only a few, mostly indeterminate fragments that do not provide enough information by themselves for taphonomic assessment.

Features 6, 8, and 10

Feature 6 is associated with the hearth (Feature 7) near the top of the stratum. Based on NISP, about 29% (53% by weight) of the remains are identifiable. Species composition is similar to that for the whole stratum (about 57% heteromyids and cricetids,

Table 10. Proportion of femora and humeri from Stratum III, Sentinel Cave with unfused epiphyses. See text for definition of animal size categories.

FEATURE	6		8		9		10	
	fem	hum	fem	hum	fem	hum	fem	hum
ANIMAL SIZE								
a	1.00	.91	.96	.86	1.00	.88	.99	.88
b	.87	.50	.83	.65	.83	.74	.65	1.00
c	.79	.91	.75	.85	.88	.94	.85	.94
d	-	.75	1.00	1.00	-	1.00	1.00	1.00
e	.75	.64	.86	.55	1.00	.83	.86	.33

18% *Neotoma, Thomomys,* and sciurids, and 25% lagomorphs). About 34% (53% by weight) of the specimens in Feature 8 are identifiable. The assemblage consists of approximately 65% heteromyids and cricetids, 15% *Neotoma, Thomomys,* and sciurids, and 20% lagomorphs. Approximately 36% (52% by weight) of the specimens in Feature 10 are identifiable. Feature 10 consists of 65% heteromyids and cricetids, 14% *Neotoma, Thomomys,* and sciurids, and 21% lagomorphs. In all three features a high percentage of immature specimens (based on state of epiphyseal fusion of femora and humeri) are present in each size category (Table 10). Element composition information is contained in Tables 11, 12, and 13. Three measures of relative skeletal completeness were calculated: percentage present (PP), relative frequency, and MNI based on each skeletal element (Figures 14, 15, and 16). Number of elements is based on diagnostic zones so that no element was counted more than once because of breakage. Skulls and innominates were not included because breakage was too extensive to calculate number of elements. MNI was

calculated for each element from breakage information contained in Table 16. PP and relative frequency were calculated as discussed in Chapter II.

Heteromyids and cricetids

Although all element types were recovered, element frequency measures fall in the range expected for carnivore assemblages rather than owl assemblages. However, effects of two possible complicating factors, postdepositional loss and loss during collection, must be considered before conclusions regarding depositional agents can be made. The data indicate a relative loss of radii, ulnae, and scapulae. It is reasonable to assume that some loss of radii and ulnae occurred during recovery of the material because of their small size. Also, Features 6 and 8 are associated with fine spall activity and a heavy rock fall area occurs in Feature 10 suggesting that postdepositional processes increased fragmentation and loss of specimens.

The possibility of loss during collection was tested by performing a simple sieving experiment. When a known number of *Microtus* and *Peromyscus* elements in a sandy matrix were screened through a 2.80 mm geological screen 22% of the ulnae, 58% of the radii, and 60% of the scapulae (articular ends) were lost. The sieved elements were obtained from owl pellets. All were whole bones, except for the scapulae, which consisted of both whole scapulae and articular fragments. None of the whole scapulae were lost. Only 4% of the femora, 11% of the humeri, and no

Table 11. Measures of skeletal completeness for microvertebrate remains from Feature 6, Stratum III, Sentinel Cave.

element	#	MNI	PP	% whole bones	Rel. Freq.	Rel. Freq.
ANIMAL SIZE a & b						
mandible	90	48	.94	.12	.27	.33
humerus	66	38	.69	.59	.20	.24
radius	22	8	.23	.45	.06	
ulna	23	13	.24	.35	.07	
femur	63	40	.66	.60	.19	.23
tibia	51	29	.53	.59	.15	.19
scapula	21	13	.22	0	.06	
		ave=	.50		s=8.2	s=5.9
ANIMAL SIZE c						
mandible	22	13	.61	0	.16	
humerus	33	18	.92	.52	.24	
radius	10	10	.28	.2	.07	
ulna	30	16	.83	.13	.21	
femur	14	12	.39	.21	.10	
tibia	19	12	.53	.32	.14	
scapula	12	8	.33	0	.09	
		ave=	.56		s=6.3	
ANIMAL SIZE e						
mandible	8	7	.5	0	.18	
humerus	9	7	.56	0	.20	
radius	8	3	.38	0	.13	
ulna	13	8	.81	0	.29	
femur	5	4	.32	0	.11	
tibia	3	2	.19	0	.07	
scapula	1	1	.06	0	.02	
		ave=	.42		s=8.9	

Table 12. Measures of skeletal completeness for microvertebrate remains from Feature 8, Stratum III, Sentinel Cave.

element	#	MNI	PP	% whole bones	Rel. Freq.	Rel. Freq.
ANIMAL SIZE a & b						
mandible	207	108	.96	.03	.25	.30
humerus	152	90	.70	.69	.18	.22
radius	57	22	.26	.53	.07	
ulna	62	35	.29	.47	.07	
femur	189	102	.88	.55	.23	.28
tibia	132	68	.61	.53	.16	.19
scapula	32	19	.15	0	.04	
		ave=	.55		s=8.4	s=5.1
ANIMAL SIZE c						
mandible	63	34	.93	.05	.18	
humerus	52	28	.76	.60	.15	
radius	34	20	.50	.54	.10	
ulna	42	24	.62	.14	.12	
femur	57	30	.84	.28	.16	
tibia	63	34	.93	.35	.18	
scapula	34	21	.50	0	.10	
		ave=	.72		s=3.5	
ANIMAL SIZE e						
mandible	13	8	.81	0	.20	
humerus	11	7	.69	0	.17	
radius	10	3	.63	0	.16	
ulna	8	5	.50	0	.12	
femur	11	8	.69	.27	.17	
tibia	5	4	.31	0	.08	
scapula	6	4	.38	0	.09	
		ave=	.57		s=4.5	

Table 13. Measures of skeletal completeness for microvertebrate remains from Feature 10, Stratum III, Sentinel Cave.

element	#	MNI	PP	% whole bones	Rel. Freq.	Rel. Freq.
ANIMAL SIZE a & b						
mandible	78	41	.95	.17	.26	.29
humerus	71	41	.87	.75	.24	.26
radius	5	3	.06	.56	.02	
ulna	19	11	.23	.63	.06	
femur	73	41	.89	.77	.24	.27
tibia	49	27	.60	.69	.16	.18
scapula	4	2	.05	0	.01	
		ave=	.52		s=11.0	s=4.8
ANIMAL SIZE c						
mandible	27	17	.79	0	.23	
humerus	16	10	.47	.44	.14	
radius	10	7	.29	.25	.08	
ulna	5	4	.15	0	.04	
femur	24	13	.71	.13	.20	
tibia	20	10	.59	.15	.17	
scapula	17	11	.50	0	.14	
		ave=	.50		s=6.6	
ANIMAL SIZE e						
mandible	9	5	.90	0	.26	
humerus	5	3	.50	.20	.15	
radius	2	1	.20	0	.06	
ulna	4	4	.40	0	.12	
femur	4	3	.40	0	.12	
tibia	4	2	.40	0	.12	
scapula	6	3	.60	0	.18	
		ave=	.49		s=6.3	

Figure 14. Minimum number of individuals (MNI) per skeletal element for size a and b animals from Features 6, 8, 9, 10, and 13.

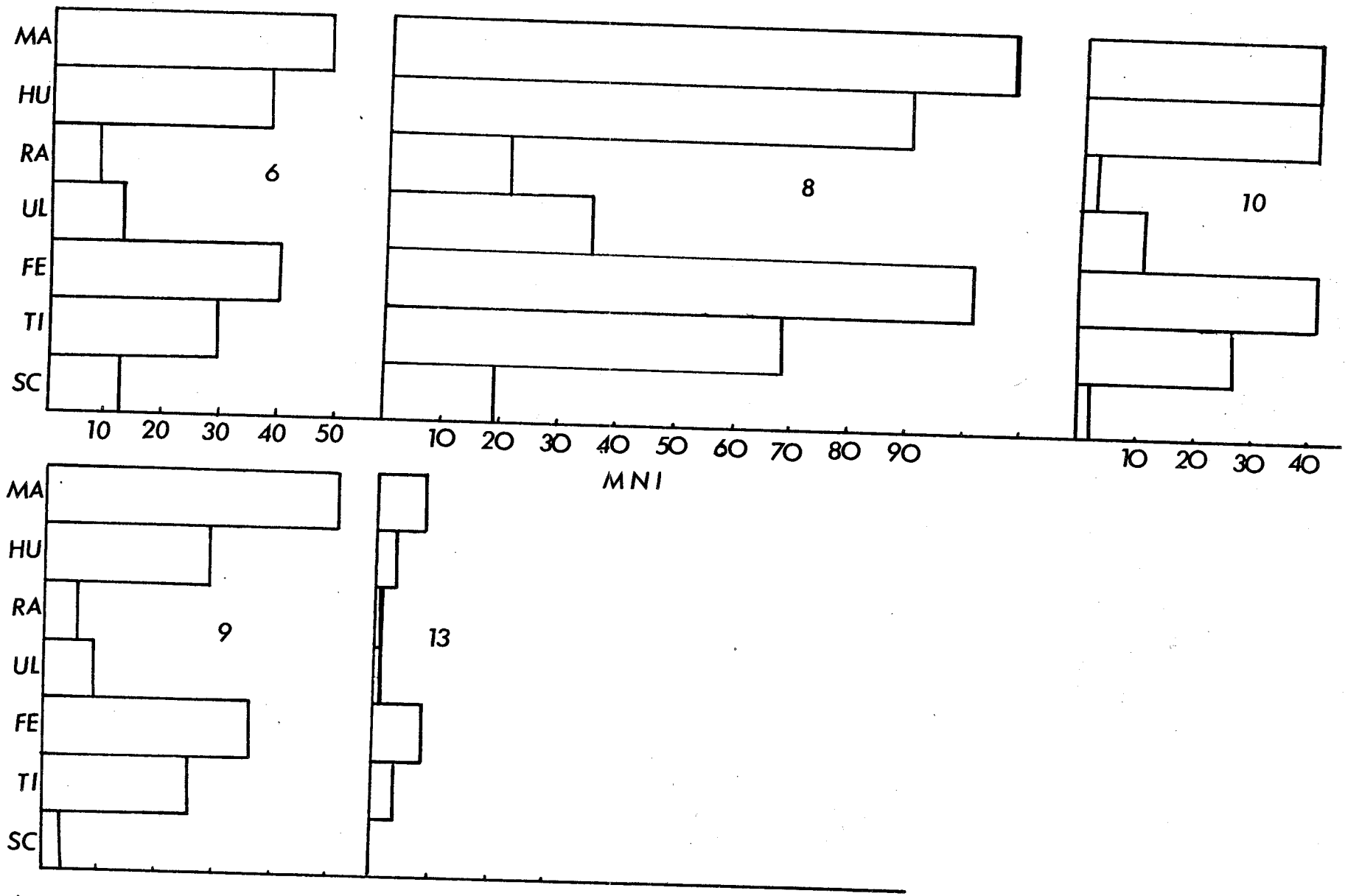
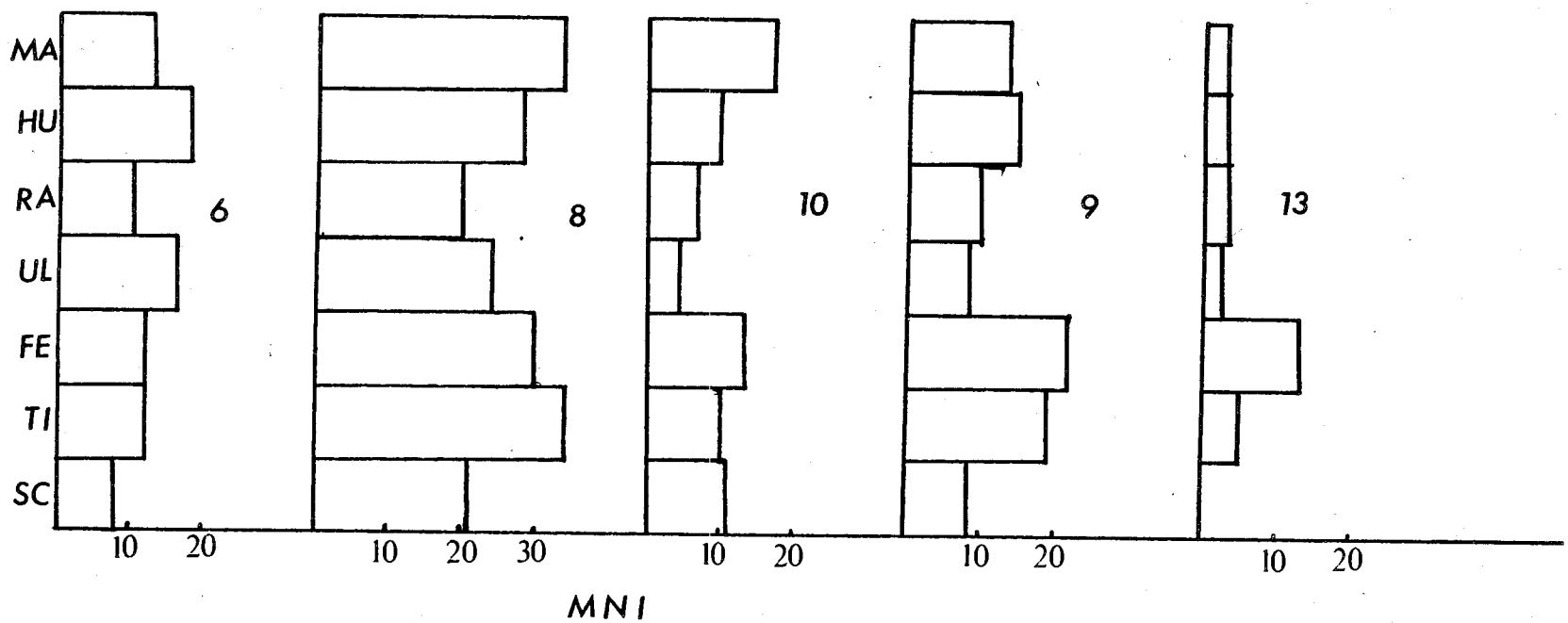

MA
HU
RA
UL
FE
TI
SC
6
8
10
9
13
10 20 30 40 50
10 20 30 40 50 60 70 80 90
10 20 30 40
MNI

Figure 15. Minimum number of individuals (MNI) per skeletal element for size c animals from Features 6, 8, 9, 10, and 13.


MA
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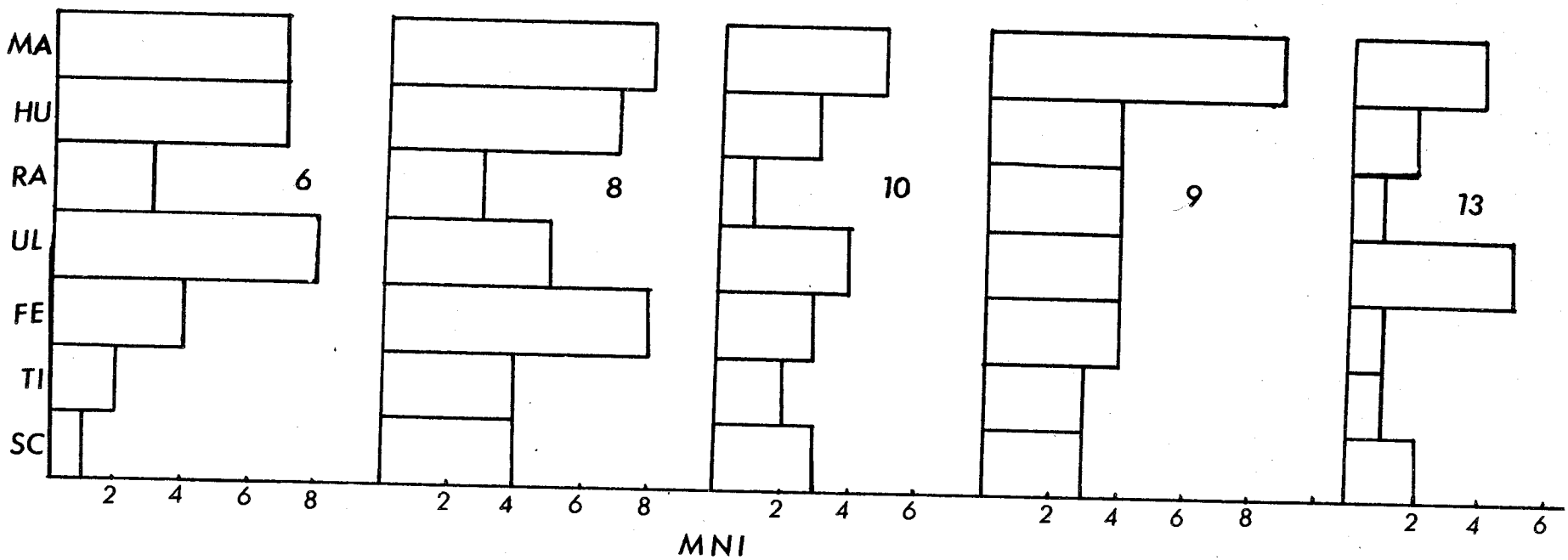
10 20
10 20
MNI

Figure 16. Minimum number of individuals (MNI) per skeletal element for size e animals from Features 6, 8, 9, 10, and 13.


MA
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13
2
4
6
8
MNI

tibiae were lost. These results indicate that the low frequencies of scapulae, radii, and ulnae present in the samples from Stratum III are probably partly due to loss during recovery. This demonstrates the need for bulk samples to control for collection loss. In this case, the unknown amount of error due to sampling bias reduces the usefulness of element representation measures for determining depositional agent.

There is, however, some information that can be extracted from these data. First, since postdepositional and collection loss of specimens is suggested, original element frequencies were probable higher. Analysis of the larger woodrat bones, which should have incurred less sampling loss, corroborates this assessment. Measures of element frequencies are similar, although a little higher, for the woodrat samples. If the woodrats died naturally, one would expect element frequencies to be higher than what is actually observed. If we assume that woodrats living in the cave did die naturally, then the lower than expected element frequencies indicate some postdepositional loss.

Second, because radii, ulnae, and scapulae frequencies probably are influenced by sampling error, relative frequency measures were calculated without these elements (column 7 of Tables 11, 12 and 13). The resultant variances are higher than variances calculated from owl data, but lower than variances calculated from carnivore data (Table 14). Unfortunately, we are losing information useful in distinguishing owl from carnivore

Table 14. Relative frequency variances of skeletal elements from carnivore scats (data from Andrews and Nesbit Evans, 1983 and Korth, 1979) and owl pellets.

1 - mandibles, humeri, radii, ulnae, femora, tibiae, and scapulae used in calculations.
2 - mandibles, humeri, femora, and tibiae used in calculations.

TAXON	S^1	S^2
coyote *(Canis latrans)*	5.7	1.4
fox *(Vulpes vulpes)*	8.6	7.6
arctic fox *(Alopex lagopus)*	14.1	18.1
marten *(Martes martes)*	9.3	17.0
coyote *(Canis latrans)*	3.9	7.0
barn owl *(Tyto alba)*	2.0	1.5
barn owl *(Tyto alba)*	2.0	0.8
horned owl *(Bubo virginianus)*	0.8	1.0
horned owl *(Bubo virginianus)*	2.1	1.8
short-eared owl *(Asio flammeus)*	1.7	2.0

deposition by eliminating these elements. The relative frequency of these elements in carnivore assemblages is generally lower than in owl assemblages due to mechanical damage and loss during consumption and digestion and contributes to the differences in variances between the two assemblage types. This is demonstrated by the reduction in frequency variability observed in the first two carnivore samples when these elements are eliminated. Thus, the size and structure of these elements, which makes them susceptible to postdepositional and collection loss, also makes them susceptible to mechanical damage and loss by depositional agents. Also, one of the coyote samples now falls in the range expected for owl assemblages, demonstrating some of the range of variability in actualistic data which precludes definite distinction between depositional agent based on one criterion.

Although the above problems reduce the reliability of interpretations based on these data, the data appear to suggest owl rather than carnivore deposition. Some differential postdepositional and collection loss is plausible for the elements analyzed in column 7, especially loss of the long bones relative to the more robust mandible. Based on this assumption, the variances, which are lower than carnivore sample variances, may have originally been even lower. This interpretation could be questioned, however, and should be backed up by other sources of information.

It may be more useful to examine types of breakage and appearance of the bone fragments for information concerning depositional agent. The percentage of whole bones is higher than one would expect from carnivore action (Tables 11, 12, and 13) (Andrews and Nesbit Evans 1983) although it is possible that more broken bones than whole bones were lost during recovery. In general, though, the high level of fragmentation associated with carnivore activity is not indicated either by amount of unidentifiable fragments or by fragmentation patterns of identifiable specimens.

Indeterminate fragments make up 64 to 70% of the assemblage from Features 6, 8 and 10 (Table 15). However only 48-53% of these are unidentifiable bone flakes. The rest of the indeterminate fragments consist of shaft pieces, skull and rib fragments, vertebrae and unfused epiphyses. Thus, about 32-35% of the specimens have been fragmented to the extent that

Table 15. Size range of indeterminate and unidentifiable bone from Stratum III, Sentinel Cave. See text for definition of indeterminate and unidentifiable.

INDETERMINATE

Size (cm)	Feature 6	Feature 8	Feature 9	Feature 10	Feature 13
0-.5	1559 (57%)	2320 (44%)	616 (30%)	490 (30%)	162 (39%)
.5-1.0	715 (26%)	1999 (38%)	673 (33%)	724 (45%)	133 (32%)
1.0-1.5	264 (10%)	600 (11%)	530 (25%)	226 (14%)	90 (22%)
1.5-2.0	144	280	190	138	20
2.0-2.5	20	54	33	28	4
2.5-3.0	12	12	9	4	0
3.0-3.5	1	9	1	1	2
3.5-4.0	0	3	1	2	0
TOTAL	2715	5277	2058	1613	411

UNIDENTIFIABLE

0-.5	945 (65%)	1617 (63%)	575 (59%)	389 (47%)	111 (51%)
.5-1.0	242 (17%)	442 (17%)	185 (19%)	232 (28%)	48 (22%)
1.0-1.5	165 (11%)	299 (12%)	125 (13%)	124 (15%)	47 (21%)
1.5-2.0	78	158	74	57	7
2.0-2.5	9	28	8	19	4
2.5-3.0	5	8	7	4	0
3.0-3.5	1	6	1	1	2
3.5-4.0	0	3	1	2	0
TOTAL	1445	2561	976	828	219

Table 16. Breakage Patterns of Skeletal Elements from Stratum III, Sentinel Cave.

ELEMENT		Feature 6			Feature 8			Feature 9			Feature 10		
		a+b	c	e	a+b	c	e	a+b	c	e	a+b	c	e
HUMERUS:	WHOLE	34	17	0	105	32	0	32	15	0	53	7	1
	DISTAL	32	14	5	47	20	11	20	14	7	16	9	4
	PROXIMAL	0	6	0	9	6	5	4	3	2	4	8	1
ULNA:	WHOLE	8	4	0	29	6	0	7	2	0	12	0	0
	DISTAL	0	0	1	1	1	0	0	1	0	0	0	0
	PROXIMAL	11	26	11	30	30	7	7	10	2	7	4	4
	SHAFT	4	0	2	3	6	1	0	1	0	0	1	0
RADIUS:	WHOLE	11	3	0	31	5	0	7	6	0	3	8	0
	DISTAL	3	0	2	2	1	4	0	0	1	0	0	0
	PROXIMAL	18	7	6	26	28	6	4	13	3	3	2	1
FEMUR:	WHOLE	31	3	0	104	17	3	44	10	0	56	3	0
	DISTAL	3	1	1	0	1	2	0	1	0	0	1	1
	PROXIMAL	32	10	4	85	40	8	19	18	6	13	20	4
	SHAFT	0	0	0	0	0	0	0	4	2	4	1	0
TIBIA:	WHOLE	30	6	0	70	22	0	22	5	0	34	3	0
	DISTAL	15	10	1	53	16	2	19	10	4	7	5	3
	PROXIMAL	11	7	2	29	40	5	10	17	3	5	8	1
	SHAFT	1	3	0	9	11	0	2	4	0	5	7	0
SCAPULA:	RIGHT ARTICULAR	8	8	1	13	13	4	1	3	3	2	11	3
	LEFT ARTICULAR	13	4	0	19	21	2	3	8	1	2	6	3

Table 16 (contin.)

ELEMENT	Feature 6			Feature 8			Feature 9			Feature 10		
	a+b	c	e	a+b	c	e	a+b	c	e	a+b	c	e
MANDIBLE: WHOLE	11	2	0	7	3	0	4	1	0	13	3	0
ACSENDING RAMUS DAMAGED	15	11	0	52	12	0	15	7	0	20	4	0
FRAGMENTARY	64	9	8	148	48	13	56	14	14	45	20	9
INNOMINATE: WHOLE	0	0	0	0	0	0	0	0	0	0	0	0
ILIUM	4	15	1	22	25	4	4	18	1	14	13	1
ISCHIUM	5	11	2	3	20	4	4	7	1	6	6	0
ISCH & PUB	1	1		2	5	0	1	6	0	0	2	0
ISCH & ILL	16	17		28	26	1	7	11	4	19	10	1

recognition of skeletal element is not possible. Size ranges for the fragments are contained in Table 15. Most of the fragments are 0-1 cm. in length. The unidentifiable portion contains a slightly higher percentage of fragments in the smallest size range (0-0.5 cm.). The ratio of unidentifiable to identifiable fragments appears to be lower than that generally expected in carnivore assemblages (Andrews and Nesbit Evans 1983).

Breakage patterns (Table 16) appear similar to owl breakage patterns (Table 5). Types of breaks are also similar to those found in owl assemblages (Figure 17). Mandibles are fragmentary only in the sense that the ascending ramus is usually broken; individual skull bones and innominate bones are common. Carnivore remains generally sustain more damage although some of the bones of small prey may escape damage (Korth 1979; Andrews and Nesbit Evans 1983).

The majority of bones from Stratum III show no evidence of surface corrosion or rounded, abraded edges. Three to seven percent of the bones (Table 17) exhibit slight erosion on the epiphyses which appear similar to that found on owl pellet remains (Figure 18). There is no evidence of enamel or dentine corrosion on teeth. Digestive erosion by carnivores produces either surface rounding of broken edges or more extensive corrosion with removal of the cortex (Andrews and Nesbit Evans 1983). A few specimens (less than 1%) from Features 6, 8, 9, and 10 are severely corroded (Table 21) (Figure 18c & d).

Table 17. Percentage of specimens from Stratum III, Sentinel Cave that exhibit digestive erosion. See text for definition of animal size.

FEATURE	6	8	9	10	13
ANIMAL SIZE					
a	1.79	2.39	0	3.35	0
b	0.50	6.20	2.86	5.00	0
c	8.10	11.04	6.42	11.49	1.67
d	5.90	10.50	8.93	10.53	0
e	3.04	3.32	3.49	6.03	14.71
TOTAL	3.89	6.20	3.83	6.69	4.14

Neither gnaw marks nor other tooth marks were found on any of the mammal bones. However, a few of the duck bones from Features 6 and 8 exhibit carnivore tooth punctures. The only carnivore specimens, a spotted skunk *(Spilogale putorius)* left mandible and right molar, were found in Feature 9 and may have been brought to the midden by woodrats. Carnivore tooth marks are not common on small prey remains (Andrews and Nesbit Evans 1983) and, in caves utilized by carnivores, their skeletal remains are generally less common than the remains of their prey. However the virtual absence of carnivore remains in Stratum III and the above data strongly suggest that the cave was not commonly used by carnivores and that they played only a limited role in accumulation of the assemblage.

Woodrats

Woodrat middens are common in Sentinel Cave and these specimens may represent natural death. On the other hand, it is possible that predators contributed to the accumulation of

Figure 17. Typical breakage observed on small mammal bones from Sentinel Cave.

Figure 18. Scanning electron microscope photographs of digestive erosion on bones from Sentinel Cave. a) lagomorph proximal ulna (x10), b) lagomorph proximal ulna (x60), c) lagomorph proximal humerus (x10), d) lagomorph proximal humerus (x60), e)control (x10), f) control (x60).

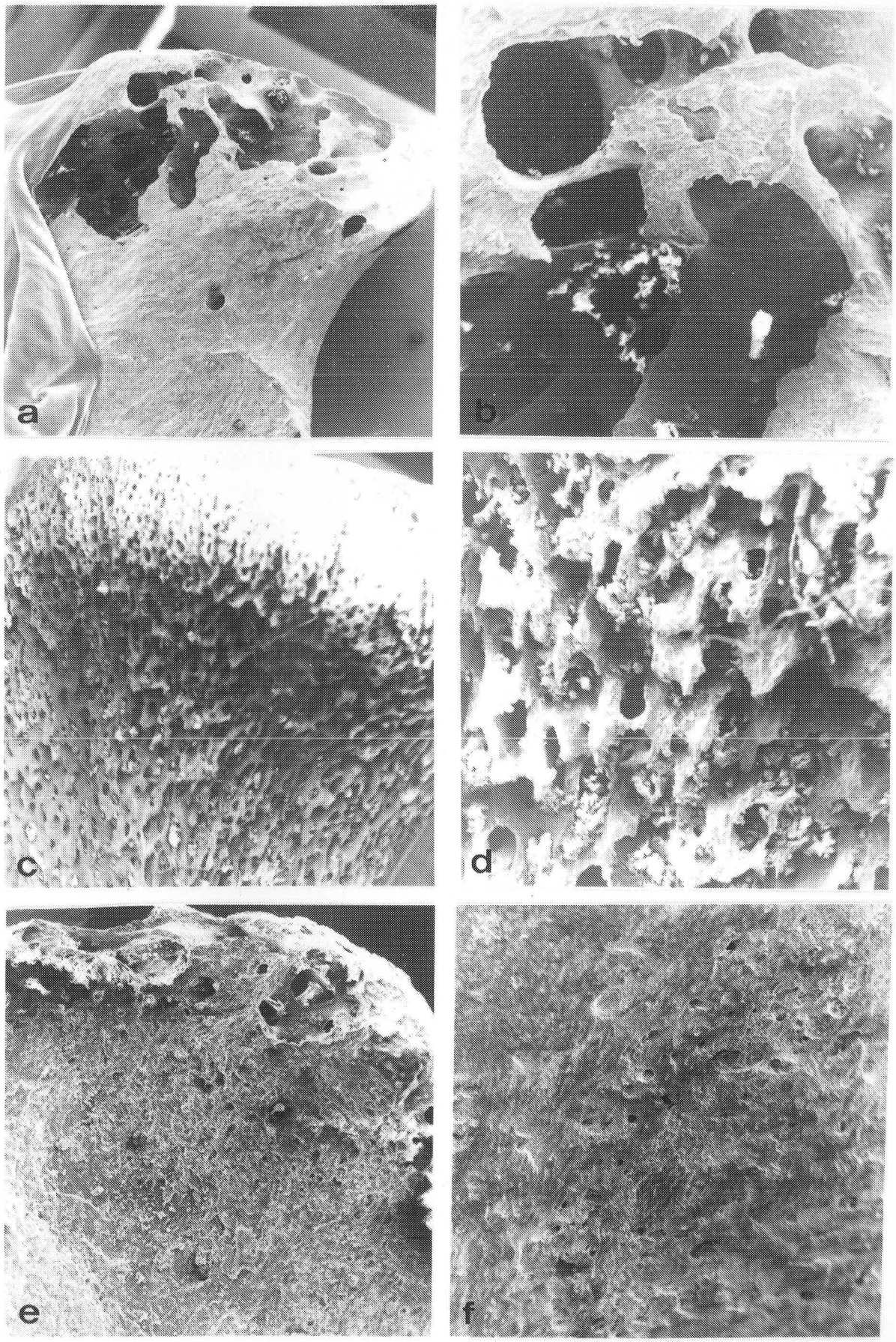
a
b
c
d
e
f

Figure 19. a) Breakage observed on lagomorph bones from a great horned owl pellet. b) and c) Typical breakage observed on lagomorph bones from Sentinel Cave.

b
c
a

Neotoma in Features 6, 8, and 10. The high percentage of immature specimens may indicate predation on inexperienced and highly dispersive subadults. It appears too high for natural mortality (Escherich 1981).

Skeletal representation in Feature 8 suggests owl deposition or natural death, with some postdepositional loss, rather than carnivore deposition. This is supported by breakage patterns and types and condition of the bones as discussed above. A slightly higher percentage of size c specimens exhibit eroded epiphyses (Table 18). This may be ascribed to owl predation with the larger prey items remaining in the owls' digestive systems for longer periods of time.

Skeletal representation information in Features 6 and 10 is more ambiguous, although statistically the data do not significantly differ from Feature 8 (Kolmogorov-Smirnov $D=0.0865$, $p>.50$ for the difference between Features 6 and 8 for MNI values. Figure 15). The percentage of whole elements is considerably less in Feature 10, suggesting more fragmentation and loss (primarily of radii and ulnae) due to large rock falls in this feature. Feature 6 contains relatively fewer mandibles, femora and tibiae than the other features. This loss of robust skeletal elements is difficult to explain, but suggests some sort of disturbance. Perhaps there was more carnivore activity during deposition of this feature. Alternatively, human activity and trampling (a hearth is associated with this feature) may have resulted in scattering and loss of specimens.

Lagomorphs

As discussed in Chapter 2, actualistic data concerning remains in this size range is limited. Also, because prey of this size cannot be swallowed whole by predators, one may expect a large amount of variability in treatment of the prey and resultant deposited element frequencies.

Element representations in Features 6, 8, and 10 are not significantly different from the great horned owl pellet sample discussed in Chapter 2 (Table 6)(Kolmogorov-Smirnov D=.184, .064, .071, p>.50, for the difference between the actualistic data and Features 6, 8, and 10, respectively, based on MNI values.). All the samples contain primarily immature specimens and similar breakage patterns (Tables 7 and 17). Most of the long bones are broken in half, but are not heavily fragmented. It is probable that carnivores would have crushed and fragmented the bones to a greater extent than is indicated in the Sentinel Cave samples.

Types of breakage may yield more information, but actualistic information is lacking for most depositional agents and limited for all agents. Breakage of Sentinel Cave maxillae and scapulae is similar to that in the small actualistic sample (Figure 19). Mandible breakage is different, but that may be due to the size difference. The modern remains were smaller and more immature than the Sentinel Cave remains. The separate bones of the innominates were not fused in the modern sample. Maxillary

fragments are also similar to those depicted by Brain (1983:125) from cape eagle owl pellets and differ from hyrax skulls left under a black eagle roost (Brain 1983:108).

Organic matter (mostly fur) is tightly packed in many of the bones in the modern sample. This is caused by the compression of fur and bones into a pellet. Similar organic matter was observed in some of the Sentinel Cave specimens, particularly in vertebrae. This appears to be a good indication of owl pellet deposition; it seems unlikely that other processes could cause this.

None of the bones were in the form of "bone tubes". Evidence of possible cultural modification in the form of cut marks or burning on any of the remains was limited to a few burned bones dispersed through the stratum (Table 18).

Features 9 and 13

Feature 9 is a consolidated woodrat midden area and is associated with a large rock fall. Feature 13 is the midden area at the base of Feature 9 which shows evidence of disturbance by burrowing rodents. About 35% (65% by weight) of the remains from Feature 9 and 31% (45% by weight) of the remains from Feature 13 are identifiable. Heteromyids and cricetids make up about 50% of the assemblage, *Neotoma*, *Thomomys*, and sciurids about 16%, and lagomorphs about 34%. Like the other features, a high percentage of specimens in each size category are immature (Table 10).

Table 18. Distribution of burned bone in Stratum III, Sentinel Cave.

FEATURE	6	7	8	9	10	11	12	13	15
NUMBER OF FRAGMENTS:	4	12	1	13	8	33	5	19	3

Element composition information is presented in Tables 19 and 20.

Woodrats, or packrats, collect vegetation material, small bones, etc. to construct dens. These materials are generally collected within a relatively small area (usually <100 meters) (Thompson and Mead 1982). Studies of *Neotoma lepida*, the desert woodrat and most commonly identified woodrat in Sentinel Cave, indicate these woodrats forage within a restricted area (movements average 14 meters) in a .1-.4 hectare home range (Stones and Hayward 1968; Bleich and Schwartz 1975). Dens range in size from less than 60 cm. basal diameter and 60 cm. high to more than 150 cm. basal diameter and 120 cm. high and consist of passages and chambers for nesting and food caches (Stones and Hayward 1968). During Stones and Hayward's study, dens were occupied by one adult woodrat and woodrat density was 4.5-7.8 per hectare. Midden accumulations, which can become hard and indurated by trampling and urine markings, form through periodic cleaning of the den (Mead 1980).

Woodrat activity in Sentinel Cave is a complicating factor in the taphonomic history of the small mammal bones. Other than the general information that woodrats collect bones for den

construction, little seems to be known about the effects of woodrat activity on microvertebrate assemblages.

Features 9 and 13 do not differ from the other features with respect to amount of unidentifiable fragments (Table 15) or amount and type of bone corrosion (Table 17). The amount of bone recovered from Feature 13 is much less than that recovered in the other features. Bulk samples from the bottom of Feature 9 and Feature 13 contain only a very small amount of very friable bone, indicating decomposition of bone in this area, possibly from urine. Feature 13 is also the only feature in which the bones differ significantly with respect to surface coloration (Table 21). Fifty percent of the specimens in Feature 13 are stained with a dark brown mottling. Less than 20% of the specimens in the other features exhibit dark brown staining. Although quantitative data for Feature 13 is presented in Table 20, sample sizes are too small for accurate interpretations of these data.

Heteromyid and cricetid element representation in Feature 9 is similar to that in Features 6, 8, and 10, except for a greater loss of radii, ulnae, and scapulae (Figure 14). Part of this loss may be due to trampling activities of woodrats living in the midden. Woodrats probably do not move these tiny bones around to any great extent for den or nest construction, although it is possible that they move whole pellets. Heteromyids and cricetids make up slightly less of the assemblage in Features 9 and 13. This appears to be caused by a

Table 19. Measures of skeletal completeness for microvertebrate remains from Feature 9, Stratum III, Sentinel Cave.

element	#	MNI	PP	% whole bones	Rel. Freq.	Rel. Freq.
ANIMAL SIZE a & b						
mandible	75	51	.74	.05	.28	.32
humerus	53	29	.52	.60	.20	.22
radius	11	7	.11	.55	.04	
ulna	14	9	.14	.50	.05	
femur	63	36	.62	.70	.24	.27
tibia	45	26	.44	.49	.17	.19
scapula	4	3	.04	0	.02	
		ave=	.37		s=10.5	s=5.7
ANIMAL SIZE c						
mandible	22	14	.50	.05	.15	
humerus	29	15	.66	.52	.19	
radius	19	10	.43	.45	.13	
ulna	13	8	.30	.15	.09	
femur	30	22	.68	.33	.20	
tibia	27	19	.61	.19	.18	
scapula	11	8	.25	0	.07	
		ave=	.49		s=5.0	
ANIMAL SIZE e						
mandible	14	9	.78	0	.30	
humerus	7	4	.39	0	.15	
radius	5	4	.28	0	.11	
ulna	5	4	.28	0	.11	
femur	8	4	.44	0	.17	
tibia	4	3	.22	0	.09	
scapula	4	3	.22	0	.09	
		ave=	.37		s=7.4	

Table 20. Measures of skeletal completeness for microvertebrate remains from Feature 13, Stratum III, Sentinel Cave.

element	#	MNI	PP	% whole bones	Rel. Freq.	Rel. Freq.
ANIMAL SIZE a & b						
mandible	12	7	.86	0	.33	.35
humerus	4	4	.29	.75	.11	.12
radius	1	1	.07	0	.03	
ulna	1	1	.07	0	.03	
femur	12	7	.86	.33	.33	.35
tibia	6	4	.43	.33	.17	.18
scapula	0					
		ave=	.37		s=13.7	s=11.8
ANIMAL SIZE c						
mandible	5	3	.19	0	.12	
humerus	5	3	.19	.60	.12	
radius	3	3	.12	.67	.07	
ulna	3	2	.12	0	.07	
femur	17	13	.65	.06	.41	
tibia	8	5	.31	.25	.20	
scapula	0					
		ave=	.23		s=12.9	
ANIMAL SIZE e						
mandible	4	4	.40	0	.22	
humerus	3	2	.30	0	.17	
radius	1	1	.10	1.0	.06	
ulna	6	5	.60	0	.33	
femur	1	1	.10	0	.06	
tibia	1	1	.10	0	.06	
scapula	2	2	.20	0	.11	
		ave=	.26		s=10.3	

Table 21. Surface condition of bone from Stratum III, Sentinel Cave. Numbers are proportion of total bones.

FEATURE	6	8	9	10	13
Light Brown	.98	.86	.81	.80	.46
Dark Brown Stains	.01	.13	.18	.19	.53
Porous, Eroded	.01	.01	.01	.01	.01

slightly higher percentage of lagomorph remains. The lack of a significant difference between the heteromyid and cricetid bones in the woodrat midden areas and in the other features suggests the woodrats had little effect on this part of the assemblage. These remains were probably deposited primarily by owls throughout the excavated area of the cave.

Neotoma remains in Feature 9 do not significantly differ from *Neotoma* remains in the other features (Kolmogorov-Smirnov D=.0667, p>.50, for the difference between Features 8 and 9 for MNI values. See Figure 15.). Element representation appears most similar to that in Feature 10, with a relative loss of radii, ulnae, and scapulae. Woodrat activity and rockfalls may have contributed to loss of these vulnerable elements, as in Feature 10. The woodrat remains are probably composed of both animals that died naturally and those that were prey for predators utilizing the cave. Quantitative information is inadequate for distinguishing between these types of deposition. In any case, it is evident that these animals inhabited the cave and knowledge of how they died would add little paleoenvironmental information.

Lagomorph skeletal representation does not significantly differ from Features 6, 8, and 10. (Kolmogorov-Smirnov D=.0839, p>.50, for difference between Features 9 and 8 for MNI values. See Figure 16.) However, within Feature 9, lagomorph remains do significantly differ from *Neotoma* skeletal remains (Kolmogorov-Smirnov D=.1885, .002<p<.001). (Lagomorph and *Neotoma* skeletal representation does not significantly differ in the other features.) This is mainly caused by relatively more mandibles and fewer tibae in the lagomorph sample with respect to the *Neotoma* sample. The higher percentage of lagomorph remains in Feature 9 suggests, though only feebly, that the woodrats were moving lagomorph bones into the midden area from other areas of the cave. In particular, they may have been differentially selecting mandibles (Figure 16).

Discussion

When element frequency data is used in conjunction with information concerning condition of the bones and contextual information it appears that owls were major depositors of the heteromyid and cricetid remains (large quantity of small, immature, nocturnal species, relatively high element frequencies, types of breakage, good bone condition with limited digestive erosion). Lagomorph remains were probably also largely deposited by owls, although the evidence is not as strong because of a lack of actualistic data. A limited amount of carnivore deposition is indicated by the few tooth punctures and

small amount of corroded bone. There is no evidence of water transport and diurnal raptor activity is unlikely because of the condition of the bones and teeth. Characteristics of remains from the hearth and nearby areas are not different from other areas and give no indication of human utilization of the remains.

The woodrats living in the cave may have collected a limited amount of lagomorph bones but, on the whole, the woodrat middens do not differ from the other features. This suggests that the remains were deposited relatively evenly over the excavated area and that the woodrats had little effect on the assemblage.

This analysis illustrates the complex situation one faces when attempting to determine the depositional history of microfaunal remains. It is clear that adequate sampling procedures should be a major consideration of archaeologists excavating small remains for taphonomic and paleoenvironmental assessment. Although processing bulk samples is time consuming and logistics usually result in small samples, this is one problem area over which archaeologists have some control.

Deposition information contained in element frequency data is masked not only by sampling bias, but also by postdepositional loss and the addition of remains to the assemblage by a variety of sources. Amount of breakage, types of breaks observed on individual bones, and condition of the bones appear to be quite useful for identifying probable depositional

agents and future actualistic work should focus on these types of data. It seems evident, however, that very few characteristics are unique to any one depositional mechanism and information from as many sources as possible should be used in taphonomic analyses.

CHAPTER VI

PALEOENVIRONMENTAL RECONSTRUCTION AND OWL DEPOSITED MICROVERTEBRATES

Initial Considerations

As discussed in the introduction, taphonomic studies in archaeology are not an end in themselves but are conducted to identify possible human utilization of remains and as a precursor to paleoenvironmental reconstruction. Paleoenvironmental investigations based on microvertebrate remains face problems at two levels: first, the relationship between the excavated sample and the originally deposited assemblage should be established; second, one must attempt to understand the relationship between the deposited assemblage and the living community (Lawrence 1971; Dodson 1973; Grayson 1981; Shipman 1981; Maas 1985). The first problem is shared by archaeologists attempting to make cultural inferences from faunal remains and has led to an extensive body of literature on MNI, NISP, and other quantitative methods. Grayson (1981) has addressed this problem as it specifically applies to paleoenvironmental reconstruction. The second problem is approached by attempting to identify mechanisms that deposited an assemblage and then investigating how these mechanisms differentially select organisms from living populations. Of course, the difficulties involved in explaining how microvertebrate assemblages accumulated is a major impediment to

their usefulness in paleoenvironmental reconstruction. However, the preceding taphonomic analysis suggests that owls were primary depositors of microvertebrate remains in Sentinel Cave. The valid use of owl pellet remains for paleoenvironmental reconstruction should then be examined.

It is imperative that one be familiar with the range of present-day owl predation patterns to make accurate inferences about past environmental conditions based on owl pellet remains. One may then be able to infer some aspects of the paleoenvironment, under the assumption that owl-environmental interactions and interactions of their prey with the environment have remained relatively constant through time.

Like most aspects of ecology, owl behavior and its relationship to the environment is complex, especially when one must take into consideration more than one owl species. This will be true at most archaeological sites, since it is impossible in most cases to determine which owl species (or if more than one species) deposited the bones. Depending on the age of the site, it may be possible to compose a list of likely owl species from those inhabiting the area today. If the feeding habits of these species are known, the information may aid in postulating what habitats their prey came from. Guilday et. al. (1977), on the other hand, hypothesized that medium-sized field hunting owls deposited remains in a Virginia cave site, based on size and ecological requirements of the deposited prey species.

Since owls do not select prey species in the same proportion in which the prey exist in natural populations, remains deposited by owls do not directly reflect either relative species abundances or diversity of the living community of small mammals. Relative availability of prey primarily determines owls' diet (Mikkola 1983). Relative availability is affected by a multitude of factors including method of hunting, size, color, and locomotion of prey, habitat, owl feeding range, prey behavior, activity rhythym synchronicity between owl and prey, time of year, age and sex of prey, prey population fluctuation, and size of the owl (Maser and Brodie, Jr. 1966; Glue 1970; Marti 1974; Mikkola 1983). Owls diets vary both interspecifically and intraspecifically as habitat and prey availability varies.

A change in species composition over time in an assemblage deposited by owls may not reflect major environmental changes, but may be the result of smaller changes in owl and prey distributions and prey population fluctuations. For example, Marti (1974) found a significant yearly difference in prey composition over a three year period, from one habitat, in great horned owl and barn owl pellets.

On the other hand, habitat changes may occur that are not reflected in an owl's diet. For example, Marti (1974) found no difference in prey composition in the pellets of long-eared and burrowing owls from different habitats (short-grass prairie and farm land). Also, Brain (1981) found that barn owl prey from two

different habitats in Africa, open grassland and savanna woodland, were extremely similar. This indicates not only that owl pellet remains would not be reliable ecological indicators in this case, but also that the identified small mammals are not good indicators since any microenvironmental restrictions are provided for, and masked, in two different habitats. This does not negate the usefulness of owl pellets that produce remains of species more sensitive to the habitat changes in question. It does demonstrate that similar species assemblages may have originated from different habitats, and that environmental changes over time may be masked. Prey species with more restricted environmental requirements are more important for reconstruction, as in other paleoenvironmental work.

Changes in owl species using a roost over time can also result in species composition changes which relate to different owl species hunting behavior and not environmental change (Grayson 1981). However, there may be ways to get around this problem in some cases. Changes in owl species in an area may themselves have been caused by environmental changes, which may be indicated by the remains. Presence of indicator species does suggest certain habitat availability even if absence of the species does not preclude that habitat's availability. If the owls changing roosts over time are sympatric, changing characteristics of the assemblages, such as prey size range and species diversity, which are known to differ in modern sympatric owl pellets (e.g. Marti 1974; Roth and Powers 1979), may suggest

this.

Klippel and Parmalee (1982) demonstrate another possible way of diminishing this problem. They investigated only the insectivore remains from a deeply stratified cave in Tennessee. By only investigating changes in species composition within the insectivores (7 Soricidae and 2 Talpidae), they probably eliminate most of the chance of bias due to owl species change. Within each family, the insectivore species are probably similar enough in their behavior in relation to owl hunting behavior so that sympatric owls would not differentially select, say for example, different species of *Sorex*. Changing relative abundances of *Sorex* species probably therefore reflect real changes in their abundance.

Paleoenvironmental Data From Stratum III

It was hoped that excavation at Sentinel Cave would provide cultural and environmental sequences for much of the Holocene to help develop explanations of cultural change and stability in the northern Great Basin. At this time, only small mammal remains from Stratum III have been analyzed. Analyses of microvertebrates from the other strata, and bird, reptile, and amphibian remains from Stratum III have not been completed. Stratum III spans the 3500 year period beginning after the Mazama ash fall about 6900 B.P. Analysis of remains beneath the ash layer is necessary to elucidate possible paleoenvironmental

changes linked to two events that occurred about 7000 B.P., the Mazama ash fall and the beginning of a postulated period of decreased effective precipitation.

Relative abundances of select taxa from Stratum III, calculated as both NISP and MNI, are presented in Table 22. Grayson (e.g. 1981b, 1984) discusses pitfalls associated with interpreting relative abundances based on either measure and the preceding discussion examines depositional factors that can bias interpretations based on relative abundance. While these cautions are kept in mind, some speculative interpretations are proposed.

All of the species, with the exception of the sciurids, are nocturnal and are commonly found in the pellets of the two species of owls most likely to inhabit suitable caves in the area today, great horned owls and barn owls (Brodie and Maser 1967; Maser et al 1970; Roth and Power 1979; Maser et al 1980). *Spermophilus townsendii* does not appear to be a common prey item (Maser et al 1970) and their low relative abundance in the assemblage is probably due to depositional bias. All of the species identified from Stratum III presently occur in southeastern Oregon and are associated with semi-arid to arid sagebrush desert. Only two species, *Microtus montanus* and *Thomomys umbrinus* could be classified as preferring mesic habitats (Bailey 1936; Hansen 1956) and these are relatively rare in the assemblage.

Differences in rank order of relative abundances based on NISP versus MNI are minimal for all features except 10. Generally, the cricetinae are slightly more abundant when based on MNI, while, based on NISP, *Neotoma* is ranked first. The taphonomic analysis indicates loss of elements from the smallest species, suggesting MNI values are more accurate than NISP in this case. If the MNI values are more accurate, the rank orders suggest some differences in relative abundances in Feature 10. In particular, microtines appear to be significantly less abundant and *Dipodomys* and other heteromyids more abundant than in the other features. Since microtines may be considered more mesic than *Dipodomys*, one possible explanation for this could be a decrease in effective precipitation during deposition of Feature 10. This correlates well with other environmental evidence which suggests a period of minimum Holocene precipitation and maximum temperature from about 7000-5200 B.P. in the Steens Mountain area (Wilde 1985).

The apparent dominance of *Lepus californicus* rather than *Lepus townsendii* in the stratum also occurs at Connley Caves in south central Oregon (Grayson 1977a) (see Systematic Accounts) and also supports this interpretation. (*L. californicus* prefer shrubbier habitats and lack some cold climate adaptations.) In general, the relative abundances of mammals at Sentinel Cave are relatively stable throughout Stratum III and the taxa are indicative of a semi-arid, shrubby environment similar to the present. The Sentinel Cave data support climatic indications

Table 22. Rank Order Relative Abundances Based on MNI and NISP for Select Taxa from Stratum III, Sentinel Cave.

TAXON	NISP								MNI							
	Feat 6		Feat 8		Feat 10		Feat 9		Feat 6		Feat 8		Feat 10		Feat 9	
	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank
Lepus	4.4	4	4.9	4	4.5	3	3.9	4	4.9	5.5	3.4	6.5	3.6	5.5	5.4	5
Sylvilagus	2.2	6	.80	8	.97	9	1.8	6	4.9	5.5	1.4	9	3.6	5.5	4.0	6
Sciurids	.86	9	.57	9	1.1	8	1.1	8	3.1	8	1.7	8	2.9	7	3.4	7.5
Thomomys	1.8	7	1.1	6	1.7	6	1.3	7	2.4	9	3.4	6.5	2.2	8	2.7	9
Dipodomys	9.7	2	8.4	2	7.2	2	9.5	2	11.0	3	12.4	2.5	10.9	.5	14.1	3
Neotoma	15.5	1	14.0	1	10.7	1	15.8	1	14.0	2	12.4	2.5	10.9	3	16.1	1
heteromyidae(excl. *Dipodomys*)	1.2	8	.88	7	1.3	7	1.0	9	4.3	7	3.9	5	5.1	4	3.4	7.5
cricetines	5.8	3	5.5	3	4.3	4	4.9	3	18.3	1	19.1	1	10.9	.5	15.4	2
microtines	2.6	5	2.1	5	3.3	5	2.4	5	7.9	4	7.0	4	2.2	9	8.7	4

from small mammal faunas at Connley Caves, the Dirty Shame Rockshelter in extreme southeastern Oregon, and Owl Cave in southwestern Idaho (Grayson 1977b, 1979). More detailed interpretations may be possible when all the microvertebrate remains from Sentinel Cave have been analyzed.

CHAPTER VII

CONCLUSION

At present, taphonomic investigations of microvertebrate remains in archaeology are largely limited to a small number of actualistic studies. This situation must change if we are to gain a better understanding of human utilization of small animals and more accurately reconstruct past environments.

The present actualistic examination of owl accumulated remains has led to the development of a set of characteristic patterns of fragmentation and element representation and an understanding of the variability to be expected in these patterns. Unfortunately, these characteristics are not truly diagnostic criteria in that they do not satisfy "if and only if" statements. An examination of other sources of microvertebrate deposition reveals that different processes may produce similar characteristics. However, our increased knowledge of owl deposition is useful and allows us to make more educated hypotheses concerning the taphonomic history of sites. Our ability to understand microvertebrate taphonomy will increase as other depositional mechanisms are better known. In particular, much work remains to be done in two important problem areas: the effect of human utilization on small animal remains and the taphonomy of rabbit-sized remains.

Actualistic research provides only the foundation upon which analysis of site taphonomy is conducted. The potentially

diagnostic characteristics developed through actualistic studies are characteristics of freshly deposited assemblages. The applicability of this information to archaeological sites, in which complex depositional histories and postdepositional processes are the rule, must be assessed by testing criteria and developing methodology through analyses of sites.

The complexity of the problem is evident from analysis of microfauna from Sentinel Cave. The analysis of element representation data is complicated by sampling loss, postdepositional breakage, multiple depositional agents, and woodrat activity. However, by allowing for loss due to sampling and postdepositional processes, and by examining and comparing different contexts and size classes of animals, some information was extracted from the data. Examination of patterns and types of breakage and condition of the bone sidesteps some of the above problems but encounters other problems. Certain breakage characteristics are ambiguous, and inferences based on a few bones are indirectly applied to the whole assemblage. When all the evidence is examined in conjunction, however, it appears most likely that owls were the primary depositors of cricetine, microtine, heteromyid, and lagomorph remains and that woodrats either died naturally or provided food for owls. A limited amount of carnivore activity is also indicated. The best evidence (least open to multiple interpretations) comes from digestive erosion patterns, tooth puncture marks, organic matter packed in bone cavities, and the extremely high frequency of

immature, nocturnal animals in the assemblage.

This study increases our knowledge of one important factor in microvertebrate deposition and demonstrates some of the things that can and cannot be done with our present knowledge of microvertebrate taphonomy. Although we must be satisfied with hypotheses in this retrodictive science, the quality of our hypotheses can be increased through indepth analyses of multiple sources of information.

APPENDIX A

Descriptors and Descriptor States Recorded for Mammalian Faunal Specimens From Stratum III, Sentinel Cave.

DESCRIPTOR	DESCRIPTOR STATES
1. Provenience	horizontal location, feature #, F.S. #
2. Element	all element types observed plus indeterminate
3. Side	left, right
4. Portion of element represented	whole, fragmented, distal, proximal, shaft, ilium, ischium, pubis, isch & pub, isch & il, pub & il, ascending ramus damaged, indeterminate: appendicular, axial (vertebrae, ribs, skull frags), unfused epiphyses
5. Segment (subsection of portion	spine gone, dorsal feathery, ascend ing ramus, horizontal ramus, coro noid process broken, angular process broken, mandibular process broken, cor & ang broken, cor & mand broken, ang & mand broken, indeterminate (appendicular): bone flake, shaft piece [1]
6. Type of break	a: transverse fracture at right angles to long axis b: single spiral fracture c: splintered single-step fracture d: multiple-step fracture e: multiple spiral fracture

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[1] A shaft piece is defined as greater than half the circumference of a long bone (Brain 1974). I have defined bone flakes as long bone shafts less than or equal to half the circumference plus all fragments unidentifiable to skeletal element.

7.	Location of erosion	whole bone, distal, proximal, posterior edge of pelvis, mandibular toothrow
8.	Modification	cutmarks, toothmarks, burning
9.	Location of modification	whole bone, distal, proximal
10.	Weathering	light brown, mottled with dark stains, porous and eroded.
11.	Fragment size (for indeterminate frags)	in .5 cm increments
12.	Animal size (for identifiable frags	a:(0-30 g.) *Perognathus, Microdipodops, Peromyscus, Onchomys, Reithrodontomys* b: (30-85 g.) *Microtus, Dipodomys* c: (85-170 g.) *Neotoma lepida*, sciurids d: (170-580 g.)*Neotoma cinerea, Thomomys* e: (>580 g.) lagomorphs
13.	Taxon	
14.	State of epiphyseal fusion	prox unfused + distal unfused prox unfused + distal fused prox fused + distal unfused prox gone + distal fused prox gone + distal unfused distal gone + prox fused distal gone + prox unfused prox fused + distal fused
15.	Teeth in mandibular or maxillary frags	all, none, some

APPENDIX B

Systematic Accounts

Mammalia - Mammals

Order Insectivora - Insectivores

Family Soricidae - Shrews

Sorex sp. - Shrews

MATERIAL: 2 mandibles.

Sorex cf. *preblei* - Preble's Shrew

MATERIAL: 1 mandible.

REMARKS: Preble's shrew has been collected on Steens Mountain in subalpine dry bunchgrass areas (Hansen 1956) and at lower elevations (Bailey 1936, Hall 1981).

Order Chiroptera - Bats

Family Vespertilionidae - Vespertilionid Bats

Antrozous pallidus - Pallid Bat

MATERIAL: 5 mandibles, 1 skull, 6 maxillary fragments.

REMARKS: Pallid bats occur in Catlow Cave on Steens Mountain and have been collected in a cave on Windy Point (1280 m.), 20 miles north of Steens Mountain (Hall 1981).

Order Lagomorpha - Rabbits, Hares, and Pikas

Family Leporidae - Rabbits and Hares

MATERIAL: 2 mandibles, 49 skull fragments, 346 isolated teeth, 1 scapula, 23 humeri, 4 radii, 17 ulnae, 9 innominate fragments, 24 femora, 16 tibiae, 206 phalanges, 35 metapodials, 22

carpals/tarsals, 3 astragali, 7 calcanea.

Sylvilagus sp. - Rabbits

MATERIAL: 2 mandibles, 5 skull fragments, 1 sternum, 1 ulnae, 1 innominate fragment, 2 femora, 3 metapodials, 7 astragali, 3 calcanea.

Sylvilagus cf. *nuttalli* - Nuttall's Cottontail

MATERIAL: 7 mandibles, 6 skull fragments, 3 scapulae, 14 humeri, 4 radii, 3 ulnae, 6 innominate fragments, 5 femora, 3 tibiae, 1 astragalus, 1 calcaneum.

REMARKS: Two species of *Syvilagus* presently occur in southeastern Oregon: *S. idahoensis*, the pygmy rabbit, and *S. nuttalli*. *S.* cf. *nuttalli* identifications were based on size (no mature elements the size of pygmy rabbits were found) and dental characteristics. *S. nuttalli* upper first molars have more than one reentrant angle on the anterior face, *S. idahoensis* has only one (Hoffmann and Pattie 1968). It is possible that the remains are those of another species of *Sylvilagus*, such as *S. audubonii*, which may have occurred in the area in the past. However, *Syvilagus* identifications are difficult and the remains were too fragmentary to conclusively identify. Nuttall's cottontail generally inhabits rocky or cliff areas in the big sage belt (Bailey 1936, Hansen 1956).

Lepus sp. - Hares

MATERIAL: 39 mandibles, 41 skull fragments, 37 isolated teeth, 2 sternums, 16 scapulae, 24 humeri, 21 radii, 26 ulnae, 12 innominates fragments, 9 femora, 13 tibiae, 2 patellae, 10 phalanges, 11 metapodials, 7 carpals/tarsals, 7 astragali, 14

calcanea.

REMARKS: Two species of *Lepus* currently occur in the Steens Mountain area: *L. townsendii* and *L. californicus*. These two species are extremely difficult to identify, even with complete skulls (Hoffmann and Pattie 1968). *L. townsendii*, the more northerly species, tends to be larger than the more southerly *L. californicus*, but there is a large amount of size overlap (Grayson 1983). Grayson (1977) distinguished *L. townsendii* and *L. californicus* remains from Connley Caves, Oregon, on the basis of alveolar length of the toothrow with some success. Grayson (1983) also constructed bivariate plots of 24 variables for seven postcranial elements in an attempt to distinguish the species; but concluded the time involved did not merit the results obtained (Grayson 1985). I was not able to measure mandibular toothrows to compare to Grayson's 1977 data because most of the Sentinel Cave mandibles are too fragmentary. In an attempt to identify the Sentinel Cave specimens by size, I measured the alveolar length of the maxillary toothrow. Table 23 gives data on maxillary toothrow lengths for modern hares and the Sentinel Cave specimens. As Grayson (1977) found, measurements of *L. townsendii* and *L. californicus* overlap, but the means are significantly different ($t = -2.86$, $p<0.01$). The mean for the Sentinel Cave specimens is significantly smaller than the mean for *L. townsendii* ($t = -2.69$, $p<0.02$), but is not significantly different from the mean for *L. californicus* ($t = -1.43$, $2.0>p>1.0$). These data, although sample sizes are small, suggest that the Sentinel Cave leporids from Stratum III may be

mostly *L. californicus*. This corroborates Grayson's (1977) proposal that a shift occurred in the local leporid population after the circa 7000 B.P. Mazama eruption, sometime in the middle Holocene. *L. townsendii* is relatively more abundant in Connley Caves strata beneath Mazama ash, while *L. californicus* appears to be more abundant in later strata. *L. californicus* continues to be more abundant in the northern Great Basin today.

Order Rodentia - Rodents

Family Sciuridae - Squirrels

Amnospermophilus leucurus - White-tailed Antelope Squirrel

MATERIAL: 1 mandible.

REMARKS: The antelope squirrel was observed in the vicinity of Sentinel Cave during excavation (Wilde 1981). They frequent dry sagebrush/greasewood habitats (Bailey 1936; Hansen 1956).

Spermophilus sp. - Ground Squirrels

MATERIAL: 6 mandibles, 2 skull fragments, 6 loose teeth.

Spermophilus cf. *townsendii* - Townsend's Ground Squirrel

MATERIAL: 2 mandibles, 4 skull fragments.

REMARKS: Five *Spermophilus* species occur in southeastern Oregon today: *S. richardsonii, S. elegans, S, townsendii, S. beldingi,* and *S. lateralis*. *S. townsendii* was identified by its small size and shape and position of the infraorbital canal and massetric tubercle. Townsends ground squirrels inhabit dry, sandy, open sagebrush areas of the Upper Sonoran Life Zone (Bailey 1936; Ingles 1965).

Family Geomyidae

Thomomys sp. - Smooth-toothed Pocket Gophers

MATERIAL: 19 mandibles, 3 skull fragments, 14 isolated teeth fragments, 7 scapulae, 15 humeri, 6 ulnae, 3 innominate fragments, 3 femora, 7 tibiae, 10 calcanea.

Thomomys umbrinus - Southern Pocket Gopher

MATERIAL: 1 premaxillary fragment.

REMARKS: Hall (1981)subsumes *T. townsendii* under *T. umbrinus*. The position of the opening of the infraorbital canal (Thaeler 1980) was used to distinguish *T. umbrinus* from *T. talpoides*, the other pocket gopher that occurs in southeastern Oregon. The southern pocket gopher reaches the northern limits of its distribution in southeastern Oregon. It occurs in relatively mesic habitats in deep soils of river bottoms and old lakebeds in the Upper Sonoran Life Zone (Bailey 1936; Ingles 1965).

Family Heteromyidae - Pocket Mice, Kangaroo Mice, Kangaroo Rats

Perognathus cf. *parvus* - Pocket Mice

MATERIAL: 4 mandibles, 4 skull fragments.

REMARKS: Two species of pocket mice inhabit southeastern Oregon today; *P. parvus* and *P. longimembris*. The Sentinel Cave specimens were identified primarily on the basis of size. *P. parvus* is larger than *P. longimembris*. *P. parvus* occurs on Steens Mountain in loose, dry soils in sagebrush areas to an elevation of about 2620 meters (Hansen 1956).

Microdipodops megacephalus - Dark Kangaroo Mouse

MATERIAL: 5 mandibles, 1 skull fragment.

REMARKS: *M. megacephalus* is the only kangaroo mouse presently occurring in southeastern Oregon. It is associated with fine, gravelly soils in the Upper Sonoran sagebrush desert (O'Farrell and Blaustein 1974).

Dipodomys sp. - Kangaroo Rat

MATERIAL: 103 mandibles, 53 skull fragments, 20 isolated teeth.

REMARKS: Two species of kangaroo rat presently occur in southeastern Oregon: *D. ordii* and *D. microps*. These species are rather difficult to distinguish (Hall 1946) and remains were too fragmentary to allow specific identifications.

Family Muridae - Murids

Subfamily Cricetinae - Cricetine Rodents

Reithrodontomys megalotis - Western Harvest Mouse

MATERIAL: 7 mandibles, 4 skull fragments.

REMARKS: Western harvest mice occur in weedy or grassy areas such as salt grass and cheat grass habitats around Steens Mountain (Bailey 1936; Hansen 1956).

Peromyscus sp. - White-footed Mice

MATERIAL: 64 mandibles, 22 skull fragments.

REMARKS: Two species of white-footed mice occur in the area today: *P. crinitus* and *P. maniculatus*. *Peromyscus* are notoriously difficult to identify to species because of the large amount of variation in dental pattern in some species (e.g. Guilday and Handley, Jr. 1967). No attempt was made to speciate the Sentinel Cave specimens, but see Hooper (1957) and Grayson (1983, 1985) for criteria used to distinguish these two

species.

Onchomys leucogaster - Northern Grasshopper Mouse

MATERIAL: 3 mandibles, 1 skull fragment.

REMARKS: These carnivorous mice inhabit hot, dry, sagebrush desert valley areas (Bailey 1936; Hansen 1956).

Neotoma cf. *cinerea* - Bushy-tailed Woodrat

MATERIAL: 2 scapulae, 5 humeri, 4 radii, 5 ulnae, 4 innominate fragments, 1 femur, 2 tibiae, 1 calcanea.

Neotoma cinerea - Bushy-tailed Woodrat

MATERIAL: 6 mandibles, 2 skull fragments, 3 isolated teeth.

Neotoma cf. *lepida* - Desert Woodrat

MATERIAL: 22 scapulae, 129 humeri, 36 ulnae, 50 innominate fragments, 72 femora, 83 tibiae, 51 calcanae.

Neotoma lepida - Desert Woodrat

MATERIAL: 115 mandibles, 68 skull fragments, 187 isolated teeth.

REMARKS: Desert and bushy-tailed woodrats both occur in the Steens Mountain area today. A number of crieria distinguish these two species (e.g. Harris 1984; Lundelius 1984). Most of these may be a function of size since *N. lepida* is significantly smaller than *N. cinerea* (Grayson 1983). *N.* cf. *cinerea* and *N.* cf. *lepida* identifications were based primarily on size. *N. cinerea* and *N. lepida* identifications were based on size and dental morphology. In particular, the anterointernal re-entrant angle of the M1 is shallow in *N. lepida* and deep in *N. cinerea* (Harris 1984). Out of a total of 63 M1's, only 8 exhibit a deep re - entrant angle.

Subfamily Microtinae - Microtine Rodents

MATERIAL: 48 mandibles, 22 skull fragments, 22 isolated teeth.

Microtus sp. - Vole

MATERIAL: 21 mandibles, 1 skull fragment, 23 isolated teeth.

Microtus montanus - Montane Vole

MATERIAL: 2 skull fragments.

Lagurus curtatus - Sage Vole

MATERIAL: 6 mandibles, 1 skull fragment, 1 isolated tooth.

REMARKS: Two species of *Microtus* presently occur in the area: *M. montanus* and *M. longicaudus*. These two voles are difficult to distinguish by dental morphology alone (Chomko 1980). *M. montanus* identification was based on constricted incisive foramen and ridged interorbital regions (Maser and Storm 1970). *Lagurus curtatus* identification was based on dental morphology and shape of the incisive foramen (Maser and Storm 1970. *Lagurus* and *Microtus* can also be distinguished by position of the mandibular foramen (Grayson 1983). Most of the Sentinel Cave mandibles have damaged ascending rami. However based on this criterion, three edentulous mandibles were identified as *Lagurus* and eighteen as *Microtus*. The sage vole is generally found in habitats dominated by sagebrush, rabbitbrush, and bunchgrass (Carroll and Genoways 1980). The montane vole prefers wet or moist grasslands (Hansen 1956).

Order Carnivora - Carnivores

Family Mustelidae - Mustelids

Spilogale putorius - Spotted Skunk

MATERIAL: 1 mandible, 1 upper first molar.

REMARKS:Spotted skunks are common inhabitants of dry cliffs and rocky areas in southeastern Oregon (Bailey 1936; Hansen 1956).

Table 23. Alveolar length of the maxillary toothrow of modern *Lepus californicus* and *Lepus townsendii* and the Sentinel Cave lagomorphs. Measurements are in millimeters.

Sample	Mean	N	Range	Standard Deviation
Lepus townsendii	17.0	20	15.1 - 18.2	0.75
Lepus californicus	16.1	18	14.5 - 17.9	0.98
Sentinel Cave	16.2	11	14.5 - 16.7	1.05

APPENDIX C

Number of skeletal elements found in Stratum III, Sentinel Cave. (Frequencies of the other skeletal elements are given in the text.)

Feature / Element	6	8	9	10	13
rib fragments	43	61	40	18	6
skull fragments	447	1208	427	298	61
unfused epiphyses	121	199	65	49	12
vertebrae	566	1019	462	342	79
metapodials	101	215	75	106	22
carpals/tarsals	61	113	33	27	5
phalanges	57	153	71	85	18

APPENDIX D

Percentages of break types exhibited on long bones from Stratum III, Sentinel Cave. (See Appendix A for definition of break types.)

Feature Break	6	8	9	10	13	Average
a	7.3	11.4	3.3	6.6	4.2	8.3
b	45.6	44.9	48.7	52.2	54.2	47.0
c	10.0	7.5	7.5	5.5	10.4	7.8
d	24.5	27.1	33.3	31.3	8.3	27.6
e	12.6	9.1	7.1	4.4	22.9	9.3

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