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POSTDEPOSITIONAL LEACHING OF SHELL IN TWO
NORTHWEST COAST SHELL MIDDENS

by

Gregg Matthew Sullivan

B.A. (with distinction), University of Washington, 1988

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARTS
in the Department
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ABSTRACT

Leaching is the dissolution and removal of a chemical constituent from a sedimentary deposit. Recent research has questioned the assumption that dark, shell-less deposits found at the base of some prehistoric shell midden sites on the Northwest Coast represent periods during which shellfish were not being exploited by ancient peoples. Instead, the composition of this layer is thought to be caused by postdepositional leaching of shell by groundwater. The applicability of this hypothesis is assessed using sediment samples from two archaeological sites on the British Columbia coast, Namu and Tsawwassen, both of which possess a black, shell-less layer at their bases.

The mobility of calcium carbonate, the main component of shell, in sedimentary environments is reviewed, and the main factors in its dissolution are identified. Archaeological studies are reviewed which propose the loss of shell from archaeological deposits to explain differences in shell content. Based on this literature review, a list of the expected effects of chemical weathering and leaching of shell on the composition and texture of archaeological shell-bearing deposits is presented. Samples are analyzed for particle size distribution of shell and mineral component, carbonate and organic matter content, pH, and composition of part of the sand size fraction by point counting. At Tsawwassen the dark layer does not appear to have been affected by cultural processes, although other layers show evidence of chemical weathering of shell. While shell seems to have undergone severe chemical weathering in the dark layer at Namu, it is difficult to ascertain the extent to which leaching has removed shell content over time. In conclusion, the technical and theoretical difficulties presented by the use of leaching to explain differences among archaeological

shell-bearing deposits are discussed, and alternative approaches for the future study of this phenomenon are presented.

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CHAPTER ONE: INTRODUCTION

From the very beginning the thrust of the new archaeology was not that we knew everything, or even that we knew how to accomplish our goals. Rather, we were arguing that we did not know what the archaeological record meant, and that we must accept the challenge to reduce this ignorance as much as possible.

—Lewis R. Binford (1983:214)

As the above quote indicates, one of the major contributions of the "new archaeology" to the discipline has been a concern for understanding what patterning within the archaeological record actually means. In more traditional approaches to prehistory the utilized archaeological record consisted mostly of objects classified as "artifactual", which usually meant well-formed tools, art objects and various features such as architectural elements, hearths, and human burials. These are the standard building blocks of culture history, or the placing of archaeological assemblages into a framework based on inferred chronological and geographical relationships (Dunnell 1986:34; Willey and Sabloff 1980:84). However, as archaeologists began in the 1960s to pose questions about the social organization, interactions with the environment, and changes in diet and subsistence patterns of ancient peoples, they discovered that the traditional sorts of information recorded and materials recovered were inadequate to address such questions. One example of this problem surfaced in the debate between L. Binford and M. Schiffer around the "Pompeii premise" and the nature of the archaeological record (Binford 1981; Schiffer 1985). This debate underlined the fact that the archaeological record has been too simply conceptualized, and that how it comes to be formed, and how these formation processes affect the patterns of archaeological remains, is a subject worthy of study in itself. Such studies have gradually become more numerous in the

discipline, and fall under the rubrics of "middle range research" and "taphonomic studies."

Interpretation of the archaeological record rests, then, upon a good understanding of the processes which lead to its formation. Broadly stated, the archaeological record results from a complex combination of human and nonhuman activities and processes (Butzer 1982:120; Schiffer 1986:10-11). In North America, archaeologists are for the most part trained as anthropologists, and ultimate research goals tend to be primarily of an anthropological nature, such as how people were organized socially at a given point in time; how people living at a given location interacted with people at a more distant location during the same time period; how activities were organized at a given archaeological site; what sorts of animals and plants were utilized for subsistence; what their relative importance was to the diet; and how any of these reconstructed patterns have changed through time. In focusing on these sorts of questions, there is a tendency to ignore or downplay the fact that much of the material we study has spent most of its existence as part of an active sedimentary or soil system and only a fraction of that time participating in a human social context. The more time objects spend subjected to mechanical and chemical activity in these sedimentary systems, the greater the potential that distinctive traits or patterning within the archaeological record will be due to nonhuman agency (Wood and Johnson 1978).

In attempting to address questions about past human societies, archaeologists have traditionally operated under an unstated assumption. In interpreting archaeological materials, a researcher reconstructs people's activities in the past, assuming that there are no nonhuman processes that can produce the

same outcome in the archaeological record. This places the onus on the researcher to consider and rule out the possibility that patterns he or she is observing might be due to nonhuman agency. After discovering and ruling out the possible role, if any, such nonhuman processes may play in forming that segment of the archaeological record, it will only then be appropriate to infer human agency; otherwise, such "cultural" interpretations are subject to serious doubt.

In oceanic coastal areas of the world, prehistoric peoples tended to depend on gathering marine resources for their subsistence, including shellfish. The remains of shellfish exploitation may in time come to form great heaps or "shell middens." Shell middens are sites in which the dominant matrix is the skeletal remains of shellfish collected by humans for subsistence purposes (Muckle 1985:16). Shell middens often form the most significant part of the archaeological record for maritime regions due to the prominent size, visibility, and high frequency of occurrence of these sites, as well as their good preservation conditions, especially of bone and other organic remains (Muckle 1985). This is particularly the case for the Pacific Northwest Coast region of North America. The contents of these shell-bearing deposits are studied by archaeologists for a variety of purposes, but most often to determine the kinds of animals gathered, processed and utilized by the inhabitants of the site for subsistence. However, as some researchers have noted (e.g, Muckle 1985:23; Sanger 1981; Waselkov 1987:146), the role of postdepositional alteration of midden contents is rarely addressed. Postdepositional alteration or preferential loss of different midden components will affect the accuracy of any reconstructions based on shell midden evidence. Thus, a consideration of

nonhuman processes in the formation of shell middens is an important first step in reconstructing the prehistory of any coastal region.

One aspect of shell midden formation that is little understood is the origin of different strata that have been identified by archaeologists. In particular, archaeologists on the Northwest Coast (and elsewhere) have noted the presence of distinctive layers that are dark colored, largely shell-less and rich in organic matter (King 1950:9; Mitchell 1968:11; Sanger 1981:40; Stein 1984a:27, 1992a:12-15). Often these layers are found at the base of middens, overlain by a lighter colored layers that contain more shell and relatively less other organic matter. Traditionally, the formation of those dark layers has been explained in purely "cultural" terms, usually as a shift in subsistence activities at the site, i.e., the eschewing of shellfish in favor of other subsistence resources at the time that the dark layer was being deposited (Charlton 1980:48; King 1950:9). Alternatively, however, such a sequence might also be explained by a combination of human and nonhuman factors, human activity transporting the midden material to the site, while nonhuman agents caused the removal of shell by chemical weathering from part of the midden after deposition (Mitchell 1971:87-88; Stein 1992c:150).

For this project I will discuss the process of postdepositional leaching of biogenic carbonate using information drawn from the earth sciences, focusing on the conditions under which it might be expected to occur. Based on this information I will outline expectations for how this might affect shell midden deposits and stratigraphy. I will then review published accounts of shell middens from Northwest Coast, California, and other coastal regions of the world to determine to what extent leaching or other nonhuman processes have

been used to explain midden formation. I will then analyze sediment samples from two shell midden sites on the British Columbia coast for composition and texture: Namu (EISx 1) located on the Central Coast, and Tsawwassen (DgRs 2) located on the Fraser River Delta, both of which contain dark, shell-less layers. The analysis will attempt to separate human from nonhuman processes that led to the formation of the various deposits sampled. Using the results of these analyses I will evaluate the degree to which leaching is responsible for the formation of these dark, largely shell-less layer found at the base of many Northwest Coast shell middens, and suggest directions for future research that might further explain the origin of these dark layers.

CHAPTER TWO: MOBILITY OF CaCO_3 IN ARCHAEOLOGICAL SEDIMENTS

In this section the process of dissolution and mobilization of calcium carbonate (CaCO_3) in sedimentary environments is discussed. Cases where leaching of biogenic carbonates has been proposed as an interpretation of shell midden composition and stratigraphy are discussed. Based on this information, two models are proposed for how leaching might occur in shell middens, and how each might affect midden contents and stratigraphy.

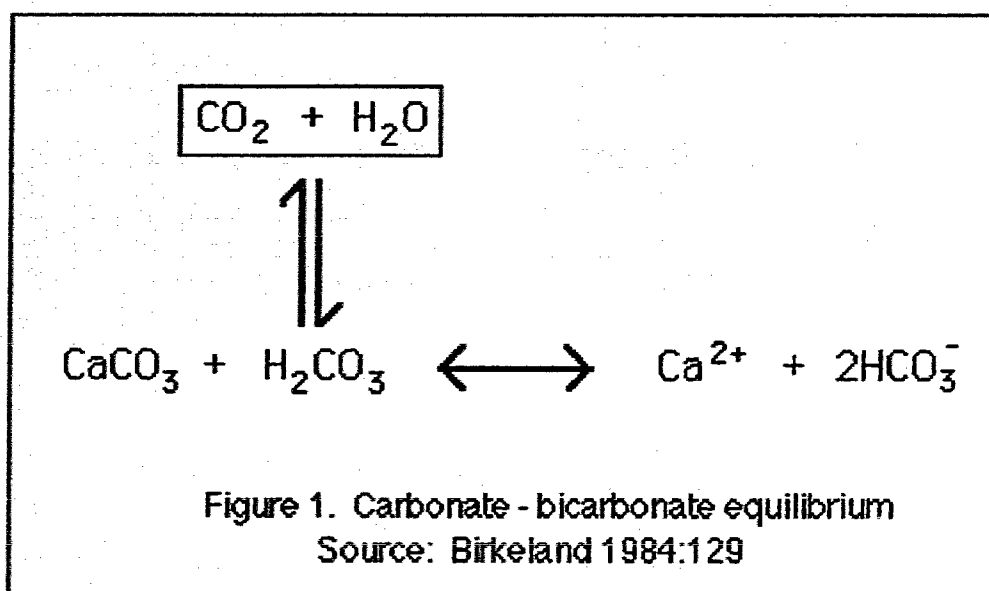
How does leaching of calcium carbonate occur?

Leaching is defined here as the removal of chemical constituents from a sedimentary deposit by dissolution and transport in groundwater. In pedology, leaching of various substances (e.g., humic substances, aluminum and iron compounds, calcium carbonate) from the upper part of the soil profile (A horizon) and precipitation in a lower part of the profile (B horizon) is the main basis of soil horizonation. In most depositional environments the source of CaCO_3 is from sedimentary rocks such as limestone. In the context of shell middens the source is biogenic, the exoskeletons of various species of molluscs which were collected and processed for subsistence purposes by prehistoric peoples and discarded with other organic residues in that location.

The main factors controlling the mobility of CaCO_3 in sedimentary environments are the amount of water and concentration of carbon dioxide (CO_2) in the soil atmosphere. To a lesser extent, the amount of organic matter present will also influence ability of groundwater to dissolve carbonates. All of these control the relative activity of hydrogen ions (pH). The form of the carbonate itself will affect

how soluble it is; biogenic carbonates contain different mineral phases of CaCO_3 , each with different stability in the presence of water. The microstructure of a shell will also affect how susceptible it is to chemical weathering.

In the earth sciences the role of rainwater and groundwater in dissolving, transporting and precipitating CaCO_3 has long been recognized and understood, and is shown symbolically in Figure 1 below. In soils, whether CaCO_3 dissolves or precipitates at a particular location depends on conditions in the soil environment, especially the amount of CO_2 and water (H_2O) present in the soil. Carbon dioxide dissolves in water to form carbonic acid (H_2CO_3), which reacts with CaCO_3 to liberate calcium (Ca^{2+}) and form bicarbonate (2HCO_3^-), raising the pH of the solution to a more basic or alkaline condition.



The concentration of CO_2 found in soil can be ten to one hundred times greater than that in the atmosphere (Moore 1989:161-162). It tends to be so much

higher in soils because plants, soil fauna and microorganisms produce it as a by-product of respiration and metabolism, and their activity tends to be concentrated in the surface horizon of the soil (Bohn et al. 1985:139).

Generally, the amount of water that percolates through a soil also tends to be highest at the surface, and decreases with depth. Thus, higher inputs of water or CO_2 will drive the reaction displayed in Figure 1 to the right; as water evaporates and by-products of the reaction build up in solution, CaCO_3 starts to precipitate. Temperature can also affect the amount of carbonate that can be mobilized, with the solubility of carbonates being greater in cold water than in warm (Birkeland 1984:138-140; Ward 1975:106,109). Because of these factors, meteoric groundwater (i.e., water that falls as precipitation and percolates from the surface downward through the soil profile) has been described as being "very aggressive" in dissolving carbonates (Moore 1989:161-162).

The presence of groundwater is necessary in order to dissolve and transport carbonates. There are three basic hydrologic regimes found in any sedimentary section: vadose, phreatic, and mixed zones. The vadose zone is the sedimentary environment which lies between the ground surface and the water table, where the pore space contains both gases and water. In the vadose zone the source of most water is meteoric – water that precipitates in the atmosphere and enters the zone as rainfall. The phreatic zone is that lower part of the sediments where pore space is completely saturated with water. The water table forms the boundary between the vadose and phreatic zones, and the location of this boundary may vary through time. A mixed zone can occur where marine waters blend with groundwater in coastal areas (Moore 1989:172-174). Waters flowing through the vadose zone are often saturated with carbonates before they reach the water table, which may result in the

formation of cements or hardpans just above this boundary; thus, dissolution and precipitation of carbonates in the vadose zone is often balanced (Moore 1989:179-181). Generally, carbonate diagenesis and removal is more intense and efficient in the phreatic zone due to the greater volume of water and the continual recharging by new water entering through the vadose zone (Moore 1989:181).

The presence of organic matter can also affect how much CaCO_3 is dissolved, as by-products of organic decomposition lower the pH of the soil or sediment. Soil organic matter tends to be concentrated in the upper portion (top 10 to 50 cm) of an active soil as the result of biotic activity at the interface between the earth and atmosphere. Organic matter consists of three different fractions: Decomposing plant matter ("fresh parts") that is renewed every few years; microbial remains and metabolic by-products, which have a half-life of 5-25 years; and a resistant fraction, called humus, that can be 250-2500 years old (and older in some paleosols). The first fraction constitutes 50-80% of the total organic matter in temperate soils, and the rate at which it decomposes is proportional to the amount of organic material added; the more there is, the faster it will be broken down (Bohn et al. 1985:140-141). Soil fauna, microbes and plants are all participants in the metabolism of soil organic matter, although they make up the smallest proportion of the total soil organic matter (Tate 1987:7). Humus is a complex mixture of compounds resistant to further decay by microbes. After it has broken down, organic matter can become associated with different sized mineral clasts in the sediment, for example with clay particles through electrostatic bonds, thus helping to retain the organic matter and lending an improved structure and nutrient content to the soil that encourages plant growth (Tate 1987:12; Varadachari et al. 1991:220).

Although soil scientists have been studying the chemical components of soil organic matter for some time now, the various fractions extracted chemically are still described as "nondescript mixtures of many chemical compounds" (Bohn et al 1985:142-143).

Meteoric groundwater passing through the upper levels of the soil profile containing organic matter in various stages of decomposition will accumulate organic acids in solution, such as tannic, fulvic and humic acids, which increase the acidity of the water coming in contact with shell, and therefore the amount of CaCO_3 that can be dissolved and removed (Bohn et al. 1985:139). As Birkeland (1984:23) has stated, "An important H^+ [hydrogen cation] source is the wide variety of organic acids produced within the soil." Even where soil pH is somewhat buffered, as is the case in shell middens, mineral dissolution can still occur because the solubility of CaCO_3 and other minerals may increase in the presence of organic acids and other compounds in solution (Tate 1987:226).

The form of carbonate also affects its solubility. Shell is made of different mineral phases (aragonite and calcite) of the same compound (CaCO_3) embedded in an organic matrix which usually doesn't exceed 5% of the total weight (Muckle 1985:9). The proportion of aragonite to calcite varies from species to species and is influenced both genetically and environmentally. The organic matrix influences the formation of mineral crystals in the shell structure. How much of one phase or another is present also depends on local environmental conditions, especially salinity and temperature (Muckle 1985:9; Taylor et al. 1969:14). Aragonite and calcite are found together in the valves of the following superfamilies of mollusc: Mytilacea, Pinnacea, Pteriacea.

Pectinacea, Limacea, and Ostracea. Aracea and Limopsacea shells are composed entirely of aragonite. No mollusc has a shell entirely of calcite. In species that possess both phases of carbonate in their valves, the different phases always appear in separate layers (Taylor et al. 1969:13). Calcite occurs in the outermost layers in a limited number of subclasses of bivalves. Aragonite is a less stable phase of CaCO_3 , and thus would tend to be more soluble than calcite (Moore 1989:167). When placed in a terrestrial sedimentary environment, the shells of species that produce a greater proportion of aragonite in their valves would tend to suffer preferential loss over those that have more calcite, given identical chemical conditions.

The microstructure of shell also has a great bearing on how susceptible it is to postdepositional leaching of calcium carbonate. Shell microstructure is determined genetically, and varies according to species (Taylor et al. 1969:12). Some eleven different types of shell microstructure that have been identified (Muckle 1985:9). However, in general the microstructure of the outer portion of all shell is described as "prismatic", containing numerous small rod-like crystals bundled in an organic matrix; that of the smooth inner portion is termed "nacreous", and is made up of platy blocks of carbonate crystals, forming a brick-like appearance (Kobayashi 1969; Taylor et al. 1969:18,35). The former structure provides a greater surface area to volume ratio for acids to attack. One recent study found that biogenic carbonates with a greater reactive surface area were subject to greater degree of chemical weathering, and the grain size of the carbonate clast was also a factor in its susceptibility to chemical attack, with smaller sized particles being preferentially affected (Walter and Morse 1984).

In paleontology, studies comparing living and fossil shellfish assemblages approximately one million years old show that about 75% of the species represented in the fossil assemblage are found in the living shellfish community for the same vicinity (Kerr 1991). This has led some researchers to conclude that fossilized assemblages of mollusks are fairly representative of the original death assemblage. However, they recognize that few such assemblages actually survive to be studied due to diagenesis; in fact it is acknowledged that elements of fossilized communities are altered or removed by postdepositional processes (Valentine 1989:90). Driscoll (1970:905) states that shells with lower surface area per unit weight that are buried rapidly are subject to destruction by dissolution in groundwater, and that this process of preferential destruction is one possible explanation for the lack of smaller, thinner bivalve shells in some fossil assemblage, especially those below the present sediment-water interface.

The above discussion shows that there are many factors that affect the solubility of carbonates, and thus the susceptibility of shell to being removed by chemical weathering in a particular sedimentary environment. The most significant factors in this process are the amount of water added to the deposits and their concentration of CO_2 . The presence of large amounts of water, such as in the phreatic zone, will lead to more rapid removal of CaCO_3 . Generally, many of the processes active in recently deposited archaeological sites, such as the concentration of a large amount of organic matter, its subsequent metabolism in the soil, and the addition of those products to groundwater, enhance the ability of groundwater to dissolve shell, by increasing the concentration of CO_2 in pore spaces, and by adding organic acids, both of which lowers pH. Finally, the form of CaCO_3 also has a bearing on its susceptibility to chemical attack; shell often contains large amounts of aragonite, an unstable phase of calcium

carbonate, and a given species' shell structure also affects how resistant it is to chemical weathering.

Has leaching of shell from shell middens been recognized by archaeologists?

The above discussion of leaching begs the question: If the process of decay and dissolution of biogenic carbonates has been known for some time, why haven't archaeologists paid closer attention to its effects on shell midden deposits? The answer is that a few have, but knowledge about various nonhuman processes that lead to the formation of deposits and the deformation of patterning in archaeological deposits has been slow to diffuse into the discipline, due in part to a lack of awareness of recent developments in the earth sciences on the part of anthropologically-oriented researchers.

Also, until recently most excavations in North America have been done to construct culture historical units based largely on the artifactual component or on gross changes in subsistence; projects focusing on more detailed reconstruction of site formation processes and other goals have become popular in the literature only since the late 1970s (Claassen 1991:269). In reconstructing those aspects of human activity that led to the formation of the archaeological record, researchers examined "nonartifactual" or "ecofactual" materials — shell, bone, and sometimes botanical remains — and became aware of the many taphonomic factors influencing the validity of their interpretations (Schiffer 1986:8). One of these factors is postdepositional removal of components which, if not recognized, could lead to biased interpretations of midden materials. As discussed in the previous section, the material most readily affected is shell.

Shell midden sites form a large part of the prehistoric archaeological record of the Northwest Coast and other coastal areas, and on the Northwest Coast they tend to be the most frequently investigated part of the archaeological record. This is due to the prominent visibility and large size of shell midden sites, the excellent preservation within them of organic (especially bone) remains, and the considerable time depth that is often represented in their deposits (Burley 1980:11; Thompson 1978:3). On the Northwest Coast, the accessibility of such sites associated with the modern sea level has also played a role in their being so well investigated, since most archaeological surveys of the islands and coastal areas have been conducted by boat, leaving interior areas largely unexplored (for example, Bryan 1955; Carlson and Hobler 1976; Wessen 1986).

Again, although shell middens retain a high degree of importance in piecing together the prehistory of maritime regions all around the world, there has been very little interest in understanding the processes by which they may have formed (Stein 1992:7; Waselkov 1987:140). Investigations of shell middens on the Northwest Coast and other areas of North America have largely focused on two main concerns: providing a basis for building a culture history of the region, and providing data by which diets and subsistence patterns of past occupants of these sites can be reconstructed. The former has been the most favored approach on the Northwest Coast because the deposits of many Northwest Coast shell middens tend to be deep and seem to represent relatively long periods of continual occupation. Both of these goals tend to focus on the human contribution to shell middens while downplaying the role of nonhuman (or "natural") processes in forming and altering these sites: culture history

because the focus of study is on artifacts whose stylistic attributes provide means of dividing assemblages into chronological units, and reconstruction of diet because it is based on the assumption that the frequency of remains found during excavation largely reflects what was originally deposited.

The effects of postdepositional alteration of shell midden deposits are rarely discussed in published works, but this is changing gradually as researchers seek to understand the taphonomic variables that might affect their interpretations (Ford 1989a:143, 1989b:168,170; Koloseike 1968; Muckle 1985; Stein 1992a:10). Published analyses of shell midden sites which discuss leaching of shell are even more rare, and those that do often fail to explain how the process may work or indicate whether it has significantly altered the deposits at the site. What follows is a brief summary and discussion of published works which deal directly with postdepositional dissolution of shell in archaeological sites. It is not meant to be an exhaustive review, but it demonstrates the degree of awareness of this phenomenon in the archaeology of coastal areas of the world, and that "degree of awareness" has affected the study and interpretation of shell middens.

Researchers in Australia and New Zealand seem to be on the forefront of interpreting shell midden composition in terms of shell loss via leaching. Coutts (1969) examined factors that contributed to the loss of shell from a shell midden near Victoria, Australia. He focused mostly on aeolian movement of shell exposed on the surface as a factor leading to its break-down and removal from the site. Through a series of experiments in which whole specimens of different species of shell were marked and placed at varying exposures to wind, Coutts (1969:136) found that different species of shell had different capacities for

aeolian displacement, and shell from those species that were more prone to movement tended to show a greater degree of fragmentation. Aeolian movement of shell as a primary causal factor in the break-up of shell in shell middens is difficult to support, given the numerous other processes that can yield similar results, such as trampling by people and animals. However, Coutts (1969:137) also notes the importance of chemical decay in addition to human and animal activity in causing the fragmentation of shell, although he does not explicate how that decay occurs.

In his doctoral dissertation, Hughes (1977) discussed the effects of postdepositional loss of shell from shell-bearing deposits in Australia. He identified two processes that are most important in this regard: the breakdown of the original constituents of deposits, and the disturbance of earlier deposits by subsequent occupants of the site. He notes that in sites on the coast of New South Wales in Australia, shell began to enter archaeological deposits by 9,000 BP, and by 7,000 BP it formed the bulk of such deposits. Assuming that the relative proportion of materials discarded in middens remains the same through time, Hughes asserts that differences in the amounts and proportions of various materials are likely due to differential rates of decay of the shell component; differences between sites may be due to environmental differences that affect the decay process (Hughes 1977:206-207; also discussed in Hughes and Lampert 1977).

Hughes then evaluated experimentally the rate of decay of shell under differing conditions. According to Hughes, decay of shell is brought about by percolation of meteoric groundwater through the midden, and the rate of decay is influenced by the amount of water and the permeability of the deposits. His

experiment placed shell in two different media: a poorly-sorted matrix derived from the floor of rockshelters and containing fine (silt-clay sized) materials and about 5% "other organic matter"; and a better-sorted sand to simulate conditions in open coastal sites, with a similar "other organic matter" content. These were set in plastic flower pots, and different amounts of water were added (50 and 500 mL every two days) over a period of 80 days. Whole shells were weighed before and after treatment (Hughes 1977:207-208). Hughes found that the matrix from the rock shelter retained more water than the better-sorted sand did (Hughes 1977:208-209). The results of his experiment showed that overall, there was greater loss of weight from the sandy matrix (0.16% and 0.36% average weight loss, depending on amount of water added) than from the one containing finer particles (.10% and 0.20% average) (Hughes 1977:209).

Hughes applied the results of his experiment to various archaeological sites, indicating that shell from midden deposits inside a cave protected from rainwater (Currarong Shelter 2) showed little decay; shells from deposits outside the rockshelter also showed little decay (deposits here date back to 7000 BP) but were thought to be undergoing some weathering. At open-air midden sites with a sandy matrix, the amount of shell "decreases rapidly with depth" and shell is "progressively more poorly preserved" in deposits 3000-3500 BP (Hughes 1977:210). At Burrill Lake Shelter and Currarong Shelter 1 the author says lack of shell in their deposits is due to rapid dissolution from flooding by a nearby river and rainwater run-off, the shells having completely disappeared in 800-1500 years (Hughes 1977:210, 1983:110).

Hughes' work represents an important step toward demonstrating that percolation of water through shell-bearing deposits leads to some loss of shell

by dissolution. While the experiment was of relatively short duration, it represents a necessary first step in understanding how this process may affect archaeological shell. However, one might question whether water percolating from the surface is responsible for all the decrease in shell in the lower deposits of the sites he examined. As noted in the previous section of this chapter, as groundwater flows through the profile, it dissolves more CaCO_3 until it becomes saturated, when it may begin to precipitate calcite as water evaporates, unless it is recharged by groundwater flowing through the lower levels, or by inclusion of other compounds (such as organic acids) that lower the pH. The more likely pattern of leaching by rainwater or floodwaters would result in the opposite pattern, namely lack of shell in upper levels, and the relative amount of shell increasing with depth. Unless there is subsurface flow of groundwater through the lower deposits, it is possible that there simply was less shell in the lower deposits to begin with. Alternatively, those lower deposits may have been exposed as a stable surface for a prolonged period of time, perhaps during a period of site abandonment, and the shell decayed then as a result of intensive weathering by meteoric groundwater and pedogenic activity.

Other researchers of Australian shell middens have also employed postdepositional leaching of shell as a means of interpreting the history of site deposits. For example, Sullivan (1984) excavated a shell midden at Pambula Lake on the southern coast of New South Wales. She analyzed column samples from the midden for grain size distribution, pH, and organic matter content to detect changes in the composition of deposits within the shell midden, and compare those results to other shell middens in the vicinity. Her interpretations are based largely on Hughes' (1977) work described above. She found that the upper seven levels (5 and 10 cm arbitrary) contained higher

amounts of organic matter (10-20%) which steadily decreased with depth to 5-10%; in the lowermost deposits of the midden the proportion of organic matter was higher again, which was thought to be the product of illuviation from upper levels (Sullivan 1984:6). Shell content decreased abruptly about 90 cm below the surface, thought to be due to dissolution of shell by rainwater percolating through the porous deposits. However, the leaching at this site was thought not to be as severe as at other sites due to impeded drainage in the lower deposits, brought about by the impervious bedrock on which the midden was deposited (Sullivan 1984:6). Activities taking place at the site are thus thought to have remained unchanged through time despite the apparent discontinuity in shell content within the midden (Sullivan 1984:11).

In the 1970s and 1980s there also appeared discussions in the literature of the Northeast Coast of North America about the nature of shell middens and their contents, especially how they come to be formed and disturbed. This was brought about by apparent chronological contradictions between assemblages recovered from some shell middens and radiometric dates of associated material, which demanded explanation (Brennan 1977). Because the radiocarbon dates did not match the dates of the ceramics and projectile points associated with them, Brennan (1977:122) hypothesized that the associations between materials may be spurious, and that the cultural material found was "intrusive", coming from occupations that occurred after the shell deposits had been laid down and weathered to present an attractive surface on which to live. While his hypothesis was later rejected by others (Sanger 1981, discussed below), Brennan's attempt to deal with this problem led him to consider postdepositional alteration of the shell deposits. He states:

Undoubtedly the most overlooked aspect of shell midden archaeology has been that weathering and solvent action literally obliterates shell ... in that, as chemically base calcium carbonate, it blackens the soil into which it dissolves. Given the thousands of years of exposure of most shell middens it is clear that whole horizons must have vanished and with them the archaeological context of whole cultural phases (Brennan 1977:123).

He notes that the upper layer of the midden consisted of a black, highly organic layer about 20 cm thick, which contained some shell, under which was a shelly layer 20-25 cm thick lying on top of yellow "clay-sand". He interprets this upper layer as having been weathered by rainwater filtering down through the profile, and by run-off from nearby wooded slopes, where water would pick up organic acids from the leaf litter (Brennan 1977:124). His gloomy conclusion was that because of this weathering of shell the stratigraphy within the shell midden is "not true", i.e., postdepositional, and not particularly useful for building chronologies of artifact assemblages. Thus, the artifactual content of shell-bearing deposits is not necessarily associated in time with the activities that led to the deposition of that shell. However, Brennan neglects the potential effects of other disturbance processes occurring at his site (e.g., burrowing animals, agriculture) which are probably more likely causes for mixing of deposits (Wood and Johnson 1978). He may also have been unaware of "carbon reservoir effects" and potential contamination that can result in radiocarbon dates on shells being significantly older than they really are in calendar years (Ralph 1971:25; Taylor 1979:51,55). Interestingly, other researchers in the area continue to find unusual artifact associations in Northeastern shell midden deposits which appear to represent a single occupational event, but which come from quite different time periods (based on stylistic criteria), a phenomenon they find difficult to explain, and conclude that one "must be

extremely conservative when using shell-midden stratigraphic data to build chronological sequences" (Spiess 1988:177).

Sanger (1981) attempts to evaluate Brennan's hypothesis regarding lack of chronological association between shell-bearing layers and the artifacts found within them, and concludes that in the midden he studied there was no such pattern. He then discusses the many unresolved problems in the archaeological study of shell middens, particularly the lack of interest in identifying factors in midden formation. He singles out the lack of recognition of the effects of postdepositional alteration of midden deposits, especially the effects of shell decomposition. He mentions that shell decomposes at different rates, stating that mussel shell (Mytilus edulis) tends to disintegrate faster than that of clams (Mya and Venus spp.); decomposition of shell is also speeded by burning. He also notes the presence of "greasy, black layers to be seen at the base of many Northeastern shell middens" (1981:40), but that there were no studies available of how these came to be formed. To improve our understanding of this part of the archaeological record Sanger advocates drastic rethinking of recovery strategies and research goals in shell midden excavation. My review of several archaeological periodicals from the Northeast indicates that as yet no one has taken up his challenge.

In coastal California, shell middens form a significant part of the archaeological record, and researchers have been excavating them systematically since the early 1900s (Moratto 1984). However, until the 1950s the overriding research goal was development of local regional chronologies based on artifact types or other features such as burial form; shell middens were viewed as a convenient medium in which many objects of perishable material were fortuitously

preserved. This focus on artifactual content detracted from attempts to understand how the middens themselves came to be formed (Ambrose 1967:177). In fact, there was some debate as to whether there was genuine stratification in shell middens at all; at the Emeryville shell midden in central California one investigator denied the existence of identifiable layers, despite the fact that others had drawn stratigraphic profiles for the same site showing many distinct layers (Greengo 1951:6). Apparently, this lack of concern for stratigraphy within shell middens was not uncommon during early excavations of California shell middens (Beardsley 1948; Gould 1964:128). Indeed, the assumption that the midden represents a homogeneous deposit of material underlies the "California method," and is thought to be the reason that researchers often failed to detect cultural differences through time (Ambrose 1967:173-174).

The dominant approach to excavation and analysis of shell middens in California came to be named the "California method" of midden analysis. This approach to the analysis of shell midden contents was first introduced by Nils Nelson in the early 1900s, and later refined by Cook and other researchers in the 1940s and 1950s (e.g., Cook and Treganza 1947); it became a popular method for the analysis of shell middens in other parts of the world as well (Ambrose 1967:175). The main goals of this approach were to quantify midden constituents and to use this information to infer the age of the midden via assumed rates of accumulation; the rate of deposition at the site was assumed to be constant. Later studies also attempted to estimate the size of the population inhabiting the site, and the relative contribution of different shellfish species to the diet (Gould 1964; Hester and Conover 1970:141-142). Attempts were also made at identifying and explaining the chemical composition of

middens, but with little success judging by how few such studies were done and the lack of any firm conclusions drawn from them (e.g., Cook and Heizer 1962; Cook and Treganza 1947).

In the late 1960s this traditional approach was questioned along with many methods and assumptions about the archaeological record that had prevailed up to that time within archaeology. Integral to most of these criticisms was the failure of the California method to account for possible postdepositional alteration of midden constituents. For example, Koloseike (1968) questioned the accuracy of the results from such analyses on the grounds of sampling problems. "Midden analysis" focused on constituents 1/8" or larger, while the "residue" (material that fell through the screens) is weighed and discarded unanalyzed, even though this fraction can constitute more than 50% of the midden by weight. Importantly, he also mentioned the fact that shell is very soluble in groundwater, due to the presence of carbonic and organic acids (Koloseike 1968:376). Thus, the shell present in the midden may actually be less than what originally went into it, which would make inferences based on quantification of shell inaccurate.

Meighan (1972) attempted to dismiss Koloseike's criticisms of the California method, as he feared that such criticisms would lead to cessation of the analysis of midden constituents without good justification. He identified two sources of error in California style midden analysis, sampling error and translating shell weight into meat weight. He downplayed the importance of leaching of shell as a source of sampling error, except in the oldest shell middens (Meighan 1972:4-5). In the same volume, Glassow (1972) noted that dissolution of shell by groundwater is a more common problem than Meighan realizes, and that it can

affect midden deposits younger than 5000 years. He cited his work in the Santa Barbara Channel where artifacts dating to about 2000 BP were coated with a patina of CaCO_3 , which is presumed to have come from shell dissolved in percolating groundwater. Glassow (1972:19) suggested using such patinae on artifacts as a possible indicator of leaching, although in the arid environment of southern California there is the possibility that some CaCO_3 is from an inorganic source occurring naturally in the soil or groundwater.

Aside from this exchange in the published literature I could find no consideration of postdepositional factors in the formation of California shell middens, let alone specific mention of leaching. In none of these cases was there any attempt to assess the extent to which leaching might have affected shell midden deposits. However, recently some researchers of California middens are beginning to focus more attention on postdepositional alteration of shell midden deposits (e.g., Gross 1991).

On the Northwest Coast of North America there has been some discussion of the role of CaCO_3 mobility in the formation of shell midden sites. Mitchell (1971) mentions finding a black layer, called zone B, at the Montague Harbour site (DfRu 13) on Galiano Island in the Strait of Georgia. Zone B is described as a compact sandy sediment which is black when wet. Some areas contain sparse fragmented shell (mainly horse clam, but also fine shell fragments of mussel). Near the top of this layer are some thin lenses of bay mussel shell; it also contains much fire affected rock, particularly at the base of this deposit, which ranges in thickness between 25 and 125 cm (Mitchell 1971:87). This zone is divided into two sections, a lower section mostly devoid of shell and an upper part containing fragmented shell, the boundary between the two described as

"almost horizontal" (Mitchell 1971:88). He attributes the lack of shell in the lower part of the zone to leaching by a raised water table. No change in artifact types was observed at this boundary, so it was interpreted as a postdepositional phenomenon (Mitchell 1971:88).

Stein (1984a) also considered the possibility of postdepositional changes to midden deposits, and how these changes may have affected constituents of these deposits and stratigraphy in middens. She noted a stratigraphic sequence commonly found in Northwest Coast shell middens: a lower layer of "dark, almost black matrix", the upper unit being mainly of shell (Stein 1984a:27), similar to that described by Mitchell at Montague Harbour. The black layer was damp and contained enough water to maintain its shape, while the matrix in shelly layers was dry and powdery. Stein sought to explain the formation processes that produced this black, largely shell-less layer, using evidence obtained from column samples from two sites, Oak Harbor, Washington (45-IS-81) and English Camp, San Juan Island, Washington (45-SJ-24).

The black layer at Oak Harbor was about 50 cm thick, contained shell, mammal bones, angular rock and charcoal, and rests on "glacial drift and beach sand" (Stein 1984a:27). The overlying shelly layer was about the same thickness. The surface had been disturbed by recent dumping and earth moving equipment. At English Camp the black layer was 90 cm thick and contained shell, bone, rock fragments and charcoal. The lighter-colored shelly layer was 60 cm thick and had similar contents. The boundary between shelly and dark layers was not diffuse, but abrupt. The surface 20 cm was a plough-zone. Stein

(1984a:27-29) proposes five hypotheses that might explain formation of this basal black layer:

- 1) The black layer is formed by organic matter being leached from upper layers and transported to the lower midden deposits, representing postdepositional alteration of (addition to) the lower midden deposits.
- 2) The flow of meteoric groundwater down through profile to water table was responsible for transporting material down to bottom, i.e., the water table acted as barrier to further illuviation (variation of #1).
- 3) Shell midden was deposited on top of an active soil surface, causing the shell to dissolve, concentrating the organic matrix and resulting in the black appearance. After the pH had been brought up to alkaline conditions, shell that was deposited afterward became preserved, resulting in the lighter, shelly deposits.
- 4) The two layers were the result of two different kinds of activities or occupations. The black layer was from permanent occupation of the site, laying down an even layer of material across the whole site, while shelly layers are the result of seasonal use of site and local shellfish beds. This is supported by the fact that dates for the black layer were always older than shelly layer.
- 5) The two layers were deposited at roughly same time, but represent two different kinds of activities occurring at different parts of the site. A shift in activity loci across space resulted in observed vertical relationship. Stein proposes that this shift was brought about by sea level rise – shell was originally deposited more shoreward, but rising waters forced deposition on the dark layer. This assumes that the deposits were formed by two different sets of activities, and thus should contain different artifacts and other components. It also assumes that parts of the black layer were contemporaneous with parts of the shelly midden.

Vertical column samples were taken at every 10 cm at both sites. Grain size analysis, pH, carbonate, organic matter, and phosphorus content were all determined. The presence of lipids was also tested for in the dark layer using gas chromatography, but none were identified. This was done because some

interpreted the "greasy" texture of the sediment as evidence of accumulation of fats from the processing of fish at that locale (Stein 1984a:29-30).

At English Camp the average amount of organic matter (by weight) for the shelly layer is 7.2%, and for the dark layer 11.2%, while shell content is 77.4% for the shelly layer and 44.3% for the dark layer. There were no significant differences between the two layers along other parameters examined (e.g., pH, phosphorus content). For the Oak Harbor site, results yielded a mean organic matter content for the shelly layer of 3%, and for the dark layer of 6.1%; mean carbonate percentage was 75.4% for the shelly layer and 51.8% for the dark layer. Again, no significant differences were found between the layers along other parameters (Stein 1984a:30).

The results of this analysis were used to evaluate the appropriateness of each hypothesis. The first hypothesis was seen as not applicable because organic matter is not easily leached, and if it were the lower layers should have shown elevated amounts of carbonates, since carbonates are more readily leached. The second hypothesis seemed inapplicable because the current groundwater table is located much lower today than the boundary between the light and dark midden. Groundwater level is related to sea level, so it may have been higher in the past due to subsequent isostatic rebound and uplift of coastal areas during the Holocene (Stein 1984a:31). However, one would again expect to see a diffuse boundary between the two layers, or a dark layer that began to be leached again due to lowering water table, which is not the case. The third hypothesis could not be supported because whole shells were found in the black layer, as well as a high pH, which would be difficult to explain if they had been always exposed to acid conditions. The fourth hypothesis could not be

resolved with the results presented, and was still considered a possibility. The fifth hypothesis was deemed unlikely because the stratigraphy at Oak Harbor is more complex than this hypothesis would allow in current form. The presence of "many black layers and many shell layers" (Stein 1984a:32) was noted at the site, which suggests that the model was too simplistic; the numerous black layers were also thought to have been the result of disturbance by interment of human remains. The few radiocarbon dates from the site were all too recent for sea level change to have been a factor.

Stein concluded that the processes involved in the formation of the basal dark layer couldn't be determined with the available data. Leaching of chemical constituents was ruled out, and she didn't think that shell had been dissolved. The results of chemical tests tended to indicate that pedogenesis was not the cause of the stratigraphic profile, and Stein feels that some combination of the fourth and fifth hypotheses may be the answer. To determine this, she suggested that numerous radiocarbon dates need to be obtained from all areas of the site, and the site needs to be excavated so as to separate it into distinct deposits rather than gross, extensive "strata."

Subsequent excavation and analysis at the English Camp site on San Juan Island, Washington, led to a re-evaluation of the view held in Stein's (1984a) article. The analysis of molluscan faunal remains indicated a puzzling fact that much of the shell from the basal dark layer could not be identified to the species level because the shell fragments had many of their identifying features etched away, presumably by organic acids mobilized by the moist conditions in the lower portion of the site, in the "dark layer" (Ford 1989b:170). This led Stein to conclude that the intersection of the groundwater table with the lower part of the

midden, in combination with relatively high concentrations of organic matter in the midden, produced greater chemical weathering of shell in the lower deposits of the midden. These conditions may have been caused by a gradual rise in relative sea level in the area, which raised the water table enough to inundate the lower midden deposits at the site (Stein 1992c:148-149).

This information led Stein (1989) to put forward a revised hypothesis regarding the origins of this dark layer, based on data from the English Camp midden and personal observations of other shell middens excavated on the Northwest coast. This hypothesis posits that three preconditions are required for dark layers to occur. First, the mineral portion of the shell midden must contain at least 10% clay; second, there must be at least 10% organic matter content (other than biogenic carbonates); and third, there needs to be a sufficient flow of groundwater through the lower portion of the midden to supply oxygenated water. These factors all interrelate in that the clay portion possesses electrochemical properties that attract and hold on to organic matter, thus maintaining a source of organic acids to speed leaching; the presence of clay also tends to impede the flow of water through the sediments, keeping moisture near the shell in that layer, as will organic matter. The groundwater flow needs to be sufficient to prevent the build-up of carbonates which would slow the leaching process. If one of these factors is missing, then the dark, organic matter-rich layer will not occur.

Recent consideration by Stein (1992c:138-139) of this process does not specify precise quantities of organic matter and clay content, but reiterates the basic necessity for the intersection of the groundwater table with the lower midden deposits, with sufficient force of flow to permit recharge of the pore water, not

already saturated with regard to CaCO_3 . Organic matter must be present in sufficient amounts to supply additional acids to the groundwater to speed the dissolution of shell particles. Silt and clay must be present in the sediment help retain organic matter content and water in the sediment. Finally, these processes require a sufficient amount of time for shell to be leached.

The significance of understanding how this dark layer at the base of shell middens comes to be formed is potentially great. For the most part, researchers of Northwest Coast shell middens have interpreted these layers as reflecting the fact that people at that site at that particular point in time were not collecting, processing and dumping shell (e.g., Charlton 1980; King 1951). If, however, as Stein believes, the nature of this layer is due to greater postdepositional weathering of the shell component, then the meaning of such layering will have to be reconsidered, since observed differences may not be related to cultural processes.

Aside from the works described above there has been little research into the potentially myriad processes involved in the formation and alteration of Northwest Coast shell-bearing sites. Muckle's (1985) M.A. thesis is one of the few exceptions. He focused primarily on "cultural" alteration of shell, conducting experiments in discard and trampling effects on bivalve taphonomy, and used the results to interpret the stratigraphy of two shell middens on the coast. While recognizing that chemical weathering of shell occurs in shell middens, he noted that it is "... a very complex process, not yet fully understood" (Muckle 1985:91). Using the results of his experiments and review of postdepositional disturbance processes in shell middens, Muckle examined column samples from Pender Canal sites (DeRt 1 and DeRt 2) to apply these results to an archaeological

context. He found that the relative amount of shell varied within the midden: 33-65% except at the top and bottom of the midden deposits, which were 10% and 21% in DeRt 1; at DeRt 2 the shell content was lowest in upper levels (3-6%), but higher in lower levels (42-55%) (Muckle 1985:84). The lack of shell at DeRt 1 is described as "distinct", and corresponds with the presence of groundwater in those deposits below the 2.4 m level. Muckle explains the lack of shell relative to other material in the lower levels of DeRt 1 to loss by dissolution in groundwater. "Researchers can expect... that an increase in groundwater percolation will increase the rate of chemical weathering and ultimate removal of the shell" (Muckle 1985:90).

Muckle (1985:97) concluded that an understanding of taphonomic processes affecting shell in sedimentary environments is necessary to improve the accuracy of inferences drawn from shell midden deposits, in identifying activity areas within a shell midden, and in assessing the integrity of those deposits. Among the problems yet to be resolved are the lack of studies of the interactions of one taphonomic process with another (for example, the effect of chemical weathering on shell fragmentation) and the need to identify criteria for the various taphonomic processes at work in shell middens (Muckle 1985:98-99).

Though not a comprehensive review of the state of shell midden formation studies in archaeology, the above indicates that the role of postdepositional change to midden constituents is something rarely considered by archaeologists. When postdepositional loss of shell is recognized, with few exceptions (Hughes 1977; Stein 1992c) it is usually taken for granted that some leaching might have occurred in deposits at a given site, but that the extent of loss of shell is unknown, and the processes by which this occurs is usually left

unexplicated. However, most archaeologists who discuss chemical weathering of shell underline the importance of knowing whether it has occurred and to what extent, as it would have a definite influence on the validity of analyses of midden constituents and subsequent reconstructions of prehistoric activity and subsistence patterns. Chemical weathering of shell may also have a significant effect on apparent stratigraphic patterning within shell middens. These and other effects of leaching of shell are discussed in the next section.

Proposed models for leaching of shell from shell midden sites

What follows is a description of two tentative models for anticipating the main effects of leaching of shell from shell midden deposits. Both models are based on the geochemical processes outlined in the previous section. One model looks at the effects of percolation of meteoric groundwater through the deposits. The other examines the effects of a horizontal flow of groundwater, where the water table intersects archaeological deposits. In both models the process is explained while taking into account effects of the build-up of leaching by-products in solution. Effects on stratigraphic boundaries, composition, and texture of leached deposits are also addressed. Each model is based on the assumption that, given layers that are equally shelly, certain effects will occur. If differences in human activity produce less shelly matrix, then these models may not hold true. However, implications for each are provided; if they do not apply, or offer ambiguous results, then the assumption of uniformity is most likely not valid, and variation in shell content is more likely the result of changes in human activity.

There are several factors that would be present in any deposit affected by leaching of shell. First and most obvious, a shell-bearing layer that has been affected by chemical weathering will contain a smaller percentage by weight of carbonates than layers that have not been so affected. Furthermore, leaching will tend to remove the smaller clasts of shell (silt to fine sand range) preferentially; one would expect to find most of the shell (by weight) to be sand sized or larger, since the rate of dissolution and removal will be greater among smaller particles because of their larger surface area relative to volume. Larger shell particles may become structurally weaker from the chemical weathering and thus more susceptible to mechanical stress and breakdown, possibly increasing the relative proportion of shell in the sand-size range (Muckle 1985).

Second, loss of the shell component of a portion of a midden would result in reduced deposit volume. Among the effects this might produce is a higher density or "lag" concentration of other midden constituents (such as lithics and bones) than found in deposits containing more shell. However, since leaching would result from locally acidic conditions, one would expect some loss of bone as well, thus an increased density of lithic remains would be a more reliable indicator of loss of shell due to groundwater. The loss of shell from a deposit would result in relatively higher frequency of certain other components, such as charcoal and organic matter, which would produce a deposit darker in color. A confounding factor here is our lack of understanding of different activity areas within shell middens, let alone a given midden deposit. It is conceivable that an elevated density of stone artifacts or debitage in one layer could be due to that area having been a special activity locus, and that there simply was no shell there to begin with.

Third, if the appearance of a dark, highly organic, mostly shell-less layer in a shell midden is due to postdepositional leaching of shell, one would expect a close correspondence of the ratio of charcoal to nonshell mineral fraction between shelly and leached deposits, since both types of material are more stable chemically than shell. This is a difficult factor to determine using published accounts of excavations of shell middens because the information needed to derive such a ratio has not commonly been obtained or published. In cases where this ratio can be determined, however, it is possible that different ratios may be the result of different activities contributing to different amounts of charcoal and mineral clasts to that deposit.

Fourth, shells that are present in deposits subject to chemical weathering would have many of their identifying characteristics eroded (Ford 1989b:170).

Remaining shells would be weakened by chemical breakdown and thus quite friable; they may also have powdery or chalky films (Glassow 1972). Where identification of bivalves is undertaken as part of the analysis of faunal remains, assemblages from layers most affected by chemical weathering will possess a larger percentage of "unidentifiable" specimens than layers less affected by leaching (Ford 1989b:166). Smaller particles viewed microscopically will also have a more weathered appearance; for example, the edges of the particles will be rounded.

Thus, most compositional characteristics of a deposit that has been leached of shell by groundwater should be similar however that leaching occurred, including a lesser amount of shell or carbonates, a greater relative density of stone artifacts, a similar ratio of charcoal to mineral component, and the poorer condition of preservation of shell particles that are found in the deposit. There

would be some patterned differences, reflected primarily in stratigraphy, given different sources of water flow through the deposits, whether by meteoric groundwater, or by vertical intersection of the shell midden deposits with the groundwater table. The operation of each kind of groundwater flow and their different effects on stratigraphic patterning and composition within a midden is discussed below.

Leaching by meteoric groundwater. Where rates of accumulation of shell fall within the weathering ability of chemical forces, primarily controlled by groundwater, a loss of shell mass will occur. Of course, the nature of the occupation of a site, and activity locations within a site, will change through time. In a single location, input of midden material may decrease due to a number of factors, such as a decrease in location population density, a change in the sorts of activities undertaken at that location or site, a decrease in the length of occupation or change in the season of occupation, and outright abandonment of that site, or location, for extended periods of time. All these alterations in human activity will affect the input of shell into the midden deposits at the ground surface, which in turn is subject to greater or lesser intensity of chemical weathering by the action of groundwater that enters the deposits through rainfall.

The surface receives water from precipitation which percolates vertically through the profile, dissolving shell in the process. As stated earlier in this chapter, carbon dioxide is dissolved in rainwater to form carbonic acid, which lowers the pH of the rainwater. As rainwater penetrates the ground surface and percolates through the deposits, it may acquire even more CO₂ as there are higher concentrations of this gas in sediment pore space than in the

atmosphere due to the activity of soil organisms. Decaying organic matter in the upper 10-50 cm of an active soil profile will lend organic acids to the groundwater (noted in the previous section), further increasing its hydrogen ion concentration and therefore its competence to dissolve shell. The shell-bearing deposits exposed on the surface of a shell midden would be subject to a higher degree of chemical weathering than lower shell-bearing deposits until they are, in turn buried by new deposits.

As the water makes its way through shell-bearing deposits, it eventually becomes saturated with carbonates, and so leaching would become less intense or cease altogether. Saturation of meteoric groundwater with regard to carbonates would occur much more quickly in deposits containing large amounts of shell. Where meteoric groundwater is the primary weathering mechanism there should be a zone below the leached layer which is itself partially leached or contains carbonates that have precipitated out of solution in pore spaces due to evaporation (see Figure 2A and 2B).

One would also expect patination of CaCO_3 to occur on stone, bone and artifacts within this intermediate zone. Patinae may form on the bottoms of platy artifacts or stone as any carbonates that precipitate on the tops would be more easily be washed away if sufficiently charged water reached that depth from the surface. In extreme cases a hard pan may form (called a Bk or Bkm horizon in Canadian soil classification) after pore spaces in and around individual clasts become cemented with precipitated carbonates; this horizon would tend to follow the contours of the existing surface (Birkeland 1984:22-23).

Figure 2: Potential stratigraphic and compositional changes caused by leaching in shell-bearing deposits.

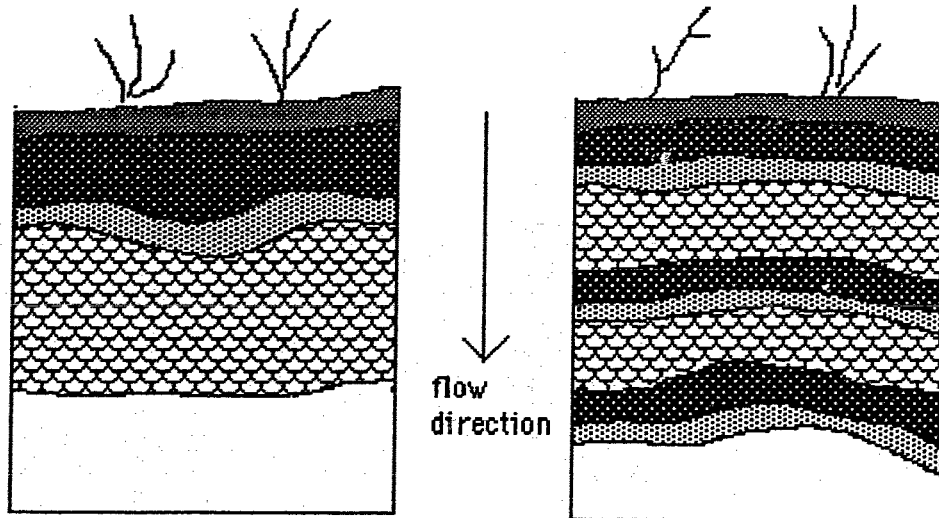
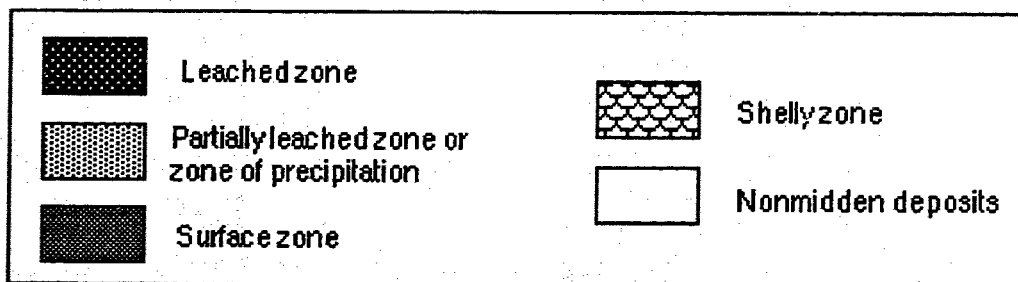


Figure 2A: Leaching by vertical groundwater flow. Zone of partial leaching or precipitation is located beneath fully leached layer.

Figure 2B: Leaching by vertical groundwater flow. Lower leached layer represents period of stability during which increased weathering could occur, followed by later deposition of midden.



Stratigraphically, there should be a highly organic layer with less shell overlying a shelly layer; with the boundary between these layers usually being fairly gradual under these conditions, since the intensity and depth of weathering would depend on the amount of water percolating through the deposits, which in turn would depend on the amount of rainfall or run-off in a given precipitation event (see Figure 2A). On the southern inner coast of British Columbia there is

enough seasonal variation in annual precipitation for this to be the case; however, as one moves toward the outer coast, annual precipitation rates increase and the degree in seasonal variability in rainfall decreases due to the lack of "rain shadow" effects. This variability in the amount of water entering the profile would theoretically result in a gradual, rather than abrupt, transition between layers. The resulting leached layers should be present across the entire site, though the depth of the deposit will vary with local conditions (especially vegetation cover and topography).

Variation in stratigraphic patterning in shell midden deposits would occur where there was an interruption or decrease in deposition of midden material for a long enough period of time for chemical weathering at the surface to occur, followed by addition of more shell. According to figures presented by Ward (1975:106) and assuming 176 cm annual rainfall for the Northwest Coast area (Espenshade 1986:14-15), a 25 cm thick layer containing a large amount of shell (based on sample 1 from Namu, which contains 86.6% by weight of shell, or 7734 g/25 cm³) could conceivably be completely dissolved in about 140 - 690 years, depending on the concentration of CO₂ in solution. The process described above might affect the material exposed at the surface, which then would be buried later with shelly midden debris after the site was reoccupied. This might produce a dark layer sandwiched between two shelly deposits, or even a dark layer at the base of shelly deposits (Figure 2B).

Prolonged stability of the surface of the deposit will encourage pedogenesis. This process includes inputs of organic matter from vegetation that colonizes stable (nondepositional) areas of a site, which in turn encourages the activity of soil organisms, all of which increases the efficiency of the weathering regime for

CaCO₃. A consequence of this would be the alteration of the structure of the sediment, creating voids and dissolving and precipitating minerals, all of which are identifiable from microscopic analysis and should be distinguishable from a sediment that has been leached solely by passage of groundwater.

Leaching by intersection with water table. In coastal areas the groundwater table is often quite near the surface, and can pass through and thus affect archaeological deposits such as shell middens. This movement would affect the lowermost deposits in the site, at a depth near current sea level, except where the underlying substrate is impervious to water (such as nonporous bedrock or sediments with a high clay content) along which groundwater would flow, in which case the leached layer may be higher than sea level. The flow of water through the deposits is lateral, and would carry any dissolved carbonates out of the midden entirely (Buol et al. 1973:121). However, groundwater could flow upward from this layer through capillary rise, and chemical constituents, in particular iron oxides, may precipitate out to form a hardpan layer. Where such a hardpan develops from intersection with the groundwater table it would parallel the surface of the groundwater table, and not the ground surface contours (Birkeland 1984:22-23). In environments more arid than the Northwest Coast, where evaporation is high, capillary rise could also help precipitate carbonates dissolved from shell, forming a layer of "calcrete" within the midden (Buol et al. 1973:121); the activity of plant roots can also contribute to this process (Semeniuk and Meagher 1981).

Intersection with the groundwater table would result in a stratigraphic profile in which the lowermost shell-bearing layers would be leached of shell, creating a highly organic, mostly shell-less layer at the base of the midden, in cases where

the midden deposits are near or below present sea level (see Figure 3A). However, this layer may occur well above sea level, where there is an impermeable deposit underlying the archaeological deposits which conducts the groundwater flow along its upper boundary, results in a "perched" water table. The boundary between the leached and unaffected deposits would in most cases be abrupt, since the flow of groundwater would be less subject to significant amounts of variation (such as with meteoric groundwater) which might produce a more gradational transition. In sites where intersection with the groundwater table is possible, patination and calcic (Bk or Bkm) horizon formation may not occur because groundwater flow would be sufficient to carry solutes out of the site (but see below).

The ability of groundwater to remove carbonates can be diminished by local effects on the chemical composition of groundwater solution. For instance, if groundwater flows through naturally-occurring carbonaceous deposits, it may become saturated with respect to CaCO_3 , and thus rendered unable to dissolve shell when it flows through midden deposits. The accumulation of so much carbonate in groundwater would result in some precipitation of carbonate, as patination on individual clasts near the interface with the groundwater table, or in extreme cases as a "hard pan" (Birkeland 1984). Water in the water table may be recharged by meteoric groundwater flow or run-off, which is better oxygenated and possibly carries the by-products of organic matter decay from the surface, which include a variety of organic acids (Bohn et al. 1985:139; Moore

Figure 3: Potential stratigraphic and compositional changes caused by leaching of shell-bearing deposits

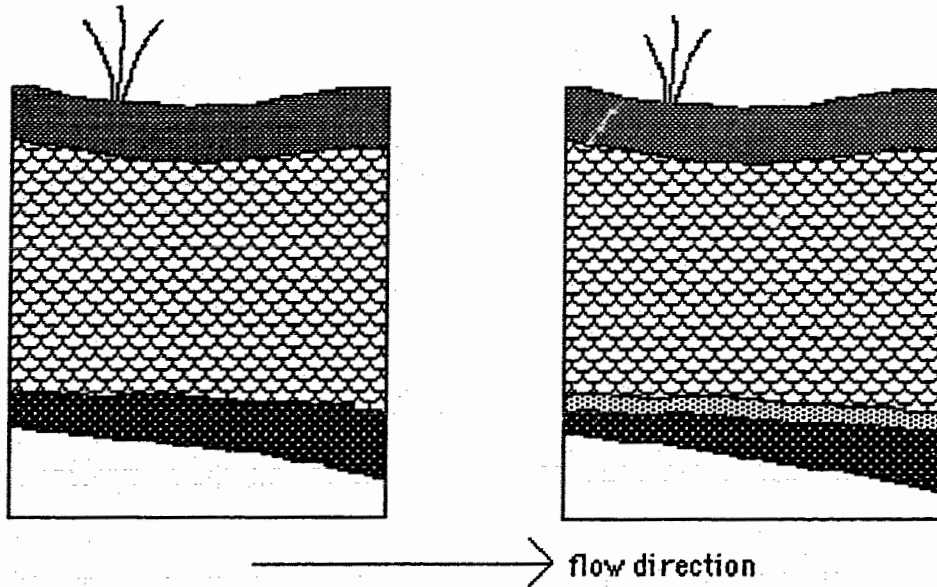
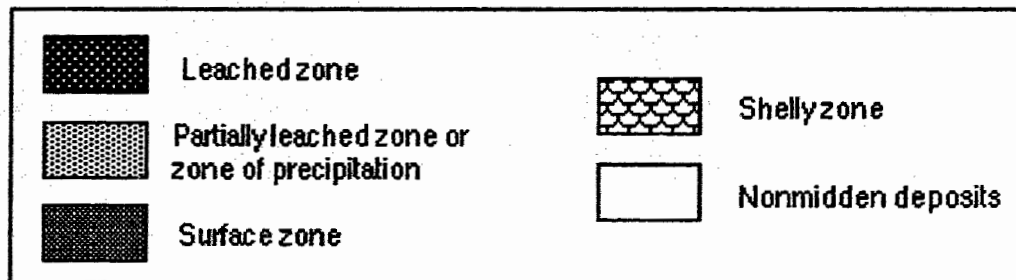


Figure 3A: Leaching by intersection with groundwater table. Note abrupt boundary between basal dark layer and overlying shelly deposit.

Figure 3B: Leaching by intersection with groundwater table, with zone of precipitation above leached layer due to capillary rise or fluctuating water table.



1989:181). Except under unusual circumstances, the flow of water laterally through the deposits should carry away the products of shell decomposition, so precipitation of carbonates as patination would not occur within the deposits.

Since most shell-bearing sites on the Northwest Coast lie directly adjacent to the sea, groundwater flow would carry them into sea.

Groundwater also tends to carry large amounts of dissolved metals and ions (Ward 1970:106). Reaction with components of midden deposits may result in retention of some of these ions. One very likely result would be accumulation of dark ferrous oxides under reducing conditions, which when oxidized would become ferric oxides with a lighter red or rust color. When oxidized these minerals assume a phase that is less soluble in water, causing the formation of a hardpan near the interface with the vadose zone (shown in Figure 3B) (Birkeland 1984:104-105; Bohn et al. 1985:326). Some studies of shell middens have reported such layers. On the Northwest Coast, the site of Namu has an iron oxide hardpan layer near the boundary between a basal, mostly shell-less deposit associated with groundwater flow (Luebbbers 1978:26-27); the presence of reduced iron oxides in a similar basal black layer has also been observed at English Camp, San Juan Island, Washington (Stein 1990, personal communication). The same phenomenon has been noted in shell middens in Florida (Palmer and Williams 1977). Hardpans may also result when there is a fluctuation in the water table level, which can occur due to changes in sea level. In an archaeological context, even minor fluctuations of sea level could determine whether groundwater flow reaches archaeological deposits (Stein 1992c:149).

The two models proposed here for postdepositional leaching of shell bearing archaeological deposits are based on differences in sources and flow direction of groundwater. Deposits leached by either process produce similar effects on the composition and texture (of the shell component) of each deposit, but could

result in slightly different stratigraphic patterning. Black basal deposits, however, could be formed through either process. The models are not mutually exclusive, but are meant to isolate the different consequences of each. The various compositional and stratigraphic criteria discussed above provide a means of identifying which is the primary process at work in a given archaeological site.

Summary

The susceptibility of calcium carbonate to dissolution in a sedimentary environment has been long recognized in the earth sciences, and the process by which it occurs is well understood. This same process can affect biogenic carbonates (shell) with equal vigor. Factors influencing the severity of leaching of shell are 1) The amount of water entering the deposits, and 2) The concentration of carbon dioxide in the soil environment. To a lesser degree, organic matter also plays a role by increasing the acidity of the groundwater solution. The kind of shellfish remains present influences the composition and microstructure of the shell particles, two variables that affect how readily they will be weathered chemically. The significant role this process plays in the diagenesis of fossil shell assemblages has been recognized, and the degree to which it has altered fossil assemblages is beginning to be studied experimentally in paleontology.

In many regions of the world (Oceania, California, Northeastern and Northwestern North America) diagenesis of shell in shell middens has been used to interpret the depositional history of some sites, but has rarely been studied in any depth (but see Hughes 1977; Stein 1992c). Depending on local

conditions, this process can significantly alter the contents and stratigraphic patterning of shell midden deposits. In light of this information two models are proposed by which postdepositional leaching might occur in shell midden deposits, based on the source of the hydrologic regime (meteoric water percolating vertically through the vadose zone, or the intersection of midden deposits with phreatic zone).

CHAPTER THREE: RESEARCH OBJECTIVES AND METHODS

In this section I will examine a hypothesis which seeks to explain the formation of a dark, shell-free deposit found in many Northwest Coast shell middens in terms of postdepositional leaching of the shell by groundwater as stated by Stein (1989, 1992c:150), and corresponding to the second model proposed in the previous chapter. Analytical techniques will determine whether the factors proposed in this hypothesis are present in two representative Northwest Coast shell middens in which this dark, shell-less layer exists. Samples analyzed are from Namu (EISx 1) on the Central Coast of British Columbia, and from Tsawwassen (DgRs 2) on the Fraser River Delta, British Columbia.

Stein's (1989) hypothesis and why it is of interest

As described more fully in the previous section, one explanation for the formation of a dark shell-less layer at the base of shell middens involves postdepositional leaching of shell. With continuous deposition of midden materials there was no opportunity for a soil to form, and the dark layer represents shell midden that has had its shell leached by movement of groundwater into and through that part of the midden (Stein 1989 and others [Brennan 1977; Hughes and Lampert 1977; Mitchell 1971]). The groundwater provided an acidic medium to dissolve and remove the shell from that layer, leaving the upper portions of the midden relatively unaffected. This coincides with my second model, regarding the intersection of the groundwater table with shell midden deposits, discussed in the previous chapter.

Specifically, Stein (1989) proposes three factors to be significant in this process. First, there needs to be a sufficient amount (more than 10%) of soil organic matter. Organic matter breaks down under bacterial and other chemical processes and combines with water to form organic acids powerful enough to cause the breakdown of calcium carbonate in shell (Birkeland 1984). Second, there must be a sufficient amount (at least 10%) of clay in the midden. Clay particles are tiny, platy minerals which, because of their high surface area to volume ratio, possess unusual electrochemical properties; they tend to attract and hold onto organic matter, preventing it from washing away with groundwater flow and keeping it near the shell, where it can continue to produce acids (Bohn et al. 1985:138). Third, groundwater must saturate parts of the midden and flow through it slowly without lying stagnant, in order to prevent the build-up of by-products of leaching, so that organic acids continue to form. According to this hypothesis, if one or more of these three factors is missing, then the dark basal deposit will not form.

The information required to evaluate Stein's hypothesis is readily available. The presence of groundwater movement through the midden can be determined by direct observation in the field. In cases where such field observations were not made by the archaeologist, a good indicator of groundwater movement through midden deposits would be the presence of a ferric oxide "pan" at or near the boundary between the dark, largely shell-less layer and overlying lighter shelly midden material. These pans develop because ferrous oxides in solution in the groundwater are drawn up by capillary action or seasonal fluctuation in the water table to the contact with the drier and more porous shelly midden deposits, where they precipitate as relatively insoluble ferric oxides (Birkeland 1984:21-22). The precipitation of iron oxide

compounds seems to have occurred at Namu (Carlson 1988:9; Luebbers 1978:24), to a limited extent at English Camp on San Juan Island (Julie Stein 1990, pers. com.), and has been noted in middens in Florida (Palmer and Williams 1977). Personal observation of groundwater movement through these deposits during excavation also bears on this phenomenon. Organic matter content can be determined more directly using a variety of techniques, such as chemical or thermal combustion. Clay content is a function of the texture of the sediment, and is also easily determined using techniques borrowed from sedimentology.

The approach taken in this study is a geoarchaeological one by necessity, as the selected factors thought to be significant in forming dark basal deposits in shell middens are also basic attributes of sedimentary bodies. The amount of clay present is an aspect of the deposit's texture, and the amount of organic matter and the presence of groundwater are compositional attributes. Earth scientists may use these and other attributes of a sediment to determine its depositional and postdepositional history. Interpretations that make up this history are the source, transport agent, depositional environment, and postdepositional alteration of the deposit, and these represent the primary interpretations undertaken in this study (Stein 1985,1987). The specific techniques employed are discussed below.

Samples analyzed

Samples were analyzed from two sites (see Figure 4). Namu (EISx 1) is an extensive, deep shell midden located on Fitzhugh Sound on the central mainland coast of British Columbia, approximately 450 air kilometers northwest

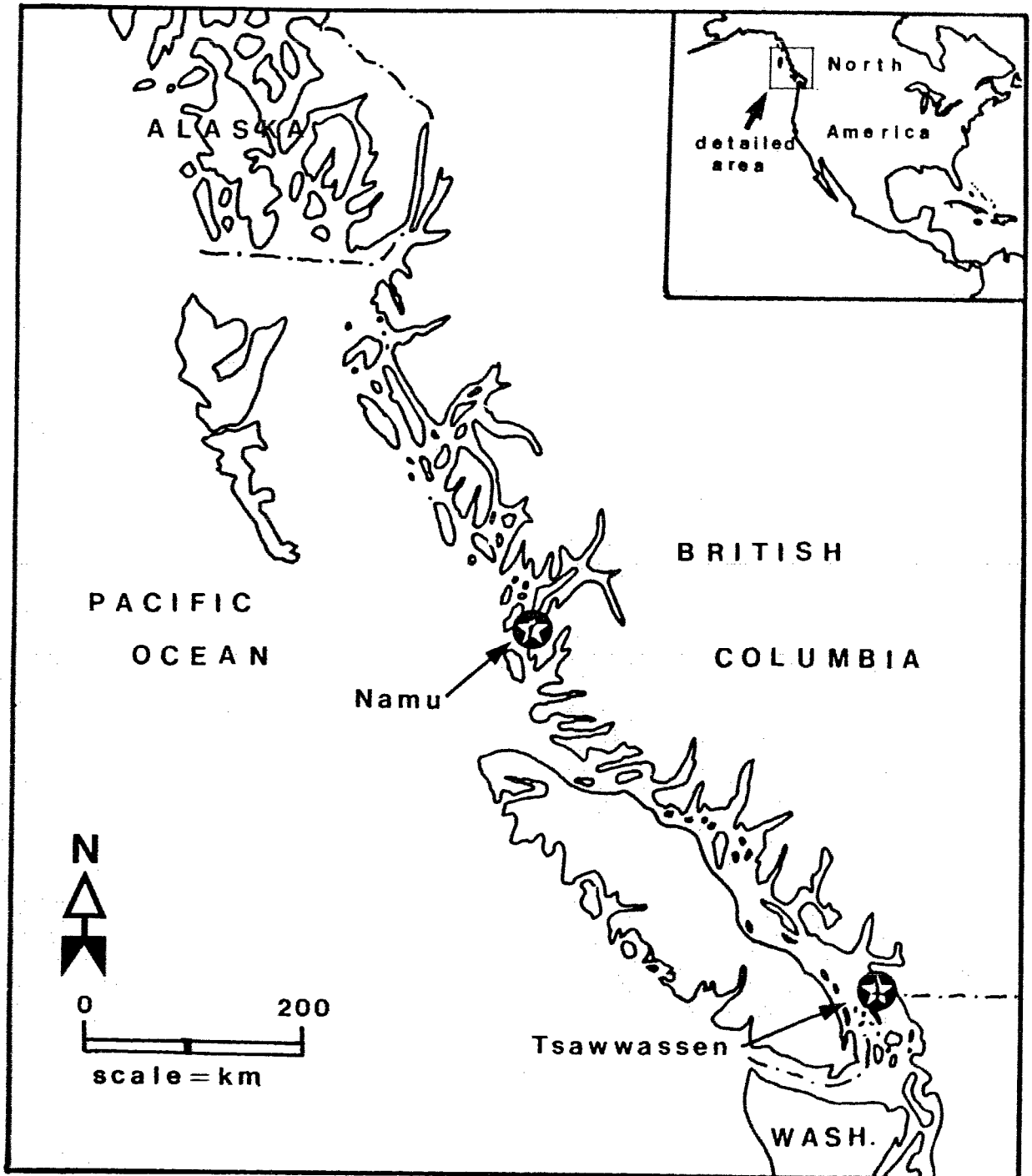


FIGURE 4: Location map of Namu and Tsawwassen sites.

of Vancouver. This site was chosen for a number of reasons. First, it contains the requisite basal dark, highly organic, largely shell-less layer. Second, it is one of the most intensively studied shell middens on the Northwest Coast to date, and the results of these studies are fairly well published and available (Andrews and Retherford 1978; Cannon 1989, 1991; Carlson 1979, 1988; Conover 1973; Curtin 1985; Hester and Nelson 1978). Samples of the identified strata were collected from a single location in July 1977 during excavation by Roy L. Carlson (Simon Fraser University) and were available to me for this study.

The second site examined is Tsawwassen (DgRs 2), located on the Strait of Georgia on the Fraser River Delta, about 15 km south of Vancouver. This site is of interest for different reasons. Like Namu, adequate samples were taken of the different deposits identified in August 1989 during excavation by Arcas Consulting Archaeologists, Ltd., of Coquitlam, British Columbia (Stryd et al. 1991). Unlike Namu, samples were taken from two different areas of the site: one in which the dark basal deposit was present (Area A) and one where it was not (Area C). Thus, samples collected from this site offer an opportunity for an intra-site comparison that may help identify the factors that led to the formation of the dark organic-rich layer.

More detailed descriptions of the environment, geological history, chronology and excavation methods for each site are provided in the next chapter, along with the results of the analyses outlined below.

Laboratory techniques

Since different analyses are required for different size fractions of the sediments collected, the bulk sediment samples are split, first into coarse (≥ 2 mm) and fine (< 2 mm) fractions. This was done using a series of five nested screens, with meshes of -5, -4, -3, -2, and -1 \emptyset ("phi"). The material that passes through the -1 \emptyset screen is the fine fraction. Each of the coarse fractions was bagged separately for later sorting, while the fine fraction was quartered using a sample splitter, yielding a subsample of the fines of approximately 500 grams, to be used for textural and chemical analyses. All particle sizes are reported using the \emptyset scale, which is explained in Appendix A.

Coarse fraction. The coarse fraction was sorted according to material type using the following categories: Mytilus shell, other shell, unmodified bone, angular rock, rounded rock, and charcoal. Categories were selected to separate components introduced by human activity (shell, charcoal, bone) from those deposited through nonhuman processes (particularly rounded rock) in the smaller size range (-3 and -2 \emptyset). The material in each category was then weighed and recorded. For -5, -4, and -3 \emptyset fractions, 100% of the fraction was sorted; for smaller-sized fractions (some of the -2 and -1 \emptyset fractions), a sample was taken (about 25% by weight), sorted and weighed, and the results extrapolated to the entire fraction. For this analysis, only shell ("other shell" and "Mytilus") and mineral ("rounded" and "angular rock") weights were integrated with comparable material categories from the fine fraction.

Fine fraction. The fine fraction was evaluated for grain size distribution and chemical composition using the techniques outlined below.

For grain size analysis a sample of approximately 50 grams was taken, pretreated, and suspended in a deflocculant solution (ca. 3 g sodium hexametaphosphate/1000 mL deionized water). It was then wet sieved through a +4 Ø geologic screen to separate sand from mud (silt sized and smaller particles) fractions according to procedures outlined by Folk (1980). The mud fraction remained in suspension in deflocculant, and was placed in a 1000 mL graduated cylinder for hydrometer analysis (described below), while the sand fraction was placed in a beaker, dried, mechanically sieved through a series of nested geologic screens (-1, 0, 1, 2, 3, and 4 Ø mesh), and then weighed.

Sediments containing large amounts of carbonates, organic matter, or iron oxides may require pretreatment to remove these compounds before analysis for grain size distribution. These compounds can cause the particles to aggregate, which would yield an underestimate of the percentage of smaller particle sizes in the sample (Folk 1980:16; Holliday and Stein 1989:355; Kunze 1965). Thus, pretreatment of samples is often critical for an accurate estimate of textural parameters; this also implies that there is no one single pretreatment method that is applicable in all cases. All samples in this study were pretreated before wet sieving by soaking in a 6% solution of NaOCl (commercial Javex® bleach) whose pH was lowered to 9.5 by adding HCl (as outlined in Anderson 1963; also in Jackson 1985:37). This pretreatment undoubtedly affects other components, such as bone, and can potentially bias results of microartifact studies (Stein 1990, personal communication). Because the shell, which makes up the largest portion of the sediment in most of these samples, is attributable to human activity, a second grain size analysis was run after pretreating the samples to remove both organic matter (as outlined above) and

calcium carbonate (by oxidation in a 10% solution of HCl). Results of the two separate analyses were combined (method described below) to yield separate size distributions for shell and mineral.

There are two ways of determining the grain size distribution of silt and clay sized clasts using a settling column, both of which were used in this study. The first analysis employed a hydrometer (Bouyoucos scale) to measure the density of liquid in the settling column at certain time intervals (according to Crozier 1981:37-39; and Lewis 1985:101-106). The hydrometer method was chosen for the first grain size analysis for several reasons. It requires less lab equipment than the pipette method; it yields results more quickly; and it is easier to run and keep track of multiple settling columns simultaneously. Drawbacks to this method are that it is less accurate when applied to small concentrations of sediment in suspension (Sternberg and Creager 1961, discussed in Appendix A), and that there is greater disturbance to the settling particles when removing or placing the hydrometer in the settling column. However, most of the samples had concentrations within the "safe range" for the method as determined by Sternberg and Creager (1961). In the samples analyzed here, only two had mud concentrations of less than 10 g/L; none of the midden samples fell below 6 g/L concentration.

The second grain size analysis, which characterized the mineral fraction after pretreatment to remove all shell, employed the pipette method. In this method 20 mL samples are withdrawn from a settling column at specific times and depths, which are calculated using Stoke's Law, dried and weighed (according to Folk 1980:33-44). This technique was more appropriate for the second analysis because the removal of shell particles often reduced the overall

concentration of mud per sample to less than 6 g/L. Since results of the hydrometer method become less accurate in such low concentrations, the pipette technique was necessary. Studies comparing both techniques indicate that they yield comparable results (Holliday and Stein 1989; Sternberg and Creager 1961).

By combining the results of the two different grain size analyses it is possible to consider the shell and mineral populations separately, which is necessary since both components have very different life histories. An example of this procedure is provided in Appendix A. Subsample weights for each ϕ interval were converted to the weight of the total sample in that ϕ interval by multiplying the subsample weight by a split factor (Folk 1980). This split factor is determined by dividing the total <2mm sample weight by the total subsample weight used in the grain size analysis. The total <2mm sample weight used in this equation is reduced to account for the removal of constituents during pretreatment (e.g., organic matter and carbonate). (These percentages are estimated from the loss on ignition technique outlined below.) For each sample the weight of material in each ϕ interval of the second grain size analysis, which represents only the mineral (nonshell) component of the sample, is subtracted from the weight of material in the same ϕ interval from the first grain size analysis, which represents the weight of both CaCO₃ (shell) and noncarbonate mineral particles. The remainder represents the total weight of CaCO₃ (shell) in that ϕ interval. Because the results of the grain size analysis were converted to the weight of CaCO₃ in that ϕ interval for the entire sample, the weight of shell in the coarse (≥ 2 mm) fraction could be added, and weights of each ϕ interval were added together to produce a total weight of shell in each sample. Each ϕ interval weight for shell was then divided by this total weight to yield the

percentages used to create the bar graphs of shell distribution presented in Appendixes B and C. This technique is similar to the "calcimetry" technique used by Laville et al. (1980:91-92), but differs in the way the data are presented. Laville et al. display two graphics, one of untreated distributions and one of a decalcified distribution, rather than a single graphic that isolates the distribution of the CaCO_3 fraction alone; they also lump results into three larger particle size categories (sand, silt and clay) rather than individual ϕ intervals used in this study.

However, there are several factors that reduce the accuracy of this estimate of the amount of shell in each size interval, particularly those smaller than -1ϕ (2mm). First, the estimate is the result of two separate analyses of a sample (i.e., two separate subsamples of a population), thus each will have some variability between size classes resulting from sampling error. This particularly affects samples and size intervals within samples that contain small amounts of shell, since that small amount can be masked if the second subsample (to estimate the mineral content only) happened to contain a slightly greater proportion of mineral grains in that size interval. A second problem is the fact that the amount of "mineral" also includes bone fragments which are not completely removed by the pretreatment process, and increases the weight percent in various size categories by weathering into smaller fragments from the exposure to HCl. However, bone makes up only a very small percentage by weight of the entire sample, and in most cases wouldn't significantly alter the overall textural distribution. Third, the two grain size distributions were produced by two different analytical techniques, hydrometer and pipette methods. Although comparable in most cases, the pipette method is slightly more accurate, and may combine with the other factors mentioned above to

produce error. In fact there are instances where the resulting estimate for the amount of shell in a given size interval came out negative (recorded as zero); these occurred in samples containing relatively small amounts of shell, and in size intervals with low frequency of occurrence. Therefore, the distribution of shell in the <2 mm size range should be viewed as a broad estimate whose accuracy decreases for samples containing small amounts of carbonates. For this reason the resulting histograms of size frequency distribution of shell in samples are useful primarily as a broad indicator of patterning.

The cumulative frequency curve of mineral fraction for each sample was used to compute statistical parameters of each mineral population sampled, according to formulae in Folk (1980:40-45). Grain size parameters used in this study are graphic mean (abbreviated as "mean"), inclusive graphic standard deviation ("SD"), inclusive graphic skewness ("skew"), and kurtosis ("kurt"). Formulas for deriving these statistics and an explanation of their meaning are presented in Appendix A.

The organic matter and carbonate content of the fine (<2mm) fraction was determined using the loss-on-ignition technique (Stein 1984b). In this technique, a small sample of material is burned in a high temperature furnace at 550°C for one hour to oxidize all organic matter. The sample is then removed and weighed, and returned to the furnace where it is burned for another hour at 1000°C to remove all carbonates. The sample is again weighed. The weight difference between beginning and end yields a percent by weight of organic matter; the weight difference between the first and second burns is divided by .44 (the proportion of CO₂ in CaCO₃) to determine the weight of carbonates present in the fine fraction (Dean 1974:244; Stein 1984b). This analysis was

conducted at the Archaeological Sediments Laboratory of the Department of Anthropology at University of Washington, Seattle.

Loss on ignition was chosen over other available techniques for a number of reasons. First, the technique is relatively economical in that multiple samples can be run simultaneously, yielding fast, accurate results. Techniques employing chemical oxidation are more time consuming, require the handling of caustic chemicals by the researcher, sometimes require more specialized equipment, and are often less accurate as not all chemically-based techniques can remove all the desired components (e.g., hydrogen peroxide method in Robinson 1927). Second, the technique is well suited to shell midden samples because the amount of clay minerals in them is usually low. Large amounts of clay can add error in the form of weight loss due to the driving off of water associated with clay minerals during the burn at 1000°C, which can lead to an overestimate of actual carbonate content (Stein 1984b). In the samples used for this study, the clay content did not exceed 12.5% (before removal of carbonates).

The pH of each sample was recorded using a Fisher Accumet model 230 pH meter. The pH was determined using a 1:1 sediment-to-water ratio according to procedures outlined in Jackson (1985:603-607). Twenty grams of fine fraction were measured and placed into 50 mL glass beaker, to which 20 mL of deionized water was added. The slurry was mixed using a glass stirring rod and allowed to sit for one hour before readings were taken. A series of readings were taken on each sample by inserting the glass electrode in the slurry and leaving it there until the needle stopped moving. If three identical

readings in a row were recorded, then that was accepted as the pH estimate for the sample.

The pH is a measure of relative concentration of free hydrogen ions in the soil solution (Jackson 1985:603). It provides a useful measure of the kind of chemical activities that are likely to take place in the sampled deposits. For instance, some kinds of postdepositional chemical changes occur only under either acid or basic conditions. The pH uses a logarithmic scale from 1-14: 7 is neutral, a pH less than 7 is acid, and one greater than 7 is alkaline or basic. The pH may itself indicate an ongoing chemical process; for instance, a high (basic) pH in a deposit devoid of shell or other carbonate-bearing minerals, but which would normally be in an area characterized by highly acidic conditions (such as a podsollic soil), is probably due to the products of leaching from deposits higher in carbonates. The results of pH determinations are limited by the fact that once a sediment sample is removed from the ground, it is isolated from the chemical processes that formed and maintained it. The longer the sediment sample is away from its natural context, the more likely it is that the sample has undergone chemical changes while awaiting processing in the laboratory. In the case of pH, samples that have been in storage for long periods of time tend to become more neutral (Jackson 1985). This process may have affected the samples from Namu, which were collected more than ten years prior to this study. The deposits at Namu may therefore actually be somewhat more alkaline than the results in this study indicate (none were in the acid range).

A detailed compositional study was undertaken of part of the sand-size fraction using point counting. A small subsample was taken from the fine fraction of

each sample, was wet sieved with a +2 Ø screen with deionized water, and the remaining particles were allowed to dry in a drying oven at low temperature (60-70°C). Each sample was then mechanically sieved through geologic screens (0, 1, and 2 Ø) for 15 minutes. Each fraction was examined under an optical microscope using the "band technique" outlined by Galehouse (1971). Each particle falling between two parallel lines was counted by being placed in one of the following compositional categories: Mytilus shell, other shell, bone, charcoal, and mineral. Between 400 and 500 grains per size fraction was counted. This results in a percentage by count of each compositional category. This provides a useful means of seeing whether smaller shell particles are being weathered, and of checking ratios of certain materials that are resistant to chemical weathering (charcoal:mineral), which should remain within the range for the shelly layers if a layer had become deflated in volume through loss of its shell to leaching.

Summary

Bulk sediment samples from two prehistoric shell midden sites, Namu and Tsawwassen, were analyzed to determine the composition and texture of each deposit represented, and to reconstruct the depositional history of site deposits. Using this information, I will determine whether the conditions outlined by Stein (1989) for the occurrence of the basal dark shell midden deposit are present at the two sites. Specifically, sufficient amounts (10%) of organic matter and clay need to be present, as does a constant flow of groundwater laterally through the lower midden deposits, in order for the dark, shell-less midden (i.e., leached) deposit to form. Results from these analyses are presented in the next chapter (chapter four).

CHAPTER FOUR: ANALYSIS AND RESULTS

In this section the results of the analyses outlined in chapter three are presented separately for the Namu and Tsawwassen sites. Background information on each site is presented, including a brief summary of previous archaeological work, local geological context, site stratigraphy, and sample provenience and type. Results of analyses are presented and discussed. These data are integrated into a depositional history of each deposit, and the applicability of Stein's (1989) hypothesis (outlined in the previous chapter) is assessed.

Namu

Namu (EISx 1), on the Central Coast of British Columbia, is a deep, strikingly stratified shell-bearing site whose earliest (nonshell) deposits date back approximately 10,000 years, making it the oldest dated human occupation on the British Columbia coast (Carlson 1988). The site was first investigated by a team from the University of Colorado under the direction of James Hester in 1969 and 1970 (Hester and Nelson 1978). These excavations established the extent of the midden deposits, described the basic stratigraphy and recovered a small localized sample of artifacts, faunal and other remains. The site was excavated again in 1977 and 1978 by Roy Carlson of Simon Fraser University, which resulted in a refined stratigraphy and a more extensive sampling of the midden and non-midden ("off site") areas and several published analyses of stratigraphy, artifacts, human and faunal remains (Cannon 1991; Carlson 1979; Curtin 1984).

The area of the coast near Namu has been little studied geologically (Andrews and Retherford 1978). The geology of the area around Namu is dominated by the Coast Range Batholith, a large body of rock of volcanic origin that intruded during the Upper Jurassic period (about 170 to 140 m. y. a.) (Graham 1909:38). Most of the overlying rock has long since weathered away to expose the batholith; however, in some areas there remain metamorphosed and sedimentary deposits, mainly schist, argillite and limestone. Some of these minerals were noted near the entrance of Fitz Hugh Sound (Graham 1909:39). The upper part of batholith is a light colored granite, medium to coarse grained, containing "more hornblende" (Graham 1909:39). Products from the decomposition of the granite, which outcrops at Namu, dominate the lithology of the mineral sediments in the site vicinity. Andrews and Retherford (1978) state that significant deglaciation was underway from Alaska to the Fraser Delta area by 13,000 BP, and the glacial diamicton directly underlying archaeological deposits at Namu was probably deposited around this time.

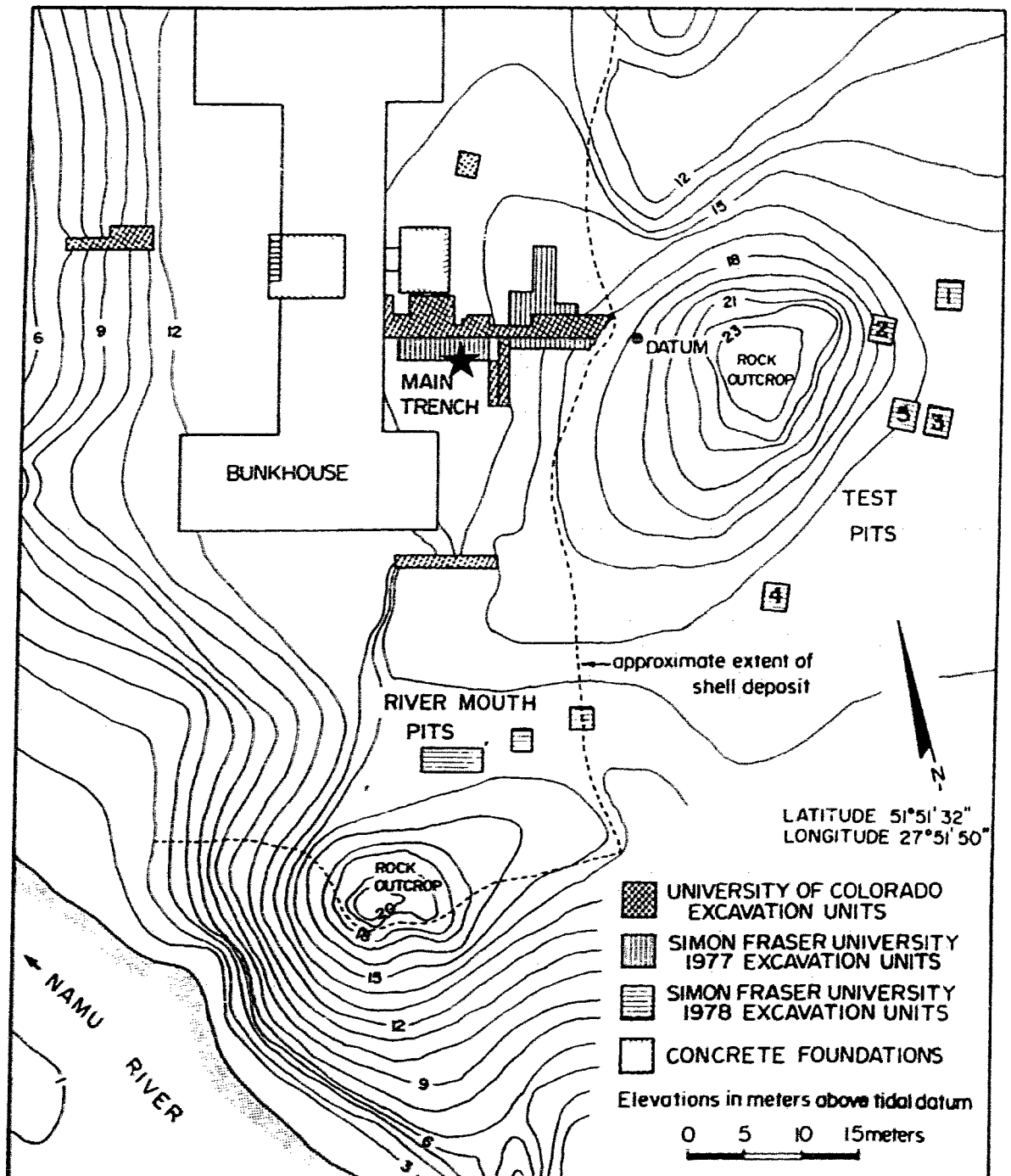
Close to centers of ice-loading, sea level during and just after glaciation was generally higher than today, but after the glacial retreat sea level began to lower rapidly due to isostatic rebound of the land (Fladmark 1975:144). By about 10,200 BP it is estimated that sea level around Namu was about 17 m above current high tide mark (Andrews and Retherford 1978:348). Sea level continued to drop rapidly until 7-8,000 BP, when it reached current levels. It then continued to drop 3-5 m below current high tide mark until about 3,500 BP, after which time it began to rise again to current levels, possibly causing the inundation of local coastal archaeological deposits dating between 7,000 and 3,500 BP (Andrews and Retherford 1978).

Site stratigraphy and sampling

Like most Northwest Coast shell middens, the stratigraphy of Namu is a complex series of many deposits, differing greatly in extent and thickness. During the Simon Fraser University project the site was excavated in natural layers, arbitrary levels being employed within "strata" identified in the field. Several different deposits were identified during excavation and were given numbers and letters as labels. Samples used in this study were collected in the western extension of the "main trench", from the south profile (34S line) at 4W (see Figure 5). Not all strata identified during excavation are represented in this area. Stratum 1 consists of a poorly sorted gravelly sand, most likely glacial in origin, and underlies all the deposits except those in the eastern part of the "main trench," which rest on a granitic rock outcrop. Stratum 2 is a black, highly organic fine material, containing lenses of shell, ash and charcoal, bone and stone artifacts. Stratum 5B lies just above stratum 2 in the profile from which the samples analyzed here came; it is very shelly, containing much whole shell and barnacle. Stratum 5 contains mostly fragmented shell in a dark, highly organic matrix. Stratum 6 is primarily composed of shell, mostly barnacle, which underlies the surface deposit (stratum 12) (see Figure 6).

Carlson (in Cannon 1991:Appendix B) groups the deposits which were identified in the field into six time periods, which in total span about 11,000 years. These groupings are based primarily on radiocarbon dates on charcoal and bone, and to a lesser extent on changes in deposit composition, color, or artifact content. Because these are different criteria than those used to identify layers during excavation, the two sets of units do not necessarily correspond. These periods are:

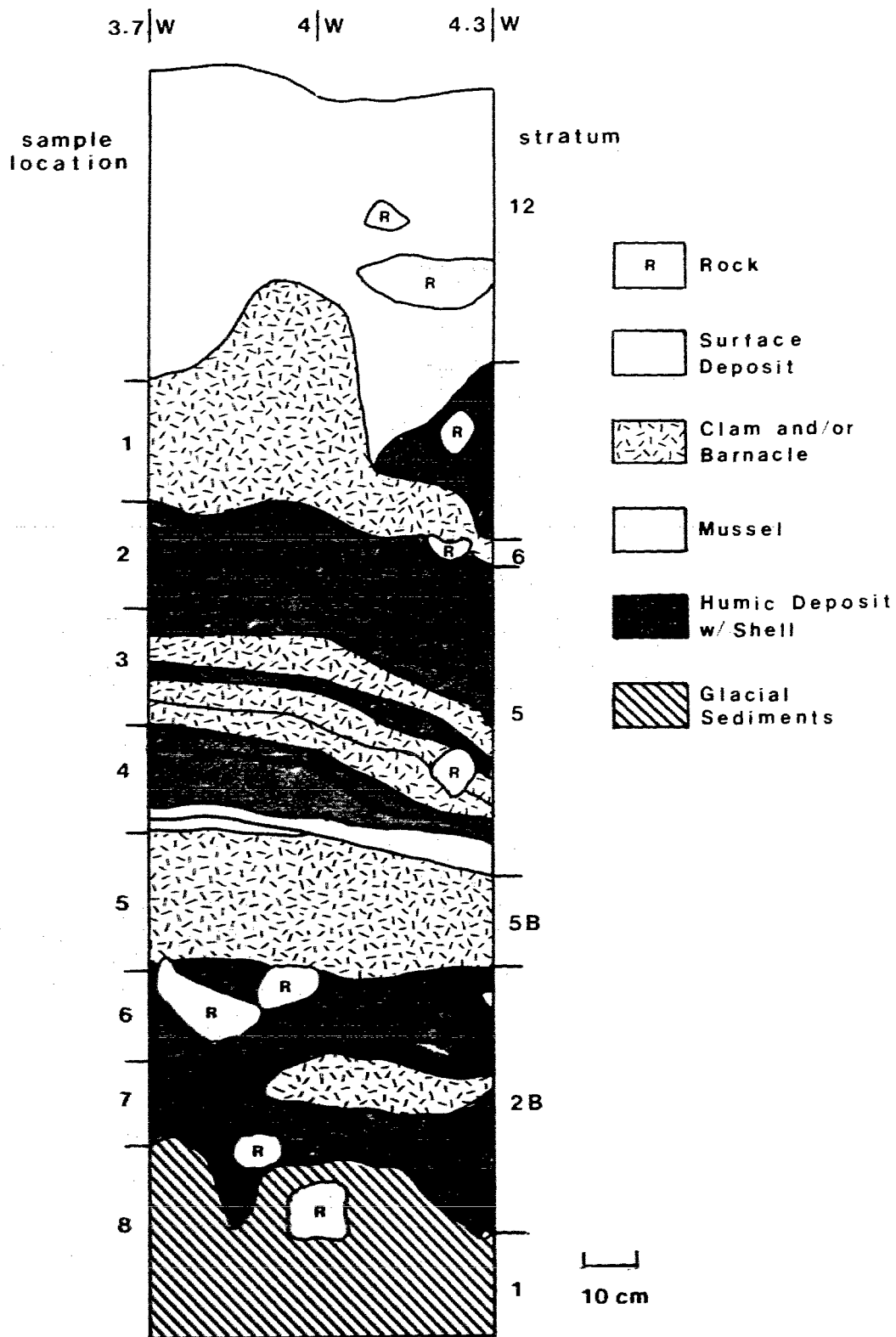
FIGURE 5: Site Map of Namu (EISx 1)



★ SAMPLE LOCATION

After Cannon (1991:86)

FIGURE 6: Profile of Sample Location at Namu (34S, 3.7-4.3W)



1. Spanning 11,000 to 7000 BP (corr.), this unit overlies the culturally sterile glacial till, and is found only in the "rivermouth trench" and at the eastern end of the "main trench" where it rests directly on the rock outcrop. It is described as "black matrix", about 60 cm at its thickest, and is devoid of faunal remains and bone artifacts, although lithic materials abound. This unit is not represented in the series of samples analyzed in this study.

2. This period spans 7000 to 6000 BP (corr.) and is composed of sparse amount of highly fragmented shell in a black matrix containing a large amount of organic matter, lithic remains, and bone. Mussel shell occurs in lenses. This period includes layer 2B, and is represented by samples 6 and 7 in this study.

3. Period 3 spans 6000 to 5000 BP (corr.), and is found only in the western portion of the "main trench" excavations. The deposits belonging to this period consist of numerous burials found within a dark matrix containing fragmented shell (greater amount than in layer 2B), but also discrete layers of mostly shell (barnacle and clam). This period seems to be represented in sample 5, which comes from stratum 5B.

4. This period spans 5000 to 4000 BP (corr.). Most deposits for this period are found in the "rivermouth trench" but is shown also in the profile from which the samples analyzed here came. The deposits lie above those dated to Period 3, but are very similar to those in composition, so it is difficult to determine which, if any, sample represents these deposits. Sample 4 is the lowermost one from layer 5, and may fall within this period.

5. This period spans 4000 to 2000 BP (corr.). The deposits representing this time period are similar in composition to those for Period 3 and 4. This time period is said to include all of strata 5B, 5C, and 6, which are represented by samples 1, 2, 3, 4, and 5. However, assuming that the drawn profile with radiocarbon dates is accurate, at least samples 1, 2, and 3 contain material from this period (Cannon 1991:89).

Samples were taken from the sides of excavation units after excavation was completed. Eight samples were collected in vertical succession from the "west trench" of the Simon Fraser University excavation in July 1977, and represent five different layers identified during excavation (strata 1, 2B, 5B, 5, and 6). One

sample was listed as coming from stratum 2A, but Carlson (personal communication 1992) states that this layer, corresponding to Period 1, was not actually identified in the sampling location, and feels the sample belongs to stratum 2B. These are not "true" column samples (sensu Stein 1985:7-8), which are usually taken at systematic intervals in order to look for evidence of postdepositional change through the vertical profile, such as pedogenesis. Instead, they were collected within an identified layer, and thus are better characterized as bulk samples that happen to have been collected in vertical succession to interpret depositional events (Stein 1985:8-9). Samples ranged in weight between 1385.5 g (sample 8) and 9317.3 g (sample 4), with a mean of 6831.9 g.

Each of these gross strata is a composite of smaller depositional events, each of which may be quite variable in its composition (Stein 1992b:79). Thus, each stratum is inhomogeneous to an unknown extent, which violates one of the assumptions underlying the validity of extrapolating from a sediment sample to the layer which it is supposed to represent (Krumbein and Pettijohn 1938:40). Therefore, the results reported in these analyses cannot be said to represent the entirety of the identified units, particularly with regard to shell content, which varies in density and particle size distribution within a given stratum. However, based on field descriptions samples from stratum 2B (samples 6 and 7), stratum 6 (sample 1) and stratum 5B (sample 5) seem to come from deposits that are sufficiently homogeneous that the samples could be representative of them (Figure 6).

Results of analyses

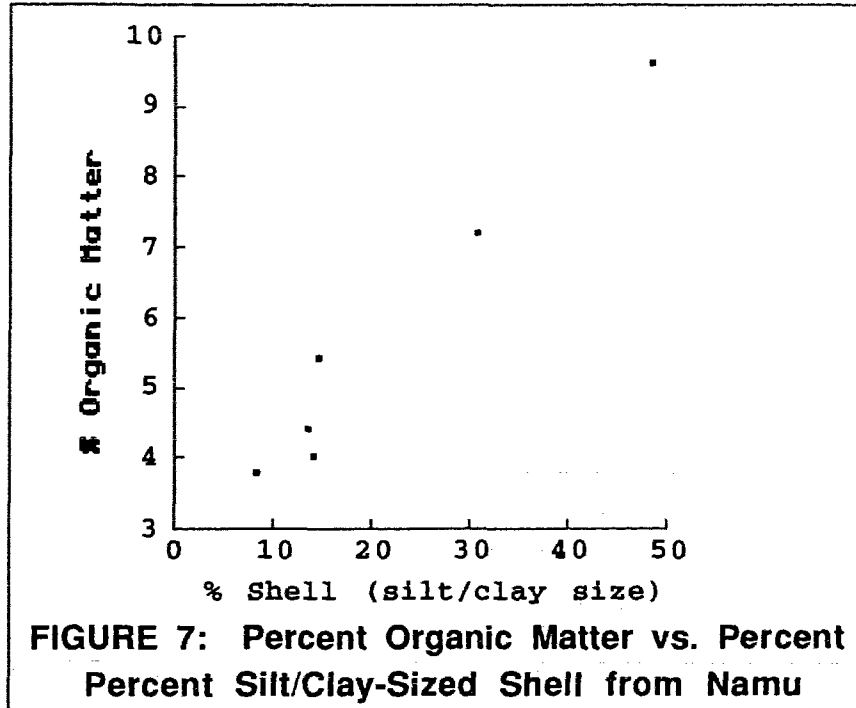
Texture. Appendix B contains bar graphs of the grain size distribution of shell and mineral components in each sample, the latter representing only the <2mm fraction (matrix). For samples 7 and 8 only bar graphs for the mineral fraction are presented, since sample 8 contained no shell, and sample 7 contained so little shell that the comparison of the two grain size analyses are not meaningful, given the amount of error inherent in the technique of combining the two separate analyses, discussed in the previous chapter. All bar graphs represent the distribution of particle sizes within that compositional category (shell or mineral), and so all figures add up to 100%.

Visual inspection of the size distribution of shell indicates three different patterns. Samples 1 and 5 both have a similar amount of shell overall (generally higher than samples 2 and 4; see Table 2 below) and show a trimodal distribution, the primary mode being at -3 ϕ , the secondary at 0 ϕ , and a tertiary mode at +8 ϕ . In samples 3 and 4 a slightly different pattern prevails. While the distribution is still trimodal, the primary and secondary mode are reduced to -2 ϕ and 1 ϕ respectively, and overall there is substantially less shell than in samples 1 and 5 (see Table 2). There also appears to be a slightly greater proportion of carbonate particles around the tertiary mode (8 ϕ), especially in sample 2. Samples 2 and 6 show a pattern very distinctive from those noted above. Both samples have their primary mode in the >9 ϕ category, well into the clay range and possibly representing carbonates in solution rather than discrete particles. In sample 6 the secondary mode is -3 ϕ and the tertiary mode 8 ϕ ; the intermediate mode in the sand size range of samples 1, 3, 4 and 5 (at 0 or 1 ϕ) appears to be absent. The secondary and

tertiary modes in sample 2 are at $-2 \text{ } \emptyset$ and $0 \text{ } \emptyset$, and so bears more resemblance to samples 3 and 4.

Ford (1992:299) has found that the abundance of shell in a given size class is primarily influenced by relative abundance of different taxa. For instance, a relatively high abundance of mussel tends to create a mode at the 3-6 mm size class; and a higher relative abundance of cockles tends to create a peak in the 25 and 12.5 mm size ranges. Cultural processes, such as burning of shell and trampling, also influence which size classes dominate, mitigated by the taxon's shell structure, and probably increase representation in the $-2 \text{ } \emptyset$ to $3 \text{ } \emptyset$ size range. As shell particles are reduced in size, the role of chemical weathering in reducing particle size increases because of their larger surface area relative to volume, and is most likely the main source of CaCO_3 particles in fine sand-sized class and smaller. These may represent individual crystals liberated from the organic matrix of the shell. For instance, Mytilus edulis is reported to have an outer layer with a prismatic microstructure, composed of calcite "needles" about 1-3 microns in diameter, which correspond to the 8-9 \emptyset interval; these are the smallest prisms of any bivalve family (Taylor et al. 1969:81).

Samples 2, 3 and 4 may represent deposits in which the shell component has been exposed to a greater degree of weathering, mainly mechanical, than that in samples 1 and 5. In fact, profile drawings and field descriptions for the deposits from which samples 2, 3 and 4 were taken indicate a series of thin deposits, with less shell, or shell that has been fragmented to a greater degree than that in samples 1 and 5, surrounded by a dark brown matrix high in organic matter. These layers were interpreted by Luebbers (1978:34-35) as resulting from "hearthside activities" such as concentrated trampling in the area by



people, based on the apparent association of these layers with hearth features. In sample 6 and to a lesser extent sample 2 more intense or longer exposure to chemical weathering may be responsible for the high abundance of shell in the >9 Ø fraction; acids produced by groundwater and high organic matter content may have reduced the shell to much smaller particles (silt size and smaller). In support of this, the proportion of shell in the silt size and smaller fraction is positively correlated with organic matter content (Pearson's $r=0.982$) (see scatterplot, Figure 7). However, the small sample size probably exaggerates the actual strength of this relationship.

The results of the second grain size analysis alone, which was conducted after removing all organic matter and carbonates, are shown in Table 1. The results of grain size analysis which include the gravel-sized fraction are presented in Table B-1 in Appendix B, but are not included in the discussion below.

TABLE 1: Grain Size Data from Namu Samples. <2 mm Fraction.

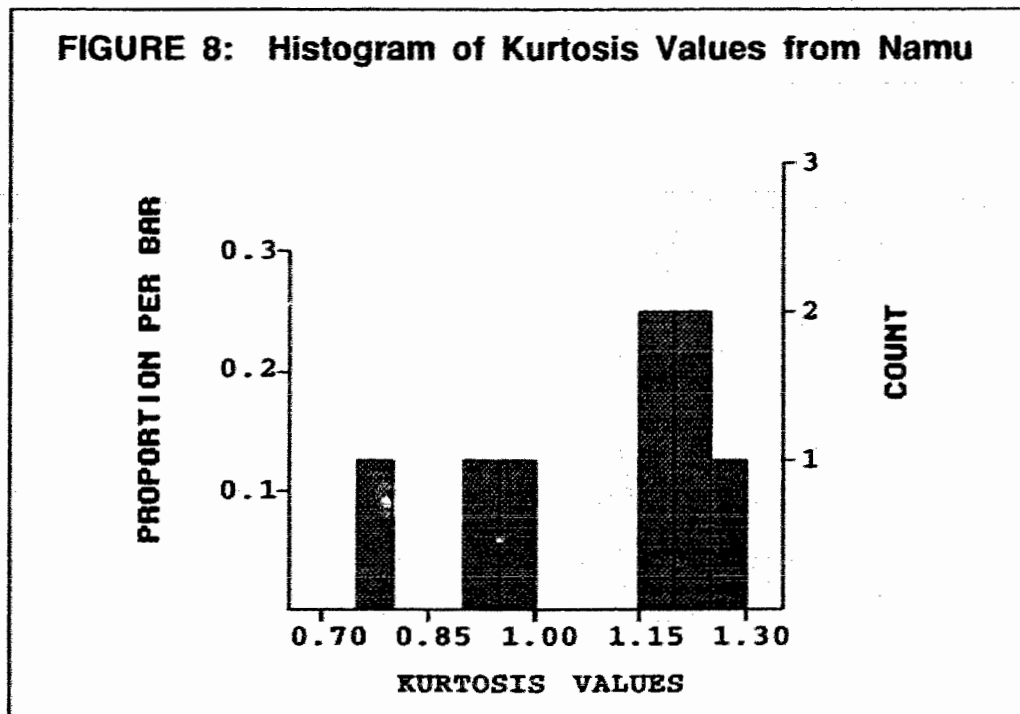
Laye r	Sampl e	%Sand	%Silt	%Clay	Mean	S D	Skew	Kurt
6	1	89.0	9.3	1.7	2.0	1.7	+0.26	1.23
5	2	84.9	10.6	4.5	1.9	2.1	+0.36	1.25
5	3	80.2	16.3	3.5	2.3	2.2	+0.27	1.20
5	4	79.0	16.0	5.0	2.4	2.2	+0.28	1.21
5B	5	72.6	20.5	6.9	2.8	2.6	+0.35	1.17
2B	6	81.4	16.6	2.0	2.1	1.9	+0.43	0.94
2B	7	81.2	17.4	1.4	2.2	1.8	+0.20	0.97
1	8	89.1	10.9	<1	1.7	1.5	+0.10	0.75

Outlined rows indicate data from basal black layer.

In the mineral fraction of the deposits there seems to be a change in the primary mode at the 2 Ø interval in the mineral fraction, while samples 3, 4, and 5 have a distinctive peak at the 3 Ø interval. Samples 6 and 7 represent a third pattern, the mode being "shared" somewhat between 2 and 3 Ø. This last pattern is similar to the grain size distribution of sample 8, which is the underlying, culturally sterile glacial diamicton.

Samples 8 (the underlying glacial sediments), 6 and 7 (the basal dark layer), and 1 (shelly) rate as poorly sorted (1-2 Ø), while samples 2, 3, 4 and 5 (all shelly layers) all were very poorly sorted (>2 Ø). The kurtosis values (Table 1) indicate that, as more shell is added, sand from a better-sorted source is introduced to the population of mineral grains. This results in a more "peaked" grain size distribution curve for the shelly layers, and increases their kurtosis values. All shelly layers are leptokurtic (>1.10), while the two samples from the basal dark layer are within the mesokurtic range (0.90-1.10), and the "sterile" layer is platykurtic (<0.90). Kurtosis values are presented graphically in Figure

8. The difference between shelly and dark layer kurtosis values is statistically significant (Student's *t*-test, $t=18.357$, $p<0.001$), as is the difference between the underlying sterile and the dark layer, although to a lesser degree ($t=13.667$, $p=0.05-0.02$). Fine particles (silt/clay size range) are added by other processes; this leads to a positive skewness value for all samples. As a result, skewness varies randomly among the different samples, sample 8 (underlying glacial sediments) having the lowest value due to the relative lack of silt and clay sized particles.



What does the particle size distribution of the mineral fraction indicate about the probability of the basal dark layer (sample 6 and 7) being the leached residue of deposits containing formerly greater amounts of shell? The texture of the mineral component seems to resemble that of the underlying sterile glacial sediments to a greater extent than it does the texture of the mineral fraction of the shelly layers. The <2mm fraction of the mineral component in the shelly

layers have higher kurtosis values, and generally contain proportionally more mud (silt and clay). Based on the different affinities I believe that stratum 2B, as represented in these samples, has been less affected by the human activities that introduced the mineral fraction into the shelly layers. The basal dark layer may mainly represent an upper portion of stratum 1 which has been slightly transformed through human activity.

In the shelly layers, the shift in the modal grain size of the mineral component between samples 2 and 3 reflects a change in the source of the material, and may be interpreted in two ways. First, it may reflect a change in the location from which shellfish was harvested. Harvesting from different locations in the harbor, or from different parts of the intertidal zone, would result in a change of modal grain size because the environments of deposition are different. Second, it may represent a change in the depositional regime prevalent in a single harvesting location through time, caused for instance by a change in relative sea level. As noted above, just such a change occurred on the Central Coast around 3500 BP, which roughly corresponds to the stratigraphic location of the two samples (within Period 5), when sea level began to rise to the present level. Around this time there also seems to have been a shift in the kinds of shellfish being deposited in the midden, from primarily rock-dwelling species such as mussel, whelk and barnacle, to those that prefer a sandy substrate -- clam and cockle (Cannon 1991:42-43; Conover 1978:79). However, a Kolmogorov-Smirnov test conducted on the <2mm mineral fraction showed no significant difference among the different layers in the cumulative frequency of the mineral component (see Appendix B). This means the mineral fraction of all samples could have come from the same sediment population.

Composition. Compositional data from the loss on ignition technique and pH assay are presented in Table 2 below.

TABLE 2. Compositional Data for Namu.

Layer No.	Sample No.	% Organic Matter*	% CaCO ₃ *	Total % shell**	pH
6	1	4.4	78.3	86.6	7.6
5	2	7.2	49.9	55.6	7.8
5	3	5.4	58.7	67.7	7.7
5	4	4.0	69.3	73.6	7.8
5B	5	3.8	72.9	81.2	7.7
2B	6	9.6	13.0	16.5	7.6
2B	7	7.7	3.8	3.3	7.3
1	8	2.5	1.2	<1†	7.3

*Percentage by weight of <2mm fraction only.

**Includes weight of shell in gravel fraction and represents percentage of total sample.

†Amount is too small to quantify more precisely.

Outlined rows indicate data from basal black layer.

The shelly layers contain a mean of 5.0% organic matter (range 3.8-7.2%), while the dark basal layer contains an average of 8.7% (range 7.7-9.6%). Thus, the black basal deposit contains a much higher percentage of organic matter than the shelly layers. This helps to explain the dark appearance of these layers; because the dark layer contains far fewer gravel-size particles (see Table B-1, Appendix B), the finer matrix tends to dominate the appearance of the layer to a greater extent than for the shelly layers.

Another striking difference lies in the amount of carbonates in the dark layer. On average, the <2mm fraction of the shelly layers contains 65.8% calcium carbonate (range 49.9-78.3%); after including the weight of shell from the gravel

fraction, the average rises to 72.9% (range 67.7-86.6). In comparison, the dark basal deposit contains substantially less CaCO₃ (mean 8.4%, range 3.8-13.0% for <2mm fraction; including shell in gravel fraction mean 9.9%, range 3.3-16.5%). There is also less shell overall, and less shell in the sand-sized fraction which lend a lighter color to the shelly layers.

The pH is remarkably similar throughout the profile, and does not seem to be strongly correlated with the amount of carbonates or organic matter present in the sample. The two lowermost samples show a drop in pH to 7.3, but are still alkaline. It is possible that the time lapsed since the samples have been removed from the ground has affected the pH results, yielding readings that are closer to neutral (Jackson 1985, discussed in chapter three above). However, because of the lower pH readings in layers 1 and 2B (samples 8 and 7, respectively) a lateral flow of groundwater is plausible. Yet, the pH is still alkaline, which is not characteristic of the surrounding soil environment; a sample from the soil surface just east of the midden deposits yielded a pH of 4.5. If groundwater is affecting the lowermost deposits, it is moving slowly enough to accumulate the by-products of carbonate dissolution to give it an alkaline pH, or it is not being recharged to a significant degree by meteoric water flowing through the soil profile in the area surrounding the site.

Point counting data are presented in Table 3. Data from point counting of the 0, 1, and 2 Ø fractions show that the sand-sized fraction of shell bearing layers are composed of 50-90% shell (by count), followed by the mineral component (4.6-34.1%), bone (2.2-14.8%), and charcoal (0.2-9.6%). The dark layers have significantly less shell (0.9-20.6%), much more mineral (65.7-85.6%), but a similar range of bone (4.5-15.9%), and charcoal (2.5-6.6%).

TABLE 3. Point Counting Data from Namu.

sample/Ø	shell	Mytilus	bone	charcoal	mineral
1-0	57.3 (32.9)	36.0 (45.2)	2.7 (23.7)	0.2 (2.4)	3.8 (14.4)
1-1	57.9 (33.2)	26.7 (33.5)	4.2 (36.8)	1.9 (23.2)	9.2 (34.9)
1-2	59.2 (33.9)	16.9 (21.2)	4.5 (39.5)	6.2 (74.4)	13.4 (50.8)
2-0	46.4 (35.5)	27.2 (46.1)	8.0 (21.5)	2.2 (14.2)	16.3 (28.3)
2-1	44.9 (34.3)	18.5 (31.4)	14.4 (38.7)	3.7 (23.9)	18.5 (32.2)
2-2	39.5 (30.2)	13.3 (22.5)	14.8 (39.8)	9.6 (61.9)	22.7 (39.5)
3-0	54.0 (35.2)	25.4 (44.5)	4.4 (19.4)	0.4 (6.9)	15.4 (26.2)
3-1	54.3 (35.4)	20.4 (35.7)	9.7 (38.8)	2.0 (34.5)	13.6 (23.2)
3-2	45.0 (29.4)	11.3 (19.8)	10.6 (41.8)	3.4 (58.6)	29.7 (50.6)
4-0	41.0 (34.8)	46.1 (43.1)	4.1 (26.1)	1.8 (30.5)	7.0 (13.0)
4-1	43.7 (37.1)	33.7 (31.5)	7.1 (45.2)	2.8 (47.5)	12.8 (23.8)
4-2	33.1 (28.1)	27.1 (25.4)	4.5 (28.7)	1.3 (22.0)	34.1 (63.1)
5-0	54.5 (35.0)	38.3 (40.4)	2.2 (21.8)	0.4 (9.8)	4.6 (13.0)
5-1	47.1 (30.2)	36.1 (38.0)	3.3 (32.7)	1.3 (31.7)	12.3 (34.8)
5-2	54.3 (34.8)	20.5 (21.6)	4.6 (45.5)	2.4 (58.5)	18.1 (51.3)
6-0	16.3 (48.2)	4.3 (50.0)	4.5 (15.7)	2.5 (16.5)	72.4 (33.8)
6-1	8.3 (24.6)	2.0 (23.3)	8.3 (28.9)	6.1 (40.1)	76.0 (35.5)
6-2	9.2 (27.2)	2.3 (26.7)	15.9 (55.4)	6.6 (43.4)	65.7 (30.7)
7-0	2.2 (50.0)	0	9.9 (27.4)	4.8 (36.4)	83.1 (33.7)
7-1	1.5 (34.1)	0.2 (50.0)	15.4 (42.7)	5.7 (43.2)	77.3 (31.4)
7-2	0.7 (15.9)	0.2 (50.0)	10.8 (29.9)	2.7 (20.4)	85.6 (34.8)

Nonparenthetical figures represent the percentage by count of particles in that Ø fraction that fall within that compositional category. Addition of these percentages across the row add up to 100 percent.

Parenthetical figures represent the proportion of that compositional category that falls within the size fraction. Addition of these percentages down the column within each sample will equal 100 percent.

Outlined rows indicate data from basal black layer.

The distributions of shell across size intervals (parenthetical numbers) show interesting differences. In the shelly layers, the distribution of shell within a sample seems to be split nearly into thirds; in the "dark layers" (samples 6 and 7) the shell content is smaller, and its distribution is slanted more toward the

larger \emptyset fraction (0 \emptyset =48.5-50.0%), with significant reduction in the small particle range. This seems to fit the expectation for chemical weathering of shell, where smaller particles of carbonates will tend to be preferentially dissolved or weathered into even smaller particles because of their greater surface area relative to their volume.

If the dark layers had once contained more shell, and had become significantly deflated from the leaching of shell, I would expect to see a similar ratio of charcoal to mineral, since both substances are relatively chemically stable through time. The ratio of charcoal to mineral particles varies considerably across size classes within each sample. Shelly layers have a mean ratio of 10.7, with a standard deviation of 10.0 (range=2.4-38.5); dark layers have a mean ratio of 19.0, with a standard deviation of 9.1 (range=10-29), placing them within the range of the shelly layers, albeit at the high end on average. A Student's *t*-test found no statistically significant difference between the averages of the ratio of charcoal to mineral clasts at the 0.05 level (Student's *t* =2.231, *p*=0.08). The wide range in charcoal content across samples seems to render the use of such a ratio problematical. Activities that add charcoal to midden deposits probably vary independently of those that contribute shell, and so the content varies greatly among deposits, making this factor unreliable on its own as an indicator of leaching of shell.

Source

The sources of the shell found within the deposits at Namu varied through time. Stratum 2B contains much smaller amounts of shell than any of the overlying layers. According to faunal analyses for the site, rock-dwelling species

(Balanus, Thais, and Mytilus spp.) dominate during Periods 2-4. After Period 4 there is a sharp increase in the proportion of clams and cockles, which prefer sandy to muddy substrates, at the expense of rock dwelling species (Conover 1978:98-99). Cannon (1991:39) attributes this to a change in the local intertidal environment brought about by a change in sea level around this time, causing more sediment to be deposited in the bay and increasing the availability of the clams and cockles in the site vicinity.

Other components of the midden deposits can be attributed directly to human activity. Faunal analysis of the vertebrate remains indicate differing quantities of bone input through time, but the sources remain relatively constant. The proportion of charcoal in each sample is quite variable. It entered the midden either as a result of human activity, through dumping of hearth waste, or through natural or human-caused fires.

The mineral component of the deposits at this location in the site seems to be derived from a similar source — the glacial till that mantles the local bedrock, and probably to a lesser extent the decomposition of local granite bedrock. However, variations in the modal grain size and skewness toward the silt/clay range seem to indicate additions of mineral particles from other sources. The mineral population of stratum 2B resembles the underlying glacial sands and gravels, but has been somewhat affected by human activity, which introduced sand and perhaps mud from other locations, such as the intertidal zone, resulting in higher kurtosis values and a more peaked frequency curve. The overlying shelly layers show a mode in the 3 Ø interval until the boundary between Periods 4 and 5 (within stratum 5), when the modal size shifts to 2 Ø. This shift coincides with a change in shellfish species being deposited in the

midden, and may reflect the change in shellfish habitat being exploited. However, the sediments in all layers are too poorly sorted to represent only those from an intertidal zone; furthermore, a statistical test of differences between the cumulative curves of all samples showed no significant differences between them, indicating that the sediments may originate from the same population. Additions from other sources affect the primary mode in each deposit, but not enough to radically alter the overall texture.

Transport Agent

The dominant transport agent for the dark layer appears to have been glaciers which brought clastic sediments from the coast range and transported them on to the site. Later human activity probably introduced more minerals in the silt/clay range, and perhaps some sand from the intertidal zone. Nonmineral constituents make up only a small proportion of this deposit, and these were mainly introduced as a result of human activity.

In layers 5B, 5, and 6 the dominant transport agent is human. These deposits are made up primarily of shell, with minor amounts of other materials related to human subsistence and settlement at the site. The mineral component may well have been introduced in part by humans through shellfish collection, but other activities and perhaps colluvial movement of sediments from the area east of the site, seem to have introduced the bulk of the material. This conclusion is based on an inability to separate the different samples statistically, and their poorly sorted nature. No adequate control samples from the area above the site were available for this study, and they would be necessary in order to substantiate this interpretation.

Environment of deposition

Of all the interpretations, this is probably the most difficult to make with the samples used for this study, because they represent a mixture of separate depositional events of effectively unknown energy, direction and continuity. In general the materials found within the shelly and basal dark layers are very similar in composition within the range of attributes which were assessed, suggesting that similar cultural processes produced these deposits. However, the differences in the ratios of charcoal to mineral between shelly and basal black deposits, though not statistically significant, seem to indicate that relatively less charcoal was being incorporated into the dark layer, which may indicate a less intense occupation of the area sampled during that time, or a very different suite of activities prevailed at that time, than occurred during deposition of the shelly layers. Shell in samples 2, 3 and 4 (layer 5) seem to have become more fragmented than that in samples 1 and 5, possibly because of greater energy in the depositional environment, which increased fragmentation.

Postdepositional alteration

Groundwater seems to have affected the lower dark shell-less layer at Namu, which may explain the low amount of carbonate present in sample 7. Conover (1973) mentions that the lower part of stratum 2B was saturated with water during excavation. This saturated zone is capped with a red iron oxide pan, which precipitated near the top of the black basal layer. As noted in chapter two, groundwater often contains large amounts of minerals in solution which precipitate near the interface between the reduced conditions prevalent in the

phreatic zone and the more oxidized vadose zone, either through capillary action or seasonal fluctuations in water table levels. However, it is unclear how effective an agent the local groundwater is in removing shell. The alkaline pH of the two lowermost samples indicates that the flow of groundwater is not rapid enough to flush the by-products of carbonate dissolution from those deposits, making the water less aggressive in dissolving shell.

Further possible evidence of groundwater activity was observed during the loss on ignition analysis. Two samples (7 and 8) turned a bright red color after burning, suggesting postdepositional addition of iron oxides in a reduced state through groundwater. These samples represent the underlying sterile deposit and the lower part of adjacent stratum 2B, which was the lowermost, shell-free part of the dark basal layer. However, a sample from the humic surface horizon east of the midden, which was black in color, also turned bright red after loss on ignition, which suggests that iron compounds in a reduced state is inherent to the local soil environment. Thus, intersection with the groundwater table may not have enriched this layer with iron, but the lower portion may represent a paleosol.

From the information at hand it seems that some leaching of carbonates from the shell in the site is occurring. The alkaline pH is the first obvious indicator of this. Comparison of the two grain size analyses of all samples indicates that the shell has been weathered into smaller particles, and possibly dissolved, through a combination of mechanical and chemical weathering, particularly in samples 2 and 6. Further, shell present in the dark layer is subject to a greater degree of chemical weathering than the overlying shelly layers. Also, the proportion of shell in the silt size and smaller fraction is positively correlated

with organic matter content, pointing to the significant role this substance plays in chemical weathering of shell at Namu. The lower part of stratum 2B (sample 7) may have had its shell leached, based on its overall similarity to sample 6, with the exception of carbonate content and the possible presence of groundwater flow. However, it is difficult to find in these results firm evidence that there was once significantly more shell in the dark basal layer (stratum 2B) in the past. In the upper part of stratum 5 (sample 2) there is no evidence of leaching of significant amounts of shell because there was no precipitation of leached carbonates in the underlying layer, an expected outcome of leaching by vertical flow of groundwater.

Tsawwassen

The Tsawwassen site (DgRs 2), at the base of the Point Roberts Uplands, is a complex, extensive shell-bearing site with deposits covering approximately 70,000 m², and spanning about the last 4,000 years. The site was excavated in 1988 and 1989 by Arcas Consulting Archaeologists Ltd., of Coquitlam, BC, in order to mitigate disturbance by road building through the site (Stryd et al. 1991). Despite the salvage nature of the project, the excavation resulted in a comprehensive analysis of recovered materials (e.g., Curtin 1991; Curtin and Bedard 1992; Howe 1992; Kusmer 1992).

The history of the site began with the formation of the Fraser River delta, after the end of the last glaciation. Around 9000 years ago the Fraser River began to discharge its flow and suspended sediments into the Strait of Georgia around the area currently occupied by the city of New Westminster. At this juncture Point Roberts was an island. Over time the Fraser River delta prograded south

and west; by 4500 BP the delta's tidal flats were within a few kilometers of Point Roberts Island. Point Roberts Island was eventually connected to the mainland sometime between 3500 and 2500 BP (Stryd et al. 1991:76; Williams 1988:198,200). As the delta advanced across the northern part of the island, current and tide deposited sand in a more northerly direction, forming several linear beach ridges.

Sea level had a great effect on the rate of growth of the delta through time. Sea level for the delta area was about 13 m lower than present between 9000 and 8000 BP. Between 8000 and 6200 BP it rose to about 4-5 m below current levels, followed by a stillstand for about 400 years. Between 5800 and 4500 BP sea level rose again; after 4500 BP the rate of sea level rise diminished until about 2250 BP, when it reached current levels (Williams 1988:186).

The site consists of three discrete areas of midden which accumulated over different periods of time, representing about 4000 years of human occupation (see Figure 9). The oldest deposits, Area D, lie at the western extent of the site nearest to the bluffs of the Point Roberts Upland. These were deposited before Point Roberts was fully attached to the mainland, but tidal flats had probably connected it by then; sea level was relatively stable, but still rising. Cultural activity seems to have shifted to Area C around 1800 BP, which extends eastward along the bluffs on top of an old beach ridge. Around 1000 years ago midden began to accumulate in the westernmost part of the site again, extending northward along one of the more recent ridges (Stryd et al. 1991:16-19). Since European contact a variety of activities, including the building of Provincial Highway 17, agriculture and leveling of midden areas for house construction, have disturbed parts of the site, especially Area A, although much

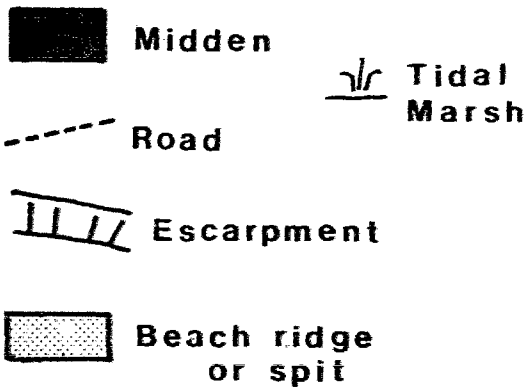
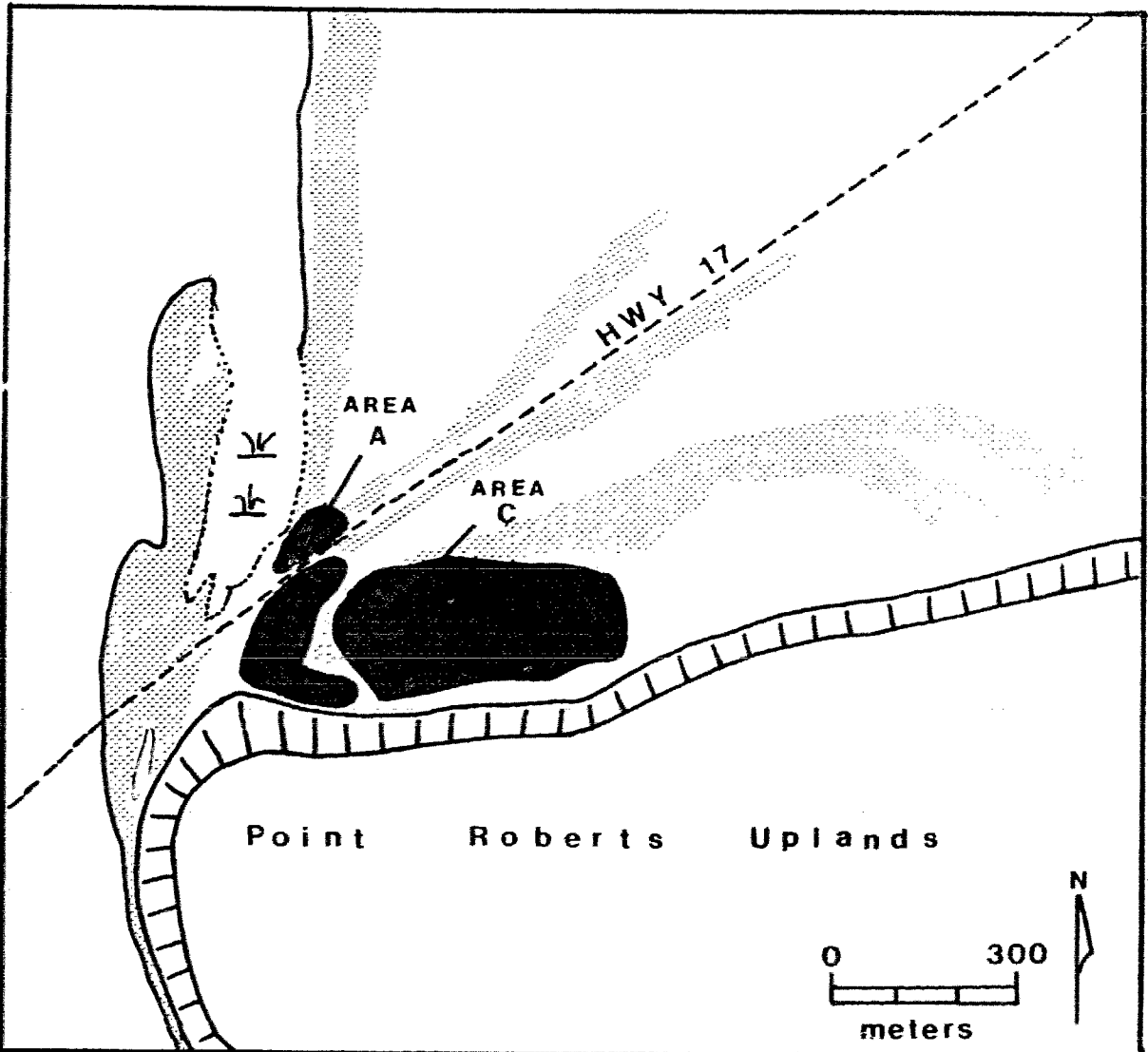


FIGURE 9: Site Map of Tsawwassen (DgRs 2)

of the site remains intact. Area C is a less disturbed portion of the site, and lies under forest cover; Area A is covered by open vegetation, mostly grass (Howe 1992).

Site Stratigraphy and Sampling

As at Namu, the Tsawwassen sediment samples were collected from excavation walls in vertical relation to each other, each taken within one of the identified layers and intended for studying the depositional history of the site. Sample weights range from 1121.9 g to 4933.3 g (mean weight 2309.9 g), and come from two areas of the site (Figure 9). Samples 1, 3, 5, 7, and 9 come from Area A, which is located on the northwestern edge of the site on the north side of Highway 17. Based on artifact styles and radiocarbon dates, all layers found in Area A appear to have been deposited during the Stselax period (about 1000 AD to contact), which is the local manifestation of the Gulf of Georgia "culture type" or phase. Each sample represents a single layer identified during excavation; the following deposits were identified:

Layer A. (Sample 1). Surface deposit, described as a black gravelly loam, containing a small amount of fragmented shell, about 30 cm thick. Munsell color was 10 YR 3/1 (dry) "very dark gray"; 10 YR 2/1 (moist) "black". This layer represents a surface deposit, heavily disturbed by ploughing and other activity. It may represent material deposited here from other parts of the site as a result of grading and construction of Highway 17. Photographs reveal no apparent structure; overlying vegetation appears to be grass. Sample comes from 10-20 cm DBS.

Layer B1. (Sample 3). A layer of very fragmentary, poorly preserved shell in a dark matrix, approximately 15-18 cm thick, 35-50 cm DBS. It is less shelly than underlying layer B2. Munsell color is 2.5 Y 3/2 (dry), "very dark grayish brown"; 10 YR 2/1 (moist), "black".

Layer B2. (Sample 5). A layer made up mostly of shell, less fragmentary and better preserved than that found in layer B1, approximately 20 cm thick, 50-70 cm DBS. It has a higher gravel content than B1, consisting mostly of shell. Munsell color is 2.5 Y 4/2 (dry), "dark grayish brown"; 2.5 Y 2/0 (moist), "black".

Layer C. (Sample 7). Black "basal dark layer", sandy, virtually no gravel fraction at all, and containing no shell, about 12-15 cm thick. Sample 7 comes from 72-76 DBS. Layer was described as moist during excavation. Upper boundary of this layer is said to be abrupt and "slightly wavy", while the lower boundary is described as "distinct but irregular", possibly due to intrusion of features such as post-holes; it's unclear whether cultural material ascribed to this layer was actually in it or at the upper boundary. Munsell color is 5 Y 2.5/1 (dry), "black"; 2.5 Y 2/0 (moist), "black".

Layer D. (Sample 9). Well sorted sands, devoid of cultural materials, organic matter, shell, and gravel, probably representing an old beach. Munsell color is 2.5 Y 4/2 (dry), "dark grayish brown"; 2.5 Y 3/2 (moist) "very dark grayish brown". Deposit was moist during excavation; water table was reported to be 60 cm below the top of this layer.

Another seven samples (samples 11, 13, 15, 17, 19, 21, and 23) were collected from Area C at Tsawwassen, again representing the different layers found there. No dark basal layer was found in Area C deposits, which are of interest because they allow an intrasite comparison of factors that may contribute to the formation of the basal dark layer. Area C is said to date between 1800 and 1200 BP, representing the Marpole period (about 500 BC to AD 500) (Burley 1980), and a period transitional between Marpole and Stselax (about AD 500 to 1000), a period poorly known archaeologically (Stryd et al. 1991:87). Layers identified in Area C are described as follows.

Layer A. (No sample). Surface horizon, about 10 cm thick, composed mostly of organic matter in various stages of decay, some mineral, heavily turbated by plant roots and other organisms.

Layer B. (Sample 11). Layer just below surface horizon, containing coarsely broken shell, charcoal, and fire-affected rock,

DBS 10-22 cm. Munsell 10YR 3/1 (dry), "very dark gray"; 2.5Y 2/0 (moist), "black".

Layer C. (Sample 13). Fine black sediment containing few round pebbles and sparse fragmented shell, roots and rootlets, DBS 10-22 cm; the layer was cut into by a burial pit. The lower boundary was described as obscure in places. Munsell 10YR 3/1 (dry), "very dark gray"; 2.5Y 2/0 (moist), "black".

Layer C1. (Sample 15). No field description available. DBS 62-68 cm, based on profile drawing. Munsell 10YR 3/1 (dry), "very dark gray"; same color (moist).

Layer C2. (Sample 17). No field description available. DBS 92-99 cm, based on profile drawing. Munsell 10YR 4/1 (dry), "dark gray"; 10YR 3/1 (moist), "very dark gray".

Layer D. (Sample 19). Dense concentration of crushed shell, mainly barnacle and mussel; moist field condition, with roots and rootlets present, DBS 116-125 cm; lower boundary is described as distinct. Munsell 5Y 4/1 (dry), "dark gray"; 2.5Y 2/0 (moist), "black".

Layer E. (Sample 21). Layer of dense shell in large fragments, some whole butterclam and cockle shell, less organic matter, moist field condition, DBS 124-135 cm; lower layer boundary is described as distinct. Munsell 5Y 5/1 (dry), "gray"; 10YR 3/1 (moist), "very dark gray".

Layer F. (Sample 23). Beach sands and gravel containing some cultural materials, rare, poorly preserved small shell fragments, and traces of charcoal, DBS 150-164 cm. Munsell 10YR 5/1 (dry), "gray"; 5Y 4/2 (moist), "olive gray".

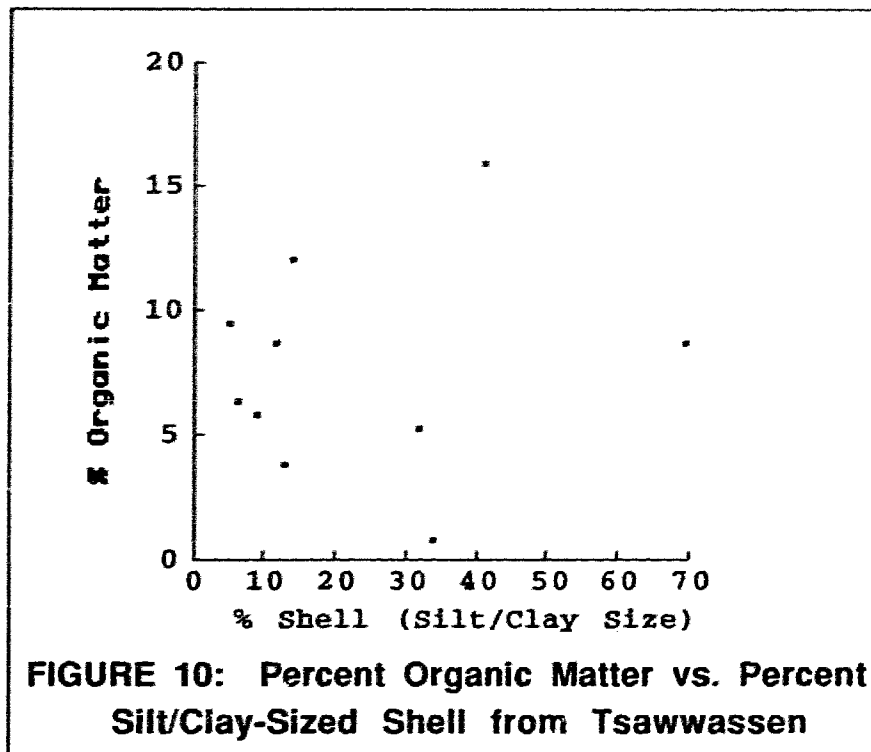
Results of analyses

Texture. Histograms of grain size distributions for both the shell and mineral fractions are presented in Appendix C. Table 4 contains grain size distribution data and parameters for each deposit. Similar data which include the gravel fraction is presented in Table C-1 in Appendix C.

In Area A, layer A, which represents the current surface, much of the shell is in the >9 Ø category. The size distribution of shell is very different between layers B1 and B2. Most of the shell in layer B1 is sand size or smaller, while most of the shell in layer B2 is larger than 2mm. The underlying layer C, the "black layer", had only trace amounts of shell in the sand size range (see Table 6 below), too small to attempt the procedure for determining a shell particle distribution. The particle size distribution of layers A and B1 indicate a more intensive chemical weathering based on the large proportion of shell in the silt/clay range.

In Area C there appear to be several different patterns for shell. Layer B shows a definitive trimodal pattern: primary mode at 0 Ø, secondary at -3 Ø, and tertiary at >9 Ø, indicating strong mechanical and perhaps chemical weathering of shell in this deposit, which lies just under the present-day surface. Layer E has a similar trimodal pattern, but the primary mode is in the gravel range (-2 Ø), secondary mode at 0 Ø, and tertiary again in the silt/clay range (8 Ø). Layers C and C1 show a trimodal pattern with the primary mode at -2 Ø, a secondary mode at -4 Ø, and tertiary mode at 8 Ø. Layer C1 has more shell in the silt/clay range, especially >9 Ø. Layer C2 share similarities to layers C and C1, except for its mode at -4 Ø, a lower secondary peak at 9 Ø, and overall less carbonate in the silt/clay fraction. Overall, the shell in layers C, C1, and C2 has probably been subject to less mechanical weathering than that of layer B. Layer D shows many similarities to the pattern in the C layers, but has a larger proportion of shell particles in the silt/clay range, indicating more intense chemical weathering. The strong secondary mode at 5 Ø may be due to error from the small amount of carbonate in the sample and sampling error, rather than a real peak. Unlike at Namu, there appears to be no strong relationship between the

proportion of organic matter by weight in the >2mm fraction and the weathering of shell into fine (silt/clay size) particles (Pearson's $r=0.135$) (see scatterplot, Figure 10).



The size distribution of the mineral component from all samples in Area A shows remarkable similarity to that of the underlying sterile beach sands (layer D), which has a strong peak in the 2 ϕ interval but lacks material in the silt/clay range. Layer A was reported as being heavily disturbed by construction and agricultural activity, and has probably been mixed with underlying layers, but is very similar to B1. Layer B2 has relatively more fine sands, silts and clays than either layer A or B1, and has the largest proportion of silt/clay sized particles of any sample from the site (see Table 4); it also has a greater amount of shell. The distribution of layer C's mineral component more closely resembles the underlying sterile beach sands than that of the shelly deposits (layers B1 and B2), and it possesses a much smaller proportion of silt/clay sized

B2), and it possesses a much smaller proportion of silt/clay sized particles than any of the shell-bearing layers. It differs from underlying layer D in possessing slightly more silt and clay, and fewer gravels.

In Area C there appear to be two separate groups based on the texture of the mineral fraction. Layers B, C, C2 and E possess a primary mode at 3 Ø, contain a larger proportion of shell (relative to layers D and F), appear to be less well sorted, and possess a larger proportion of silt and clay particles. Layer C1 has its primary mode at 2 Ø, although it is nearly shared with the 3 Ø interval, contains slightly less shell overall than layers B, C, C2 and E. Layers D and F contain little or no shell, and both show a strong peak in the 2 Ø interval, are well sorted, and possess very few silt or clay-sized particles.

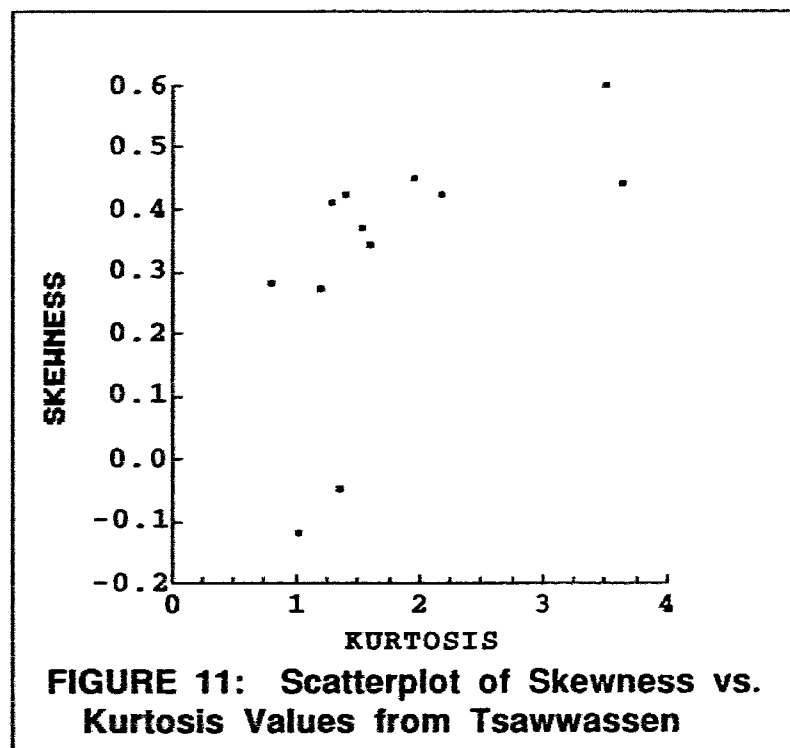
Table 4. Grain Size Data from Tsawwassen Samples, <2mm Mineral Fraction

Layer	Sampl	%Sand	%Silt	%Clay	Mean	SD	Skew	Kurt
Area A								
A	1	83.9	11.2	4.9	2.1	2.0	+0.60	3.51
B1	3	84.4	12.6	3.0	2.2	1.8	+0.45	1.97
B2	5	47.0	33.2	19.8	4.9	3.5	+0.28	0.81
C	7	89.7	4.8	5.5	1.7	1.5	+0.44	3.64
D	9	99.3	<1	<1	1.3	0.8	-0.12	1.02
Area C								
B	11	71.9	21.2	6.9	3.2	2.5	+0.42	1.40
C	13	72.6	24.0	3.4	3.1	2.0	+0.27	1.21
C1	15	76.2	19.4	4.4	2.7	2.1	+0.41	1.30
C2	17	78.5	16.1	5.4	2.5	2.1	+0.34	1.60
D	19	88.8	8.1	3.1	2.0	1.5	+0.42	2.19
E	21	77.1	17.7	5.2	3.0	2.0	+0.37	1.54
F	23	99.6	<1	<1	1.4	0.5	-0.05	1.37

Outlined rows indicate data from basal dark layer.

Grain size parameters show some interesting differences among the deposits. Kurtosis and skewness values are plotted together in Figure 11, from which three groupings of layers (shelly layers, sterile beach deposits, and

surface/black layer) seem to stand out. The underlying nonmidden sediments are well-sorted beach sands with virtually no silt/clay size particles; they are slightly skewed toward the coarse end (negative values), with kurtosis in the mesokurtic to leptokurtic range. Shelly layers are skewed toward the fine range, while kurtosis is quite variable, but generally in the leptokurtic (1.11-1.50) to very leptokurtic (1.50 to 3.00) range. The surface layer and basal dark layer in Area A are similar; both have extremely high kurtosis values (>3.00) and are very positively skewed. A Kolmogorov-Smirnov test was conducted on the cumulative frequency percentage of the <2mm mineral fraction of each sample to determine whether the differences observed in the grain size distribution were significant. The only significant differences were noted



between the underlying beach deposits (Area A-Layer D and Area C-Layer F) and all other deposits sampled. No significant differences were observed between the basal dark layer (Area A-Layer C) and shell-bearing

between the basal dark layer (Area A-Layer C) and shell-bearing layers (see Table C-1 in Appendix C for full results).

Composition. Results of loss on ignition for organic matter and calcium carbonate, as well as pH determinations, are presented in Table 5. In Area A organic matter content ranges between 5.8 and 15.9 percent in the shelly deposits, with a mean value of 7.3 percent (excluding surface layer A). Layer C, the basal dark deposit, contains 7.2 percent organic matter, while the underlying culturally sterile beach sands contain virtually none. In Area C organic matter content ranges from 12.0 to 3.8 percent, decreasing steadily with depth, with a mean content of 7.6 percent. Thus, organic matter content for the black basal layer falls within the range for the shelly deposits in both areas.

TABLE 5. Compositional Data from Tsawwassen

Layer No.	Sample No.	% Organic Matter*	% CaCO ₃ *	Total % shell**	pH
Area A					
A	1	15.9	16.1	12.4	6.8
B1	3	8.7	11.8	12.0	7.3
B2	5	5.8	48.2	65.1	7.6
C	7	7.2	2.2	2.0	7.3
D	9	<1†	1.5	<1†	7.7
Area C					
B	11	12.0	51.7	47.4	7.2
C	13	9.5	50.4	71.2	7.5
C1	15	8.7	42.9	61.9	7.7
C2	17	6.4	51.3	70.9	7.8
D	19	5.2	17.5	28.8	7.8
E	21	3.8	54.6	66.9	8.0
F	23	<1†	6.6	9.8	8.2

*Percentage by weight of <2mm fraction only.

**Includes weight of shell in gravel fraction and is a percentage of total sample.

†Amount is too small to quantify more precisely.

Outlined rows indicate data from dark basal layer.

Carbonate content varies considerably. In Area A the percentage by weight of CaCO_3 in the fine fraction (<2mm) ranges from 11.8 to 48.2 percent (mean 24.3 percent) in the shelly deposits and was only 2.2 percent in the dark layer. This small value in layer C may reflect a combination of weight loss due to water loss and a small amount of carbonate occluded to mineral grain surfaces, rather than from the presence of shell particles. In Area C, CaCO_3 content ranges from 17.5 to 54.6 percent, with a mean of 44.7 percent. The underlying layer F, presumed to be basal beach sands, contains 6.6 percent carbonate, a higher amount than that of layer D in Area A, and indicates that this layer has had some shell added to it through human activity, which affirms field observations about this layer.

The pH of the Tsawwassen samples provides some interesting insights into the nature of the leaching process at this site. In Area A the pH seems to follow no consistent pattern through the profile. The pH readings range from 6.8 at the surface to 7.7 in layer D, the basal sterile sands. The pH increases from the surface down to the shelly layer C (7.6), then drops in the dark layer (7.3), and rises again in the sterile underlying sands (7.7). In Area C the pattern is much more regular, with pH values increasing consistently from 7.2 (nearest the surface) up to 8.2 in layer F (base of excavation). This suggests that water percolating vertically through the deposits is taking up carbonates in solution increasingly with depth, as the pH does not seem to be correlated with the amount of shell present in the deposit. In particular the sample from layer F, which has the highest pH, is composed primarily of mineral sands.

The results of point counting particles in the 0, 1, and 2 ϕ fractions are presented in Table 6 below. As with the Namu results, it is interesting to note

the distribution of mussel shell (Mytilus) across size intervals, which because of its structure is thought to be more susceptible to chemical weathering. In Area A layer B1 shows a decrease in the proportion of shell in smaller size classes and a relative increase in the largest size class; this is reflected in the shell category as well. This layer contains a higher amount of organic matter and a smaller amount of shell generally than the other shell-bearing layer, B2. In layer B2 the shell category is divided much more evenly between size categories; the mussel category shows a greater percentage of particles in the smaller size classes, indicating less intensive leaching in this layer. The dark layer, layer C, contains only a trace of shell and bone, which may have been introduced into the sample when collecting it from the profile, or may have been mixed in by some other postdepositional process. There is very little charcoal in this layer (0 to 2.9%, versus 3.4 to 20.3% in layers B1 and B2).

In Area C mussel shell particles dominate layers C2 and E, and have nearly equal frequency with other shell taxa in layers C and C1; other shellfish taxa dominate in layers B and D. Regarding the distribution of shell particles across size classes within each layer, most layers show a similar pattern to that of layer B2 in Area A, with little indication of postdepositional loss of smaller shell particles. Layer D contained overall less shell; it shows remarkable lack of shell particles in the 2 Ø category. Like layer B1 in Area A it shows strong indications of postdepositional loss of shell in the smaller size classes, a pattern consistent with expectations that smaller shell particles are more susceptible to destruction through leaching.

TABLE 6. Results of Point Counting from Tsawwassen

Layer-Ø	shell	Mytilus	bone	charcoal	mineral
Area A					
A	no data	no data	no data	no data	no data
B1-0	38.0 (50.9)	7.1 (60.7)	5.9 (43.4)	20.3 (36.8)	28.7 (21.2)
B1-1	26.3 (35.3)	3.4 (29.1)	4.0 (29.4)	19.4 (35.2)	48.1 (35.5)
B1-2	10.3 (13.8)	1.2 (10.3)	3.7 (27.2)	15.4 (30.0)	58.8 (43.4)
B2-0	60.0 (35.8)	33.8 (54.4)	0.7 (25.9)	3.4 (16.2)	2.1 (4.5)
B2-1	65.3 (39.0)	18.7 (30.1)	0.2 (7.4)	8.5 (40.5)	7.3 (15.6)
B2-2	42.3 (25.2)	9.6 (15.5)	1.8 (66.7)	9.1 (43.3)	37.3 (79.9)
C-0	0	0.6 (100)	0.6 (100)	2.9 (90.6)	96.0 (32.6)
C-1	0.9 (75.0)	0	0	0.3 (9.4)	98.8 (33.5)
C-2	0.3 (25.0)	0	0	0	99.7 (33.9)
Area C					
B-0	55.3 (37.9)	37.7 (45.6)	1.4 (31.1)	0.2 (1.7)	5.3 (9.3)
B-1	49.4 (33.9)	32.2 (38.9)	1.2 (26.7)	2.8 (23.3)	14.4 (25.2)
B-2	41.2 (28.2)	12.8 (15.5)	1.9 (42.2)	9.0 (75.0)	37.4 (65.5)
C-0	40.5 (34.0)	45.5 (47.2)	5.7 (27.3)	3.6 (19.0)	4.7 (10.6)
C-1	40.4 (33.9)	34.9 (36.2)	8.3 (39.7)	5.5 (29.0)	10.9 (24.6)
C-2	38.4 (32.2)	16.1 (16.7)	6.9 (33.0)	9.9 (52.1)	28.7 (64.8)
C1-0	40.9 (40.9)	41.3 (53.8)	8.4 (22.8)	2.7 (12.3)	6.8 (10.6)
C1-1	35.7 (35.7)	24.8 (32.3)	12.0 (32.5)	5.6 (25.6)	21.8 (33.9)
C1-2	23.5 (23.5)	10.7 (13.9)	16.5 (44.7)	13.6 (62.1)	35.7 (55.5)
C2-0	43.2 (42.7)	50.4 (43.8)	2.5 (18.5)	1.1 (4.6)	2.8 (6.0)
C2-1	34.9 (34.5)	40.0 (34.8)	6.1 (45.2)	9.4 (39.3)	9.6 (20.7)
C2-2	23.0 (22.8)	24.7 (21.5)	4.9 (36.3)	13.4 (56.1)	34.0 (73.3)
D-0	46.2 (64.4)	27.0 (58.0)	6.1 (42.5)	3.2 (33.7)	17.6 (11.2)
D-1	21.2 (29.6)	15.8 (34.0)	6.1 (42.5)	3.1 (32.6)	53.8 (34.1)
D-2	4.3 (6.0)	3.7 (8.0)	2.4 (16.4)	3.2 (33.7)	86.4 (54.7)
E-0	28.0 (36.3)	67.4 (44.5)	1.5 (12.4)	1.3 (17.8)	1.9 (3.6)
E-1	25.0 (32.4)	57.1 (37.7)	4.9 (40.5)	2.9 (39.7)	10.2 (19.5)
E-2	24.1 (31.3)	26.9 (17.8)	5.7 (47.1)	3.1 (42.5)	40.2 (76.9)

Nonparenthetical figures represent the percentage by count of particles in that Ø fraction that fall within that compositional category. Addition of these percentages across the row add up to 100 percent.

Parenthetical figures represent the proportion of that compositional category that falls within the size fraction. Addition of these percentages down the column within each sample will equal 100 percent.

Outlined rows indicate data from dark basal layer.

Source

Study of shell from the site for faunal analysis (Kusmer 1992) indicates a shift in emphasis among utilized mollusc species between different areas of the site. In Area C layers C-E basket cockle (42-69%) predominates, while mussel represents 2-11% by weight, and decreases to 3% in layer B. In Area A, mussel shell increases dramatically to make up 42% by weight of shell. This pattern seems to indicate emphasis on sand and mud flat species during the earlier (Marpole) period, with a change toward the rock-dwelling mussel in the Transition and Gulf of Georgia periods, a pattern which is unusual for the region (Kusmer 1992). However, relative contributions of shellfish taxa in this study differ significantly from those recovered by Kusmer (1992), particularly in Area C layers C, D, and E. The samples analyzed for this study contained mostly mussel shell, and is probably due to a local concentration of mussel (Mytilus edulis) shell in the sample locations not characteristic of the layers as a whole (Kusmer, personal communication 1992).

The mineral fraction of shell-bearing layers shows a probable change in source between Area A and Area C. In Area C, the minerals in the shelly deposits generally have a mode at 3 Ø which is not typical of the underlying beach deposits and distinguishes them from deposits in Area A. Layers C1, D, and F have modes at 2 Ø, although the 3 Ø interval also has a high frequency of occurrence in layer C1. In Area A all layers have a mode at 2 Ø, which is quite similar to the underlying beach sands. The change in the texture of the mineral population between the two areas mirrors the overall change in shellfish taxa represented in those locations (Kusmer 1992). Thus, this change in the mode

may represent different parts of the muddy intertidal zone being used over time as reflected in changes in taxa represented in the midden, or a change in the location (e.g., a different beach altogether) being exploited. In general, layers with a large shell component seem to have a larger proportion of mineral fraction in the silt/clay size range.

Transport agent

In Area A, layer B2 was deposited primarily through human agency. Layer B1 contains relatively more bone and charcoal fragments than B2 (see Table 6), but contains substantially less shell, so its overall composition may be less attributable to human activity than B2. Layer C seems very similar in texture to the underlying beach sands, but contains a much higher organic matter content. No other constituents that can be attributable to human activity were present, and it appears that the mineral component was deposited, like underlying layer D, by nonhuman processes (shorelong fluid transport). In Area C, composition of layers B, C, C1, C2, and E indicate humans as the primary transport agent. Layer D is similar to layer B1 in Area A in composition, and its components seem to be less directly attributable to human activity. Like layer D in Area A, layer F seems to have been transported by nonhuman processes, yet the presence of shell and charcoal in the gravel fraction in appreciable amounts may indicate human transport played some role in its formation.

Environment of deposition

Most layers sampled seem to have been deposited as a result of human activity related to subsistence at the site. Some layers (such as B1 in Area A and D in

Area C) contain fewer such remains, indicating reduced human activity at that particular location and time. Shell in layers B and E in Area C may have become broken into smaller (sand size) fragments; however, it is unclear whether this occurred during or after deposition. Layer D and probably layer C in Area A were deposited in a beach environment. Layer F in Area C was formed in a similar environment, but has had some addition of shell and other cultural materials.

Postdepositional alteration

Groundwater seems to be present today in the lower deposits at the site, but more so in Area C, where the dark shell-less layer did not form. In Area A, the water table is reported to be about 60-70 cm below the dark layer (layer C). During excavation there was no problem with water flooding the units in this area, but the sands were reported to be wet. However, flooding was a problem in Area C. Also, during loss on ignition samples from layers B1, C and D in Area A oxidized a red color, possibly indicating seasonal exposure to groundwater. Yet, if the presence of iron oxides in a reduced state is due to groundwater effects, it is puzzling that the samples from layers B1 and C both react this way, but the intervening sample from layer B2 did not. Also puzzling is the fact that none of the samples from Area C indicated large amounts of iron oxides, despite the apparent problems with flooding of those excavation units with groundwater. I conclude from this that groundwater was not a significant factor in the formation of the dark basal layer in Area A. The basal black layer (layer C, Area A) contains no visible evidence of human activity. Its high organic matter content and textural resemblance to the underlying beach sands may indicate a period of nondeposition before human occupation of the area,

during which soil formation occurred. As at Namu, it may be that iron oxides are present in a reduced state due to pedogenic processes acting on those layers (Birkeland 1984:120-124).

The elevated pH values found in all deposits indicate that some carbonate from the shell is being leached. As discussed above, the consistent increase with depth of pH in Area C may be a sign of weathering by meteoric groundwater flowing downward through deposits, rather than lateral movement of phreatic waters. Further, the distribution of shell seems to indicate greater postdepositional chemical weathering of layers A and B1 in Area A and layer D in Area C; point counting data lend further support to this conclusion. Unlike Namu, however, there appears to be no strong relationship between organic matter content and weathering of shell into finer particles. Some leaching seems likely in these two layers, but it appears to conform to expectations for meteoric groundwater as the main mechanism, due to their positions either at the current surface or between shelly deposits.

Applicability of Stein's hypothesis to both sites

Namu. Groundwater seems to have affected the lower deposit of the site, but not all of the dark layer. The presence of iron in a reduced state may indicate groundwater flow, but may also be characteristic of local soil chemistry. Organic matter content was higher in the dark basal layer (range 7.7 to 9.6%) than in the shelly layers (range 3.8 to 7.2%), and in the upper part of layer 2B it approaches the 10% suggested by Stein (1989). The highest amount of clay is present in the shelly layers (samples 4 and 5), but the amount of clay in the dark layer

(samples 6 and 7) was within the range of that for the shelly layers, although at the low end. In no case does the amount of clay approach the requisite 10%.

Tsawwassen. Current groundwater conditions do not appear to have been a factor in the formation of the dark layer (layer C) in Area A, but appears to have been operative in Area C, where a dark basal deposit did not form. In Area A only the surface deposit exceeds 10% organic matter content; the basal dark layer (layer C) contains 7.2%. In Area C, a similar pattern prevails, with layer B containing 12 %; in fact, organic matter content decreases with depth. Thus, only samples from deposits that are currently exposed to pedogenic processes have accumulated more than 10% organic matter, although only one layer contains less than 5% organic matter. In terms of clay content, all of the midden deposits have been enriched compared with the underlying beach sands, which contain almost no silt or clay. However, in Area A the dark basal layer, layer C, contains only 5.5% clay, while the clay content of shell-bearing layers generally ranges from 3.0 to 4.9, with an extremely high amount found in layer B2 (19.8%) which directly overlies the dark basal layer in Area A. In Area C clay content ranges from 3.1 to 6.9 percent. Thus, in only one deposit sampled was clay content at the 10% level suggested by Stein (1989).

Summary

The results of detailed compositional and textural study of sediment samples from Namu and Tsawwassen have been presented in order to explore the role, if any, that leaching of shell has played in the formation of site deposits. Some dissolution of carbonates seems to be occurring in all midden deposits as indicated by elevated pH values. Further, at Namu the shell in layers high in

organic matter content show more severe weathering into smaller sized particles, particularly when it is possible to control for effects of mixed biological sources for shell (i.e., looking only at Mytilus shell), although this relationship doesn't seem to hold at Tsawwassen. At Namu, shell in the basal dark layer 2B and the upper portion of layer 5 seem to have undergone the most severe chemical weathering, while at Tsawwassen layer B1 in Area A and layer D in Area C show the strongest evidence. These results conform to some of the expectations for chemical weathering and leaching of biogenic carbonates in a sedimentary environment presented in chapter two. However, while the dark shell-less layer at Namu appears to have been formed to some extent by human activity, the one in Area A at Tsawwassen was not, and is probably a paleosolic event. While groundwater seems to have affected the basal dark layer at Namu, it does not seem to have been a factor in the formation of the one in Area A at Tsawwassen. The presence of clay particles and organic matter in quantities suggested by Stein (1989) does not seem to have been necessary for the formation of the basal black layers in the sites investigated in this study.

CHAPTER FIVE: DISCUSSION AND CONCLUSIONS

Results from the analyses presented in the last chapter are summarized, and the implications for Stein's (1989) hypothesis are evaluated. Limitations of observations made in this study due to the number and nature of samples used are discussed, as are theoretical and practical problems relating to determination of the extent to which postdepositional leaching has affected shell-bearing deposits. It is concluded that dark layers in shell middens may result from different processes. Directions for future research in the effects of postdepositional leaching of shell are proposed, including experimentation with chemical weathering of shell and microfabric analysis of shell-bearing deposits. Finally, limitations of current approaches to the study of shell-bearing sites affecting the resolution of this problem are discussed.

Results summary

Results presented in the last chapter suggest that Stein's model for the formation of a dark, highly organic basal deposit does not seem to apply at Namu and Tsawwassen. While groundwater seems to have affected the lowermost deposits at Namu, the area most heavily flooded by groundwater intrusion at Tsawwassen, Area C, possessed no basal dark layer, despite the fact that this is the oldest part of the site and has thus had more time for water to leach the shell. In Area A, where there is a dark basal layer, the water table appears to be 60 cm below the base of that layer and probably wasn't a factor in its formation. Furthermore, the requirement that at least some clay be present does not seem to hold. Layers containing the greatest amount of clay also tended to be the ones with the most shell; the dark layers at both sites seem to

contain significantly less. The dark layer at Namu possesses a significantly higher amount of organic matter than the other deposits in the midden, but this does not hold for the basal dark layer at Tsawwassen, where organic matter content fell within the range for all other deposits.

Has the lower black layer been leached of its shell at either of these sites? The results of these analyses cannot answer this question with complete certainty. At Tsawwassen the dark layer contained virtually no shell or bone; it was also devoid of other artifactual content. Along textural parameters this layer looks very much like the underlying "sterile" deposit, but it differs in composition in its higher organic matter content. It does not appear to have been affected by human activity to a significant degree, and may represent a buried pedogenic horizon. Its kurtosis value was very extreme and seemed to be most similar to that of the layer representing the current surface.

At Namu, the situation is more ambiguous. The upper portion of the basal dark layer (stratum 2B) contains some shell, bone and charcoal, as well as lithic remains, so human activity has played a role in its formation. In fact, photographs and profile drawings from Namu indicate the presence of shell lenses within the dark layer (Carlson 1979; see also chapter four, Figure 6), which I would not expect in a zone subject to intense leaching by lateral groundwater flow. The sample from the lowest part of this layer contained much less shell, and groundwater flow may be responsible for this internal difference. Texturally the mineral portion of the basal dark layer resembles more the underlying glacial till than the overlying shelly deposits; in fact, the mineral component from all layers are remarkably similar, and may in part have a similar source. However, despite overall similarities among the deposits, the

kurtosis values for the mineral fraction differ significantly between the shelly layers, dark layer, and underlying glacial sediments, and probably reflect differences in human activity that has contributed to each deposit. There are also significant differences in artifact content between the shelly and dark layers (Conover 1978:97), suggesting that the dark layer is not a "deflated" shelly deposit, but represents a set of activities somewhat different from those that led to the deposition of shelly layers. The basal dark layer at Namu has been affected by human activity to a greater extent than at Tsawwassen, but to a lesser extent than the shelly deposits that overlie it.

Again, the basal dark layers at Tsawwassen and Namu seem not to fit Stein's hypothesis for the formation of such layers. Variability in the proportion of shell in the smallest size ranges seems to be positively correlated with the amount of organic matter in the matrix at Namu, which may confirm Stein's idea that organic matter provides necessary components for the chemical decay of shell; however, this relationship does not hold at Tsawwassen, suggesting that there may be an intervening factor that is related to the production of such small shell particles. Also, this relationship tends to increase the proportion of carbonates in the small (silt-clay) particle size fraction at Namu, rather than eliminating the carbonates completely, as one would expect from an intensive leaching regime. Clay content also does not seem to play a role in the weathering of shell.

The data on which these conclusions rest are based on an admittedly smaller number of samples from each site. Namu is represented by a single vertical column of samples, and Tsawwassen by two columns; the spatial limitation of the samples used in this study is not sufficient to characterize accurately the extensive deposits in their entirety. This was observed in some of the

Tsawwassen samples, where the percentage of mussel shell in some samples exceeded those reported by Kusmer (1992), who used more than one sample per layer in her analysis of faunal remains. Further, some samples are not from the smallest observable unit, but represent a mixture of several different deposits. This was certainly observed for samples 3 and 4 at Namu. Use of such large-scale stratigraphic units make it difficult to control for much of the variability known to be present in shell midden deposits by artificially homogenizing them. This may have led to the inability to find statistically significant differences between the shelly and basal dark layers, for instance in the ratio of charcoal to mineral particles in the point counting data from Namu. These limitations in sampling render the interpretations in this study suggestive rather than conclusive, since more extensive sampling focusing on smaller depositional units might yield different results.

Problems with leaching as an explanation for dark layer formation

Problems posed by choosing leaching of shell to explain the formation of dark basal layers in shell-bearing sites are both technical and theoretical. The mechanism presents technical problems because carbonates can be so readily dissolved and removed under the right conditions that no traces of their former presence remain. Most chemical residues resulting from this process (such as calcium, magnesium, phosphorus, and strontium) are themselves subject to a high degree of mobility in a soil environment, and thus their detection would yield at best ambiguous if not unreliable results (Moore 1989:59). Other possible indicators include elevated densities of more stable materials, such as debitage or other stone artifacts, since a deposit leached of shell would be deflated in volume, resulting in higher concentrations of the nonshell cultural

component. However, so little is understood about spatial distributions of activities within shell-bearing sites on the Northwest Coast, or even functional differences between artifacts (e.g., Thompson 1978) that elevated concentrations of artifacts may simply indicate some special activity locus. Without some remnant of its former presence, one cannot accurately determine the extent to which the deposit has been affected by leaching, or specifically, how shelly a deposit was when it was first laid down. Theoretically, it is far more parsimonious to argue that the shell was not deposited to begin with, despite the fact that mobility of calcium carbonate in sedimentary environments can be quite high given sufficient inputs of water and carbon dioxide.

Alternative explanations for formation of basal dark layers

The approach taken in this study of leaching of carbonates in shell-bearing sites is necessarily limited. With regard to the problem of the origin of the dark shell-less layer at the base of shell middens, there are other possible explanations that could not be explored fully but which should be in the future. One alternative explanation is that the basal deposit represents a buried soil horizon, or the original surface at the site before its occupation by humans. This may be the case at Tsawwassen, where the dark layer contained virtually no cultural materials. Such a layer would be high in organic matter because of natural accumulation from vegetation cover; rapid deposition on top of this would help preserve it by reducing the amount of oxygen available for decomposition, as would inundation by groundwater, which would preserve recognizable plant tissues such as roots, stems and leaves. Such a deposit would probably extend under the entire midden. Artifacts and other remains

would be located primarily near the upper boundary, and not distributed throughout the deposit.

Another possibility, which was explored in the first model presented in chapter two and represents the traditional explanation for many such layers, is that less concentrated human activities at the location, or activities that didn't relate to shellfish processing and discard, may have helped accumulate organic matter and other material in the surface horizon, which subsequently became buried rapidly under shelly debris. A variant of this scenario would be a cessation of cultural activity for an extended period at that location, allowing intense chemical and mechanical weathering of midden constituents, especially shell, or the introduction and mixing of sediments and organic matter through nonhuman processes (such as pedogenesis). This would be particularly useful in explaining those dark, highly organic shell-less layers found in raised positions between shell-bearing deposits at some sites, such as at both the sites in this study, and others (e.g., Coupland 1989). Support for this can be found in the evidence of greater weathering in the upper portion of stratum 5 at Namu and layer B1 in Area A and layer D in Area C at Tsawwassen.

Whether the dark layer is postdepositionally leached by groundwater alone or formed in midden deposits by pedogenic processes on a stable surface may be decided by using microfabric analysis of deposits, something that has yet to be done in a shell midden context. Pedogenesis alters the microstructure of the midden by mixing, creating voids and cementing constituents together, and microfabric analysis (Courty et al. 1989) is necessary in order to identify them. In such an analysis a portion of deposit is impregnated with some resin which hardens. Thin sections of this block allow a researcher to examine the relations

between different grains, and identify voids or other structures that do not survive when examining unconsolidated samples. Such an approach might definitely indicate (or exclude) pedogenesis as the primary modifier of dark shell-less deposits in middens.

One problem analogous to dark shell-less layers at the base of shell-bearing sites is the question of the significance of "dark earth" deposits, found in northern European urban sites (Courty et al. 1989:261). Descriptions of dark earth sound remarkably similar to those of the "dark layers" discussed in this thesis. Dark earth deposits are found over wide areas, generally overlying late Roman architectural levels (in Great Britain). They are between 0.5 and 2 m thick, are dark gray to black in color, contain few archaeological features (although they may be present, Yule 1990), and are generally described as homogeneous (i.e., lacking bedding or other evidence of stratification). Most archaeologists have interpreted these deposits as evidence of conversion of urban areas to agricultural uses. Traditional sedimentological analyses, however, have yielded no evidence to support or deny these conclusions. They have found that the dark earth deposits contain remains of subsistence activities, such as bone, shell and charred plant material, are mildly alkaline (pH 7-8), and contain some CaCO_3 (1-7%) and organic matter (1-2% organic carbon) (Courty et al. 1989:261-262; Yule 1990:620).

Macphail (Courty et al. 1989:267-268) conducted a microfabric analysis of these dark earth deposits and compared them to other kinds of deposits with which they are associated. Studies of the microstructure in thin section led him to attribute the dark earth to material that had accumulated as a result of the destruction and decay of construction materials and subsequent mixing by

nonhuman biological agents. In particular he noted evidence of Enchytreidae, which are small worms that consume organic matter and mineral clasts and leave behind casts or small aggregates. Macphail concluded that agricultural activity was probably a very minor component in the formation of dark earth deposits, which probably represent abandonment phases (Courty et al. 1989:267-268; Yule 1990:626). Enchytreidae generally live only within the top 20 cm of the surface, so some deposition of sediment must be occurring, since most dark earth deposits are much thicker than this; a solid explanation for how this deposition occurs has yet to be put forward. Ultimately, further micromorphological studies are seen as essential in resolving questions about the formation and significance of the dark earth (Yule 1990:627).

As noted above, I believe a microfabric study might prove highly informative in understanding the formation of dark layers in Northwest Coast shell bearing sites as well. From published accounts of midden excavations, and from comparisons between the black layer at Tsawwassen and Namu, it is highly probable that there are many different kinds of black shell-less layers found within shell middens, with a different combination of processes producing a similar result — at least to the naked eye. The techniques used in this study can detect some of these differences, but microfabric studies would be far better suited because both explanations involve the identification of pedogenic processes, a task for which the technique was designed.

Another fruitful line of inquiry into the process of leaching of biogenic carbonates is experimental work with shell, such as that undertaken by Hughes (1977), something that has been recently proposed by others (Claasen 1991:268). Such work has been undertaken by taphonomists studying

paleontological shell deposits in order to understand how representative they are of ancient mollusc communities (Kerr 1991; Valentine 1989; Walter and Morse 1984). While these studies are useful, archaeologists need to undertake studies of their own for several reasons. First, the species which interest paleontologists are not necessarily those that interest archaeologists, and different species have differing resistance to chemical weathering because of their unique microstructure. Second, some of the processes that affect archaeological shell deposits, such as burning and trampling, are not necessarily relevant to most paleontological deposits, and thus may not be considered. Finally, the time scale of interest to paleontologists is usually much longer than that considered by archaeologists; changes that take place over one or two thousand years, potentially of much concern to archaeologists, may not seem significant to paleontologists.

Such an experimental study of chemical weathering of shell would need to focus on several different species of bivalves of economic importance to past native peoples, and selection of species should also control for different sorts of shell microstructure. Another important aspect to be controlled experimentally would be the effects of postdepositional chemical weathering on frequency distribution of shell across different size classes, which could readily be combined with experimental studies of trampling effects on shell, such as those conducted by Muckle (1985). Still other factors that need to be controlled is the kind of mineral matrix and amount of organic matter therein, in addition to the amount of water that is introduced into the sediment (e.g., Hughes 1977). Such research would go a long way toward understanding some of the variability encountered in prehistoric midden deposits, and its results would undoubtedly be of interest to paleontologists as well.

Finally, in order for broader studies of middens as depositional environments to be possible, drastic changes must be made in the way they are excavated and in the amount and quality of information that is retained. Most importantly, archaeologists need to suspend existing preconceptions regarding stratification within shell-bearing sites (Stein 1992b:88-89). Not only is this essential for geoarchaeological studies, but for those involving assessment of seasonality, reconstruction of prehistoric subsistence, distinguishing activity areas and making functional associations among tools. Current misconceptions of midden stratigraphy tend to combine and homogenize deposits, which, along with the heavy reliance upon the ethnographic record to interpret finds, probably contributes significantly to the assumption of relative "cultural continuity" on the Northwest Coast over the past 5000 years (Ambrose 1967; cf. Hobler 1990). Archaeological methods used to investigate shell-bearing sites must allow for variability within the record, if it is present, to be expressed and recognized (Claasen 1991:249).

In the case of understanding stratification in shell midden sites and postdepositional alteration of shell in such sites, this study has contributed new information and broadened the grounds for discussion of postdepositional loss of shellfish remains from archaeological deposits. Although this study did not provide a final resolution to the origin of dark, shell-less deposits within shell middens, it has provided information on the chemical mobility of biogenic carbonates in a sedimentary environment, and the potential effects this process might have on archaeological shell-bearing deposits. This information was used to examine the extent to which these processes may have affected deposits in two archaeological sites on the coast of British Columbia, and

provides descriptive information on the composition and texture of deposits identified at these sites. Finally, this work has suggested several promising new means for identifying postdepositional leaching of shell as the primary process in the formation of the black, largely shell-less layers found in many Northwest Coast shell middens. In conclusion I believe it is essential that archaeologists continue to increase their understanding of the formation of patterning in the archaeological record, in order to place our interpretations of the past on firmer foundations.

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APPENDIX A

THE PHI (\emptyset) SCALE AND GRAIN SIZE STATISTICS

APPENDIX A

Phi (Φ) scale. The Φ scale is a transformation of the logarithmic Wentworth particle size scale, which makes the results somewhat easier to manipulate when computing grain size statistics (Folk 1980:23). Coarser particles (larger than sand) are expressed as negative numbers, while finer particles (medium sand size and smaller) are expressed as positive numbers, with 0 Φ being equivalent to particles $<2\text{mm} \geq 1\text{mm}$. The significant cut-off points between broad textural categories are: Gravels ($\geq 2\text{mm} = > -1$ phi), sands ($< 2\text{ mm} - 0.0625\text{mm} = -1$ to $+4$ phi), silt ($<.0625\text{ mm} - 0.0039\text{ mm} = 4$ to 8 phi), and clay ($<.0039\text{ mm} = >8$ phi). The table below provides a comparison between Φ intervals, Wentworth size class, and metric equivalent.

Table A-1. Metric, Phi, and Wentworth Scale Equivalents

Wentworth Class	Phi (Φ) interval	Metric (mm)
Pebble	-5	64-32
"	-4	32-16
"	-3	16-8
Granule	-2	8-4
"	-1	4-2
Very coarse sand	0	2-1
Coarse sand	+1	1-0.5
Medium sand	+2	0.5-0.25
Fine sand	+3	0.25-0.125
Very fine sand	+4	0.125-0.0625
Coarse silt	+5	0.0625-0.031
Medium silt	+6	0.031-0.0156
Fine silt	+7	0.0156-0.0078
Very fine silt	+8	0.0078-0.0039
Clay	+9	0.0039-0.002
"	+10	0.0002-0.00098

Particle size analysis using settling column. Both the hydrometer and pipette methods are based on the fact that one can predict when all of the particles of a certain size class have settled to a particular depth, assuming several variables are known (Stoke's Law). Stoke's Law assumes that a) the temperature of the fluid is known and constant, as it affects the viscosity of the fluid and therefore the resistance offered to a body falling through it, and b) all particles are uniformly round (Folk 1980:17). The first variable is often not too difficult to control, but the second is an assumption that is virtually impossible to account for, particularly when one considers the platy nature of clay minerals. Sternberg and Creager (1961) compared the hydrometer and pipette methods for determining the grain size distribution of mud. They found that the two methods yielded similar results given a moderate concentration of mud in suspension (6 to 24 g/L) up to the cut-off point between silt and clay size classes. However, where the concentration of sediments in suspension dropped below 6 g/L the pipette method was more accurate; conversely, when the concentration exceeded 24 g/L the hydrometer method gave more accurate results. Overall, the experimenters found the pipette method to yield the most consistent results.

Technique for determining the size distribution of shell particles.

The following is a hypothetical example of the procedure outlined in chapter three to determine the percentage of shell particles found in a particular ϕ interval of hypothetical sample X.

Sample X: Total sample weight = 1500 g

weight of $\geq 2\text{mm}$ fraction = 500 g

-wt. of $\geq 2\text{mm}$ shell = 200 g

weight of $< 2\text{mm}$ fraction = 1000g

-subtract wt. organic matter (5%) = 950 g

-subtract wt. CaCO_3 (50%) = 450 g

Grain size analysis #1 (pretreated for organic matter)

weight of material in $+1\phi$ = 5 g; total subsample weight = 40 g

split factor (#1) = $950 \text{ g} \div 40 \text{ g} = 23.75$

total sample weight in $+1\phi$ interval = $5 \text{ g} \times 23.75 = \underline{118.75 \text{ g}}$

Grain size analysis #2 (pretreated for organic matter and carbonates)

weight of material in $+1\phi$ = 7 g; total subsample weight = 40 g

split factor (#2) = $450 \text{ g} \div 40 \text{ g} = 11.25$

total sample weight in $+1\phi$ interval = $7 \text{ g} \times 11.25 = \underline{78.75 \text{ g}}$

total $+1\phi$ Sample X (GSA #1): 118.75 g

total $+1\phi$ Sample X (GSA #2): (78.75 g)

total shell in $+1\phi$ for Sample X: 40 g

weight of CaCO_3 ($< 2\text{mm}$) Sample X: 500 g

weight of shell ($\geq 2\text{mm}$) Sample X: 200 g

TOTAL WEIGHT SHELL SAMPLE X: 700 g

Percentage of shell in $+1\phi$ interval: $40 \text{ g} \div 700 \text{ g} = \underline{5.7\%}$

Grain size statistics. The method employed in this study is the graphic method, whereby the grain size at a particular percentile is read from a graph of cumulative frequency plotted on probabilityX90 paper, and is used to calculate

the value of the statistic. Statistics used in this study are the graphic mean, the inclusive graphic standard deviation, inclusive graphic skewness, and kurtosis. The graphic mean (mean) $(= (\phi@16\% + \phi@50\% + \phi@84\%)/3)$ describes the average grain size in ϕ units. The inclusive graphic standard deviation (SD) measures sorting in ϕ units, and is calculated by the formula:

$$\frac{\phi@84\% - \phi@16\%}{4} + \frac{\phi@95\% - \phi@5\%}{6.6}$$

Inclusive graphic skewness (skew) measures the symmetry of the frequency curve, i.e., whether there is a tail to the left or right, or whether it looks like a normal (Gaussian) distribution. Skewness is calculated by the formula:

$$\frac{\phi@16\% + \phi@84\% - 2(\phi@50\%)}{2(\phi@84\% - \phi@16\%)} + \frac{\phi@5\% + \phi@95\% - 2(\phi@50\%)}{2(\phi@95\% - \phi@5\%)}$$

The resulting value is expressed as positive or negative, and is not in the ϕ scale. A value of 0 indicates a symmetrical curve; a positive value indicates a tail toward the fine end of the ϕ scale, a negative value indicates the curve is skewed toward the coarse end of the ϕ scale. The absolute limits are -1.0 and +1.0. Graphic kurtosis measures how much of a central peak the curve has. If the curve is normal, it will have a value of 1.00 and is termed mesokurtic. However, since most grain size distributions have more than one mode kurtosis compares sorting in the tails with that of the central part of the curve. Graphic kurtosis (kurt) is expressed as:

$$\frac{\phi@95\% - \phi@5\%}{2.44 (\phi@75\% - \phi@25\%)}$$

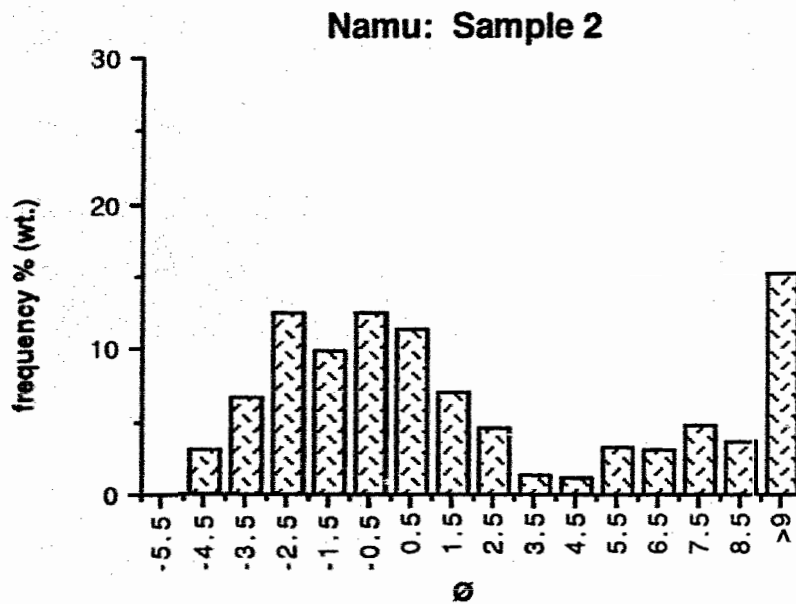
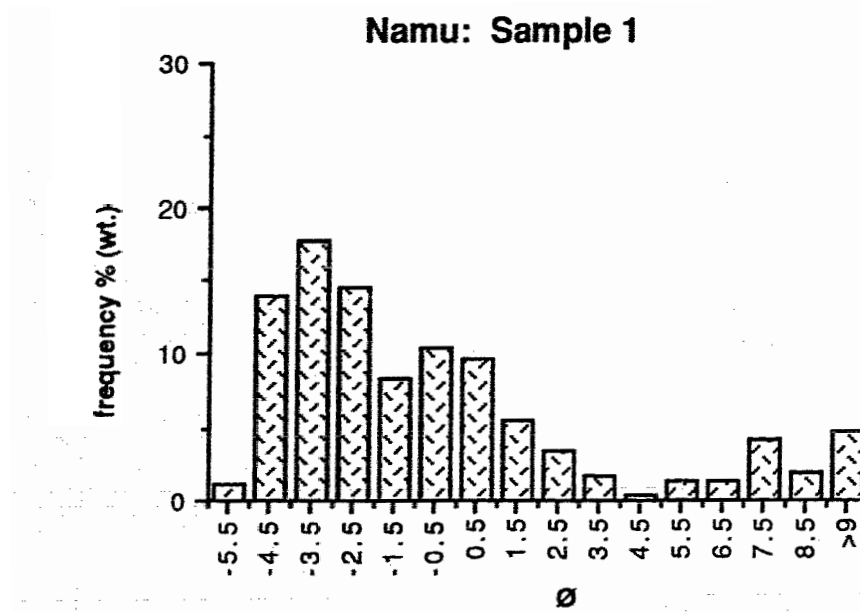
Those with a well sorted central peak are leptokurtic and have values >1 ; those with better sorting in the tails than in the central portion are called platykurtic

and have a value < 1 . (See Folk 1980:40-45 for a more detailed discussion of grain size parameters used here.)

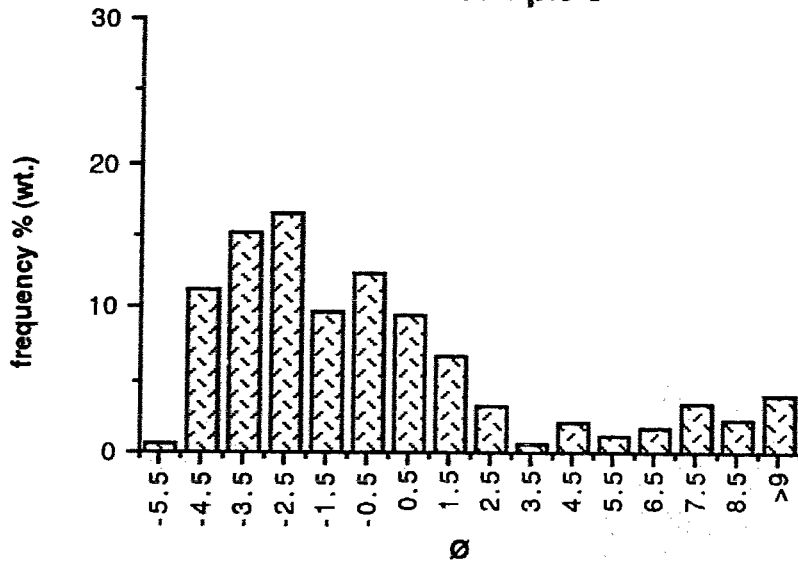
APPENDIX B
MISCELLANEOUS DATA FROM NAMU (EISx 1)

APPENDIX B

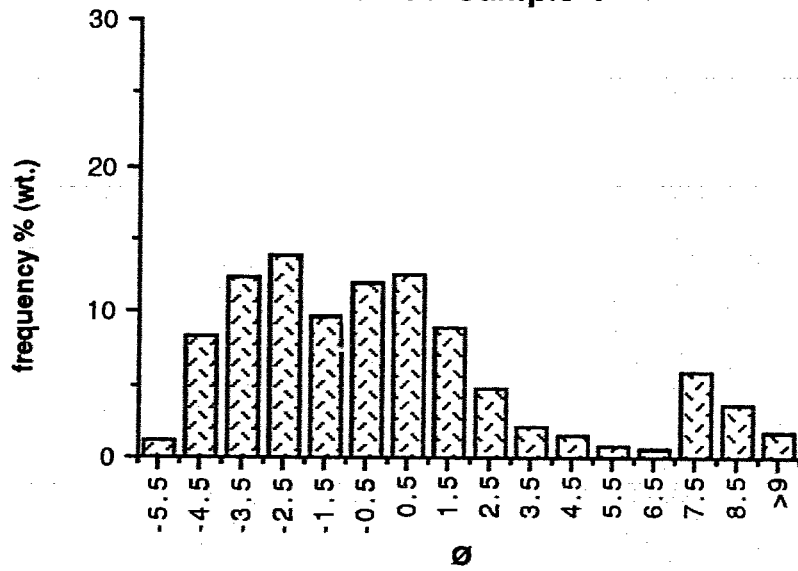
Bar Graphs of Shell Fraction (total sample):



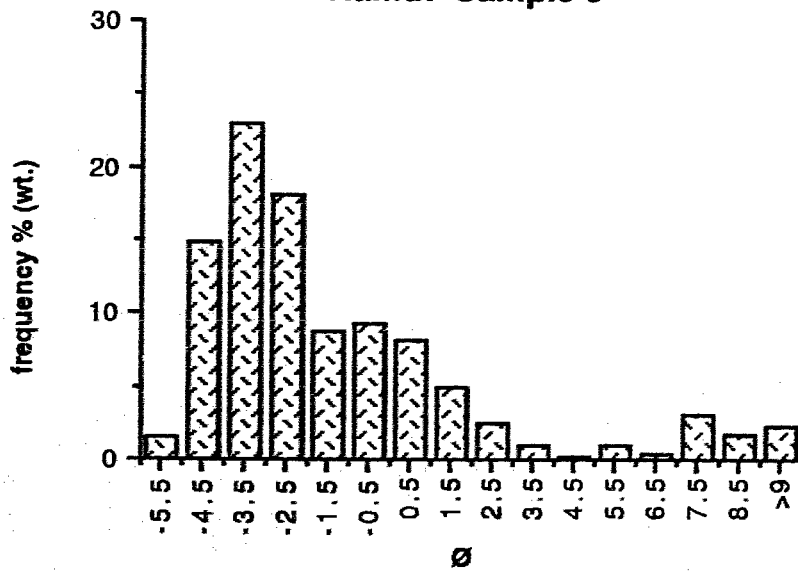
Namu: Sample 3



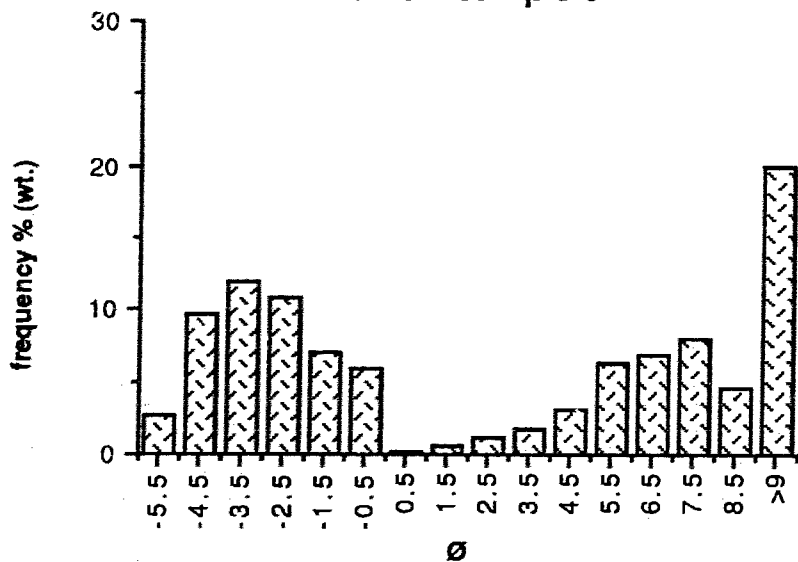
Namu: Sample 4



Namu: Sample 5

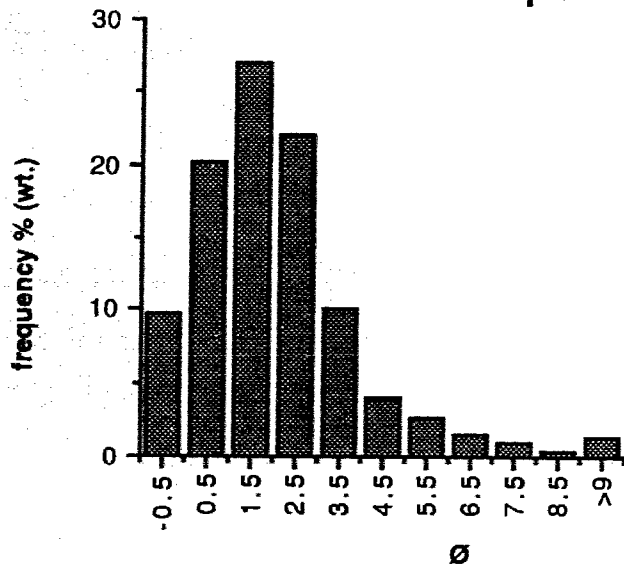


Namu: Sample 6

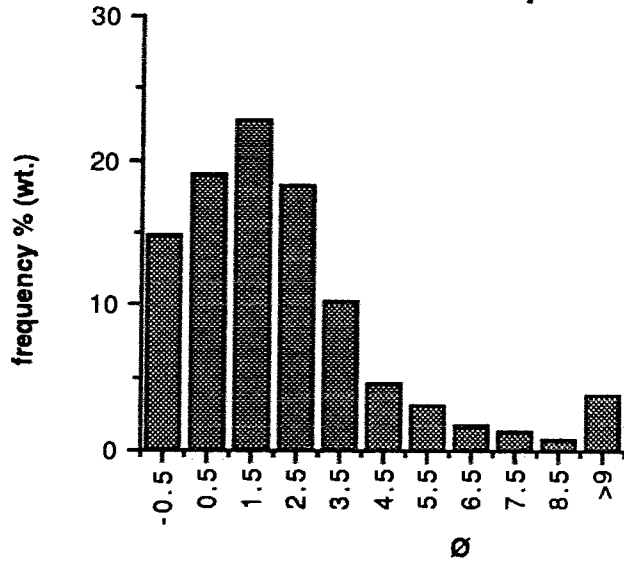


Bar Graphs of Mineral Fraction (<2mm only):

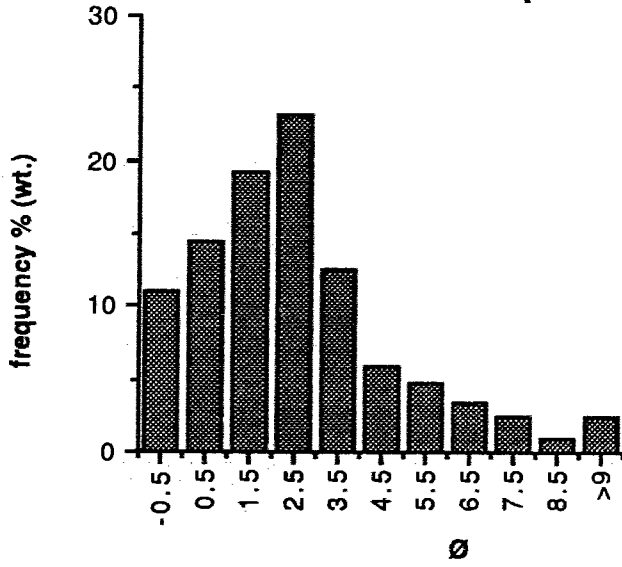
Namu: Sample 1



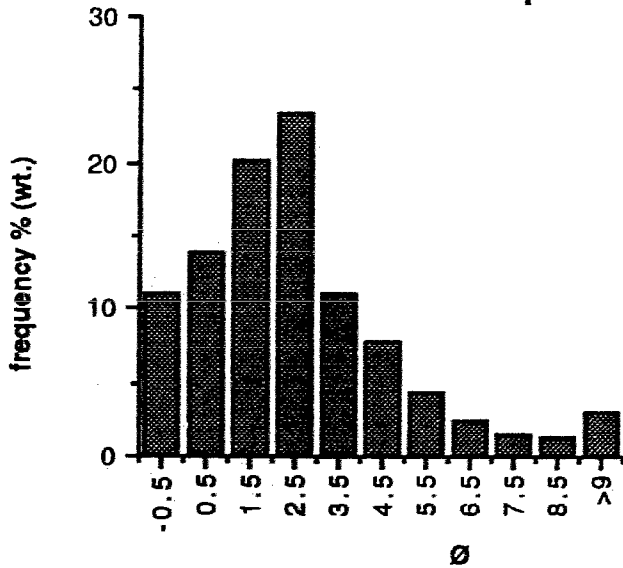
Namu: Sample 2



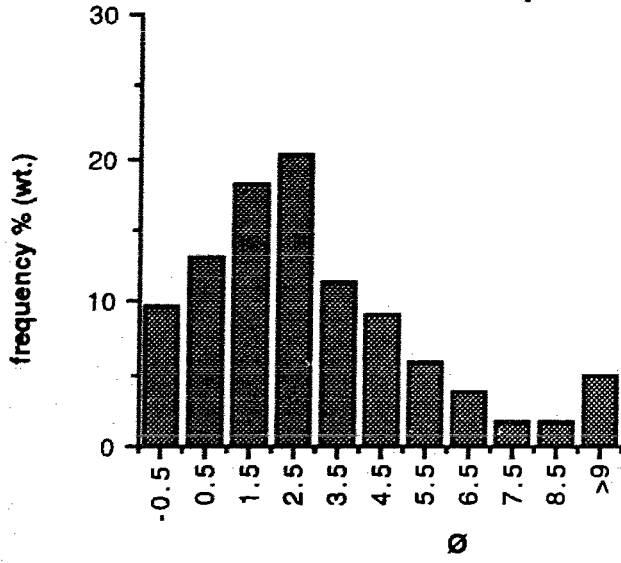
Namu: Sample 3



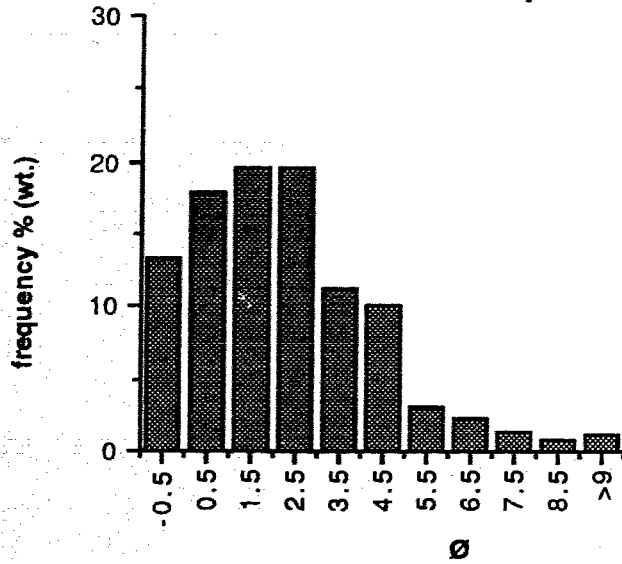
Namu: Sample 4



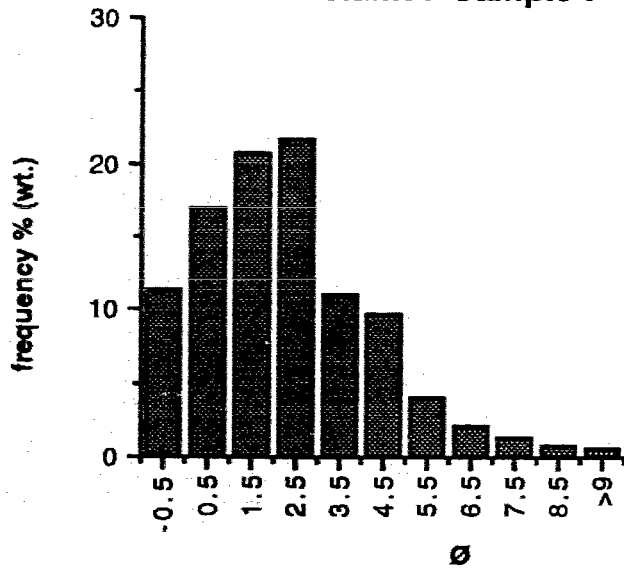
Namu: Sample 5



Namu: Sample 6



Namu: Sample 7



Namu: Sample 8

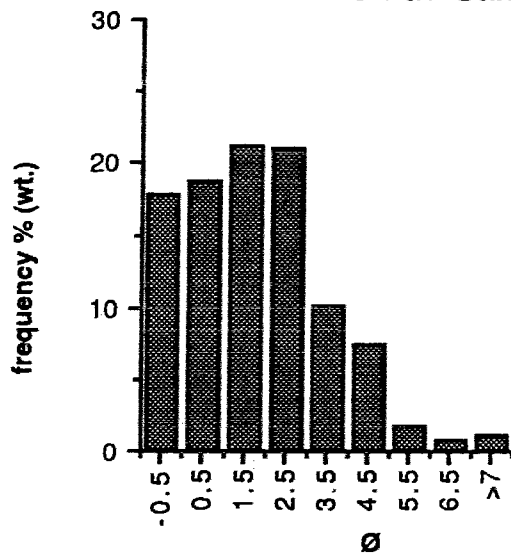


TABLE B-1. Grain Size Data of Mineral Fraction (Total Sample) from Namu

Layer No.	Sample No.	% Grav	% Sand	% Silt	% Clay	Mean (Ø)	SD (Ø)	Skew	Kurt
6	1	37.3	68.5	6.2	2.5	0.4	3.0	-0.33	1.24
5	2	17.7	69.9	8.7	3.7	1.2	2.9	-0.03	1.91
5	3	33.2	53.5	10.9	2.4	0.4	3.4	-0.13	0.91
5	4	32.7	52.7	11.2	3.4	0.6	3.2	-0.08	0.87
5B	5	45.3	39.2	12.3	3.2	-0.3	3.9	+0.04	0.63
2B	6	24.3	61.6	12.5	1.6	0.9	3.1	-0.14	1.17
2B	7	16.7	67.6	14.5	1.2	1.5	2.6	-0.05	1.11
1	8	46.1	48.1	5.8	<1	-0.9	3.2	-0.05	0.56

Outlined rows indicate data from basal dark layer.

Table B-2. Kolmogorov Smirnov Two Sample Test Results

MAXIMUM DIFFERENCES FOR PAIRS OF VARIABLES

	NAMU1	NAMU2	NAMU3	NAMU4	NAMU5
NAMU1	0.000				
NAMU2	0.300	0.000			
NAMU3	0.200	0.200	0.000		
NAMU4	0.300	0.100	0.100	0.000	
NAMU5	0.400	0.200	0.200	0.200	0.000
NAMU6	0.100	0.300	0.200	0.200	0.300
NAMU7	0.100	0.300	0.200	0.300	0.400
NAMU8	0.300	0.500	0.400	0.400	0.500

	NAMU6	NAMU7	NAMU8
NAMU6	0.000		
NAMU7	0.100	0.000	
NAMU8	0.300	0.200	0.000

TWO-SIDED PROBABILITIES

	NAMU1	NAMU2	NAMU3	NAMU4	NAMU5
NAMU1	1.000				
NAMU2	0.664	1.000			
NAMU3	0.962	0.962	1.000		
NAMU4	0.664	1.000	1.000	1.000	
NAMU5	0.309	0.962	0.962	0.962	1.000
NAMU6	1.000	0.664	0.962	0.962	0.664
NAMU7	1.000	0.664	0.962	0.664	0.309
NAMU8	0.664	0.112	0.309	0.309	0.112

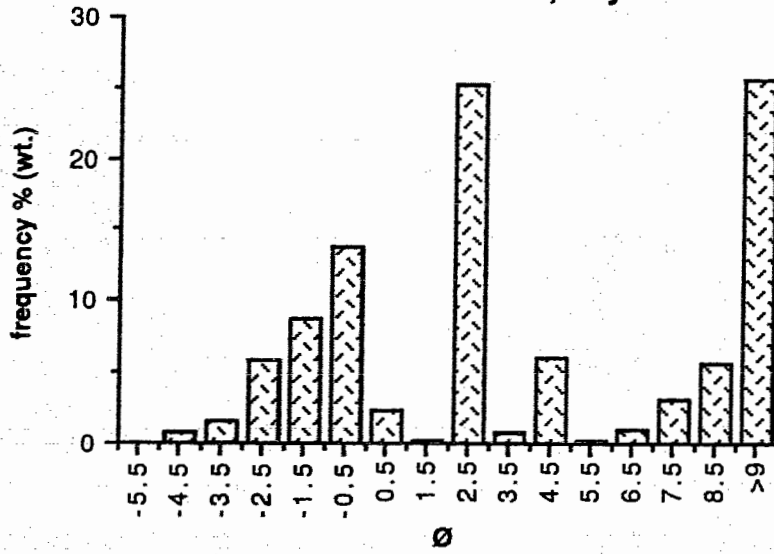
	NAMU6	NAMU7	NAMU8
NAMU6	1.000		
NAMU7	1.000	1.000	
NAMU8	0.664	0.962	1.000

APPENDIX C
MISCELLANEOUS DATA FROM TSAWWASSEN
(DgRs 2)

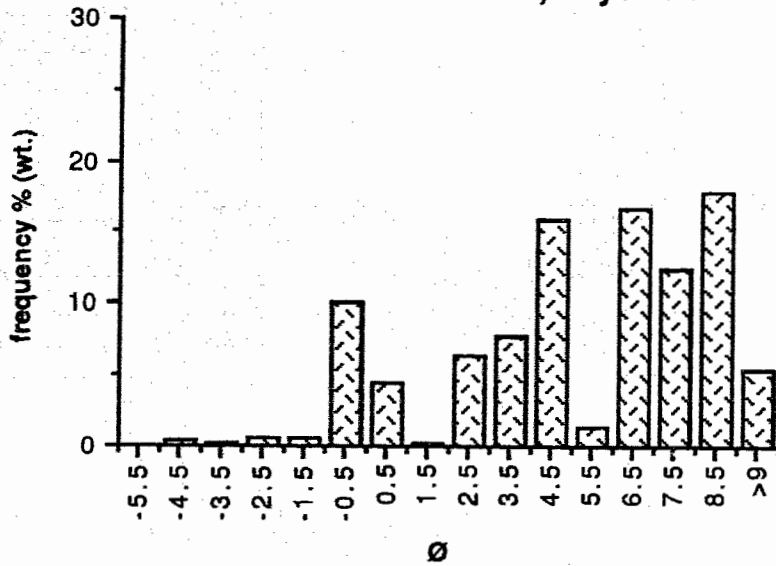
APPENDIX C

Bar Graphs for Shell (Total Sample), Area A

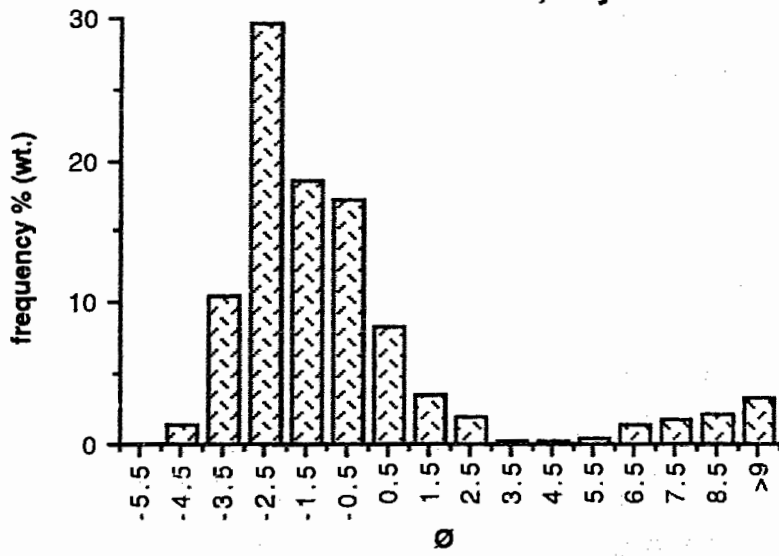
Tsawwassen: Area A, Layer A



Tsawwassen: Area A, Layer B1

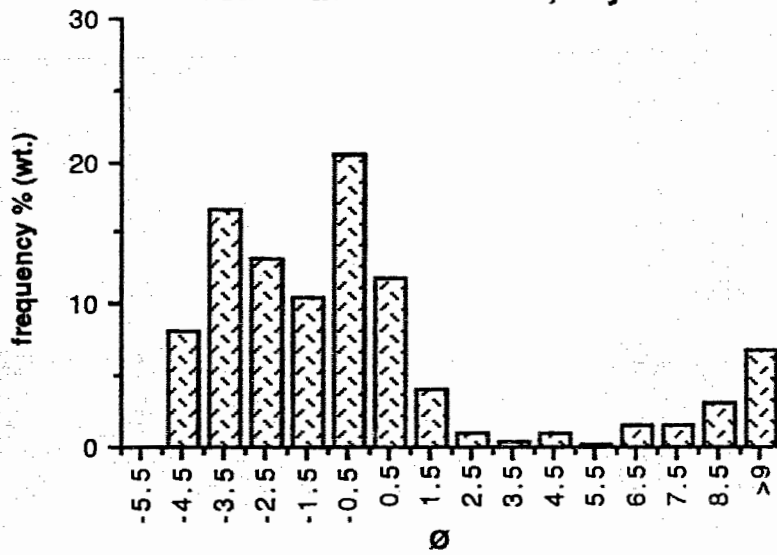


Tsawwassen: Area A, Layer B2

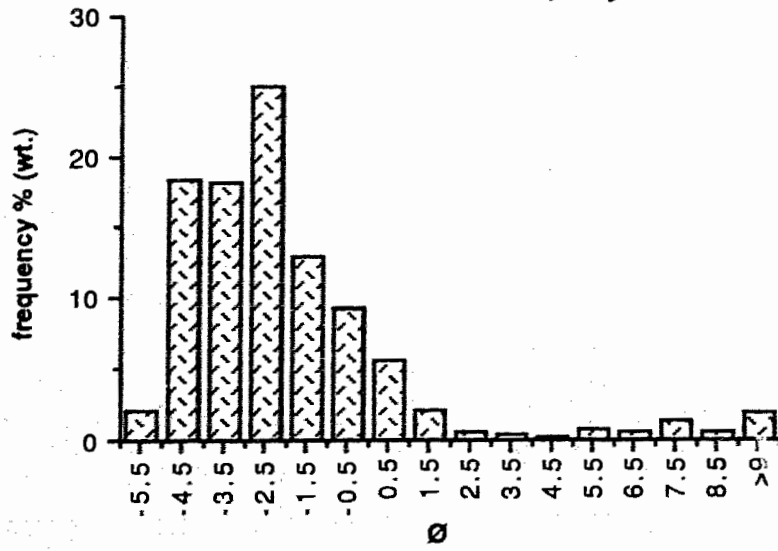


Bar Graphs for Shell Fraction (Total Sample), Area C:

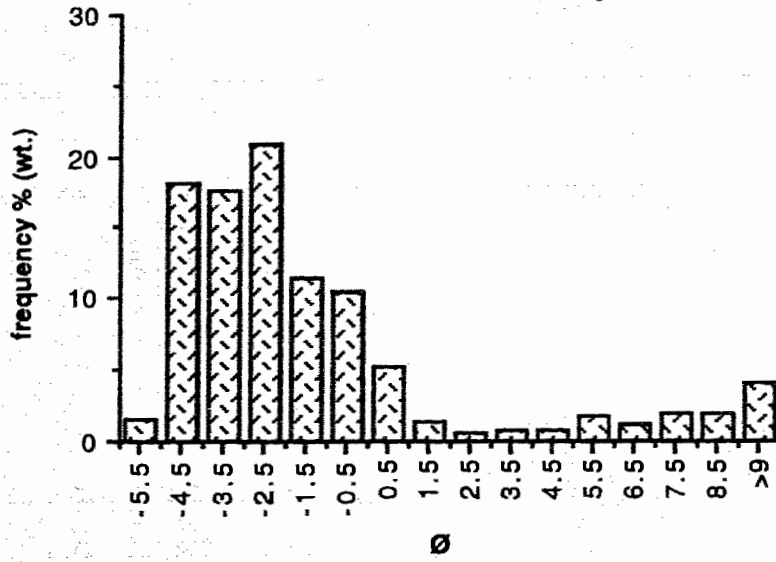
Tsawwassen: Area C, Layer B



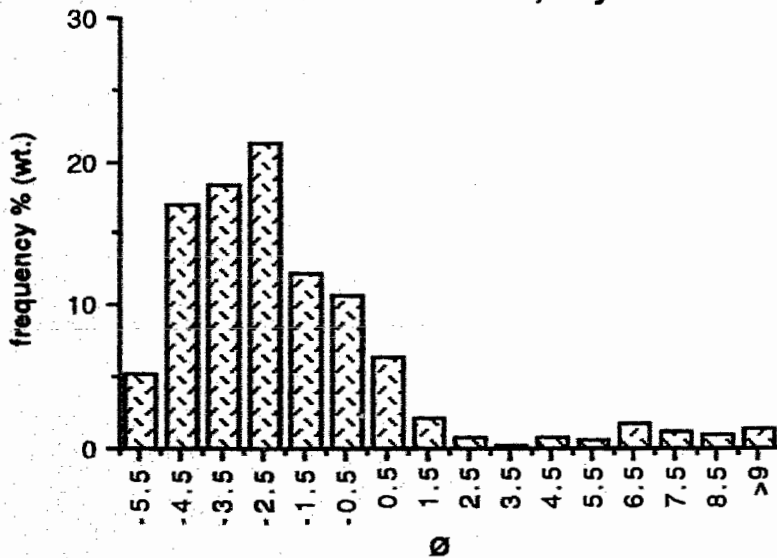
Tsawwassen: Area C, Layer C



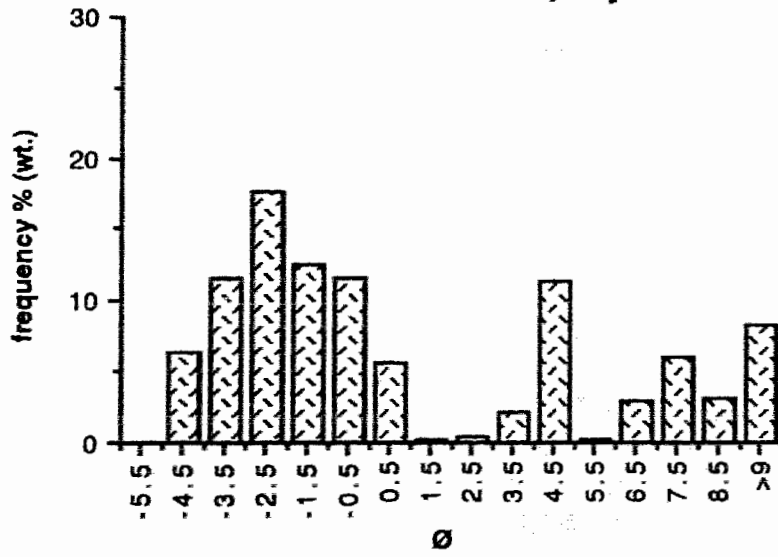
Tsawwassen: Area C, Layer C1



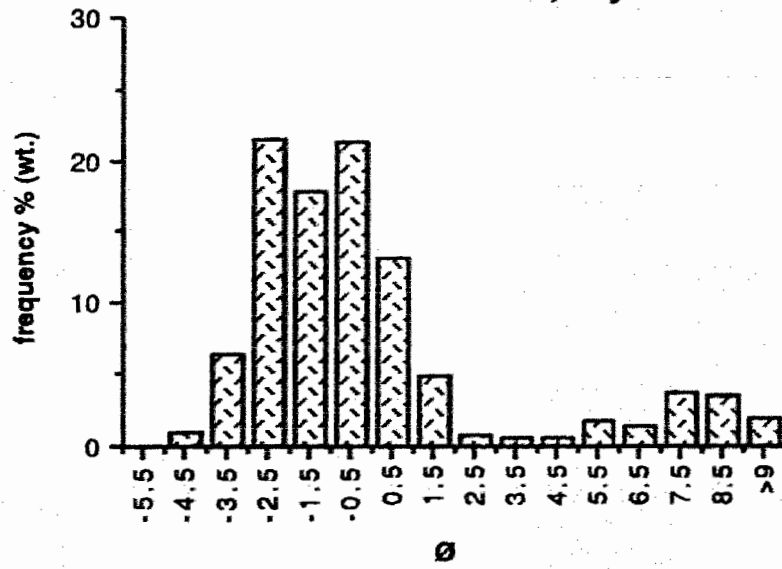
Tsawwassen: Area C, Layer C2



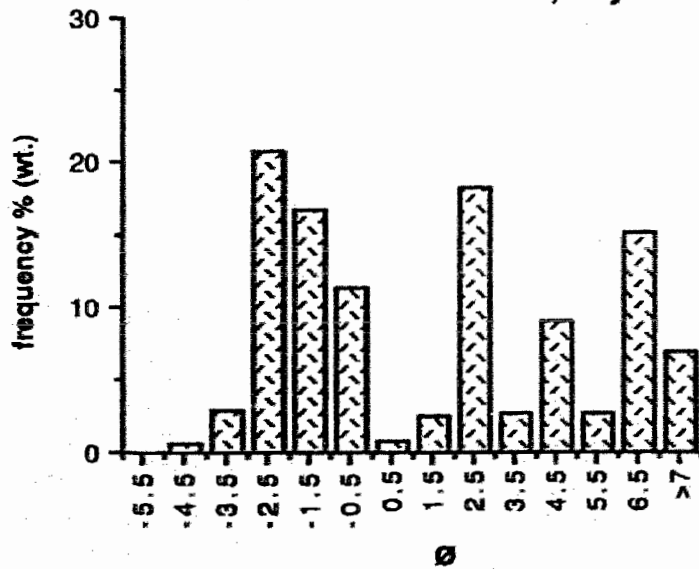
Tsawwassen: Area C, Layer D



Tsawwassen: Area C, Layer E

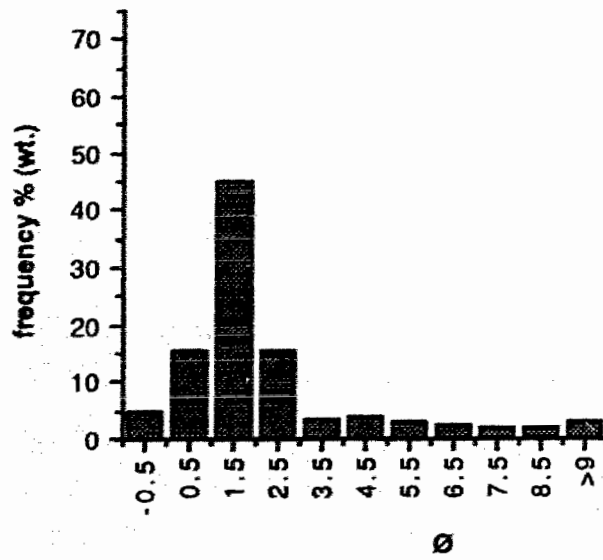


Tsawwassen: Area C, Layer F

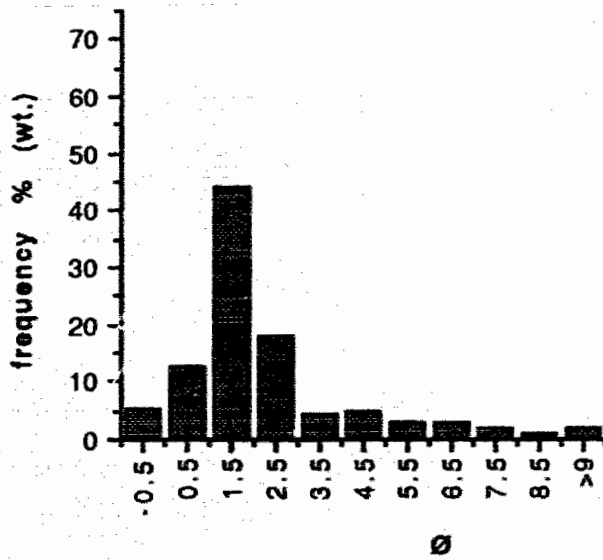


Bar Graphs for Mineral Fraction (<2mm). Area A:

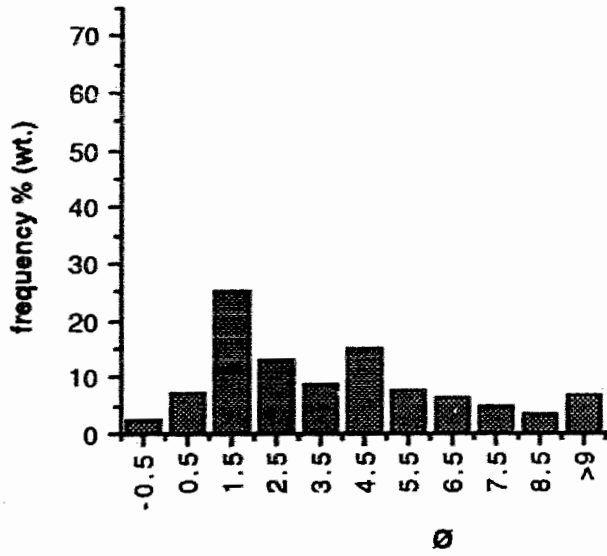
Tsawwassen: Area A, Layer A



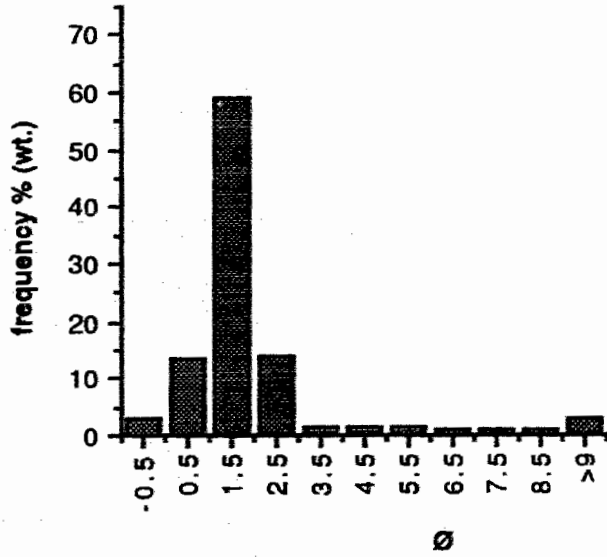
Tsawwassen: Area A, Layer B1



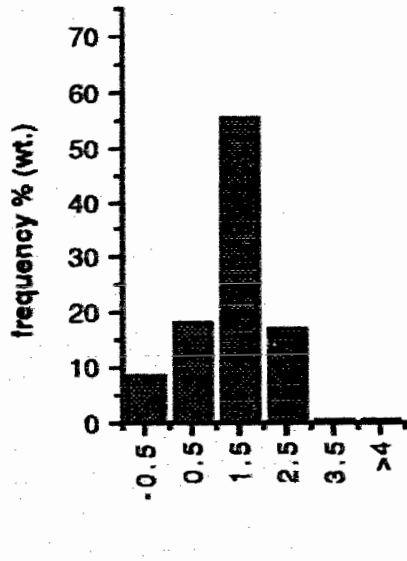
Tsawwassen: Area A, Layer B2



Tsawwassen: Area A, Layer C

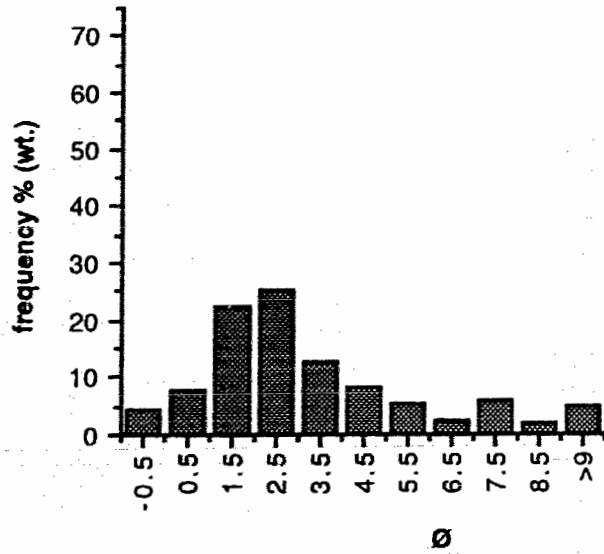


Tsawwassen: Area A, Layer D

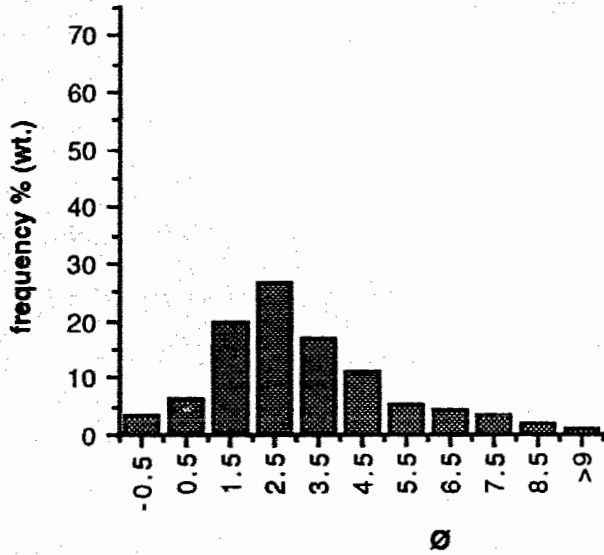


Bar Graphs for Mineral Fraction (<2mm only). Area C:

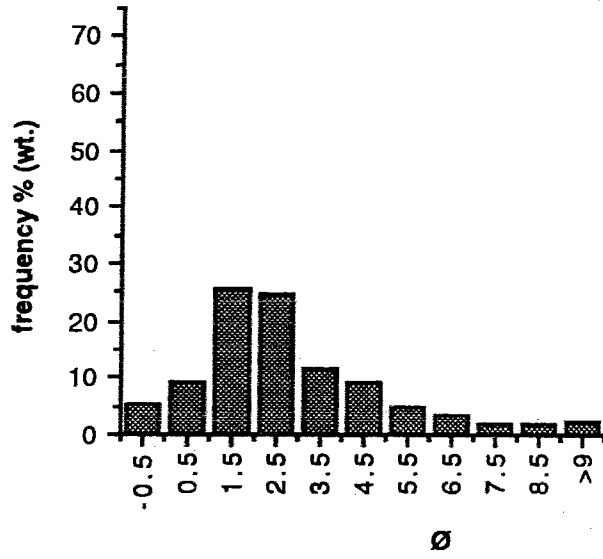
Tsawwassen: Area C, Layer B



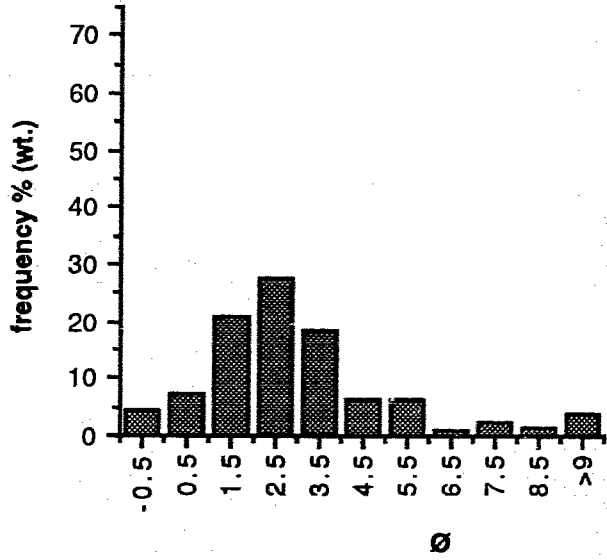
Tsawwassen: Area C, Layer C



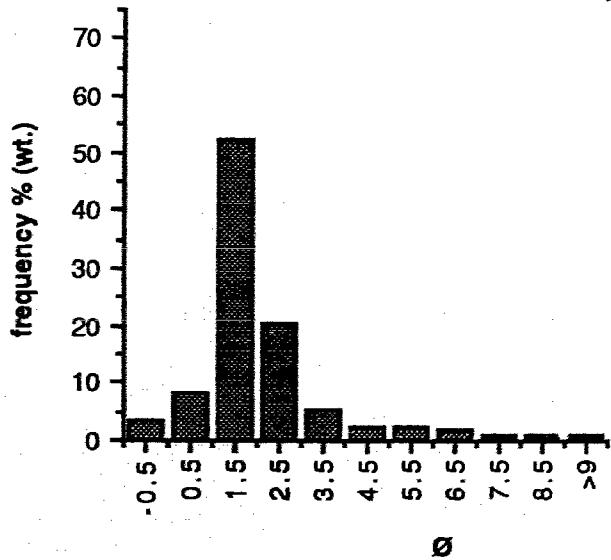
Tsawwassen: Area C, Layer C1



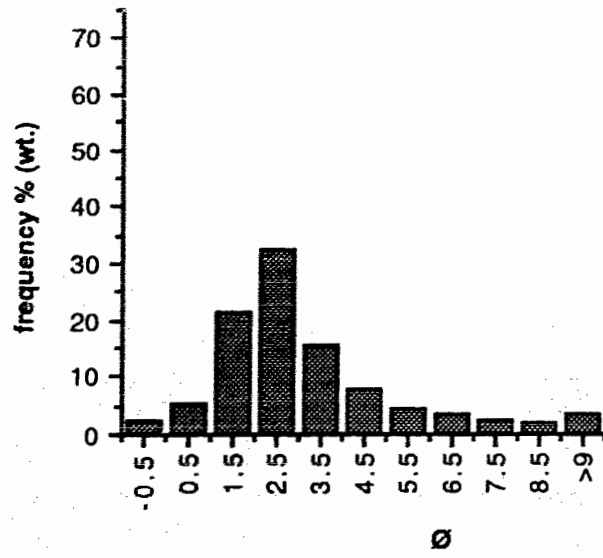
Tsawwassen: Area C, Layer C2



Tsawwassen: Area C, Layer D



Tsawwassen: Area C, Layer E



Tsawwassen: Area C, Layer F

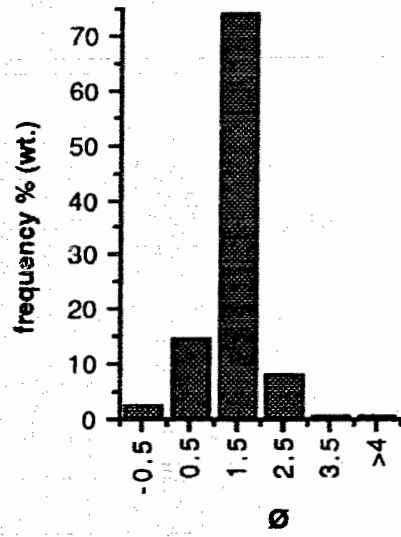


Table C-1. Grain Size Data of Mineral Fraction (Total Sample) from
Tsawwassen

Layer No.	Sample No.	% Gravel	% Sand	% Silt	% Clay	Mean (Ø)	SD (Ø)	Skew	Kurt
Area A									
A	1	24.9	63.0	8.5	3.6	0.3	3.2	-0.23	1.44
B1	3	21.6	66.1	9.9	2.4	0.6	3.0	-0.22	1.78
B2	5	26.7	41.4	24.3	7.6	1.9	5.1	-0.09	0.77
C	7	12.9	79.2	4.4	3.5	1.3	2.4	-0.10	4.47
D	9	40.7	58.9	<1	<1	-0.4	2.2	-0.50	0.63
Area C									
B	11	57.3	30.7	9.0	3.0	-2.3	4.0	-0.71	0.81
C	13	47.6	38.0	12.6	1.8	0.0	3.6	+0.04	0.64
C1	15	36.5	48.4	12.3	2.8	0.4	3.6	-0.20	0.71
C2	17	42.9	44.8	9.2	3.1	0.2	3.4	-0.19	0.66
D	19	6.6	83.2	8.4	1.8	1.8	1.7	+0.17	2.80
E	21	17.9	63.3	14.5	4.3	1.6	3.6	-0.22	2.00
F	23	8.7	91.0	<1	<1	1.2	1.2	-0.46	3.22

Outlined rows indicate data from basal dark layer.

Table C-2. Kolmogorov-Smirnov Two Sample Test Results for Tsawwassen

MAXIMUM DIFFERENCES FOR PAIRS OF VARIABLES

	TSAW1	TSAW3	TSAW5	TSAW7	TSAW9	TSAW11
TSAW1	0.000					
TSAW3	0.100	0.000				
TSAW5	0.400	0.400	0.000			
TSAW7	0.300	0.300	0.500	0.000		
TSAW9	0.700	0.700	0.700	0.700	0.000	
TSAW11	0.300	0.300	0.200	0.500	0.700	0.000
TSAW13	0.200	0.200	0.300	0.400	0.700	0.200
TSAW15	0.200	0.200	0.300	0.300	0.700	0.200
TSAW17	0.200	0.200	0.300	0.300	0.700	0.200
TSAW19	0.200	0.200	0.400	0.300	0.600	0.400
TSAW21	0.200	0.200	0.200	0.400	0.700	0.200
TSAW23	0.700	0.700	0.700	0.700	0.100	0.700

Table C-2 (continued)

	TSAW13	TSAW15	TSAW17	TSAW19	TSAW21	TSAW23
TSAW13	0.200	0.000				
TSAW15	0.100	0.000				
TSAW17	0.200	0.100	0.000			
TSAW19	0.300	0.200	0.300	0.000		
TSAW21	0.100	0.100	0.100	0.300	0.000	
TSAW23	0.700	0.700	0.700	0.600	0.700	0.000

TWO-SIDED PROBABILITIES

	TSAW1	TSAW3	TSAW5	TSAW7	TSAW9	TSAW11
TSAW1	1.000					
TSAW3	1.000	1.000				
TSAW5	0.309	0.309	1.000			
TSAW7	0.664	0.664	0.112	1.000		
TSAW9	0.006	0.006	0.006	0.006	1.000	
TSAW11	0.664	0.664	0.962	0.112	0.006	1.000
TSAW13	0.962	0.962	0.664	0.309	0.006	0.962
TSAW15	0.962	0.962	0.664	0.664	0.006	0.962
TSAW17	0.962	0.962	0.664	0.664	0.006	0.962
TSAW19	0.962	0.962	0.309	0.664	0.030	0.309
TSAW21	0.962	0.962	0.962	0.309	0.006	0.962
TSAW23	0.006	0.006	0.006	0.006	1.000	0.006

	TSAW13	TSAW15	TSAW17	TSAW19	TSAW21	TSAW 23
TSAW13	1.000					
TSAW15	1.000	1.000				
TSAW17	0.962	1.000	1.000			
TSAW19	0.664	0.962	0.664	1.000		
TSAW21	1.000	1.000	1.000	0.664	1.000	
TSAW23	0.006	0.006	0.006	0.030	0.006	1.000