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ARCHAEOLOGICAL CONSIDERATIONS OF BIVALVE SHELL TAPHONOMY

by

Robert James Muckle

B.A., Simon Fraser University, 1980

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
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ABSTRACT

In order to aid interpretations of shell midden stratigraphy, this thesis examines the sedimentary behaviour of bivalve mollusk shells during and after their initial deposition in archaeological sites. Attention is focussed on the archaeological significance of shell orientation, fragmentation, disarticulation, vertical displacement, and chemical weathering.

The methodology of the research includes a general overview of archaeological interests in bivalve mollusks, a review of pertinent literature on the sedimentary behaviour of shells, experiments involving the cultural discard of shells and human trampling on shell deposits, and an analysis of sediments from two Northwest Coast archaeological sites.

The main conclusion of the research is that accurate interpretations of shell midden stratigraphy depend not only on an understanding of past cultural behaviour, but also on an appreciation of the behaviour of shells as sedimentary particles. The value of using the sedimentary properties of shell in archaeological analysis is restricted by several theoretical and methodological problems. It is clear, however, that an understanding of bivalve shell taphonomy can be used to (i) increase the

reliability of behavioural and environmental inferences supported by shell analysis, (ii) aid the identification of specific activity areas (e.g. secondary refuse deposits of shell), and (iii) assess the level of post-depositional disturbance in shell deposits.

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CHAPTER 1. INTRODUCTION

Archaeological inferences of past cultural behaviour are commonly based on the type, frequency, distribution, and sedimentary properties of material remains in cultural deposits. One of the fundamental stages of archaeological research, therefore, should be the identification of any factors which may bias the patterning of the remains (Schiffer 1983; Wood and Johnson 1978). Unfortunately, delineating the biasing effects of site formation processes on certain classes of material remains is often difficult. This problem is especially evident in archaeological studies of shell middens, explicitly defined in this thesis as any cultural deposit in which animal shells are the dominant class of refuse larger than 1 mm. In particular, the factors which may bias the sedimentary properties of bivalve mollusk shells during and after their initial deposition in archaeological sites are poorly understood.

There are several reasons why it is important to understand how the sedimentary properties of bivalve shells are affected by depositional and post-depositional processes. Bivalve shells provide valuable information on palaeoenvironments and past human activities, including data on the physical environment and age of sites, as well as the diet, population, technology, seasonality, trade, and social organization of past populations. If inferences about these phenomena are to be accepted with confidence, then it is essential that factors which may bias the deposits of shell during and after their initial deposition in archaeological sites be understood. It is further proposed that an understanding of how depositional and post-depositional processes affect the sedimentary properties of bivalve shells is important for delineating specific activity areas in shell middens. Similarly, a knowledge of the sedimentary effects of site formation processes will allow researchers to more confidently assess the level of post-depositional disturbance in shell deposits, thus increasing reliability of stratigraphic interpretations.

Accordingly, the principal objective of this thesis is to examine the sedimentary behavior of bivalve mollusk shells during and after their initial deposition in archaeological sites. Attention is focussed on the dynamics and archaeological significance of the orientation, fragmentation, disarticulation, vertical displacement, and chemical weathering of bivalve shells.

This thesis continues the recent emphasis on taphonomic studies in archaeology. As a sub-field of palaeontology, taphonomy was originally defined as "the science of the laws of embedding" (Efremov 1940), and was initially concerned solely with the post-mortem history of animal remains. Broad usage of the term taphonomy in archaeology, however, includes all considerations bearing upon the life history and sedimentology of non-organic as well as organic remains and it is sometimes equated with the more general concept of site formation processes (Schiffer 1982:960). Although a review of gastropod taphonomy has recently appeared in the archaeological literature (Bobrowsky 1984), and it is not unusual to hear of artifact taphonomy (Shackley 1978) or the taphonomy of human sites (Gifford 1980), the overwhelming majority of taphonomic studies in archaeology have been concerned with vertebrate remains. This thesis represents the first systematic examination of bivalve shell taphonomy in archaeology.

The archaeological implications of bivalve shell taphonomy are made explicit throughout the thesis. A review of previous studies of bivalve shell taphonomy provides the foundation for a basic understanding of how shells can generally be expected to behave as sedimentary particles. Experiments involving the cultural discard of shells and human trampling on shell deposits contribute additional taphonomic information, and an analysis of sediments from two Northwest Coast archaeological sites demonstrates how an appreciation of bivalve shell taphonomy can aid stratigraphic interpretations.

The underlying premise of the research is that information on depositional and post-depositional events and conditions affecting cultural deposits can be obtained by studying the physical and chemical properties of site sediments. This basic tenet has been widely expressed in the archaeological literature (e.g. Hassan 1978; Shackley 1975; Stein 1985).

On a more general level, this thesis also is in accord with the recent trend toward "middle-range" research in archaeology. Middle-range research encompasses those studies which provide information on cause and effect, primarily through actualistic or experimental research, which is a crucial link between data collection and behavioural inferences (Binford 1981; Raab and Goodyear 1984). Binford (1977, 1981), Schiffer (1983), and others have expressed the vital need for more of this type of research in archaeology. Hitherto, however, shell midden archaeology has been largely devoid of middle-range research.

CHAPTER 2. BIVALVE MOLLUSKS AND ARCHAEOLOGY

INTRODUCTION

This chapter provides the essential background to understanding the dynamics and archaeological implications of bivalve shell taphonomy. The first section describes the general biology of bivalve mollusks. Attention is focussed on describing the composition and structure of bivalve mollusk shells as they are key variables which influence their sedimentary behaviour. The significance of these variables is incorporated into later discussions of bivalve shell taphonomy, presented in Chapter 3. The second section of the chapter reviews the human exploitation of bivalve mollusks, focussing on the reasons and antiquity of bivalve mollusk exploitation, as well as the general techniques of bivalve mollusk processing and the deposition of the shells as refuse. Finally, the chapter provides an overview of shell midden archaeology. A new definition of shell midden is proposed, the significance of shell middens, especially with regard to shell analysis is discussed, and the need for taphonomic research, particularly as it may aid interpretations of shell midden stratigraphy, is outlined.

GENERAL BIOLOGY OF BIVALVE MOLLUSKS

This study is concerned with the shells of animals belonging to the molluscan class Bivalvia, alternatively known as bivalve mollusks, Pelecypoda, Lamellibranchiata, or simply shellfish. Mollusks are generally defined as soft, unsegmented invertebrate animals (Yonge 1960:3). Their bodies are usually enclosed in calcareous shells, although there are exceptions (e.g. slugs, octopuses, squid). Distinctive features of bivalve mollusks include bilateral symmetry, lateral compression, and the subdivision of the shell into two calcified valves hinged dorsally by an uncalcified connecting ligament (Cox 1969; Morton and Yonge 1964; Seed 1983; Yonge 1960). Common types of bivalve mollusks include clams, oysters, scallops, cockles, and mussels.

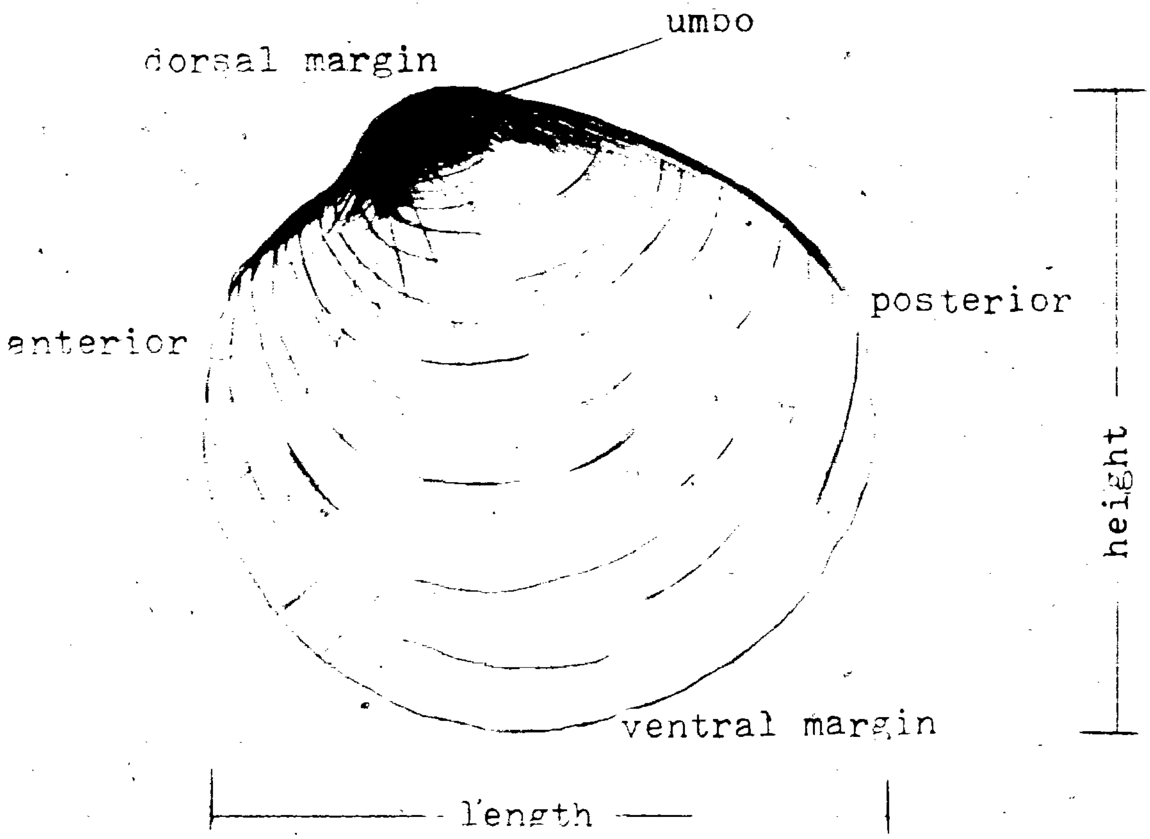
It is estimated that there are approximately 15,000 living species of marine and freshwater bivalve mollusks (Solem 1974). As noted by Seed (1983:12):

> Although they are widespread in a variety of aquatic habitats, their methods of feeding, locomotion, and reproduction effectively exclude them from the terrestrial environment. Most bivalves are relatively sedentary. Many use their straplike foot for burrowing into soft sediments; others attach to or bore into hard surfaces such as rock or wood, whereas a few have become free swimmers.

A complete bivalve mullusk shell consists of two usually convex valves, a connecting ligament, and an outer organic layer called the periostracum. The valves are the most physically and chemically durable components of the shell. The ligament and periostracum, which are mainly protein, are often missing in archaeological contexts.

Major architectural features and principal measurement axes of bivalve shells are illustrated in Figure 1. The terms used in the figure are those found in most standard references (e.g. Abbott 1974; Moore 1969; Tasch 1980). The umbo is the oldest and usually most durable part of the valve and is occasionally referred to as the beak. The end of the shell closest to the mouth or umbo is anterior and the end of the shell closest to the anus is posterior. The margin along which the valves open is ventral. The dorsal margin is where the hinge, consisting of the ligament and calcified hinge teeth, is located. Thickness refers to the distance separating the interior and exterior surfaces of the valves, at any particular location. The region of the valves near the umbo is usually the thickest.

The two valves from the same individual mollusk do not necessarily exhibit the same size, shape, or weight. Depending on species, the valves of mature bivalve mollusks may range in length from less than 1 mm to 1.35 m and weigh up to of 200 kg (Kaestner 1967). The valves of most bivalve mollusks commonly exploited by humans, however, TOP VIEW



SIDE VIEW

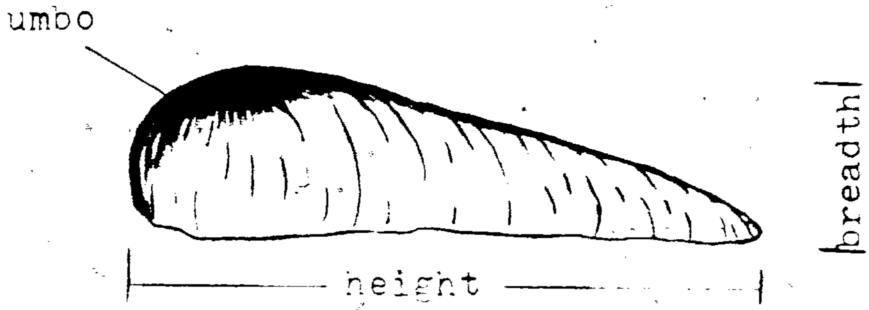


Figure 1. The Bivalve Mollusk Shell (generalized).

such as the various species of mussels, clams, cockles, and oysters, generally range from 5 to 20 cm in maximum dimension.

Bivalve mollusk shell valves are composed of an organic matrix and calcium carbonate. The organic matrix, which rarely exceeds 5% by weight of the total shell (Currey and Taylor 1974), is present between individual crystallites of calcium carbonate as well as between calcified layers of the valve. The form of calcium carbonate is aragonite, calcite, or a combination of both. Although both calcite and aragonite have the same chemical formula; $CaCo_3$, calcite generally contains small amounts of magnesium while aragonite is essentially pure calcium carbonate. The prime control on shell mineralogy is genetic although the ratio of calcite to aragonite may also be a function of sea temperature and salinity (Kennedy et al. 1969; Taylor et al. 1969).

The valves have two or more calcified layers. Each layer has a distinct patterning of calcium carbonate which is referred to as shell microstructure. A minimum of 11 types of shell microstructure have been identified (Kobayashi 1969). Typically, however, in bivalves the outer shell layer has a prismatic microstructure and the inner shell layer has a nacreous microstructure (Gardiner 1972; Quayle and Bourne 1972; Wainwright et al. 1976).

Prismatic microstructure consists of elongate needles or rods of calcium carbonate, polygonal in section, while nacreous microstructure is an aggregation of very thin tablet-like crystallites of calcium carbonate arranged into sheets, which in cross section look like a brick wall.

HUMAN EXPLOITATION OF BIVALVE MOLLUSKS

In general, archaeological and ethnographic literature indicates that the primary objective of bivalve mollusk collection has been to use the flesh as a dietary resource (Bailey 1975, 1978; Meehan 1977a, 1977b, 1982; Meighan 1969; Thomas 1981; Voight 1975). Clearly, however, mollusks may have been exploited as a dietary resource and/or for numerous other purposes. The flesh, for example, may also have been used for baits, dyes, or medicines, and the shells for tools, jewelry, or currency (Biggs 1969; Boyle 1981). Additionally, the shells may have been used to enrich soils or as construction aggregates, such as for pottery temper, deliberate mound formation (Brinton 1872; Peterson 1973), and/or to provide a suitable dry living floor (Bailey 1977; Peterson 1973; Suttles 1951). The sexual symbolism of certain mollusks among native groups has received some attention (Harris 1979:209; Meehan 1982:8), although it is uncertain whether they were ever collected solely with this in mind. It is also worth considering that some bivalve mollusks may have been sought for pearls (Fowke 1902, Jones 1973).

The following general description of bivalve mollusk collection, processing, and deposition is based on the exploitation of bivalve mollusks as dietary resources. The primary reasons for this are that there is little doubt that the dietary value of mollusks was generally the principal reason for collection and details of mollusk exploitation techniques for reasons other than diet are extremely rare in the ethnographic and archaeological literature.

Bivalve mollusks have been exploited by people for a considerable length of time. Shell remains indicate, for example, that bivalve mollusks were included in human diets 400,000 years ago in Europe (deLumley 1975), at least 60,000 years ago in South Africa (Klein 1977; Voight 1973; Volman 1978), and 25,000 to 35,000 years ago in Australia (Bowdler 1977). Along with other aquatic resources, however, the intensive and systematic exploitation of bivalve mollusks has traditionally been thought to have been a late-Pleistocene or Holocene development (Binford 1968; Evans 1978; Isaac 1971).

Based on such factors as nutritional value and ease of exploitation, opinions on the desirability of bivalve mollusks as a dietary resource range from extremely low

(Osborn 1977) to very high (Yesner 1980). As noted by Boyle (1981:27) "The flesh of most bivalves is palatable and rich in protein, lipid, and carbohydrates." It is unlikely, however, that bivalve mollusks have ever been the major dietary resource of people. The unlikely possibility of mollusks constituting the major dietary resource has been illustrated by Bailey (1978), who calculated that for one person to be supplied with enough kilocalories for one day, with no other food eaten, he or she would have to consume 1,400 cockles (Cardium edule), 700 oysters (Ostrea edulis), or 400 limpets (Patella vulgata). It is further reported that the calorific equivalent to one red deer carcass requires 156,800 cockles, 52,267 oysters, or 31,360 limpets (Bailey 1978).

Nothwithstanding the relatively low nutritional value of bivalve mollusks compared to many other dietary resources (Bailey 1978; Osborn 1977; Parmalee and Klippel 1974), they may have been particularly important as a dietary supplement or buffer in times of stress. The value of mollusks as a dietary resource is probably best expressed by Meehan (1982:110), commenting on the diet of contemporary hunter-gatherers in Australia:

> shellfish play many roles in the diet. They are a staple food, a subsidiary food, a snack, and an alternative food source when other subsistence strategies fail.

Although men and children are known to have occasionally helped, the collection and preparation of bivalve mollusks as a dietary resource is generally considered the world over to be a woman's task, occurring as both an individual and group activity (Bowdler 1976; Ham 1982; Meehan 1982; Will 1976). In general, the technology required for bivalve mollusk exploitation was relatively unsophisticated. Species which burrow in substrates could be extracted with digging sticks, while those that cling to rocks could be scraped off, and the mollusks would generally be gathered into some kind of container. As noted by Wing and Brown (1979:94), this could be a "modified gourd, basket, box, or bag made of woven, matted, or netted fabric, or animal skin."

Ethnographic literature indicates that although bivalve mollusks were occasionally opened and eaten raw (Suttles 1951:65), processing of bivalve mollusks generally involved the application of heat in the form of steaming, boiling, or roasting (Bailey 1977; Elmendorf 1960; Meehan 1982; Suttles 1951). As well as making the flesh more palatable, heat causes the valves to open, allowing easy extraction of the flesh from the shell.

The cultural deposition of shells as refuse is very poorly described in ethnographic literature. It has been observed, however, that in temporary camps, shells are likely to be carelessly distributed over the ground surface, while in more permanent camps, shells are left in discrete piles or deposited in specific areas (Meehan 1982; Schumacher 1875). These observations are in agreement with the general notion that the more intense the occupation of a site, the more likely that refuse will be gathered up and re-deposited (Schiffer 1972, 1976). Where shells have been re-deposited into specific areas, it is likely that they were gathered in a basket or other container and then dumped together. However, there are no specific observations to support this expectation.

STUDIES OF SHELL MIDDENS

In order to fully appreciate the archaeological implications of bivalve shell taphonomy, it is necessary to review the significance of shell middens in archaeology, particularly with regard to shell analysis, and methodological problems in shell midden research. This section begins with a proposal for a new definition of shell midden.

Definition of Shell Midden

The presence of bivalve mollusk shells in an archaeological deposit may lead to the designation of that deposit as a "shell midden". Unfortunately, there is no universally accepted definition of shell midden and few researchers make their criteria for classifying a deposit as a shell midden explicit. Confusion over the use of the term shell midden has led Meighan (1969:415) to note:

> So far as the physical nature of the site is concerned, "shell midden" has been applied to any archaeological deposit containing a visible quantity of molluscs. Hence the name has been used for archaeological deposits containing 1% or less of molluscan remains (by weight) as well as deposits composed almost entirely of shell."

Primary areas of concern regarding the use of term shell midden include:

(i) whether the term should be used to describe entire sites or specific deposits within sites,

(ii) whether there should be a minimum quantity of shell in the deposit,

(iii) whether shells introduced by natural agencies should be considered,

(iv) whether shells of non-molluscan animals such as arthropods and echinoderms should be considered,

(v) whether the term should be reserved for describing only <u>in situ</u> deposits,

(vi) whether the term should have a functional connotation, such as being representative of only re-deposited, or secondary refuse, and

(vii) when to use the term shell midden as opposed to one of its variants such as shell heap, shell mound, kitchen midden, kitchen mound, or simply midden.

Recent attempts to define shell midden have focussed on some of these concerns but, in my opinion, are still inadequate. Bowdler (1983), for example, suggests that in order to be classified as a shell midden, at least 50% of the deposit, by weight, should be composed of shell. Due to the relatively high volume of shell in relation to shell weight, however, this definition would likely exclude the vast majority of archaeological deposits currently classified as shell middens. It has been noted elsewhere that where shell deposits contain more than 30% of shell by weight, the rest of the material will be very inconspicuous (Meighan 1969; Shackley 1981).

Another recent definition, which is excessively long without specifying a minimum amount of shell, describes shell middens as:

> accumulations of humanly transported mollusc shells of selected food species, <u>in situ</u>, or substantially so, and typically associated with other archaeological materials including stone artifacts, beach pebbles and various selected stones, charcoal, and vertebrate faunal remains
> (Dortch et al. 1984:83).

In order to simplify and provide more meaning to the term, I propose that shell midden be defined as any cultural deposit in which particles of animal shell are the dominant class of refuse. Other classes of refuse should be sufficiently broad, such as rock or bone, to be directly comparable to the class of animal shell. I further suggest that for ease of calculating the proportions of various refuse classes, only those particles larger than 1mm (i.e. retained by 1 mm mesh during sieving) be considered, and the proportions be calculated by weight. A deposit which contains shell, but does not meet the specified criteria of a shell midden may be described as a shell-bearing archaeological deposit.

The Significance of Shell Middens

Shell middens are a significant class of archaeological deposit for several reasons. They have promoted theoretical interest in why mollusks would be intensively exploited as a dietary resource (Bailey 1975; Osborn 1977; Yesner 1980); contain a "storehouse of information" on maritime adaptation (Sanger 1981); and, due to the release of carbonates from the shell, generally provide excellent preservation of bone and other organic remains. Additionally, because the shells represent a gathering activity, shell middens offer unique opportunities to study the presumed role of women in prehistoric economies (Bowdler 1976), and due to the often thick depositional increments, they provide a physical separation of cultural components not usually found in archaeological sites (Sanger 1981). Further, as outlined in the following section, the shells themselves provide important information about past cultures and palaeoenvironments.

Shell Analysis

Bivalve mollusk shells are an important data source in archaeology. They provide valuable information on palaeoenvironments and past human activities, including data on the physical environment and antiquity of sites as well as the population, technology, seasonality, and social organization of past populations. This information is gleaned largely from identifying the various species of shell in a deposit, examining the relative abundance of shell, and determining when the mollusk died.

The identification of shell species is one of the most common types of shell analysis undertaken in shell midden studies. Two major reasons for undertaking shell identification are (i) to provide an indication of variability in the human diet, and (ii) to support inferences of palaeoenvironments. Because bivalve mollusks express varying tolerances to environmental factors such as water temperature, salinity, wave or current activity, and texture of the substrate, the presence of certain species may be used as indicators of past environmental conditions near the site, including the type of beach or shoreline (Coutts 1970a; Evans 1978; Matteson 1960; Shackleton 1969; Voight 1975). Shell identification may also be used in support of inferences of trade, if shells are deemed to have been transported from outside of a group's normal catchment area.

Calculating the abundance of shell in archaeological sites is another common type of shell analysis. As noted by Ambrose (1967), calculating the abundance of shell in order to make estimations of human diet, the population of the people inhabiting the site, and the antiquity of the deposits has been a major research theme in shell midden archaeology throughout the first half of this century. A fundamental problem with many of these early studies was that in order to make inferences of the antiquity and human population of sites, it was generally assumed that mollusks were the primary food resource, an opinion which is not currently accepted. Further problems included the failure to consider that sites may have been occupied only intermittingly and the failure to consider the post-depositional removal of shell by physical and chemical agents.

Radiocarbon dating has significantly reduced the use of shell abundances to calculate the antiquity of shell middens. It is also worth noting that, with considerable caution, radiocarbon dates can be taken on the shells themselves (Gillespie and Temple 1977).

Recent awareness of the possibility of only intermittent or seasonal occupations of sites and of the relatively minor role of bivalve mollusks in prehistoric human diets have increased the reliability of using shell abundances to make human population estimates. Accordingly, calculations of how many people would be required to create observed densities of shells are not uncommon in recent studies of shell middens (Coutts 1970a; Meehan 1982; Voight 1975).

Another type of shell analysis is concerned with changes in the total amount of shell or various proportions of individual shell species to each other through time. Such changes are commonly used in support of behavioural and environmental inferences. Obvious explanations for changes in the relative abundance of shell through time include (i) changes in the length of site occupation; (ii) changes in the number of people occupying the site; (iii) fluctuating periods of resource stress, altering the need to collect mollusks; (iv) changing availability of species due to environmental change (Coutts 1970a); (v) human overexploitation of certain species (Botkin 1980; Meighan 1969); (vi) changes in food preference (Voight 1975); (vii) advancement in mollusk collection and processing technology (e.g. dredges, larger carrying containers, cooking methods, storage); and, (viii) changes in mollusk exploitative strategies brought about by a development in non-mollusk related cultural activities, such as the development of fish-hook technology in Australia (Bowdler 1976). One further important explanation for changes in the relative abundance of shell through time which has been virtually ignored in archaeological studies is the possibility of differential preservation of shells.

The horizontal distribution of shell also has generally received scant attention in archaeological literature. It may, however, be used in support of inferences of social organization and status. Wessen (1982), for example, used the horizontal distribution of various species of mollusk shells, representative of food residues, decorative items, and manufacturing materials, to infer the relative social standing of individual families and households in a Northwest Coast archaeological site.

One of the most valued aspects of bivalve mollusk shells in archaeological analysis is their use to infer site seasonality. One technique to determine seasonality is based on observations of growth rings on shells. By carefully observing daily and/or seasonal shell growth rings, it is proposed that the season in which the mollusk died can be determined (Coutts 1970b; Deith 1983; Ham and Irvine 1975; Keen 1979), thus leading to inferences of when they were collected and processed. Indications of when the mollusk died can also be obtained through oxygen isotope analysis, in which ratios of ^{16}O to ^{18}O in the shell provide information on seasonal temperature changes (Killingley 1981, 1983; Shackleton 1973). Unfortunately, there are problems with these approaches, including non-seasonal causes for variation in shell growth, non-standardized measurement criteria, and observer error in growth ring analysis (Nicholson 1980). Problems with oxygen isotope analysis include its high cost, as well as questionable assumptions involving inter and intra-species variability, effects of deglaciation, and other factors (Bailey et al. 1983).

There are many other types of shell analysis which are occasionally undertaken. Changes in the size of shells through time, for example, have been explored as a function of human overexploitation as well as environmental factors (Botkin 1980; Dexter 1977; Swadling 1976). Another type of shell analysis involves determining the ratio of calcite to aragonite in the shell. As noted by Coutts (1970a:40);

> it is possible to obtain information about the older oceanic environments by comparing the calcite/aragonite ratios of extant and archaeological shells.

Shell analysis may also include calculating the total weight or biomass of the edible portion of bivalve mollusks, as represented by the shell, in order to estimate the relative importance of the mollusk species to the human diet (Ham 1976).

Notwithstanding the information which can be gleaned from shells in archaeological sites, there are some concerns regarding the reliability and further potential of shell analysis. For instance, there have been few explicit considerations of how depositional and post-depositional processes may have biased the type, abundance, and distribution of shells in sites. Accordingly, behavioural inferences supported by these sedimentary properties cannot always be accepted with complete confidence. It is also clear that the full information potential of shells has not been realized in the vast majority of shell midden studies. There have been relatively few attempts, for example, to use the sedimentary properties of shells, other than the type or relative abundance of shells, as an aid to the identification of site formation processes. In particular, examinations of the orientation, fragmentation, disarticulation, vertical displacement, and chemical weathering of shells in archaeological sites have generally been either completely absent or of a highly cursory nature.

Methodological Problems in Shell Midden Archaeology

As with most classes of archaeological deposits, there are several methodological problems involved in excavation and analysis of shell middens. Specificly, these include distinguishing natural from cultural deposits of shell

(Bailey 1977; Coutts 1966; Gill 1951; Hughes and Sullivan 1974); the high cost of shell analysis (i.e. sorting and weighing) relative to the value of information obtained (Koloseike 1970); and developing adequate sampling and excavation strategies to deal with the frequently huge volumes of the deposit (Bowdler 1983). Perhaps the most fundamental problem in shell midden archaeology is associated with identifying shell midden formation processes.

The significance of identifying shell midden formation processes cannot be overemphasized. If archaeologists wish to use individual and aggregate properties of shells in support of behavioural or palaeoenvironmental inferences, then it is essential that the factors which may bias shell deposits be understood. Particular concerns may include assessing the contemporaneity of shells within the deposit or identifying specific site activity areas (e.g. living floors vs. dumping areas). The fundamental problem in this regard is the lack of criteria which archaeologists can use to reliably assess initial patterns of deposition and post-depositional disturbance. This problem stems from the facts that (i) the initial deposition of shells is very poorly described in ethnographic literature, and (ii) shell midden archaeology has been largely devoid of middle-range research which can link observed phenomena to specific site formation processes.

It is proposed in this thesis that the sedimentary properties of bivalve shells in archaeological deposits can be used to identify initial patterns of deposition and post-depositional disturbance, thus increasing reliability of inferences based on the analysis of the shells or any other clasts associated with shell deposits. In particular, it is thought that conclusions can be drawn regarding the depositional and post-depositional history of shell middens, based on the orientation, fragmentation, disarticulation, vertical displacement, and chemical weathering of their shells. This concept is explored in the following chapters.

CHAPTER 3. INITIAL CONSIDERATIONS OF BIVALVE SHELL TAPHONOMY

INTRODUCTION

As outlined in the previous chapter, bivalve mollusk shells are a traditional subject of theoretical and methodological interest in archaeology. However, very little attention has yet been paid to the sedimentary properties of bivalve shells, other than species identification and relative abundance, and what variations in these properties may mean.

The purpose of this chapter is to provide a basic understanding of how the sedimentary properties of bivalve shells, other than the type and quantity of shell, may aid stratigraphic interpretations and increase reliability of inferences supported by shell analysis. This is accomplished through a taphonomic framework. The orientation, fragmentation, disarticulation, vertical displacement, and chemical weathering of bivalve shells are considered. Attention is focussed on these aspects of sedimentary behaviour because: (i) they form the basis of much of the research data on bivalve shell taphonomy available from palaeontology, sedimentology, and related disciplines, (ii) they are the same types of sedimentary behaviour which have received much attention in archaeological studies of vertebrate taphonomy; and (iii) they are generally amenable to experimentation.

This chapter is largely theoretical in nature. Key shell variables and agents which are likely to control the sedimentary behaviour of shells and their potential archaeological implications are discussed. The need for further research on the sedimentary behaviour of shells, particularly the effects of the initial deposition of shells as refuse, and human trampling on shell deposits is also expressed.

ORIENTATION

In this thesis, the term orientation refers to whether single valves on a bedding plane are positioned concave-side up, concave-side down, or haphazardly, and whether articulated valves are positioned hinge-down, hinge-up, or sideways (Figure 2).

The orientations of shells are rarely recorded in archaeological fieldwork. Based on studies in palaeontology and sedimentology, however, it seems likely that recording the orientation of shells will allow researchers to draw conclusions regarding the conditions of shell deposition and post-depositional disturbance.

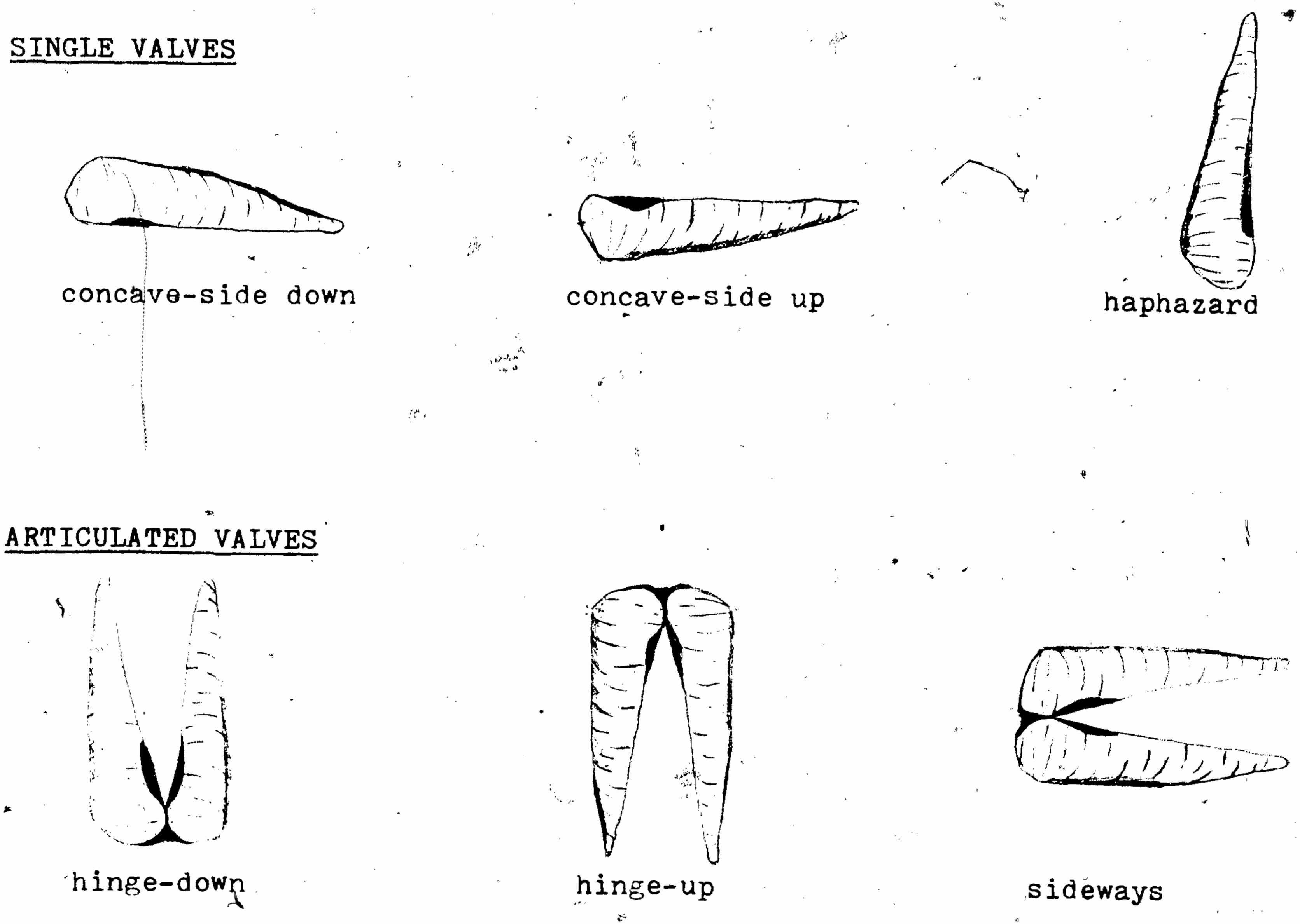


Figure 2. Types of Shell Orientation.

It is widely reported in palaeontological and sedimentological literature that when falling through air or water, bivalve shells will generally land concave-side up (Antia 1980; Clifton 1971; Emery 1968; Muller 1979). This initial orientation is caused by the shape and distribution of the weight in bivalve shells (Toots 1965). The concave-side down orientation is a theoretically more stable position however (Allen 1982), and post-depositional re-orientation often occurs (Boucot 1981; Clifton 1971; Emery 1968; Kelling and Williams 1967).

It has been suggested that a mostly uniform orientation of shells, either concave-side up or concave-side down, is indicative of natural rather that cultural deposition (Gill 1951). This thought has received little consideration in archaeological literature and lacks published experimental data to either support or invalidate the suggestion. In a series of unpublished experiments, however, a total of 312 bivalve shells of various species were thrown down a grassy slope, with over 70% of the valves landing concave-side up (Casey 1982). These results clearly do not support the suggestion that a mostly concave-side up orientation of shell valves is necessarily the result of just natural deposition.

Re-orientation of shell particles may result from several different processes. As noted by Toots (1965), an apparent random or haphazard orientation is more likely to be the result of bioturbation or mass wastage, rather than a primary depositional phenomenon. Aeolian and fluvial processes are other natural processes which may cause re-orientation of shell particles. Notwithstanding the lack of previous attention to the effects of cultural activity on shell orientation, it is likely that human trampling, scavenging for usable shells, and digging in shell deposits may also cause post-depositional re-orientation of shell particles in archaeological sites.

Re-orientation of shell particles may be restricted by an infilling of sediment around the shell, or by the loading of the valve while in the concave-side up position, with sedimentary particles (Allen 1984a, 1984b). Accordingly, researchers may generally expect that shells which have been rapidly buried by accumulating overburden will be more likely to remain in their original position than shells not subject to rapid overburden accumulation.

The archaeological implications of shell orientation are not well-established. It seems likely, however, that upon initial cultural deposition, single valves will tend to land concave-side up and a relatively rapid accumulation of overburden, such as continued dumping of refuse, will preserve that orientation. Accordingly, a shell deposit with valves oriented predominantly concave-side up may be indicative of a specific area for shell discard which has been subject to relatively little post-depositional disturbance. Conversely, valves oriented predominantly concave-side down or haphazardly may be indicative of considerable post-depositional disturbance. Clearly, however, much more research remains to be undertaken before these expectations can be accepted with confidence. Virtually nothing is known of how articulated pairs of shells can be expected to land during cultural discard, or the effects of such fundamental variables as the species of shell, or the force of discard.

FRAGMENTATION

Shell fragmentation refers to the physical separation of two or more parts of a shell valve. The primary consideration of shell fragmentation in this thesis is the size of the shell fragments.

There are several reasons why it is important to understand factors influencing the size of shell particles in archaeological sites. Without an understanding of differential rates of fragmentation according to species, archaeologists may incorrectly interpret differences in particle sizes exhibited by the various species of shell in cultural deposits. It is also important to understand that differential rates of shell fragmentation will bias the types of shell recovered during archaeological excavation, providing false indications of the relative abundance of various species in a deposit. Further, shell fragmentation may reduce the volume and porosity of deposits, affect the post-depositional movement of shell particles, and accelerate shell decomposition (Muller 1979; Schafer 1972). In order to confidently interpret these sedimentary properties in shell middens, therefore, researchers must understand the factors controlling shell fragmentation.

One of the primary agents of shell fragmentation in cultural deposits is undoubtedly human trampling (Maggs and Speed 1967; Voight 1975). Accordingly, delineation of specific areas of activity in shell middens (e.g. shell dumps vs. living floors) is occasionally based on the sizes of shell particles in the deposit (e.g. Conover 1978; Gifford 1916; Gose 1976). In general, it is assumed that areas of complete valves or large fragments of shell have been subject to relatively little human trampling, while small shell fragments are indicative of intense human trampling on shell deposits. It is important to recognize, however, that shell fragmentation by trampling is not well-understood, and besides the commonsensical knowledge that increased trampling is likely to result in smaller particle sizes, no principles or generalizations regarding shell fragmentation by human trampling have yet been established.

Another potential cause of shell fragmentation in archaeological sites is the process of cultural deposition. Particularly where shells have been gathered into containers and re-deposited as secondary refuse, the stress upon the shell when it lands may be sufficient to result in breakage. Similarly, subsequent dumping of refuse may result in breakage of previously deposited shells. Unfortunately, the effects of shell fragmentation resulting from deposition have received virtually no previous consideration in archaeological literature and researchers have little idea of how much particle size reduction occurs from this process.

Another factor deserving consideration in understanding the fragmentation of shells found in archaeological sites is the pressure exerted by overburden. Unfortunately, there has been extremely little research on the weight of overburden as an agent of shell fragmentation. One of the primary reasons for this lack of research is the fact that the effects of overburden weight, combined with weakening of the oldest and lowest shells in the deposit by chemical weathering, which may take thousands of years to accumulate, cannot be reliably and effectively duplicated by experiments. Based on a series of crude experiments on the resistance to crushing of shells however, it has been determined that mollusk shells should generally be able to support an overburden of mud or sand approximately one meter thick before breakage occurs (Allen 1974).

Because shell middens usually contain relatively large amounts of shell, humus, and other organic matter, it can generally be expected that the weight of one meter of shell midden overburden would rarely approach the weight of one meter of mud or sand. One cubic meter of shell midden, composed predominantly of shell, can weigh close to 1,000 kg or more (Bailey 1975; Meehan 1982). Accordingly, the critical overburden thickness of one meter required to crush shells should be used only as a very rough estimate of the minimum thickness required to cause shell fragmentation in archaeological sites.

In addition to the composition of the overburden, there are several other factors which can influence the critical overburden thickness required to cause shell fragmentation. The species and antiquity of the shells, moisture content of the sediments, and the rate of overburden accumulation are certain to be important variables. Shells which are thinner and less durable and/or have been subject to chemical weathering for a considerable length of time, for example, can be expected to break as a result of overburden pressure more readily than thicker, more durable, and/or fresher shells. Also, given a relatively slow rate of overburden accumulation, cementation of the sediments (caused in part by the leaching of calcium carbonate from the shells), may significantly increase the resistance of the shells to fragmentation, substantially increasing the depth of the overburden required to break the shells (Allen 1974).

There are many other agents which may affect shell fragmentation in archaeological sites. Heat, for example, may directly or indirectly lead to shell breakage. With few notable exceptions (Bailey 1977:138; Sanger 1981:40) however, this phenomenon has rarely been considered in the archaeological literature. One study of significance, however, involves a series of experiments which found that by heating shells to about 90°C., their resistance to fracture was reduced up to 30% (Currey 1979).

More research on the variables of shell species, cooking temperatures and times needs to be undertaken before the full significance of heating shells can be understood. Clearly, however, one of the primary archaeological implications of heating shells is that inter or intra-site variability in shell particle sizes may be attributable to whether the shells have been heated and the intensity of that heat. Subject to similar agents of fragmentation, for example, unheated shells can be expected to be less fragmented than heated shells. It is worth considering that heating may be applied in a number of ways. Deliberate cooking is undoubtedly the most common heating agent. However, shells may also have been heated after they have been initially discarded by culturally or naturally ignited fires. In order to get rid of debris, vegetation, and flies, for example, it has been observed that contemporary hunter-gatherers in Australia routinely burn shell-bearing refuse (Jones 1980).

Chemical weathering is another important process which undoubtedly reduces a shell's resistance to fracture of shells. Unfortunately, there has been no previous research on chemical weathering as an agent of fragmentation.

Other causes of shell fragmentation in cultural deposits which have been considered in the archaeological literature include initial collection methods (Coutts 1970a; Morse 1925), wind (Coutts 1969), animal trampling (Voight 1975), freeze/thaw cycles (Brennan 1977), and archaeological excavation and screening (Koloseike 1968). It is also worth considering that shell fragmentation may result from continued abrasion in sediments (e.g. rolling in inter-tidal zones, Driscoll and Weltin 1973), post-depositional transport (Hallam 1967), moving or grounded ice (Boucot 1981), bird action (e.g. regurgitation of shells and deliberate breakage by dropping from the air, Trewin and Welsh 1976; Wilson 1967), the force of waves, accidental or deliberate breakage during the processing of mollusks for consumption (Ellis and Swan 1981), artifact manufacture, and for use as construction aggregates (e.g. pottery temper). However, shell fragmentation by these agents is likely to generally have been of minor significance in most cultural contexts.

The overall morphology of shells clearly influences shell fragmentation. It has been observed in natural environments that, in general, "small, thin, unribbed, convex shells will crush more easily than large, thick, heavily ribbed flat shells" (Fagerstrom 1964:1206). The same characteristics are also likely to control shell fragmentation by cultural agents, although no research on this phenomenon has been undertaken. Further, it is reasonable to expect that subject to the same forces, each species of shell in a deposit will exhibit a different resistance to fragmentation and resulting particle size distributions will vary according to species. Accordingly, when making human behavioural inferences based on variability in the size of shell particles, a primary consideration should be to what extent the particle size differences of shells within and between sites may be attributable solely to the morphological differences in shell species. Additionally, when calculating the abundance of various shell species in a deposit, archaeologists should be aware of the bias that may occur as a result of differential rates of fragmentation among various shell species and subsequent differential rates of recovery of each species. As indicated in previous sieving experiments, there may be a considerable bias in the amount of materials recovered, depending on the size of screen used during excavation and analysis of sediments (Payne 1972; Thomas 1969).

The relationship between shell mineralogy and fragmentation is not clear (Wainwright et al. 1976:233). Concerning the microstructure of shells however, nacreous layers are generally considered to be the most physically durable type (Currey 1976, 1980; Currey and Taylor 1974; Taylor and Layman 1972), and therefore probably the most resistant to fracture by most forces in natural or cultural environments. The implications of this for archaeological research are not fully understood. It seems likely, however, that shells with thick nacreous layers may be more resistant to fracture than shells with thinner nacreous layers.

Some researchers have suggested that certain characteristics of a shell fragment may be indicative of the agent of fragmentation (e.g. Clarke and Clarke 1980; Coutts 1970a; Seilacher 1973). For example, chipped and broken edges may be indicative of opening the shells of living bivalves by prying them open with a sharp instrument (Clarke and Clarke 1980). Similarly, it seems likely that fragments distinguished by the separation of microstructural layers of the shells may result from slow or repeated processes such as freeze/thaw or wetting/drying cycles, or an increase in the rate of chemical decomposition of the organic matrix compared to the microstructural layers it separates. However, there have been no published research studies to demonstrate that edge damage, layer separation, or other characteristics of shell fragments could not have been caused by collection techniques, initial deposition of the shells as refuse, post-depositional human or animal trampling, the weight of overburden, or other processes. Accordingly, more actualistic and experimental studies are clearly required before the characteristics of shell fragments can be used as reliable indicators of site formation processes.

DISARTICULATION

In this thesis, the disarticulation of shell valves refers to the condition where the two valves of the bivalve mollusk shell are no longer anatomically attached by the ligament and hinge. It is not a measure of the distance separating the valves.

In natural environments, ratios of articulated to disarticulated valves have been used to estimate the rigor of post-depositional transportation (Trewin and Welsh 1972), and to a very limited extent, valve disarticulation has been used as a distinguishing criterion of cultural as opposed to natural shell deposits (Brinton 1872; Gill 1951). In general, however, the dynamics and implications of valve disarticulation are rarely considered in the archaeological literature.

The vast majority of bivalve shell valves in archaeological sites are usually disarticulated. It should be appreciated that valve disarticulation may have occurred prior to, during, or after initial deposition and an understanding of the factors controlling valve disarticulation may thus be important for identifying initial patterns of deposition and post-depositional disturbance.

Valve disarticulation prior to initial deposition may have taken place intentionally or accidently. In some instances, the valves of bivalve mollusks were deliberately disarticulated to reduce the volume of mollusks to be transported (Moreau 1978; Meehan 1982). Additionally, some valves may have been accidently disarticulated while they were initially being opened. However, as heating generally opens valves wide enough to extract the flesh without complete disarticulation, and the ligaments of unheated valves usually remain pliable for at least a few hours after collection, it is likely that valve disarticulation prior to discard is generally of minor significance in most cultural contexts.

With regard to valve disarticulation during the initial deposition of shells, it should be appreciated that the force of discard, particularly when the shells have been gathered into some kind of container and re-deposited as secondary refuse, may create sufficient stress on the ligament to result in valve disarticulation. However, there has been no previous research on this phenomenon and archaeologists generally have little idea of how much valve disarticulation occurs as a direct result of deposition.

Post-depositionally, valve disarticulation occurs as a result of ligament decomposition and/or mechanical failure. Valve disarticulation may simply result from the ligament, being almost totally organic, decomposing at a faster rate than the valves, which are largely inorganic. Additionally, stress on the ligament produced by human trampling or the weight of overburden may be sufficient to cause valve disarticulation, especially if the ligament is weakened through chemical weathering.

An influential factor in the process of valve disarticulation is heating. In general, as heating usually opens the valves wide enough to extract the flesh without completely separating the valves, it is unlikely that cooking is a major direct cause of valve disarticulation. However, heating dries the ligament, causing it to become brittle. Of course, the ligaments of shells which have not been cooked, but have dried naturally also eventually become brittle. The primary implication of this is that the ligaments of shells which have been cooked and/or dried will be less resistant to disarticulation during or after initial deposition than shells which have not been heated or dried. Accordingly, a deposit which exhibits a relatively high proportion of articulated valves may be indicative of processing which did not involve the application of heat, or it may be indicative of a fairly rapid burial of the shells, before they had time to dry and become brittle.

Another archaeological implication of valve disarticulation concerns assessing the level of post-depositional disturbance in cultural deposits. It has been suggested that the distance separating valves of the same mollusk may be used as an indicator of post-depositional disturbance, assuming that the valves were articulated upon initial deposition (Koike 1979). There is no previous research to support the assumption that valves remain articulated upon discard however, and more research on valve disarticulation, particularly as it may result from cultural deposition, is clearly needed before this assumption can be accepted with confidence.

Unfortunately, criteria for identifying which agents of valve disarticulation were influential in archaeological sites have not been established. It seems likely, however, that valves which remain close to each other have probably been disarticulated largely as a result of ligament decomposition. Conversely, valves which have been widely separated or thrust over each other are probably indicative of physical dislocation. The valve-pairing technique is described by Koike (1979).

VERTICAL DISPLACEMENT

In this thesis, vertical displacement refers to the post-depositional vertical movement of shell particles, which is important to understand the dynamics of shell displacement for evaluating the stratigraphic coherence of shell middens. In particular, if behavioural inferences are to be based on shell analyses, it is important to know if the shells were deposited contemporaneously with artifacts and other associated clasts, or if the shells were deposited later and subsequently displaced. This knowledge is especially important if shells are used for dating. It is also important to know whether variability in the species of shell present in apparently discrete lenses of shell is due to behavioural or environmental factors or simply the result of post- depositional sorting.

It has been noted that in natural environments, a vertical grading of shells, with the largest particles at the bottom, results from bioturbation (Trewin and Welsh 1976). With the notable exception of the potential of earthworms to move small shell particles (Evans 1972) and totally alter the stratigraphy of shell middens (Stein 1983), however, the vertical displacement of shell in cultural deposits by natural processes has rarely been examined.

Similarly, the effects of cultural processes on shell displacement are rarely considered. It is generally recognized that human trampling may result in substantial vertical displacement of sedimentary particles, especially in loose substrates (Gifford 1978; Gifford and Behrensmeyer 1977; Gifford-Gonzales et al. 1985; Stockton 1977; Villa and Courtin 1983). However, no principles regarding the effects of trampling on the degree of shell displacement have yet been established.

CHEMICAL WEATHERING

In this thesis, chemical weathering refers primarily to the dynamics of shell destruction caused by acids in the sediments.

There are several reasons why it is important to understand the factors controlling the chemical weathering of shells in archaeological deposits. A primary consideration is that differential rates of chemical weathering leads to differential preservation of shells. Accordingly, the relative abundance of various species of shell in a deposit may be influenced by differential rates of chemical weathering, and this potential bias should be taken into account when making inferences of the origin, intensity, and variability of bivalve mollusk exploitation. It is also worth considering that chemical weathering releases calcium carbonate into the associated sediments, generally raising the pH and thus increasing preservation of organic remains. Insofar as the differential preservation of shell results in the differential settling of deposits (Sanger 1981), an understanding of factors controlling the chemical weathering of shells may also aid interpretations of overall site morphology. Further, as chemical weathering can generally be expected to reduce the strength of shell ligaments and valves, an understanding of factors controlling the chemical weathering of shells may be useful in interpretations of valve disarticulation and fragmentation.

Carbonic acid, formed by the presence of water with carbon dioxide and present in all rain and groundwaters, is the most common geologic solvent of calcium carbonate (Friedman and Sanders 1978:134). This fact has been recognized by several researchers, who contend that variability in the amount of rain and groundwater percolation explains intra and inter-site variability in shell abundance. Sullivan (1984), for example, explains a decreasing amount of shell with increasing depth as a result of more ground water percolation in the lower levels of a site. Similarly, Hughes (1980, 1983) suggests that differences in the amount of rainwater percolation explains the fact that shell in some Australian sites has been preserved for 7,000 years while shell in other sites only lasts 3,500 years.

The potential of extreme changes in site structure resulting from percolating rain and groundwater has also been recognized. Hughes and Lampert (1977), for example, suggest a typical shell midden (i.e. composed of 70% shell, by volume), will be reduced to one-third of its original volume by the complete removal of shell in solution.

Other agents of chemical weathering include the acids produced by the decay of faunal and floral remains. As noted by Muller (1979:56):

> In general, the greater the content of organic material within the sediment, the greater the possibility for the dissolution of calcareous shell material.

Further potential agents of chemical weathering of shell in archaeological deposits include acids produced by the weathering of minerals in site sediments (Friedman and Sanders 1978), urine (Koloseike 1968), and bacteria (Muller 1979). However, these agents are likely to have been of only minor significance in most archaeological contexts.

Sedimentological studies indicate that small, thin, and fractured shell particles are likely to be the most rapidly dissolved (Muller 1979; Schafer 1972). Differential shell preservation according to species can therefore be expected. Bivalve mollusks which have relatively small and thin shells will not generally be represented as well archaeologically as bivalve mollusks with larger and thicker shells. This bias may lead to incorrect inferences of the prehistoric cultural importance of various species of bivalve mollusks.

Additionally, because fragmentation increases the rate of chemical weathering, shells which have been broken by trampling, cultural deposition, overburden weight, or other processes will not be preserved as well as large fragments or complete valves, even if the species of shell is the same. One of the primary implications of this is that evidence of intensely trampled areas, as expressed by highly fragmented shells, can be expected to be removed at a faster rate than evidence of areas in which shell is relatively undisturbed by agents of fragmentation. For example, shell dumps may remain clearly visible, while housefloors or other areas subject to high rates of shell fragmentation may be difficult to delineate, even if the species and original quantities of shell in each deposit are similar.

PROMINENT PROBLEMS

This chapter has outlined some of the implications of bivalve shell taphonomy in archaeological research. It is clear that many factors can influence the sedimentary properties of bivalve shells in archaeological sites and an understanding of these factors will aid interpretations of shell midden stratigraphy. However, there are many problems concerning the behaviour of shells as sedimentary particles in archaeological sites. In particular, there is little understanding of how depositional and post-depositional cultural processes affect shell deposits. It is especially important to understand the sedimentary effects of the initial cultural deposition of shells before archaeologists can adequately assess post-depositional disturbance in shell middens and reconstruct past cultural behaviour. Similarly, human trampling is a process which occurred on all archaeological sites, yet its sedimentary effects on shell deposits has never been examined.

With regard to the initial deposition of shells, important questions which remain unanswered involve understanding how the orientation, disarticulation, and fragmentation of shells are affected by the species of shell being discarded and the force of discard. Concerning the effects of human trampling, it would be useful to know how the fragmentation and vertical displacement of shells are affected by the species of shell being trampled upon and the intensity of trampling. These questions have led to the design of experiments which are discussed in the following chapters.

CHAPTER 4. CULTURAL DISCARD EXPERIMENTS

INTRODUCTION

As outlined in the previous chapters, it is important to understand the dynamics and implications of bivalve shell taphonomy in order to properly interpret the stratigraphy of shell middens and accept behavioural inferences supported by shell analysis with confidence. One of the prominent problems in this regard is the lack of knowledge concerning how the sedimentary properties of bivalve shells are affected by initial deposition of shells as refuse. Accordingly, this chapter presents the results of experiments intended to elucidate the sedimentary effects of the initial cultural deposition of shells in archaeological sites. Attention is focussed on shell orientation, fragmentation, and disarticulation.

MATERIALS AND METHODS

Table 1 provides a summary of the shells used in the discard experiments. The specimens of <u>Protothaca staminea</u> (native littleneck clam) and <u>Venerupis japonica</u> (Japanese littleneck clam) were collected live from Pacific Ocean beaches of British Columbia. The specimens of <u>Mytilus edulis</u> (edible mussel) were bought live from a market in Vancouver, British Columbia, but were originally collected

Table 1. Summary of Shells Used in Discard Experiments

Shell Species	Time Since Death	Total No. of Valves	Mean Valve Height (cm)	Mean Valve Length (cm)	Mean Valve Breadth (cm)	Mean Valve Weight (grams)
Protothaca staminea	1 year	875	3.51	3.88	1.14	5.14
Protothaca staminea	2 days	90	4.38	4.72	1.37	7.68
Mytilus edulis	2 days	242	2.56	4.71	1.05	1.71
Venerupis japonica	2 days	116	3.90	4.73	1.08	6.28

from the east coast of North America.

Processing involved cooking approximately equal numbers of each species by steaming, boiling, and baking. They were cooked until the valves opened. This generally took from 10 to 20 minutes. The shells subject to each cooking technique were not kept separate during the discard experiments. Consequently, the precise effects of each cooking technique cannot be determined.

After cooking, the shells were left dry and indoors for the period prior to the experiments. The measurements of the shells, as outlined in Table 1, were taken on the valves after cooking and drying.

Table 2 illustrates the research design of the experiments. The major variable examined was the species of shell. Variability in the height of discard, the number of valves, and the ratio of articulated to disarticulated valves were also examined. A further distinction was made between fresh and old shells of <u>Protothaca</u> <u>staminea</u> (i.e. 2 days vs. 1 year since death) because it was thought that the increased drying time may have reduced their resistance to fragmentation and disarticulation. The older <u>Protothaca</u> shells were used in experiments 1, 2, 3, 4, 5, 14, and 15. The fresh <u>Protothaca</u> shells were used in experiments 6, 7, 8, and 9. All valves were subject to only one dumping event, except those in experiment no. 15, which were

Table 2. Research design of discard experiments

Experiment No.	Shell Species	Height of Discard (m)	No. of Articulated Pairs of Valves	No. of Single Valves
1	*Protothaca s.*	0.7	0	133
2	*Protothaca s.*	1.0	0	133
3	*Protothaca s.*	2.0	0	133
4	*Protothaca s.*	0.7	10	0
5	*Protothaca s.*	1.0	10	0
6	*Protothaca s.*	0.7	10	0
7	*Protothaca s.*	1.0	10	0
8	*Protothaca s.*	1.0	2	21
9	*Protothaca s.*	2.0	2	21
10	*Mytilus e.*	1.0	24	31
11	*Mytilus e.*	2.0	24	31
12	*Mytilus e.*	1.0	38	8
13	*Venerupis j.*	1.0	58	0
14	*Protothaca s.*	0.7	218	0
15	*Protothaca s.*	1.0	111	214

previously discarded in experiment no. 14.

A plastic bucket, 29 cm deep and 30 cm in diameter was used for discarding the shells. They were discarded from the bucket onto a level loam substrate. Shells discarded from .70 m above the ground surface were thrown in a forward motion. Shells discarded from 1.0 and 2.0 m above the ground surface were dumped by tipping the bucket of shells directly upside down. Due to the lack of detailed ethnographic observations on shell discard, the size of bucket, height of discard, number of valves, and ratio of articulated to single valves discarded were chosen arbitrarily.

Hundreds of experiments and many thousands of shells would be required to test all possible combinations of variables. The 15 individual discard events examined in this chapter represent an initial attempt to understand the sedimentary effects of shell discard. The combinations of variables examined were chosen primarily to obtain information on how shell species differences affects the orientation of articulated and single valves.

Shell orientation was recorded as the number of single valves landing concave-side up, concave-side down, or haphazardly, and the number of articulated pairs of valves landing hinge-up, hinge-down, or sideways (Figure 2, p. 28). Disarticulation was recorded by noting the number of articulated pairs of valves in each experimental run before and after discard. A crude measure of shell fragmentation was made by recording the number of valves that remained larger than one-half of their original size. Observations were also made on the occurrence of edge damage and the separation of microstructural layers of shell valves.

RESULTS

The complete results of the discard experiments are presented in Apppendix A. As is evident, variations in the number of valves discarded together and the antiquity of the shells (i.e. 2 days vs. 1 year since death) were generally insignificant. Indications are, however, that discarding shells from a greater height generally results in increased disarticulation and fragmentation. Further, the results of experiments 14 and 15 indicate that an initial dumping of shells significantly reduces further resistance to disarticulation and fragmentation when the shells are re-deposited.

Orientation

The overall orientation of single valves was 65% concave-side up, 34% concave-side down, and 2% haphazard. The overall orientation of articulated pairs of valves was 47% hinge-down, 18% hinge-up, and 35% sideways. Table 3 illustrates the orientation of shells according to species. The orientation of articulated pairs of *Venerupis japonica* valves was not recorded.

Valve Disarticulation

Fifty-six percent of the articulated pairs of valves became disarticulated. Disarticulation according to species is illustrated in Table 4.

Fragmentation

Overall, 10% of the valves were reduced to less than one-half of their original size. Fragmentation according to species is illustrated in Table 5. The fragments were generally irregular in shape, with edge damage occurring on several valves. There was no separation of the microstructural layers of the valves.

DISCUSSION

The results of these experiments provide some insight into the effects of cultural discard of bivalve mollusk shells, contributing to an increased appreciation of factors governing the orientation, fragmentation, and disarticulation of bivalve shells in archaeological sites. In general, the results indicate that single valves will tend to initially land concave-side up and articulated pairs of valves will land hinge-down or sideways. Further, as a result of initial deposition, some fragmentation and disarticulation of shells can be expected.

Table 3. Orientation of Discarded Shells.

	Protothaca staminea	*Mytilus edulis*	*Venerupis japonica*
Single Valves			
concave-side up	61%	72%	75%
concave-side down	35%	28%	25%
haphazard	3%	0	0
Total	99%	100%	100%
Articulated Pairs of Valves			
hinge-down	24%	60%	-
hinge-up	4%	22%	-
sideways	72%	18%	-
Total	100%	100%	-

Table 4. Disarticulation of Discarded Shells.

Species	Percentage of Articulated Pairs of Valves Disarticulated as a Result of Discard
Protothaca staminea (1 year since death)	58%
Protothaca staminea (2 days since death)	75%
Mytilus edulis	42%
Venerupis japonica	60%

Table 5. Fragmentation of Discarded Shells.

Species	Percentage of Shell Valves Reduced to Less than One-half of their Original Size as a Result of Discard
<u>Protothaca staminea</u> (1 year since death)	10%
<u>Protothaca staminea</u> (2 days since death)	5%
<u>Mytilus edulis</u>	2%
<u>Venerupis japonica</u>	34%

The species of shell is clearly an important variable governing shell orientation, fragmentation, and disarticulation. The height of discard, the number of valves discarded together, and the antiquity of shells do not appear as significant factors in these experiments.

The results of the experiments support previous studies of bivalve shell taphonomy. The dominantly concave-side up orientation of single valves is in accord with the general notion in sedimentological studies that shell valves will tend to be initially deposited concave-side up (e.g. Emery 1968; Muller 1979). The orientation results are also in agreement with a previous unpublished experimental study of shell orientation in archaeology which demonstrated a tendency for shell valves to land concave-side up upon cultural deposition (Casey 1982). The disarticulation results support the notion that the strength of valve articulation varies according to species (Trewin and Welsh 1972). With regard to the orientation of articulated pairs of valves and shell fragmentation, the results are not directly comparable to any previous studies. The results do illustrate, however, that the species of shell is an important variable in these aspects of sedimentary behaviour.

The orientation results may be of significant value with regard to assessing the level of post-depositional disturbance in shell middens. The fact that shell valves exhibited a marked tendency to land concave-side up means that a deposit in which the majority of valves ~~are~~ oriented concave-side up has probably been subject to relatively little post-depositional disturbance.

Conversely, a deposit in which the majority of shells are not oriented concave-side up may be an indication of post-depositional disturbance. Re-orientation of shells from the concave-side up position could occur either while the shells were exposed on the ground surface or after they were buried. Human trampling, scavenging, and subsequent refuse deposition are major agents which could re-orient shells while they were still exposed. Bioturbation and deliberate digging in shell deposits by humans are likely the major agents of the re-orientation of buried shells.

It should be appreciated, however, that using shell orientation to assess the integrity of shell deposits is complicated by the fact that not all valves are disarticulated prior to or during the discard process. As the results of the experiments indicate, the orientation of articulated valves is substantially different than the orientation of single valves upon initial deposition. One of the implications of this is that the decomposition of the ligaments of articulated valves will result in a large proportion of single valves being oriented in a haphazard or concave-side down position.

It should also be appreciated that valves deposited into a pit or onto a rough surface will not necessarily tend to assume a concave-side up position. As noted by Toots (1965:68):

> The most stable position of a dead animal or any part of its skeleton will have a different orientation on an inclined surface than on a level one and the stable position within a depression may be still different.

With particular regard to discarding shells into pits, it is reasonable to expect that where there is not sufficient space for each valve to land on the exposed ground surface, a haphazard orientation of valves will result.

These experiments further demonstrate that the initial deposition of shells in archaeological sites is a primary agent of valve disarticulation. The principal archaeological implication of this concerns the use of the distance separating valves to assess the level of post-depositional disturbance in shell middens. As noted by Koike (1979:69), in order to use valve separation to assess the level of post-depositional disturbance, it must be assumed that the valves remain articulated upon discard. This is a very big assumption and one that is not supported by the results of the experiments reported here.

It is also important to note that some valve fragmentation occurs as a result of initial deposition of shells. The crude measure of shell fragmentation used in the experiments precludes the establishment of detailed principles regarding the relationship between shell fragmentation and the cultural deposition of shells. However, it is demonstrated that the species of shell is a key variable in fragmentation. It is further clear that the size of most shell fragments resulting from cultural discard remain relatively large. Accordingly, the initial deposition of shell can generally be ruled out as a major agent of fragmentation in deposits of highly fragmented shells.

The fragmentation results further indicate that edge damage to shells may result from cultural deposition of the shells as refuse. Therefore, edge damage is not a reliable indicator of prying open living bivalves, as suggested by Clarke and Clarke (1980). It is also evident that separation of valve microstructural layers is not likely to result solely from the process of cultural deposition.

CHAPTER 5 TRAMPLING EXPERIMENTS

INTRODUCTION

As pointed out in previous chapters, in order to correctly interpret shell midden stratigraphy and accept behavioural inferences supported by shell analysis with complete confidence, it is important to understand the dynamics of bivalve shell taphonomy. A prominent problem in this regard is a notable lack of research on the sedimentary effects of human trampling on shell deposits. Accordingly, this chapter presents the design, results, and a discussion of experiments intended to elucidate the effects of human trampling on shell deposits. Attention is focussed on shell fragmentation, although the vertical displacement of shell particles is also considered.

MATERIALS AND METHODS

This chapter reports on two distinct groups of trampling experiments, referred to as the Series A and the Series B experiments. The Series A experiments were designed to obtain information solely on shell fragmentation. The Series B experiments were designed to obtain information on both the fragmentation of shells and the vertical displacement of shell particles.

Table 6 provides a summary of the shells used in the experiments. The Series A shells were collected from the refuse deposit of a historic shellfish cannery at Crescent Beach, on the southern coast of British Columbia. All the shell valves collected from the deposit were disarticulated and, with the exception of occasional edge damage, were not broken. The precise antiquity of the shells has not been determined. However, as the cannery ceased operation in the early 1960s, it can be assumed that the shells have been in the deposit for at least 20 years. The Series B shells were drawn from the same collection utilized in the cultural discard experiments (see pp. 50-52).

Table 7 illustrates the research design of the trampling experiments.

In the Series A experiments, the deposits of experiments 1, 2, and 3 were composed solely of *Saxidomus giganteus* (butterclam), *Protothaca staminea* (native littleneck clam), and *Mytilus edulis* (edible mussel) respectively. The deposit of experiment 4 was composed of equal proportions (by weight) of each species. Each deposit to be trampled in the Series A experiments was placed on a bed of assorted whole and broken shells in an area measuring 60 X 40 cm. The shell bed was overlaid with

Table 6. Summary of Shells Used in Trampling Experiments.

Shell Species	Total No. of Valves	Mean Valve Height (cm)	Mean Valve Length (cm)	Mean Valve Breadth (cm)	Mean Valve Weight (grams)
Series A Experiments					
Saxidomus giganteus	87	5.95	6.64	1.78	21.10
Protothaca staminea	203	3.93	4.29	1.39	9.02
Mytilus edulis	374	2.79	4.93	0.91	2.90
Series B Experiments					
Protothaca staminea (1 year since death)	875	3.51	3.88	1.14	5.14
Protothaca staminea (2 days since death)	90	4.38	4.72	1.37	7.68
Mytilus edulis	242	2.56	4.71	1.05	1.71
Venerupis japonica	116	3.90	4.73	1.08	6.28

Table 7. Research Design of Trampling Experiments.

Experiment No.	Shell Species	Weight of Deposit (grams)	Total No. of Passages	Substrate
Series A				
1	<u>Saxidomus</u> <u>g</u>.	1500 (71 valves)	640	shell
2	<u>Protothaca</u> <u>s</u>.	1500 (166 valves)	640	shell
3	<u>Mytilus</u> <u>e</u>.	750 (259 valves)	640	shell
4	Mixed	1000	640	shell
Series B				
5	Mixed	685	100	shell
6	Mixed	685	1000	shell
7	Mixed	685	100	loam
8	Mixed	685	1000	loam

a sheet of plastic to prevent mixing between the substrate and the deposit being studied. Approximately one-half of the shells were placed concave-side up and one-half of the shells were placed concave-side down. Each deposit was then subjected to a total of 640 trampling passages. A trampling passage is defined as the investigator (myself), weighing 65 kg. and wearing hard, rubber-soled shoes, walking over the deposit, with one foot striking the shells. At intervals of 80, 160, 320, and 640 passages, the deposits of experiments 1, 2, and 3 were subject to mechanical shaking through a series of nested sieves measuring 32, 16, 8, 4, and 2 mm, the weight of fragments in each sieve was recorded, and except after 640 passages, returned for further trampling. The particle size distribution of the deposit of experiment 4 was recorded only after 640 passages.

In the Series B experiments, each deposit was composed of approximately 80% old Protothaca staminea shells (one year since death), 10% fresh Protothaca staminea shells, 7% Venerupis japonica shells, and 3% Mytilus edulis shells (by weight). Large fragments (i.e. larger than 32 mm) as well as complete valves were included. The shells to be trampled on a nonpermeable, shell substrate (experiment 5 and 6) were placed on a bed of assorted broken shell in an area measuring 30 X 30 cm. A polypropelene tarp was laid over the shell bed acting as a substrate to prevent mixing with the deposit being studied. The shells to be trampled on a permeable, loam substrate (experiments 7 and 8) were placed in an area measuring 30 X 30 cm on a level loam substrate. The shells were then subjected to a pre-determined number of passages (i.e. 100 or 1000). When the trampling was completed, the weight of the shell in the size ranges 32-16 mm, 16-8 mm, 8-4 mm, and 4-0 mm were recorded. With regard to the shells trampled on the loam substrate, the trampled areas were excavated by 2 cm levels to a depth of 10 cm and the weight of shell from each level recorded. Observations were also made on the occurrence of edge damage and the separation of the microstructural layers of the shell valves.

RESULTS

The complete results of the trampling experiments are presented in Appendix B. Four mm has arbitrarily been chosen as the best size to illustrate shell fragmentation as a function of trampling in the Tables and Figures.

Shell Fragmentation

The Series A experiments clearly demonstrate variability in particle size reduction according to shell species and the number of trampling passages. After all the trampling passages, only 61% (by weight) of purely

Mytilus edulis particles were retained by sieves measuring 4 mm and larger. In comparison, 85% of Saxidomus giganteus, 93% of Protothaca staminea, and 74% of the mixed deposit were retained by sieves measuring 4 mm and larger. Figure 3 illustrates the overall particle size distribution according to species. A graph of the results (Figure 4) illustrates considerable variation in the rate of reduction. Mytilus edulis shells exhibit a significant decrease in the rate of reduction after 160 passages, Protothaca staminea shells exhibit a relatively constant rate of reduction throughout the experiments, and Saxidomus giganteus shells exhibit an increasing rate of reduction after 320 passages.

With regard to the Series B experiments, Table 8 illustrates particle size reduction as a function of trampling intensity and permeability of the substrate. An increase in the number of trampling passages clearly produces increased particle size reduction. Additionally, a permeable substrate is demonstrated to reduce shell reduction by trampling. Edge damage was common on all types of shell and several fragments of Mytilus edulis exhibited separation of the nacreous and prismatic microstructural layers.

Vertical Displacement

Table 9 illustrates the percentage of shell (by weight) displaced downward through a loam substrate by trampling.

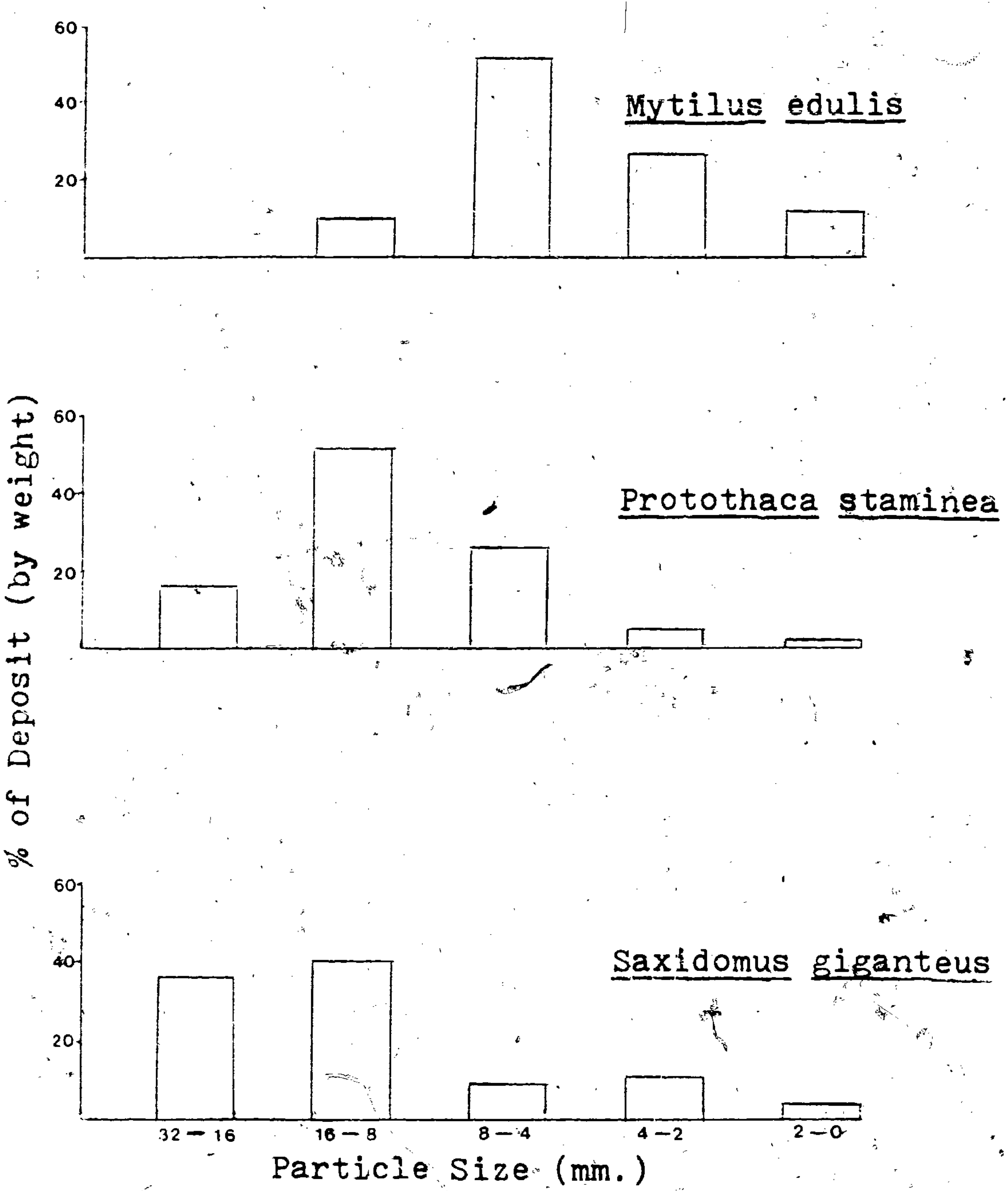


Figure 3. Shell Particle Size Distribution, Series A Experiments. Percentages were recorded after 640 trampling passages on separate deposits of *Mytilus edulis*, *Protothaca staminea*, and *Saxidomus giganteus*.

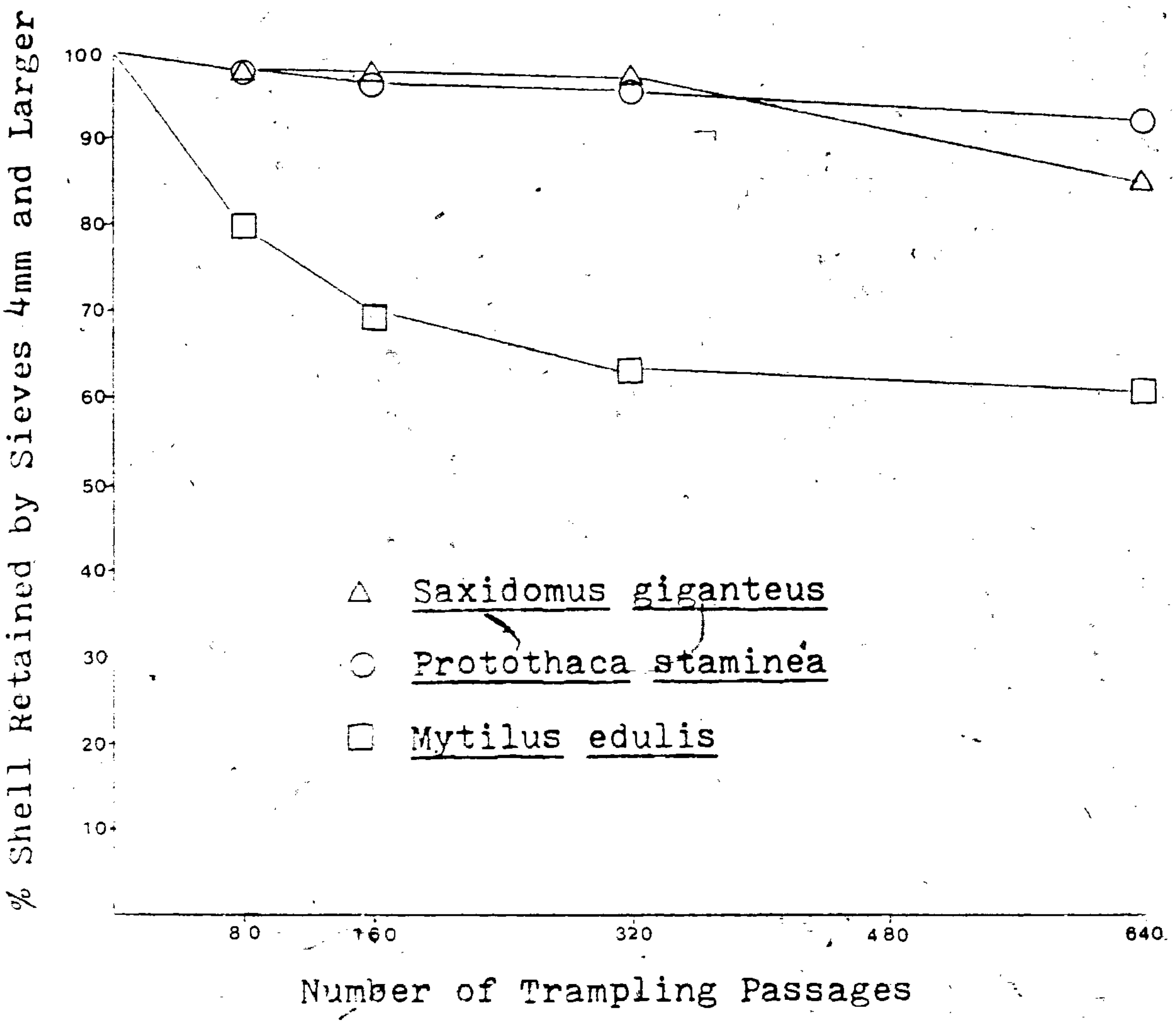


Figure 4. Rate of Shell Fragmentation During Trampling. Percentages were recorded on separate deposits of *Mytilus edulis*, *Protothaca staminea* and *Saxidomus giganteus*.

Table 8. Shell Fragmentation as a Result of Trampling, Series B Experiments.

Experiment No.	No. of Passages	Substrate	Percentage of Shell Retained by sieves of 4 mm and larger
5	100	shell	94%
6	1000	shell	80%
7	100	loam	96%
8	1000	loam	87%

Table 9. Shell Displacement as a Result of Trampling

Depth Below Surface	Percentage of Shell Recovered	
	Experiment # 7; 100 Passages	Experiment # 8; 1000 Passages
0 - 2 cm	99%	96%
2 - 4 cm	1%	3%
4 - 6 cm	0	1%
6 - 8 cm	0	0
8 - 10 cm	0	0

Overall, a relatively low proportion of shell particles was displaced more than 2 cm. It has been established, however, that at least one particle from each size range smaller than 32 mm was displaced by more than 2 cm.

DISCUSSION

These experiments provide some insight into the effects of trampling on shell deposits, contributing to an increased appreciation of the factors governing the fragmentation and vertical displacement of shells in archaeological sites. In general, the results illustrate that as a function of human trampling, the particle size distribution of shells is dependent on both the species of shell and the number of trampling passages. Further, some vertical displacement of shells can be expected as a result of human trampling.

The fragmentation results are in accord with the general notion in shell midden studies that the degree of shell fragmentation reflects the intensity of human activity on a shell deposit. They also support the contention that particles on permeable substrates will be less subject to fragmentation than particles on more resistant substrates (Wilk and Schiffer 1979). The results are also comparable to an experimental study of potsherd fragmentation, which demonstrated continual reduction in sherd size with continued trampling (Kirkby and Kirkby 1976).

The vertical displacement of shell particles, as demonstrated in the experiments, is in agreement with the general notion in archaeological studies that considerable displacement of particles can occur as a result of trampling, depending on the number of trampling passages and the permeability of the substrate (e.g. Gifford 1978).

The fragmentation results clearly illustrate the potential of differential recovery of various species of shell in archaeological excavations, depending on the size of screen used during excavation and/or analysis. In these experiments, for example, of shells subjected to the same number of trampling passages (i.e. 640), only 61% of Mytilus edulis shells, as opposed to 93% of Protothaca staminea shells were recovered by sieves measuring 4 mm and larger. However, 88% and 98% of Mytilus edulis and Protothaca staminea shells respectively were recovered by sieves measuring 2 mm and larger. The primary implication of this concerns assessing the relative abundance of each species of shell in a deposit and inferences of the cultural importance of each species based on abundance. The smaller the screen sizes used in excavation and analysis, the more accurate the relative proportions of various shell species are likely to be.

The fragmentation results may be of further significance with regard to assessing the intensity of trampling activity on shell deposits. It is impossible to reliably predict the exact number of trampling passages which would be required to create observed particle size distributions of shells in archaeological sites. Clearly, however, it can be expected that subject to the same amount of trampling in similar environments, relatively thin and weak shells, such as those of Mytilus edulis, will be reduced to a significantly greater degree than thicker and stronger shells of most clams, oysters, and cockles. Notwithstanding the limitations of experimental data, it can further be expected that in order to create a deposit in which 50% or more of the shell is not retained by a 4 mm screen, a minimum of several thousand trampling passages would probably be required.

Understandably, an explicit consideration of the similarity of the species of shell in deposits will increase confidence in interpretations of inter and intra-site variability in shell particle size distributions. One's confidence in interpetations of variability in particle size distributions will also be increased if the permeability of substrates are compared.

The fragmentation results also indicate that edge damage to valves may occur as a result of trampling, as well as cultural deposition, and therefore is not a reliable indicator of prying open living bivalves, as suggested by Clarke and Clarke (1980). The fact that the nacreous and prismatic layers of several Mytilus edulis fragments became separated as a result of trampling indicates that layer separation is not necessarily the result of chemical weathering. Clearly, more research is needed before these characteristics of shell fragments may be used as reliable traces of formation processes.

Although not clearly demonstrated in the experiments, it seems probable that, subject to continued trampling, shells will eventually be reduced to a size where no further fragmentation will occur. Additionally, it is likely that this equilibrium size will vary according to species.

Similarly, the vertical displacement of shell particles is likely to cease after a certain number of passages, depending on the permeability of the substrate. However, the relatively elementary study of shell displacement in these experiments does not allow the establishment of detailed principles regarding shell displacement as a function of trampling.

There are many variables of trampling on shell which remain to be adequately studied. For example, the weight of the person trampling, the type of footwear worn, the orientation of valves, the thickness of the deposits, and the proportion of shells to other particles in the deposit are undoubtedly important variables affecting shell fragmentation, yet their precise effects are unknown. It should also be appreciated that previous studies of trampling suggest that walking produces a significantly greater force on sediments than standing and walking downhill produces a significantly greater force than walking uphill (e.g. Harper et al. 1961; Liddle 1975; Weaver and Dale 1978). These factors may potentially be important in determining the direction of human travel on sloping pathways and the delineation of activity areas.

CHAPTER 6 A CASE STUDY IN BIVALVE SHELL TAPHONOMY

INTRODUCTION

In the previous chapters, the dynamics and archaeological implications of bivalve shell taphonomy have been discussed. It is clear that many factors affect the sedimentary properties of bivalve shells during and after their initial deposition in archaeological sites, and the identification of such factors will increase confidence in interpretations of shell midden stratigraphy. So far, however, discussions of bivalve shell taphonomy have been of a generally theoretical nature. Although I have attempted to relate the general principles of bivalve shell taphonomy and the data from the experiments to actual archaeological problems (e.g. the identification of shell midden formation processes), it would be useful to examine actual shell midden deposits with consideration of the taphonomic factors outlined in previous chapters.

Accordingly, this chapter discusses the results of a taphonomic analysis of shells from two Northwest Coast shell middens. Attention is focussed on (i) the relative proportion of shell to other clasts (by weight), (ii) the particle size distribution of shell, and (iii), the relative proportion of individual shell species to each other (by weight). Variability in these sedimentary properties are examined within one column sample from each site.

BACKGROUND

Data used for this analysis come from column samples taken from archaeological sites DeRt 1 and DeRt 2, known as the Pender Canal sites. These sites, separated by approximately 100 meters, are located on North Pender Island, in the Strait of Georgia, British Columbia. The excavation and analysis of DeRt 1 and DeRt 2 is a three year joint project, initiated in 1984, between Simon Fraser University and the British Columbia Heritage Conservation Branch, directed by R. L. Carlson. Complete site descriptions and preliminary analyses can be found in the report of the 1984 excavations (Carlson 1985).

The relationship of these sites to each other and the formation of the deposits are not yet fully understood. However, preliminary results indicate that the time span represented by these sites dates from approximately 5,000 years ago to the historic period. The main period of occupation of DeRt 1 occured between 2,600 and 400 B. P. and the main period of occupation of DeRt 2 occured between 4,000 and 2,500 B. P. Both sites have a relatively large proportion of shell, and exceed 2.0 meters in depth in portions of the deposits. Additionally, both sites exhibit a fairly complex stratigraphy, being composed of numerous species of mollusk remains, rock features, artifacts, bones, and other organic and inorganic matter.

One column sample from each site provides the basis of this analysis. The column sample from DeRt 1 was taken from one of the deepest excavation units, reaching a depth of 2.8 meters below the ground surface (Excavation Unit 6 - 8 N.; 27 - 28 W). The column sample from DeRt 2 was taken from an excavation unit reaching a depth of only .70 meters below the ground surface (Excavation Unit 22 - 24 S.; 22 - 24 W.).

The column samples were removed in arbitrary 10 cm levels, corresponding to the levels in which the units were excavated. In total, there were 27 individual samples from the DeRt 1 column and seven individual samples from the DeRt 2 column. The sample size was based on volume, measuring 10 X 10 X 20 cm.

The samples were processed using the dry sieving technique, as outlined by Shackley (1975:109-113). As heating shells has been demonstrated to reduce the resistance of shells to fracture (Currey 1979), the samples were air-dried rather than using standard techniques of drying sediment samples in ovens. In order to further reduce the potential of shell breakage during sieving, most large rocks and shells (i.e. larger than 5.6 mm) were removed from the samples by hand. The remainder of each sample was then mechanically shaken through a series of nested sieves measuring 5.6, 4, 2, and 1 mm. These are standard measures used in particle size analysis (Shackley 1975).

All the materials in the size classes of larger than 5.6 mm and 5.6 - 4 mm were sorted into the categories of shell, bone, other organic matter, and rock. Ten percent (by weight) of the materials in the size classes of 4 - 2 mm and 2 - 1 mm were sorted into the same categories. The shell which would not pass through the 5.6 mm sieve was further sorted into the size classes of larger than 16 mm, 16 - 8 mm, and 8 - 5.6 mm. The material smaller than 1 mm was not subject to analysis.

Taxonomic identification of all shell material larger than 5.6 mm was attempted. In order to examine differential recovery of shell according to mesh size, further identification of all shell larger than 2 mm was attempted for several of the samples. It is recognized that the shell of some mollusks, such as <u>Mytilus edulis</u>, may be easily identifiable even when the particles are less than 1 mm in size. In general, however, the identification of shell smaller than 5.6 mm is very time consuming, difficult, and not routinely undertaken in archaeological studies.

The weight of material in each category and size range was recorded and it is these figures which provide the basis for determining the relative proportions of shell to other clasts, the particle size distributions of the shells, and the relative proportions of various shell species to each other. Four mm has arbitrarily been chosen as the best size to illustrate the particle size distributions of shell.

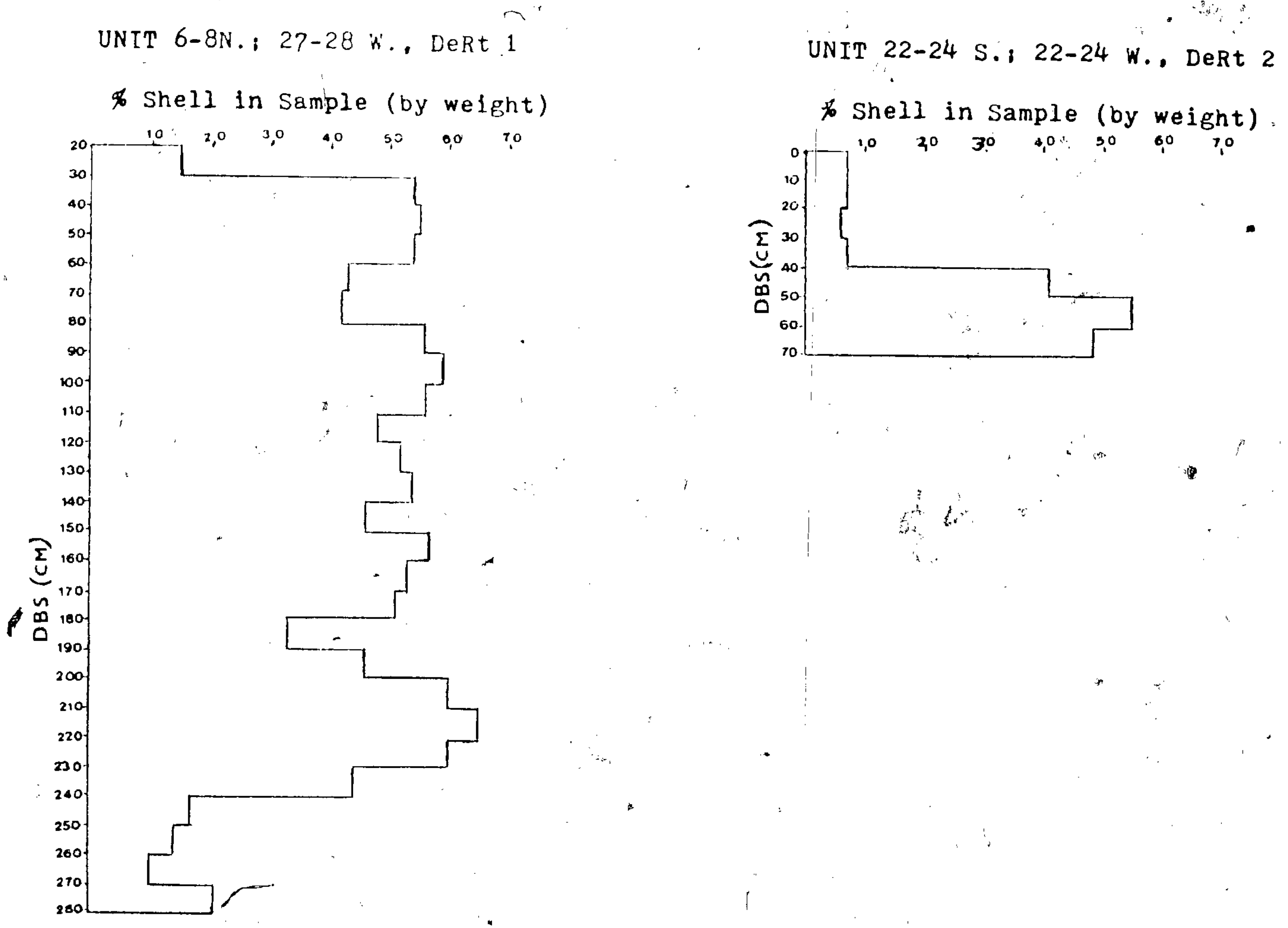
RESULTS

The raw data of the analyses are presented in Appendix C.

Proportion of Shell to Other Clasts

The proportion of shell to other clasts in the column sample from DeRt 1 generally fluctuates between 33% and 65% of the total sample weight (Figure 5). Notable exceptions occur in the top 10 cm and the bottom 40 cm, where the proportion of shell to other clasts ranges from 10% to 21% of the sample weight.

With regard to the column sample from DeRt 2, there is a distinct difference in the proportion of shell to other clasts between the top 40 cm, where the proportion of shell is relatively stable, around 6% or 7%, and the bottom 30 cm, where the proportion of shell fluctuates between 42% and 55 % of the sample weight (Figure 5).



UNIT 6-8N.; 27-28 W., DeRt 1

UNIT 22-24 S.; 22-24 W., DeRt 2

Figure 5. Percentage of Shell in Excavation Units 6-8 N.; 27-28 W., DeRt 1 and 22-24 S.; 22-24 W., DeRt 2.

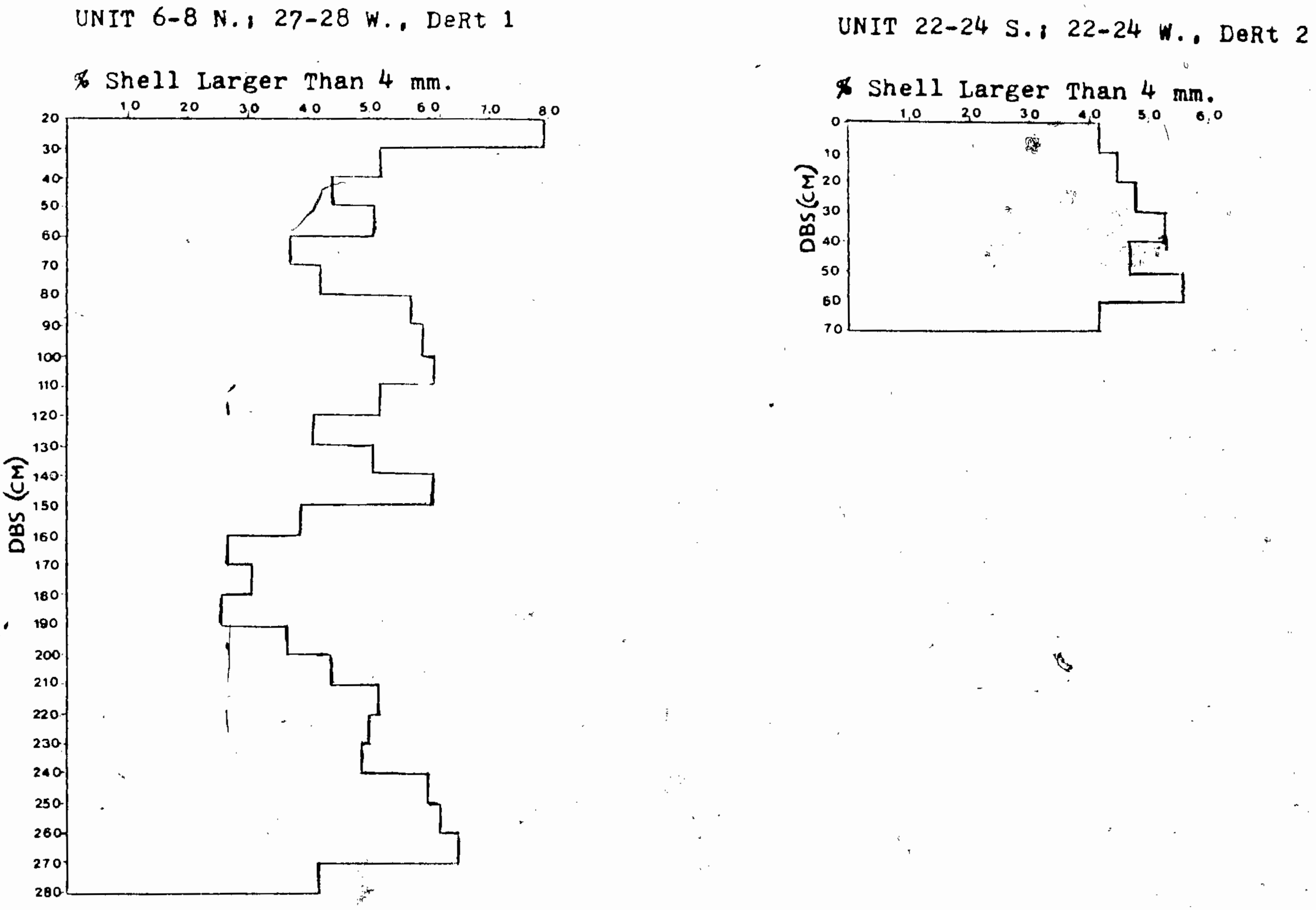


Figure 6. Particle Size Distribution of Shell in Excavation Units 6-8 N.; 27-28 W., DeRt 1 and 22-24 S.; 22-24 W., DeRt 2. Shell Particles smaller than 1 mm. were not included in analysis.

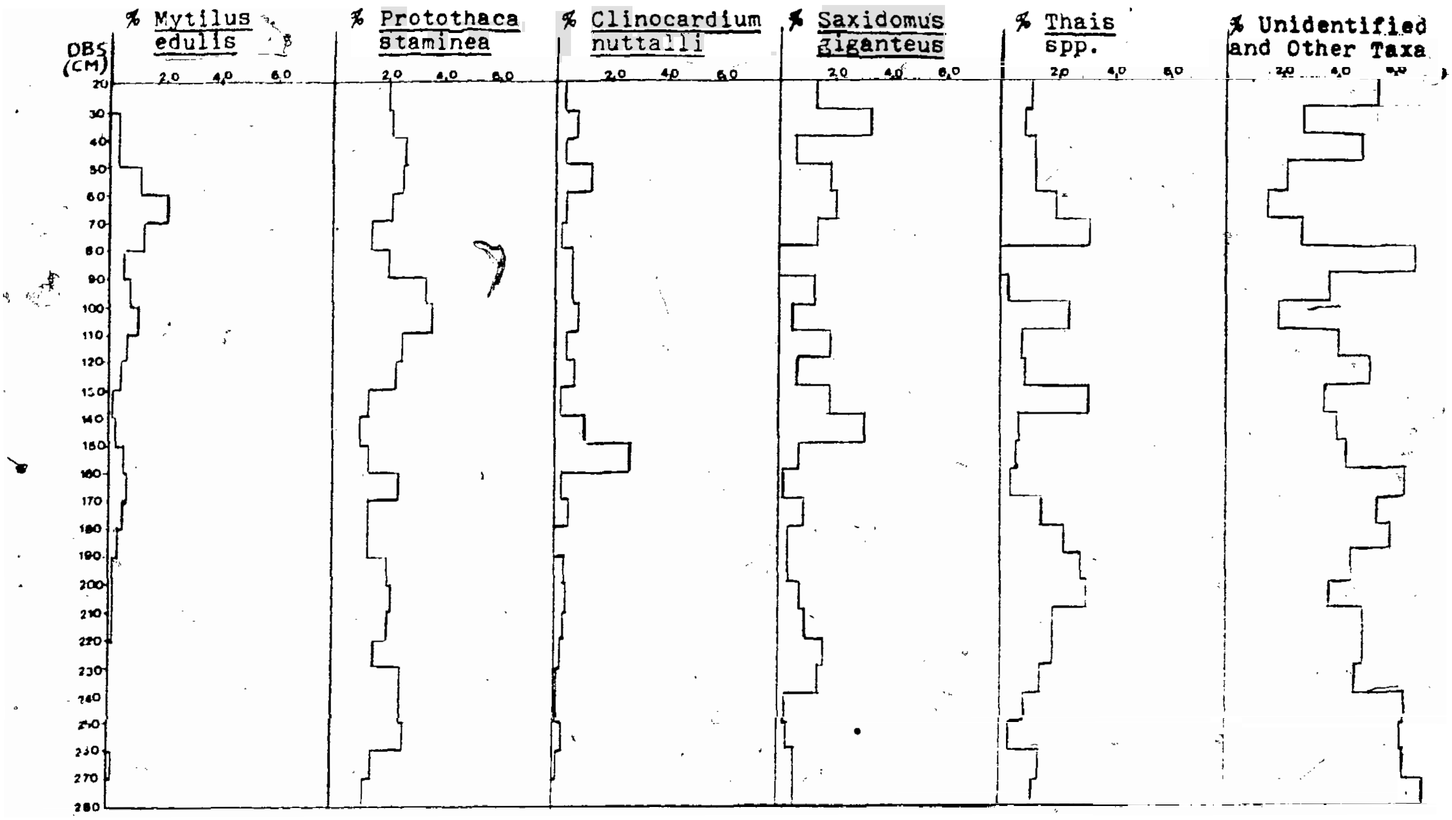
Particle Size Distribution

In general, approximately 50% of the shell (by weight) in both sites is larger than 4 mm (Figure 6). Notable exceptions occur in the top 10 cm level in the column from DeRt 1, in which 79% of the shell is larger than 4 mm, and the portion of the same unit from 1.5 to 2.0 meters below the ground surface, in which the percentage of shell larger than 4 mm fluctuates between 26% and 38% of the sample. The percentage of shell larger than 4 mm in all other samples from the DeRt 1 column and every sample from the DeRt 2 column is between 37% and 65% of the sample.

Relative Proportion of Species

As illustrated in Figure 7, the deposits are largely heterogeneous, although the relative proportions of each shell species do vary within the columns. Rarely does one species of shell account for more than 50% of the total shell weight in a sample. The predominant species of shell throughout the deposits include the bivalves Protothaca staminea (native littleneck clam), Clinocardium nuttalli (basket cockle), Mytilus edulis (edible mussel), Saxidomus giganteus (butterclam), and Schizothoerus capax (horseclam). Shells of whelks (Thais spp.), barnacles (Balanus spp.), chitons, limpets, crabs, and sea urchins are also present in the deposits. Differential recovery of various shell species according to screen size is illustrated in Figure 8.

UNIT 6-8 N.; 27-28 W., DeRt 1



UNIT 22-24 S.; 22-24 W., DeRt 2

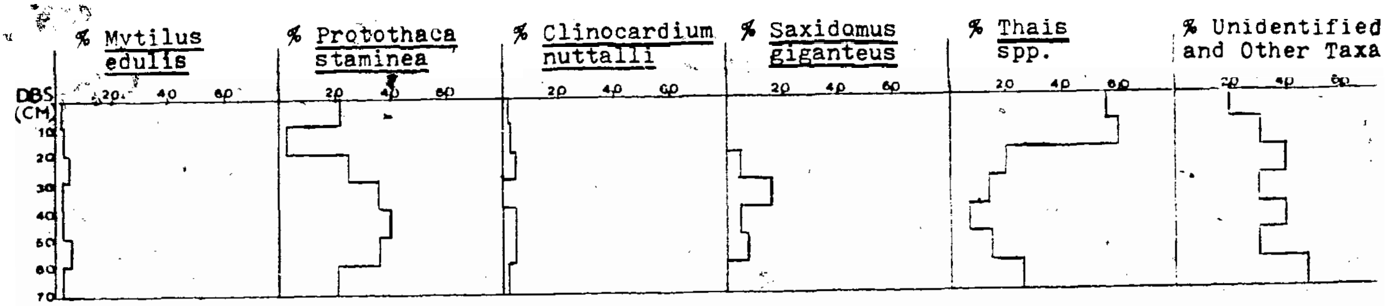


Figure 7. Proportions of Various Shell Taxa in Excavation Units 6-8 N.; 27-28 W., DeRt 1 and 22-24 S.; 22-24 W., DeRt 2. Percentages based on all shell particles larger than 5.6 mm. from column samples.

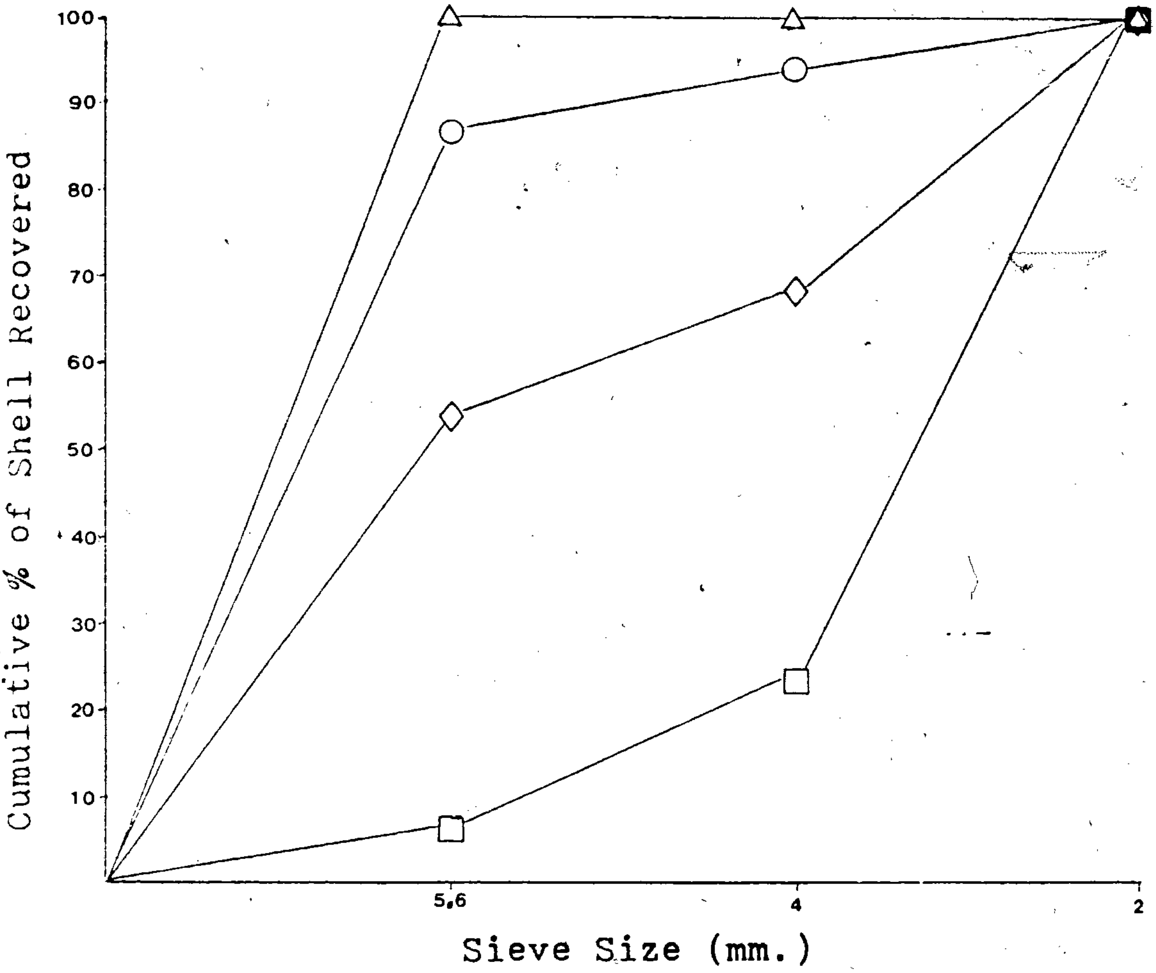


Figure 8. The Recovery of Various Shell Taxa According to Screen Size from Levels 1-5 (0-50 cm. D.B.S.), Excavation Unit 22-24 S.; 22-24 W., DeRt 2.
Symbols: △, *Saxidomus giganteus*; ○, *Protothaca staminea*; ◇, *Clinocardium nuttalli*; □, *Mytilus edulis*.

DISCUSSION

In general, the column samples can be described as being composed of a relatively high proportion of shell to other clasts, representing several different species of animals, and exhibiting extensive fragmentation. A notable exception occurs in the top 40 cm of the DeRt 2 column, in which the proportion of shell to other clasts is relatively low.

There is no clear relationship between the abundance of shell, the particle size distribution of shells, and the relative proportions of the various species of shell in the column samples. However, some of the observed phenomena can be explained with consideration of taphonomic factors outlined in previous chapters.

One factor which may explain the reduction of total shell abundance in the bottom levels of the DeRt 1 column is increased water percolation. As pointed out in Chapter 3, primary agents of chemical weathering of shells are the acids in percolating waters. Researchers can expect, therefore, that an increase in groundwater percolation will increase the rate of chemical weathering and ultimate removal of the shell. This expectation is supported by the fact that the distinct reduction in the proportion of shell to other clasts below 2.4 meters in the DeRt 1 column is associated with sediments, which in field notes, were described as very wet. The reason why these bottom levels were so much wetter than the overlying sediments is because they were below the high tide mark, as was evident by repeated flooding of the excavation units during high tide. Accordingly, it would be difficult to rule out increased water percolation as causing the sharp decline in shell abundance below 2.4 meters. It is recognized, however, that the chemical weathering of shell middens is a very complex process, not yet fully understood.

The relatively stable particle size distribution of shell in both sites (i.e. approximately 50% of the shell larger than 4 mm and 50% of the shell 4 - 1 mm) can be attributed, in part, to the heterogeneous composition of the deposits. However, the fact that such a large proportion of shell was not retained by the 4 mm sieve requires some explanation. As outlined in previous chapters, taphonomic agents of shell fragmentation which deserve consideration in archaeological research include the weight of overburden, the initial cultural deposition of shell, and human trampling on shell deposits.

With regard to the weight of overburden, it is unlikely that the weight was sufficient to be a major factor of shell fragmentation. As suggested in Chapter 3, the weight of overburden is not likely to directly cause shell breakage in shell middens unless the overburden is at least 1 meter thick. This clearly rules out the weight of overburden as a primary agent of fragmentation in the DeRt 2 column, which was only .70 meters deep. Further, if overburden were a major factor, one would expect an increase in the proportion of particles less than 4 mm with increasing depth. No such correlation exists in either deposit.

The cultural discard experiments reported in Chapter 4 indicate that although shell fragmentation does occur during initial deposition of shells as refuse, it generally results in relatively minor shell breakage and the fragments remain fairly large. It is unlikely, therefore, that the large proportion of shell less than 4 mm can be explained solely as a result of cultural discard behaviour.

The trampling experiments reported in Chapter 5 illustrated that very intense trampling would be required to reduce shells to the point where roughly half of the total shell weight would not be retained by 4 mm screens. Clearly, trampling cannot be ruled out as the primary agent of shell fragmentation in DeRt 1 or DeRt 2. However, if trampling was the primary agent of fragmentation, then it must have been very intense. Further, the relatively little variation in shell particle size throughout the depths of the columns may be interpreted as resulting from fairly constant trampling throughout the depositional history of the deposits. It is recognized, however, that the arbitrary 10 cm. levels in which the samples were taken may obscure the results (i.e. discrete layers of shell exhibiting significantly different particle size distributions may be mixed in the samples).

With regard to the relative proportion of species in the deposits, Figure 7 illustrates that shells of _Mytilus edulis_ are generally less dominant than shells of _Protothaca staminea_, _Saxidomus giganteus_, and _Clinocardium nuttalli_. Before researchers may explain such a phenomenon in terms of the relative cultural importance of each species, it is worth considering the possibility of differential rates of recovery.

As outlined in previous chapters, due to differences in the overall composition and structure of shells of various bivalve mollusks, differential rates of recovery can be expected. In particular, it was found in the trampling experiments that shells of _Mytilus edulis_ were reduced in size to a much greater degree than shells of _Protothaca staminea_ and _Saxidomus giganteus_. Further, as outlined in Figure 8, the proportion of _Mytilus edulis_ shells to other shells in the samples generally increases with decreasing sieve size. Accordingly, the observation that among all shell particles larger than 5.6 mm, Mytilus edulis shells comprise a significantly smaller proportion of the samples than the shells of Protothaca staminea, Saxidomus giganteus, and other species can be partly explained by the fact that a larger percentage of Mytilus edulis shells passed through the 5.6 mm sieve.

With further regard to the proportion of various species in the deposits, differential recovery resulting from differential rates of chemical weathering should be considered. As noted in Chapter 3, small and thin shells can generally be expected to dissolve at a faster rate than bigger and thicker shells. The shells of Mytilus edulis are generally smaller and thinner than the shells of other bivalve mollusks found in the deposits. Accordingly, differential rates of chemical weathering, with Mytilus edulis shells being the most rapidly dissolved, may partially explain the relatively low proportion of Mytilus edulis shells in the deposits.

In conclusion, it is recognized that samples taken in arbitrary levels may obscure the results and reduce confidence in interpretations of sedimentary properties in column samples. Ideally, researchers should take a sample of each discrete layer in the deposit. Accordingly, the value of this chapter lies not so much in the empirical results of the analysis as in its illustration of how an understanding of bivalve shell taphonomy can be used in archaeological research, particularly with regard to interpretations of the proportion of shell to other clasts, the particle size distribution of shells, and the relative proportion of various shell species to each other.

CHAPTER 7. CONCLUSION

Shell midden archaeology has been largely devoid of middle-range research. This thesis partially fills this void by examining the taphonomy of bivalve mollusk shells in archaeological sites. Attention is focussed on shell orientation, fragmentation, disarticulation, vertical displacement, and chemical weathering.

Some useful data and insights involving the dynamics and archaeological implications of bivalve shell taphonomy are gleaned from previous studies of bivalve shells and original experiments involving the cultural deposition of shells and human trampling on shell deposits. The principal results of the research indicate that upon initial deposition of shells as secondary refuse, single valves will tend to be oriented concave-side up, a substantial proportion of articulated valves will become disarticulated, and some fragmentation may occur. Further, subject to human trampling, shells of various species will be reduced at different rates and in order to create deposits of highly fragmented shell (i.e. 50% or more of the shell is not retained by 4mm mesh), trampling would generally have to be very intense. It is also important to note that differential chemical weathering of shells depends on the species and size of the shell as well as the amount of water percolation in the sediments.

The value of understanding bivalve shell taphonomy can be expressed with regard to (i) increasing confidence in archaeological inferences based on shell analysis, (ii) the identification of activity areas, and (iii) assessing the integrity of shell middens.

As outlined in Chapter 2, shell analysis is commonly used in support of behavioural and environmental inferences. Examples include using the species of shell in the deposits to make inferences of variability in the human diet and the characteristics of palaeo-shorelines, and using changes in the relative abundance of shell to make inferences about cultural or environmental changes. It should be appreciated that an understanding of bivalve shell taphonomy will allow researchers to more confidently assess whether the types and proportions of shells in the deposit have been biased by such factors as differential rates of fragmentation and/or chemical weathering.

With regard to the identification of specific activity areas, knowledge of shell orientation, disarticulation, and fragmentation may be useful. A deposit in which the majority of valves are oriented concave-side up is probably representative of an area which has been subject to rapid accumulation of sediments and little post-depositional disturbance, such as a secondary refuse deposit. Similarly, rapid shell burial, with no extensive disturbance, may also be indicated by the presence of articulated valves. As demonstrated in the experiments, deposits of highly fragmented shell have likely been subject to very intense human trampling, such as may occur on housefloors or trails. Conversely, relatively minor fragmentation may result from intermittent trampling, the initial deposition of shells, or the weight of overburden, such as may occur in secondary refuse deposits.

With regard to assessing the integrity of shell middens, an understanding of valve disarticulation and orientation may be useful. Clearly, the presence of articulated valves in a deposit is indicative of relatively minor disturbance by physical and chemical agents. Similarly, a dominantly concave-side up orientation of single valves may be indicative of minor disturbance.

Evidently, the dynamics and archaeological implications of bivalve shell taphonomy are still not fully understood. This thesis represents only an initial attempt at examining the taphonomy of bivalve shells in archaeological sites, and the value of the research is restricted by several theoretical and methodological problems. Prominent problems include:

1. The fact that experimental conditions are never exactly duplicated in actual sites.

2. A lack of understanding of the effects various sedimentary properties of shell have on each other. For example, there have been no previous studies of how chemical weathering affects shell fragmentation and disarticulation, how the orientation of shells may affect their fragmentation, or how the size of shell particles may affect their vertical displacement.
3. A lack of established criteria for distinguishing between the effects of various taphonomic agents. For example, there has been no research directed toward identifying how the morphology of shell particles may reflect specific agents of fragmentation, such as trampling versus the weight of overburden.
4. The considerable time required to record the sedimentary properties of shell, and
5. The fact that for recording shell orientation, disarticulation, and vertical displacement in a simple manner, large shell fragments or complete valves are generally required.

The main conclusion of the research is that, despite theoretical and methodological problems, accurate interpretations of shell midden stratigraphy depend on an appreciation of the behaviour of shells as sedimentary particles. Further, excavations and sampling should be conducted in a manner conducive to understanding shell midden formation processes (e.g. isolation of discrete layers) and an explicit consideration of bivalve shell taphonomy should be a fundamental stage of shell midden analysis.

This thesis provides an initial archaeological investigation of the dynamics and implications of bivalve shell taphonomy. Hopefully, the research will make archaeologists aware of factors which may bias shell assemblages during and after the initial deposition of shells as refuse, and stimulate interest and future research on this topic.

APPENDIX A. RESULTS OF DISCARD EXPERIMENTS

The following tables present raw data of the discard experiments. See text for a complete description of the research design.

Table 10. Orientation Results of Discard Experiments. Due to shell breakage and recording error, the orientation of all valves was not recorded.

	SHELL ORIENTATION					
	SINGLE VALVES			ARTICULATED VALVES		
Exp. No.	concave-side up	concave-side down	haphazard	gape-up	gape-down	sideways
1	75	47	6	-	-	-
2	71	38	4	-	-	-
3	58	36	7	-	-	-
4	9	1	-	1	-	4
5	4	2	-	-	-	7
6	7	9	-	2	-	-
7	7	7	-	2	1	-
8	11	9	-	1	-	-
9	16	7	-	-	-	-
10	38	9	-	9	2	6
11	40	22	-	3	3	-
12	22	8	-	18	6	3
13	6	2	-	-	2	-
14	-	-	-	-	-	-
15	67	31	-	-	-	7
Total	431	228	17	36	14	27

Table 11. Disarticulation Results of Discard Experiments

Experiment No.	Number of Articulated Pairs of Valves Before Discard	Number of Articulated Pairs of Valves After Discard
4	10	5
5	10	7
6	10	2
7	10	3
8	2	1
9	2	0
10	24	17
11	24	6
12	38	27
13	58	23
14	218	111
15	111	23
Total	517	225

Table 12. Fragmentation Results of Discard Experiments

Experiment No.	Original Number of Valves	Number of Valves Reduced by More Than One-half Their Original size
1	133	5
2	133	20
3	133	32
4	20	0
5	20	0
6	20	0
7	20	0
8	25	3
9	25	2
10	79	0
11	79	5
12	84	0
13	116	39
14	436	0
15	436	74
Total	1759	180

APPENDIX B. RESULTS OF TRAMPLING EXPERIMENTS

The following tables present raw data of the trampling experiments. See text for a complete description of the research design.

Table 13. Particle Size Distribution of Shell After 640 Trampling Passages, Series A Experiments.

Particle Size	Weight of Shell (grams) Deposit 1 *Saxidomus giganteus*	Deposit 2 *Protothaca staminea*	Deposit 3 *Mytilus edulis*
0-2 mm	61	30	90
2-4 mm	164	76	203
4-8 mm	122	389	382
8-16 mm	613	766	75
16-32 mm	540	239	0
Total	1500	1500	750

Table 14. Shell Particle Size Reduction During Trampling, Series A Experiments.

No. of Trampling Passages	Weight of Shell (grams) Retained by Sieves of 4 mm and Larger *Saxidomus giganteus*	*Protothaca staminea*	*Mytilus edulis*	Mixed
0	1500	1500	750	1000
80	1474	1471	638	-
160	1466	1454	518	-
320	1455	1440	473	-
640	1275	1394	457	740

Table 15. Particle Size Distribution of Shell After Trampling, Series B Experiments.

Particle Size	Weight of Shell (grams) Exp. 5	Exp. 6	Exp. 7	Exp. 8
0-4 mm	38	127	14	45
4-8 mm	189	351	143	212
8-16 mm	351	154	345	281
16-32 mm	107	53	176	81
32 mm+	0	0	0	21
Total	685	685	678	650

Table 16. Vertical Distribution of Shell After Trampling, Series B Experiments.

Experiment 7
(100 Trampling Passages)

Depth Below Surface	Weight of Shell (grams) 0-4mm	4-8mm	8-16mm	16-32mm	32mm+	Total
0-2 cm	11	141	343	176	0	671
2-4 cm	3	2	2	0	0	7
4-6 cm	0	0	0	0	0	0
Total	14	143	345	176	0	678

Experiment 8
(1,000 Trampling Passages)

Depth Below Surface	Weight of Shell (grams) 0-4mm	4-8mm	8-16mm	16-32mm	32mm+	Total
0-2 cm	45	204	276	77	21	623
2-4 cm	6	5	5	4	0	20
4-6 cm	4	3	0	0	0	7
Total	55	212	281	81	21	650

APPENDIX C. RESULTS OF COLUMN SAMPLE ANALYSES FROM DeRt 1 and DeRt 2

Table 17. Bulk Composition of Column Sample from Excavation Unit 6-8 N.; 27-28 W., DeRt 1.

Depth Below Surface (cm)	Weight of Constituents (grams)					
	Shell	Bone	Other Organic	Rock	Residue Less than 1 mm	Total
20-30	46	0	30	26	214	316
30-40	691	3	33	197	347	1271
40-50	696	0	7	141	416	1260
50-60	777	6	8	290	377	1458
60-70	681	3	13	384	505	1586
70-80	629	1	13	409	436	1488
80-90	889	1	7	349	351	1597
90-100	1245	1	12	477	359	2094
100-110	878	2	14	439	232	1565
110-120	709	1	10	454	306	1480
120-130	682	1	18	324	287	1312
130-140	450	6	10	154	214	834
140-150	693	3	9	522	265	1492
150-160	744	3	14	180	374	1315
160-170	816	1	11	206	503	1537
170-180	705	1	11	172	493	1382
180-190	238	1	5	260	225	729
190-200	744	1	5	260	674	1630
200-210	1038	1	5	130	570	1744
210-220	828	1	2	141	295	1267

Table 17 (continued)

Depth Below Surface (cm)	Weight of Constituents (grams) Shell	Bone	Other Organic	Rock	Residue Less than 1 mm	Total
220-230	785	1	5	284	234	1309
230-240	899	1	6	649	471	2026
240-250	376	1	7	993	789	2166
250-260	329	1	4	1035	1019	2388
260-270	231	1	5	1100	963	2300
270-280	331	0	4	766	486	1587
Total	17130	42	268	10288	11405	39133

Table 18. Bulk Composition of Column Sample from Excavation Unit 22-24 S.; 22-24 W., DeRt 2.

Depth Below Surface (cm)	Weight of Constituents (grams)					
	Shell	Bone	Other Organic	Rock	Residue Less than 1 mm	Total
0-10	180	2	8	1300	1023	2513
10-20	95	1	2	649	565	1312
20-30	73	1	12	622	509	1217
30-40	106	1	3	767	664	1541
40-50	678	13	3	555	408	1657
50-60	841	14	5	441	215	1516
60-70	1181	2	3	815	474	2475
Total	3154	34	36	5149	3858	12231

Table 19. Particle Size Distribution of Shell in Column Sample from Excavation Unit 6-8 N.; 27-28 W., DeRt 1

Depth Below Surface (cm)		Weight of Shell (grams)					
	Over 16mm	16-8mm	8-5.6mm	5.6-4mm	4-2mm	2-1mm	Total
20-30	0	20	10	7	7	2	46
30-40	117	140	47	53	170	164	691
40-50	38	142	50	76	204	186	696
50-60	41	197	66	91	216	166	777
60-70	30	86	50	88	227	200	681
70-80	38	89	58	80	206	158	629
80-90	37	268	94	108	218	164	889
90-100	175	323	102	136	302	207	1245
100-110	58	241	106	131	217	125	878
110-120	45	148	74	101	194	147	709
120-130	34	93	64	88	227	176	682
130-140	64	84	33	50	122	97	450
140-150	165	148	41	68	149	122	693
150-160	33	93	69	99	249	201	744
160-170	15	44	58	105	318	276	816
170-180	12	74	58	76	247	238	705
180-190	8	11	21	21	81	96	238
190-200	13	103	78	83	243	224	744
200-210	94	187	78	94	310	275	1038
210-220	81	164	96	88	230	169	828

Table 19 (continued)

Depth Below Surface (cm)	Weight of Shell (grams)						
	Over 16mm	16-8mm	8-5.6mm	5.6-4mm	4-2mm	2-1mm	Total
220-230	77	152	81	86	219	170	785
230-240	153	150	64	76	214	242	899
240-250	18	83	58	68	123	26	376
250-260	16	74	51	64	104	20	329
260-270	19	45	38	50	63	16	231
270-280	8	38	39	54	172	20	331
Total	1389	3197	1584	2041	5032	3887	17130

Table 20. Particle Size Distribution of Shell in Column Sample from Excavation Unit 22-24 S.; 22-24 W., DeRt 2

Depth Below Surface (cm)	Weight of Shell (grams)						
	Over 16mm	16-8mm	8-5.6mm	5.6-4mm	4-2mm	2-1mm	Total
0-10	22	24	12	18	58	46	180
10-20	4	13	13	13	44	8	95
20-30	2	9	9	15	35	3	73
30-40	3	14	19	20	48	2	106
40-50	115	110	32	63	191	167	678
50-60	163	149	61	97	223	148	841
60-70	159	135	69	129	392	297	1181
Total	468	454	215	355	991	671	3154

Table 21. Taxa of Shell Larger than 5.6 mm. in Column Sample from Excavation Unit 6-8 N.; 27-28 W., DeRt 1.

D.B.S. (cm)	Weight of shell (grams)									
	Mytilus edulis	*Protothaca staminea*	*Clinocardium nuttalli*	*Saxidomus giganteus*	*Schizothoerus capax*	*Thais* spp.	*Balanus* spp.	Other	Unidentified	Total
20-30	-	6	1	4	-	3	3	2	11	30
30-40	8	65	24	100	12	23	8	-	64	304
40-50	7	60	9	13	-	28	-	-	113	230
50-60	32	77	38	56	-	36	7	1	57	304
60-70	35	35	7	34	-	31	6	-	18	166
70-80	23	26	4	26	-	58	8	-	40	185
80-90	19	78	27	-	5	1	-	-	269	399
90-100	42	206	39	79	45	10	-	-	179	600
100-110	41	144	34	18	-	98	-	1	69	405
110-120	16	66	12	47	-	20	3	1	102	267
120-130	7	43	14	12	-	15	2	-	98	191

Table 21. (continued)

D.B.S. (cm)	*Mytilus edulis*	*Protothaca staminea*	*Clinocardium nuttalli*	*Saxidomus giganteus*	*Schizothoerus capax*	*Thais* spp.	*Balanus* spp.	Other	Unidentified	Total
130-140	2	23	4	32	3	56	4	-	57	181
140-150	6	36	40	109	-	23	15	-	125	354
150-160	9	26	52	14	-	9	12	-	73	195
160-170	7	28	2	1	-	3	4	-	72	117
170-180	7	18	7	13	-	20	3	-	76	144
180-190	1	5	-	1	-	9	1	-	23	40
190-200	2	39	5	5	-	54	1	-	88	194
200-210	5	75	15	26	-	108	8	-	122	359
210-220	2	69	10	32	-	63	24	-	141	341
220-230	1	45	7	50	-	55	11	-	141	310

Table 21. (continued)

D.B.S. (cm)	*Mytilus edulis*	*Protothaca staminea*	*Clinocardium nuttalli*	*Saxidomus giganteus*	*Schizothoerus capax*	*Thais* spp.	*Balanus* spp.	Other	Unidentified	Total
230-240	-	91	4	53	3	51	40	-	125	367
240-250	-	39	1	3	-	12	20	2	82	159
250-260	1	36	4	4	2	4	10	-	80	141
260-270	-	15	1	6	-	14	14	-	52	102
270-280	-	10	-	5	-	9	4	-	57	85
Total	273	1361	361	743	70	813	208	7	2334	6170

Table 22. Taxa of Shell Larger than 5.6 mm. in Column Sample from Excavation Unit 22-24 S.; 22-24 N., DeRt 2.

D.B.S. (cm)	Weight of shell (grams) *Mytilus edulis*	*Protothaca staminea*	*Clinocardium nuttalli*	*Saxidomus giganteus*	*Schizothoerus capax*	*Thais* spp.	*Balanus* spp.	Other	Unidentified	Total
0-10	1	13	1	-	-	32	5	-	6	58
10-20	1	1	1	-	-	18	4	-	5	30
20-30	1	5	1	1	4	4	2	-	2	20
30-40	1	13	-	6	-	5	4	-	7	36
40-50	7	103	12	13	-	18	15	1	88	257
50-60	24	136	18	28	-	54	18	1	94	373
60-70	11	76	9	-	-	96	5	-	166	363
Total	46	347	42	48	4	227	53	2	368	1137

Table 23. Particle Size Distribution of Various Invertebrate Shells in Levels 1-5 (0-50 cm D.B.S.) in Column Sample from Excavation Unit 22-24 S.; 22-24 W., DeRt 2

Taxon	Weight of Shell (grams) Larger than 5.6 mm	5.6-4 mm	4-2 mm	Total
Mytilus edulis	11	33	147	191
Protothaca staminea	135	12	9	156
Clinocardium nuttalli	15	4	9	28
Saxidomus giganteus	20	-	-	20
Schizothoerus capax	4	-	-	4
Thais spp.	77	8	-	85
Balanus spp.	30	27	78	135
Other	1	2	34	37
Unidentified	108	43	99	250
Total	401	129	376	906

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