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THE LITTORAL KARREN
OF
NEROUTSOS INLET
NORTHERN VANCOUVER ISLAND

McMaster University

Brenda Stephan

THE LITTORAL KARREN
OF
NEROUTSOS INLET
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BY

BRENDA ANN STEPHAN

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ABSTRACT

Limestones exposed in the intertidal zone display numerous pits and basins which form where bodies of water are isolated during tidal retreat. These harbour both macro- and microscopic organisms whose metabolites enhance aggressivity and cause solution; grazing and boring activities further aid rock removal.

In this area the basins are similar in shape throughout the littoral zone but they vary in size, the maximum relief being at mid tide level. Unlike the exposed west coast of Ireland, zonation is not well defined: the clearly identifiable morphologies associated with the biological zones in Ireland are not displayed here. Instead it resembles the karren of the more sheltered Bristol channel area but with less mechanical erosion. In both of these areas variations in lithology affect the details of the geomorphology, some beds being significantly more fractured and less pitted than others.

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CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Littoral karren are solutional features produced on limestone as a result of the action of seawater and of marine organisms. These produce fretted and roughened depressions. There is a sequence in forms produced from low water mark to high water mark (Sweeting, 1973). The sequence or zones are major horizontal regions on the coast which are differentiated by differing flora and fauna numbers and species (Dale, 1982), and differing karren forms.

There are many hypotheses concerning the exact processes responsible for littoral zonation patterns. Many researchers believe that the biota present in an area is the dominant factor behind formation of the zonal patterns. Biological abrasion and corrosion results in a very rough surface known as biokarst (Golubic, 1979). Others believe that the zonation is a result of physical processes: tidal action, wave action, and currents are the dominant forces behind the patterns of zonation. The air/water interface also affects the formation of zonal patterns (Dale, 1982).

These two views are linked in that the tidal regime controls the distribution of the flora and fauna (Dale, 1982). Many organisms are unable to withstand long periods of exposure to the air and are therefore restricted to areas with a constant supply of water. Other organisms are able to withstand a limited amount of exposure and can exist at a higher tide level. Therefore, the tidal regime is the primary factor controlling the biological zonation patterns (Dale, 1982).

Erosion by both tidal action and marine organisms produces a rock surface which retains at low tide, a small amount of water in the pits and depressions (Ginsburg, 1953). These isolated bodies of water become aggressive at night during low tide. Differential solution can then occur where the wet parts of the rock are dissolved but the dry parts remain intact (Lundberg, 1986).

The aim of this study was to determine (i) if a distinct zonation pattern existed in the small scale geomorphology of the limestone exposed in the littoral of northern Vancouver Island, (ii) if the geomorphology varied significantly with lithology.

1.2 ZONES AND PROCESSES

1.2.1 INTRODUCTION

No previous work has been reported on littoral karren within Canada, and little in temperate regions. This chapter reviews similar research carried out in temperate regions and focuses on zonation patterns which have been described and the possible processes responsible for these zonal patterns. Finally a comparison between tropical and temperate forms will be discussed.

1.2.2 LITERATURE REVIEW

Limestone which outcrops on the sea coast inevitably undergoes erosion (Trudgill, 1976). There are numerous processes by which the rock may be eroded such as, biological grazing/boring, wave action, hydration (wetting and drying), spray impact, salt weathering, abrasion by sand, chemical solution and salt and/or fresh water mixing (Trudgill, 1976; 1985) The result of all these various processes is a very distinctive coastline.

The limestone exhibits a variety of forms from the pavements and enlarged joints of terrestrial karren to the notches, pits, pans and pinnacles of littoral karren (Ley 1979; Lundberg, 1977; Jennings, 1985). Littoral karren are micro-relief forms found on coastal limestone within the littoral zone and below low water mark (Ley 1977).

Studies of littoral karren appear frequently in the literature, but very few refer to temperate coasts. Most of the reporting is centred around tropical coastlines as limestone coast are more frequent in the tropics because both fossil coral reefs and aeolianite calcarenites are common (Lundberg, 1986) For example, Spencer (1985) describes the lowering of the limestone surface on the Grand Cayman Island. Ginsburg (1953) studied the erosion of calcareous rocks in the Florida Keys and Emery (1946) studied rock basins at La Jolla, California. The few temperate studies which appear in the literature are centred on the British Isles (Bristol Channel, Co. Clare, Ley 1979; Lundberg 1976, 1977). From them, it would appear that the karren forms found in temperature regions are distinct from those in tropical regions (Lundberg 1977; Trudgill, 1976).

Within the littoral, several karst zones can be identified upon limestones. Many authors believe that the zonation is a result of biological erosion which is modified by mechanical erosion (Lundberg 1977; Schneider and Torunski, 1983; Trudgill, 1983). The tidal regime along the coast affects the distribution of marine organisms. The ecological niches of different organisms across the shore zones are determined by: (i) the percentage exposure (exposure refers to the period of time an area in the intertidal zone is exposed to aerial elements); (ii) the percentage of inundation due to tidal effects and wave splash (Dale, 1982); (iii) energy levels and; (iv) abrasive material and others.

1.2.3 ZONAL CLASSIFICATION

Karren zones are related to the biological zones which grade into one another where a sequence occurs down a single face (Lundberg, 1977; Schneider and Torunski, 1982). Lundberg (1977) identified four distinct biological zones on the temperate coast of Ireland. Moving from high water mark to low water mark they are: 1. the Verrucaria zone, 2. the Littorina zone, 3. the Barnacle zone, and 4. the Mussel-Echinoid zone. Each is characterized by differing morphology in the karren forms. Each is located within the littoral zone (Fig. 1.1).

The verrucaria zone is dominated by shallow, circular basins with rilled or pitted walls. The floors of these basins are smooth and flat, and there exists a sharp break in slope between the wall and floor. The littorina zone consists of deeper, more complex and more closely packed pits. The floors are relatively flat-bottomed and have rounded edges. Limpet home scars (depressions on the rock surface created by organisms which rasp out a cavity for shelter during dessication or exposure stress) are dominant at the water level within these pits. In the barnacle zone the walls of the basins become more undercut while intervening plateau surfaces become smoother. The latter is a result of barnacles covering and protecting the rock. Finally the mussel-echinoid zone has the maximum relief and is dominated by large deep basins which are inter-connected. The surface free of water is dominated by mussels, whereas that which is always below the water is dominated by Paracentrotus lividus (sea urchins) (Lundberg 1977, 1986).

Williams' (1973) classification scheme included five biological zones. The difference between Williams' and Lundberg's classifications are in zones four and five.

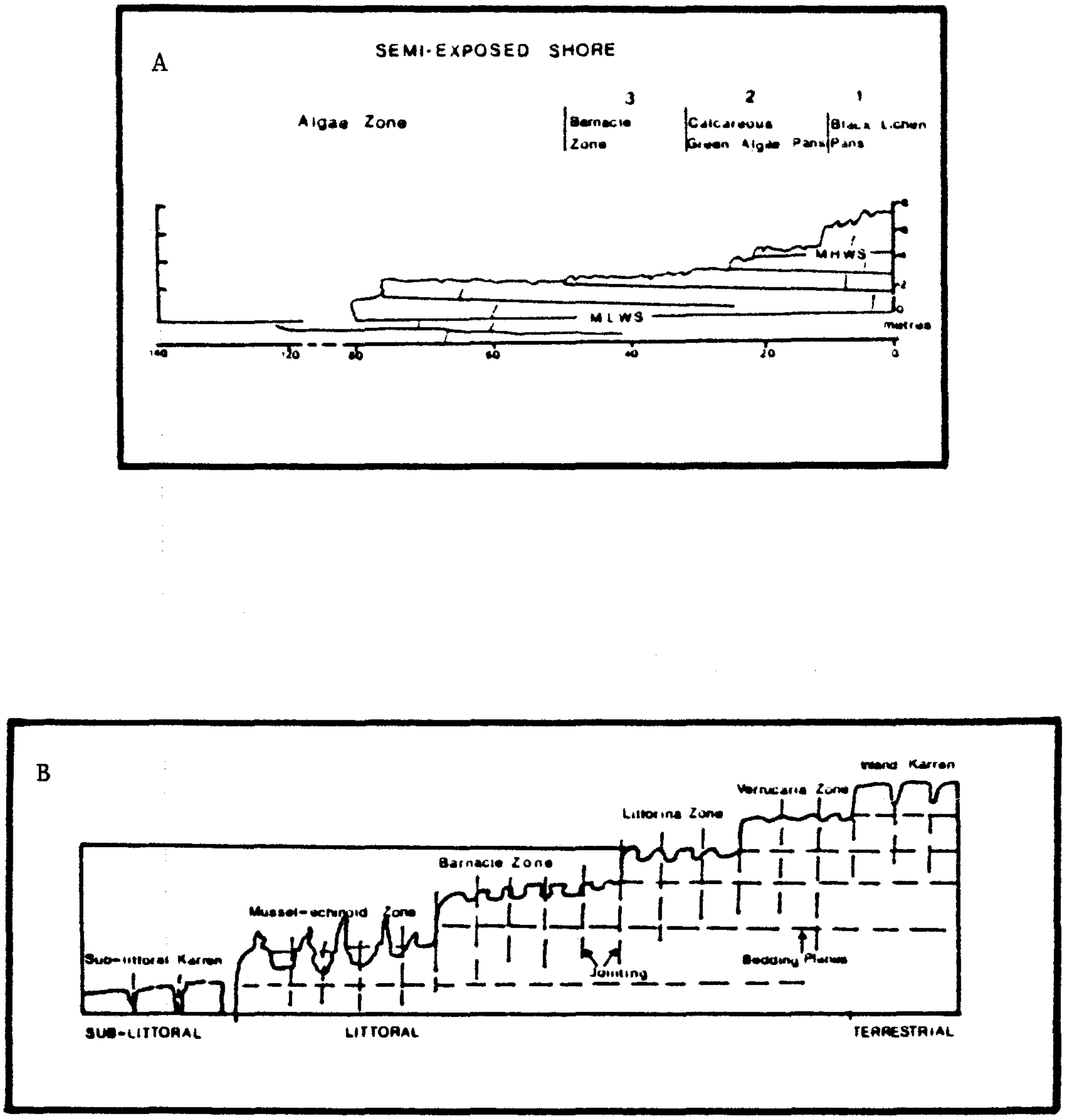


Figure 1 1

Figure 1.1 Temperate Coast Profiles taken from Williams (1970) A, and Lundberge (1977) B.

According to Williams (1973) zone four is the Mussel/pinnacle zone and zone five is the Echinoid pit zone. Lundberg (1977) suggests that this Echinoid pit zone is merely the final stage to the mussel/Echinoid zone and that it occurs below low water mark.

Ley's (1979) classification scheme differs from both Lundberg's (1977) and Williams' (1971) in that Ley does not incorporate biology into his zones. Ley's twelve zones are related to elevation with respect to the low tide mark and tidal range. The twelve zones moving from high water mark to low water mark are:

1. above high tide - smooth flat sloping surface
2. partially opened joints and pitting
3. small shallow and irregular pools develop
4. pools with flat floors and concordant divides
5. deeper incised pools and passages
6. general rounding of pools as they become more massive
7. just below mean tide level - deeply incised and coalesced pools. Second generation of pools forming within the older pools
8. pool floors become flat and dominate the karren type
9. divides decrease in size as the pools coalesce. Shallow pools cover the whole surface.
10. shallow pools become less numerous
11. a pitted but flat surface exists
12. a smooth, rounded surface is interrupted by the over deepening and widening of joints.

There exists considerable variation within each zone (Ley 1977, 1979). Maximum internal relief occurs just below mid-tide with decreasing complexity of the karren towards the tidal extremities (Ley, 1979).

1.2.4 COASTAL EROSION PROCESSES

1.2.4.1 BIOEROSION

Bioerosion is a complex of processes which result in denudation of the rock surface and the development of biokarst (Schneider and Torunski, 1983). Different processes are associated with the behaviour of different species. There are grazing organisms which, while eating the epilithic (surface) algae from the rock surface, inadvertently chew off part of the rock as well. This grazing produces grooves and channels on the rock surface called epirelief. There are also organisms which bore into the rock for protection from dessication or grazing organisms. Such boring organisms or Endolithic organisms are (i) boring Cyanophytes and Algae which create small cavities, (ii) boring Sponges, (iii) some species of Bivalves and Barnacles which make long tubular burrows and, (iv) Echinoderms making small spherical pits. Finally there are protectors (eg. some species of barnacles and mussels) that create a protective covering over the rock (Lundberg 1986; Trudgill, 1976).

1.2.4.2 INTERTIDAL EROSION

The formation of littoral karren depends upon the isolation of small bodies of water, which harbour various flora and fauna. These bodies of water occupy primary depressions in the rock surface and are then quickly colonised since they are able to retain moisture for a longer period of time then their higher surroundings. The grazing and boring organisms then increase the biological corrosion and abrasion. As a result the depressions begin to enlarge laterally and coalesce into one another. Relief is intensified as the wet areas are preferentially bioeroded as fresh seawater is brought in with high tide (Lundberg 1977; Trudgill, 1985).

1.2.4.3 LITHOLOGICAL EROSION

Limestones are difficult to classify. By definition, any rock which contains more than fifty percent (50%) by volume of carbonate (calcium, calcium-magnesium, magnesium) is termed limestone or dolomite. The most important characteristics for karren studies are the texture and composition of the rock (Ley, 1977). Ley believes in the case of Bristol channel that karren are solely solutional features as opposed to biologically modified ones. It is the susceptibility of the limestone to solution which is the dominant factor in their formation (Ley, 1977). Solubility of the rock is affected by the porosity, permeability and purity of the rock (Ley 1977; Trudgill, 1972). The impurities in the rock decrease the amount of solution that can occur, thereby decreasing the number of micro-relief forms (Ford, 1986; Ley, 1977). Impure limestones behave like non-carbonate rocks within the intertidal zone. Therefore, the best marine karren forms require a pure rock (Ley, 1979). However, limestone which is dominantly composed of magnesium calcite and aragonite calcarenites may erode by solution and disintegration at a substantially faster rate than porcellanous, well cemented algal limestone (Ley, 1977, Trudgill, 1972). Limestone with high porosity (pore space within the rock) and permeability (inter-connectivity of the spaces) values will have a greater complexity of micro-relief features (Ford, 1986, Ley, 1977).

The grain size of the limestone can also affect the micro-relief features. As grain size increases, so too does the porosity and permeability of rock. Therefore, the micro-relief features become more complex with increased grain size (Ley, 1977).

1.3 GENERAL MODELS

There are two general models describing littoral karren; (i) the tropical model and (ii) the temperate model. Within the tropical regions the typical form is an undercut notch. A notch develops in sheltered areas as a result of offshore reefs protecting the shore. In exposed areas the notch will disappear giving way to a surf platform and pitted ramp. The typical form in temperate regions is a platform dissected by rock pools. These pools develop due to the fact that the limestone is in exposed environments in most temperate regions (Lundberg, 1986). The differing karren forms found in both regions may result from the fact that the limestone coasts in the tropics are younger than the temperate limestone coasts. The younger rocks are less well cemented and metamorphosed therefore, they are heterogeneous and preserve the relationship between clasts and cements. This relationship then encourages differential erosion (Trudgill, 1985).

1.4 CONCLUSIONS

Intertidal erosion of limestone on sea coasts may occur as a result of many physical and biological processes. The cumulative effect of tidal changes and bioerosion leads to the destruction of the coastline (Schneider and Torunski, 1983).

CHAPTER 2

STUDY AREA AND METHODOLOGY

1.1 INTRODUCTION

The study area will be described in terms of its climate, geology, tidal regime, waves and energy levels. This will then be followed by a description of the methodology used in acquiring the data.

2.2 STUDY SITE

Canada's Pacific coast is a leading edge continental margin which has been modified by Pleistocene glaciers. The coastline is characterized by countless inlets, fjords and islands (Clague and Bornhold, 1980). It is one such fjord which provided the study area for this report. The study site, illustrated in Figure 2.1a,b (Fig. 2a in Appendix A) was along the eastern shore of Neroutsos Inlet. The area is situated near the town of Port Alice on northern Vancouver Island. The area consists of several limestone beds which are exposed to both biological and mechanical erosion. Geology, climate, wind, waves, tidal currents and energy levels all contribute to the morphology of the shore (Clague and Bornhold, 1980).

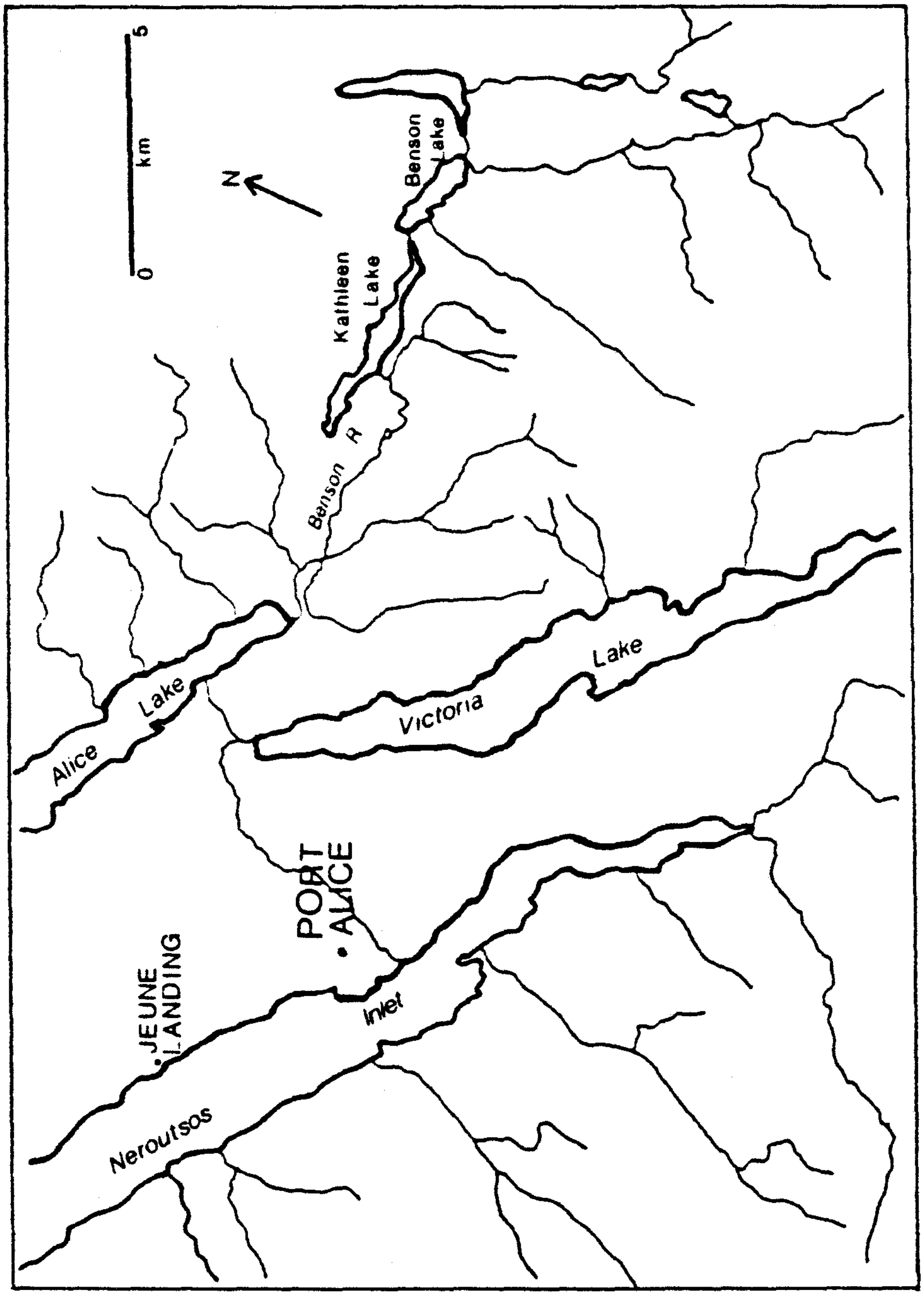


Figure 2.1b Study Area: Near Jeune Landing on the Eastern Shore of Neroutsos Inlet

2.3 GEOLOGY

The exposed beds are part of the Quastsino Formation which is the principle carbonate unit of the island, datingfrom the late Triassic (225-180 my ago) (Howes, 1981; Mills, 1981). The Quatsino Formation extends dominantly NW-SE in three linear belts and the outcrops cover approximately 1000 km2 (Fig. 2.2 in Appendix A) (Mills, 1980). The Quatsino Fm. is a thickly bedded to massive limestone. The upper part consists of medium to thin bedded limestone interlaminated with black calcareous siltstone. The lower portions of the formation rests upon the Karmutsen volcanics and consists of thick bedded to massive, fine to microcrystalline, but locally coarsely crystalline, commonly stylolitic limestone which weathers to brown-grey to black, light grey to white limestone (Muller, Northcote and Carlisle, 1974). In general, the formation consists of biomicrite limestone which exhibits a bimodal size distribution, being composed of coral and pelecypod debris in a matrix of fine carbonate muds. There is upwards grading into calcareous clastic sediments (Mills, 1981).

2.4 CLIMATE

The climate of northern Vancouver Island is dominated by dry warm summers and cool wet winters. Rainfall is the dominant form of precipitation on the island (Fig. 2.3 in Appendix A). The mean annual precipitation ranges from 1400 mm to 4600 mm with 70-80% falling between October and March (Fig. 2.4, Table 2.1 in Appendix A). Snowfall is confined to the mountain regions of the island and is short lived at sea level (Howes, 1981).

There are three precipitation zones on the island, 1. The Western Zone; 2. The Southwestern Zones; and 3. The Northwestern Zone (Fig. 2.5 in Appendix A). Neroutsos Inlet lies within the boundaries of the Western Zone. Within this zone, the mean annual precipitation increases from 2000 mm along the west coast to 4600 mm along its eastern boundary. This increase is a result of changes in topography as one moves westward. There is a convergence of air masses resulting from the uplift created by the high altitude of the Insular Mountains and the fjord inlets (Howes, 1981).

Along the coast, the prevailing winds are from the northwest in summer and the southeast in winter (Table 2.2 in Appendix A). The greatest wind velocities occur during the winter months as a result of the frequent occurrence of low pressure systems. These low pressure system are controlled by the offshore Aleutian Low (Clague and Bornhold, 1980). The wind regime within the study area has a bimodal distribution. The strongest winds come from the ESE and NNW Winds from the ESE would create the strongest waves within Neurotsos Inlet as these winds have the greatest mean velocity and occur most frequently (Fig. 2.6, Table 2.3 in Appendix A). Winds from the WNW to NNW also have large mean velocities but their frequency of occurrence is lower. Therefore these winds are associated with storm conditions and would create large waves within Neurotsos Inlet as well.

2.5 WAVES

Waves within the study area are generated by two dominant pressure systems, the Aleutian Low and the North Pacific High. The intensity and direction with which the waves hit the shore are also controlled by the wind regime. Within the protected fjord, Neurotsos Inlet has lower wave heights and energy than on the open ocean coasts (Clague and Bornhold, 1980).

2.6 TIDAL CURRENTS

Along the coast of British Columbia the mean tidal range decreases from 5 m in the northern areas to approximately 2 m near Victoria. The mean tidal range at Neroutsos Inlet is approximately 2.7 m (Table 2.4 in Appendix A). Neroutsos Inlet falls within the boundaries of the Tofino tidal zone. The study area is dominated by mixed semi-diurnal tides (Fig. 2.7 in Appendix A) and (Clague and Bornhold, 1980).

The currents in this are weak and vary in direction as a result of the Subarctic current which divides into two at about 46° - 50° N, 130° - 138° W. One current moves south to California while the other moves north to Alaska. The currents are towards the north-northwest during winter and autumn and the south during the summer (Fig. 2.8 in Appendix A) (Clague and Bornhold, 1980).

2.7 ENERGY LEVELS

Energy levels are controlled through the interactions of all the above mentioned factors (winds, waves, currents). Within the protected inlets of the fjords the energy levels are their lowest because the fjords are oriented parallel to the open ocean so that the fetch is short and therefore the waves are small (Clague and Bornhold, 1980).

2.8 METHODOLOGY

2.8.1 FIELD WORK

The shore along the eastern coast of Neroutsos Inlet was divided into eight (8) individual beds (Fig. 2.9). The beds are all of similar thickness with a dip of 32. Most of the beds extend continuously from high water to low water mark with the exception of Bed 3. From the eight beds identified, three beds 5, 6 and 7 were inaccessible during the study period (June 22-24, 1986) as they were constantly inundated with water (Fig. 2.9). Beds 1, 2, 3 and 4 were all well pitted beds and bed 0 was dominated by microfractures and contained no pitting.

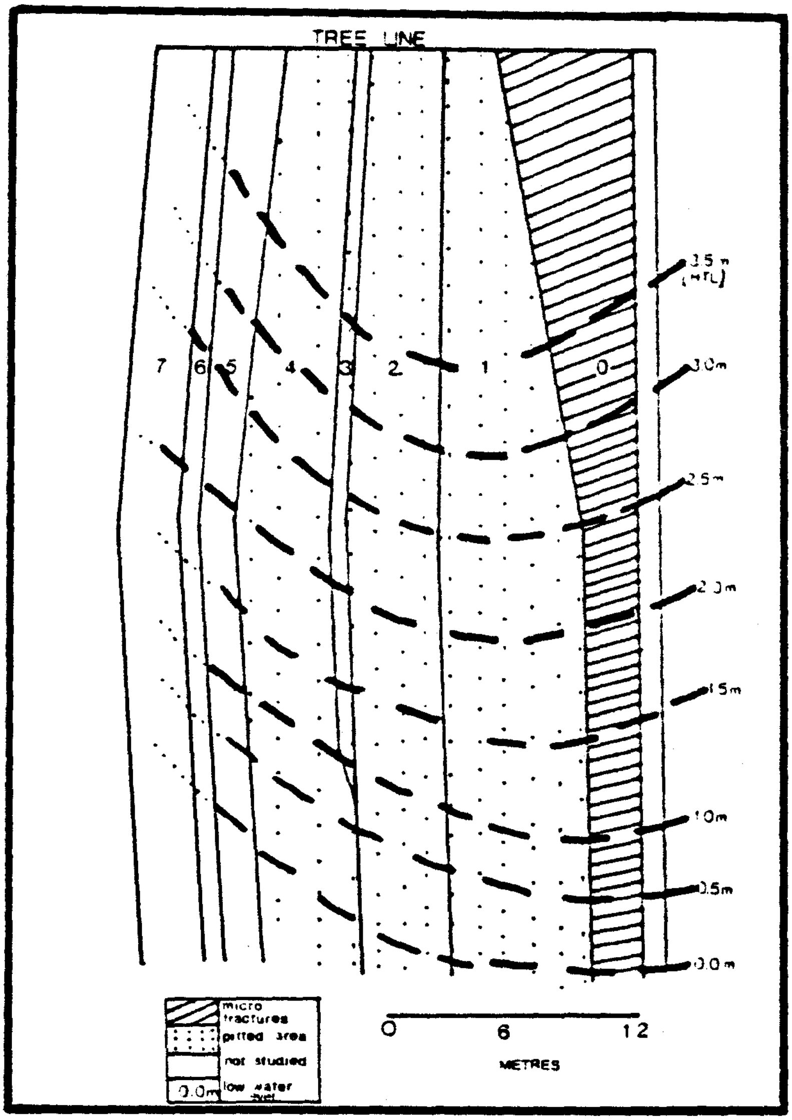


Figure 2.9 Individual Limestone Beds of Study Area

These eight beds where then examined for any karren forms from below low water mark up to high water mark. The karren forms were described and measured in terms of: 1. width in centimeters; 2. depth in centimeters; 3. adescription of the rock surface (eg. rilled, smooth); 4. a description of the wall character (eg. concave, convex) and, 5. a description of the pit floor (eg. smooth, pitted).

On each individual bed, 1 m quadrats were laid out at 2 m intervals along the transect. Starting at the high water mark, and ending at low water mark (Fig.2.10) each pits height above low low tide and position on the transect was calculated using basic trigonometry (Table 2.5 in Appendix A). The number of quadrats squares on each transect ranged from 16 on bed 1 to 17 on bed 2 and 15 on bed 4. Within each square metre, the karren forms were described and measured; any fractures present were examined in terms of their length and orientation; the relative relief of the whole quadrate was estimated; any vegetation present was noted along with, the type and percentage cover of other marine organisms present; finally a small diagram accompanied each quadrate. Small rock samples were taken from each individual bed for later analysis in the laboratory in order to determine the purity of the limestone. Sketches of the sample squares are illustrated in Figures 2.11 - 2.13 (Figures 2.11 and 2.13 are in Appendix A).

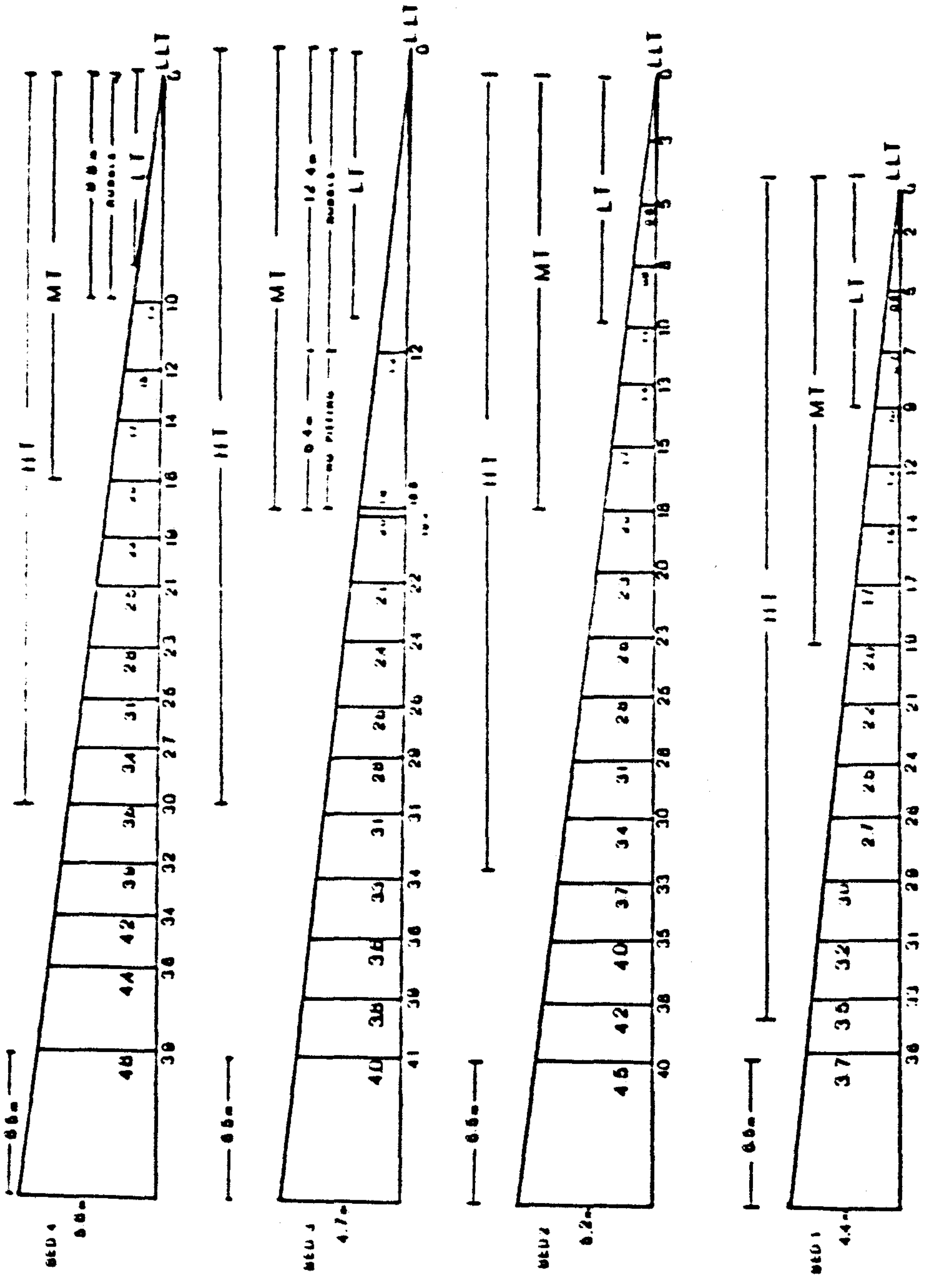
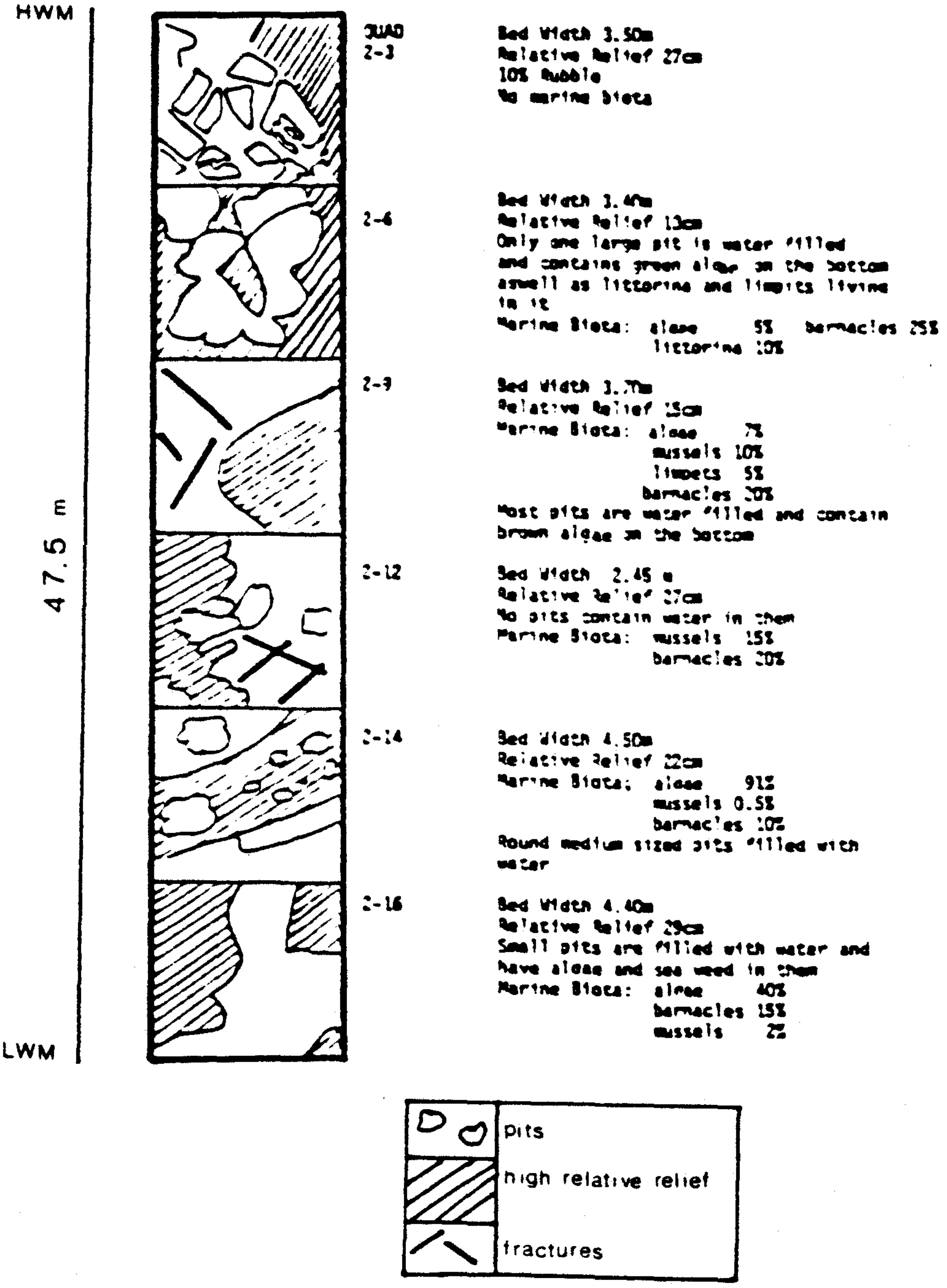


Figure 2.10 Individual Bed Profiles Indicating the Height Above Low Low Tide of the Sampling Quadrats



QUAD 2-3

Bed Width 3.50m
Relative Relief 27cm
10% Rubble
No marine Biota

2-6

Bed Width 3.40m
Relative Relief 13cm
Only one large pit is water filled
and contains green algae on the bottom
aswell as littorina and limpits living
in it
Marine Biota: algae 5% barnacles 25%
littorina 10%

2-9

Bed Width 3.70m
Relative Relief 15cm
Marine Biota: algae 7%
mussels 10%
limpets 5%
barnacles 20%
Most pits are water filled and contain
brown algae on the bottom

2-12

Bed Width 2.45 m
Relative Relief 27cm
No pits contain water in them
Marine Biota: mussels 15%
barnacles 20%

2-14

Bed Width 4.50m
Relative Relief 22cm
Marine Biota; algae 91%
mussels 0.5%
barnacles 10%
Round medium sized pits filled with
water

2-16

Bed Width 4.40m
Relative Relief 29cm
Small pits are filled with water and
have algae and sea weed in them
Marine Biota: algae 40%
barnacles 15%
mussels 2%

Figure 2.12: Examples of Sample Quadrats For Bed 2

2.8.2 LABORATORY WORK

The rock samples were analyzed in the laboratory to determine their purity. A small sample (less than 50 g) was dissolved in 9N (molar) hydrochloric acid (HCl). After the sample had been completely dissolved, the solution was filtered to capture the insoluble residue; the filter paper was dried and weighed. Percentage insoluble and then the purity of the limestone were calculated using this data. The results will be shown and discussed in the analysis section of this chapter.

2.8.3 COMPUTING

The raw field data was entered into the VAX 8600 computer. Simple two dimensional plots were computed in order to determine if any zonation patterns or relationships existed upon the limestone beds using the statistical package, MINITAB. (i) Width was plotted against depth, (ii) width/depth (W/D) ratios against width and/or depth, (iii) width and depth against height above low water mark and pit wall character, (iv) floor and surface against height above low water mark. All of the plots and results are discussed in the analysis section of this chapter 3.

CHAPTER THREE

ANALYSIS AND DISCUSSION

3.1 INTRODUCTION

The many various plots which were created from the data will be analysed for any significant trends. These trends will then be discussed in terms of coastal and geomorphological processes which act upon the shore.

3.2 FABRIC AND BULK CHEMICAL COMPOSITION

All eight beds are of fine grained micrite and appear to be lithologically identical. The five samples were chosen from beds with a great variety of surface features: Bed 0 displayed dense micro fractures but absolutely no pitting. Bed 2 and 3 were highly pitted. Beds 5 and 7 were rarely exposed to the air and have therefore little pitting on their surfaces. The limestone from all of the beds is greater than 92% pure (Table 3.1). Therefore chemically the beds are similar. This probably explains why the pits are the same size and shape in all the beds but does not explain the presence or absence of pitting.

BED	SAMPLE WEIGHT (g)	FILTER PAPER (g)	FILTER PAPER AND RESIDUE (g)	INSOLUBLE RESIDUE (g)	PERCENT INSOLUBLE	PERCENT SOLUBLE
0	42.07	4.00	6.21	2.21	5.25	94.8
2	24.35	3.91	5.26	1.35	5.54	94.5
3	31.17	4.14	5.92	1.78	5.71	94.3
5	35.99	3.95	6.18	2.23	6.20	93.8
7	46.94	3.92	7.70	3.78	8.05	92.0

Table 3.1 Purity of Coastal Limestone

3.3 MICRO-FRACTURE DENSITY

Micro-fracture density does not determine whether a bed will develop pits except in the case of Bed 0. Bed 0 ishighly fractured so that the limestone is dissected into such small sections that it is impossible for a pit to develop and grow before it comes into contact with a fracture and its growth is halted. Beds 1, 2 and 4 all have fractures present at high water mark, yet pit development is possible. The density of fracturing is not as high as on Bed 0 but fractures are present as are pits. Therefore it would appear that pit development is unaffected by the presence of fractures except in the case of Bed 0 and it is a unique bed in that none of the other beds exhibit quite as high a density of fractures as Bed 0. It is not known why Bed 0 behaves this way. Its and bulk chemical composition is similar to the other beds in the area. Persumably it must be some other factor of the lithology which controls fracturing and pitting.

3.4 ZONAL PATTERNS

3.4.1 EFFECT OF TIDE LEVELS

A zonal pattern was looked for in relation to tide levels. From Figures 3.1 - 3.3 (Figs. 3.2, 3.3 in Appendix A), it can be seen that only small pits develop at the low low tide (LLT) level (Fig. 3.4). Near high tide (HT), 3.6 m higher, small pits are also dominant, but larger pits can be

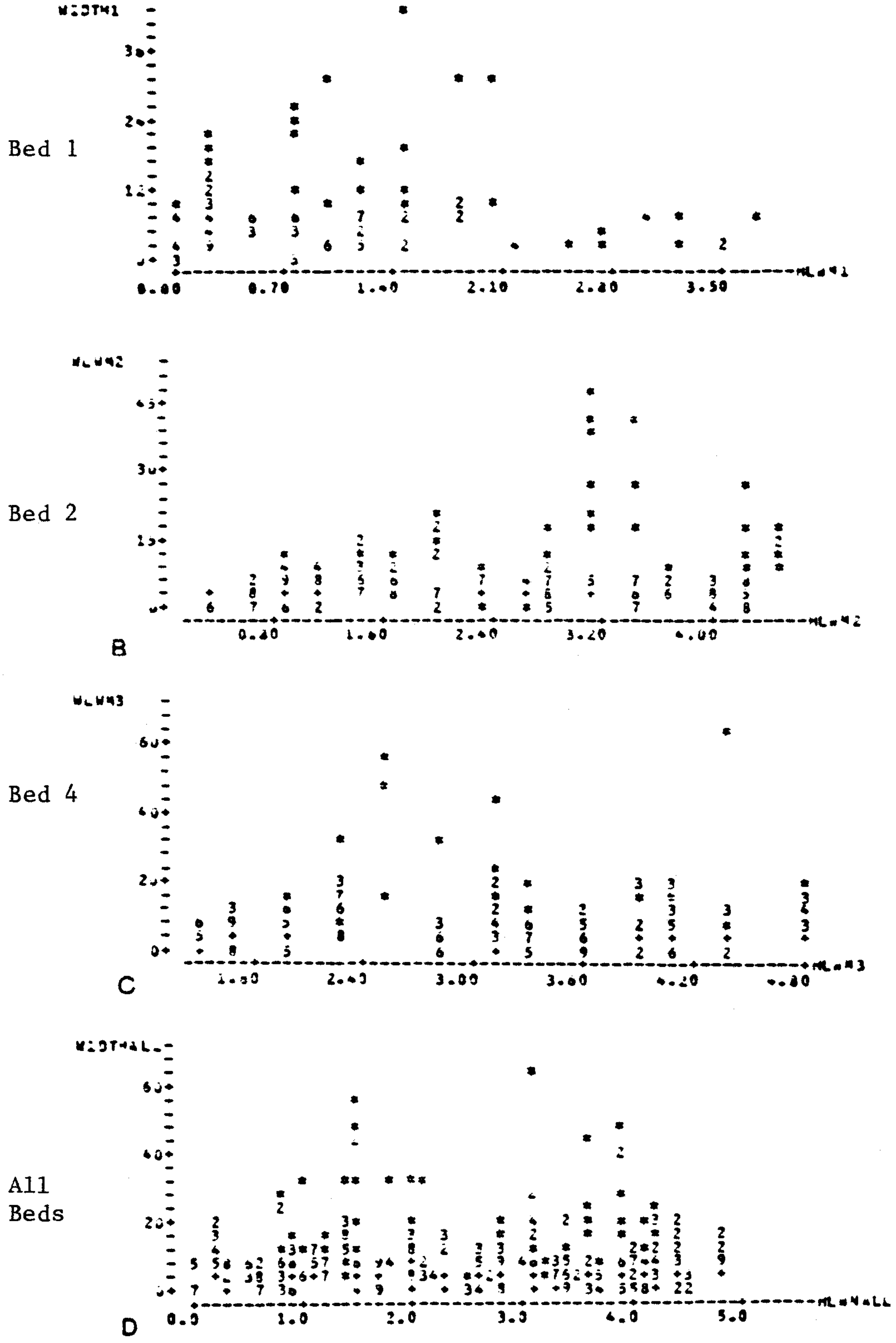


Figure 3.1 Height Above Low Low Tide vs Width Above Low Low For Beds 1, 2, 4, and all beds

Figure 3.4 Typical Low Tide Scene: Many Small Pits and Large Quantities of Algae

found (Fig. 3.5). The range in pit size increases away from low low tide, and the greatest range is found near the mean tidal (MT) mark, at a height of approximately 2 m.

This appears to be a result of the cyclic changes in tides. The pits in the MT area are frequently wetted and dried throughout each semidiurnal tidal cycle. At high water mark there may be prolonged periods of dryness without any wetting, while at low tide mark the opposite is true; pits are constantly wet for long periods. The greatest differential erosion occurs at mid tide level where there is the greatest range of conditions. The trends remain when the data are logged and plotted against height above' low water mark. Conversion to logarithmic scale emphasizes the smaller pits more efficiently (of which there are more present on the beds), the greatest range of pit size was found near the mean tide level (Figures 3.6 - 3.8; Figs. 3.7, 3.8 in Appendix A).

The smoothness of pit floors was also plotted against height above low water mark to determine if any pattern exists. From Figure 3.9, it can be seen that there is little change in the floor characteristics. At low and high water mark the floors are predominantly smooth. A small change does occur at mean tide level (MTL). Just below MTL floors become rougher or randomly fluctuate between smooth and rough classes. These trends hold true for all three of the beds that were intensely studied.

Figure 3.5 Typical High Tide Scene: Dominated by Large Pits and Fractures

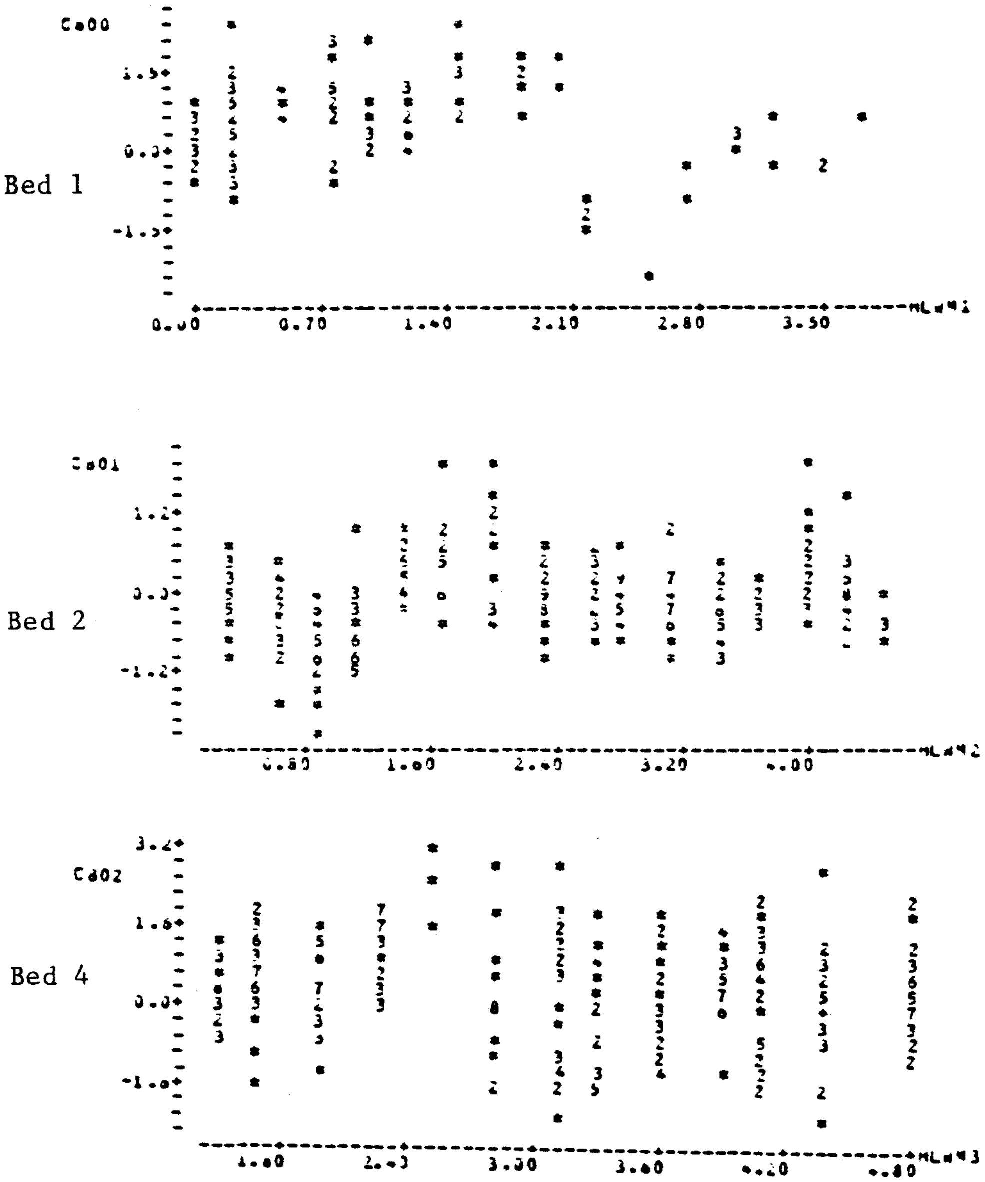


Figure 3.6 Height Above Low Low Tide vs Logarithmic Width Above Low Low Tide For Beds 1, 2, and 4

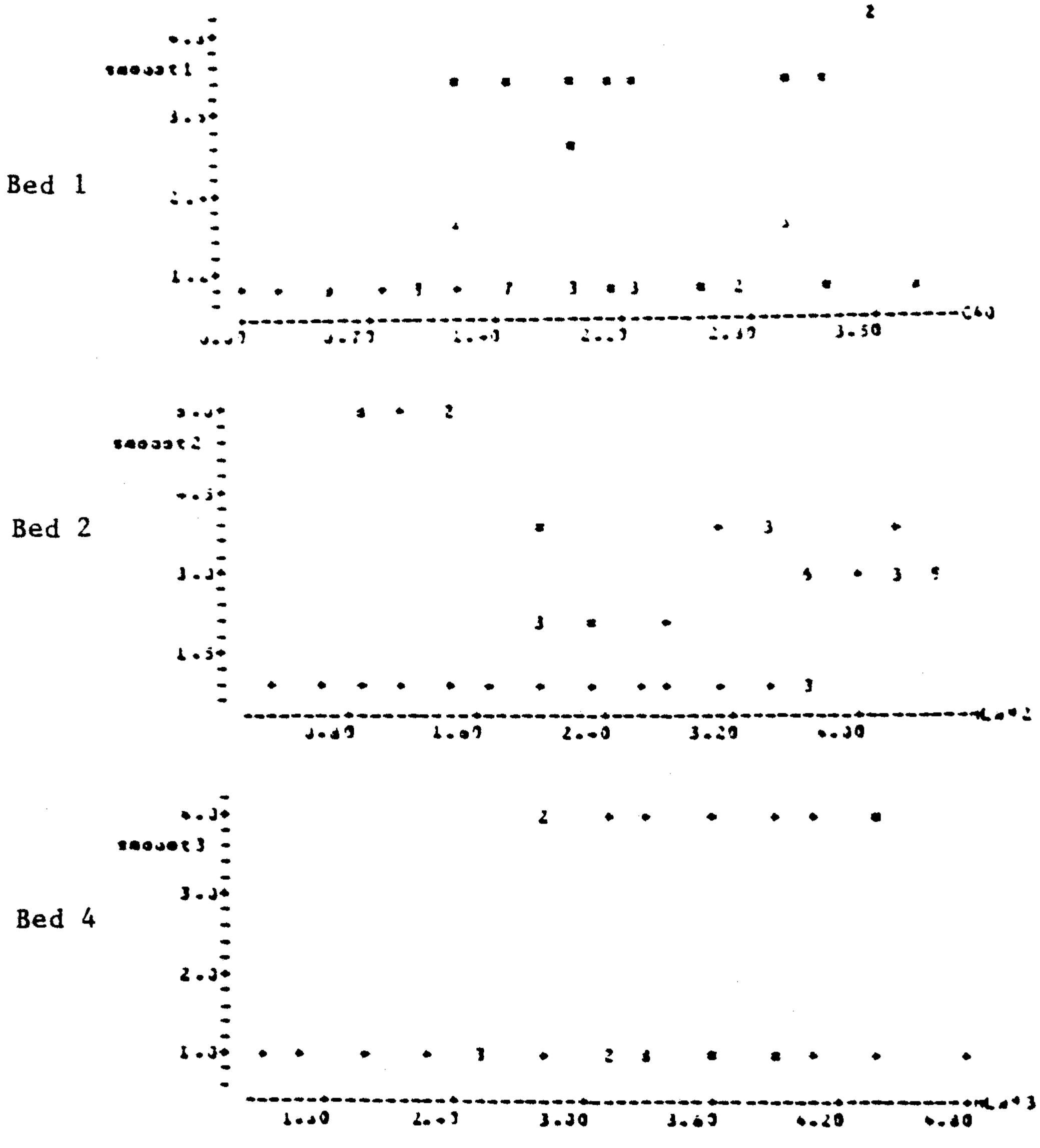


Figure 3.9 Smoothness of Pit Bottoms vs Height Above Low Low Tide For Beds 1, 2, 4

The same trends occur with respect to secondary pit development on the floors of the major pits (Fig. 3.10 in Appendix A). On beds 1 and 4 secondary pit formation occurs at low tide level, whereas on bed 2 these secondary pits can form anywhere from low to high water mark.

3.4.2 MORPHOMETRY OF PITS

To determine if a littoral zonation pattern existed in the geomorphology, the general shape (form) of the pits was examined by plotting width/depth (W/D) ratios against the width and depth for all the beds (Figure 3.11). If a distinct change in form occurs, then perhaps a zonation pattern may be identifiable. From Figures 3.11a and b, it can be seen that the points are all clustered, thereby indicating that the pits are neither wide nor deep. It becomes apparent from looking at the graphs that there is no clear change in shape with size. All the points fall within the same W/D ratio range of 1-6, regardless of their dimension. Therefore, the general shape of the pit remains constant, although the width and depth may increase.

The beds were then examined individually to determine if there was any type of shape change between them. Again W/D ratio were plotted against width and depth for the individual beds (Figures 3.12 - 3.14; Figs. 3.13, 3.14 in Appendix A). Points were once again clustered, indicating the smallness in pitform range. The pits were found within

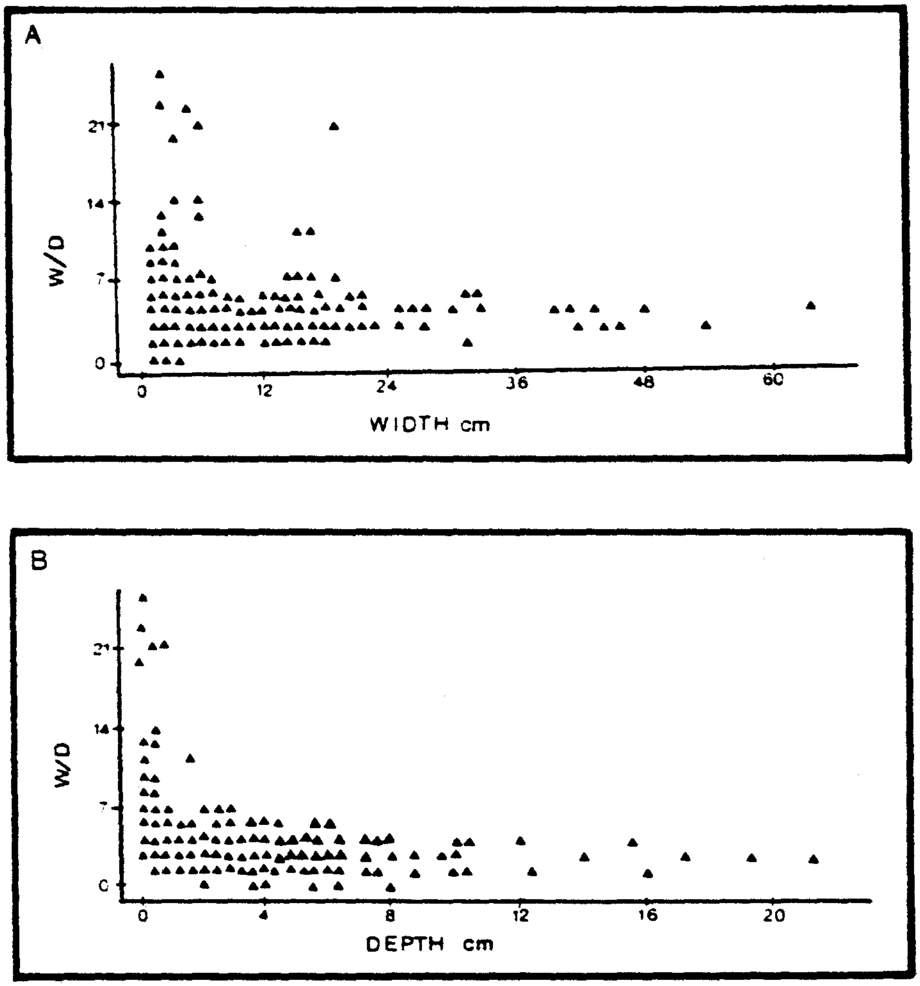


Figure 3.11 A,B Width and Depth vs W/D Ratios For All Beds

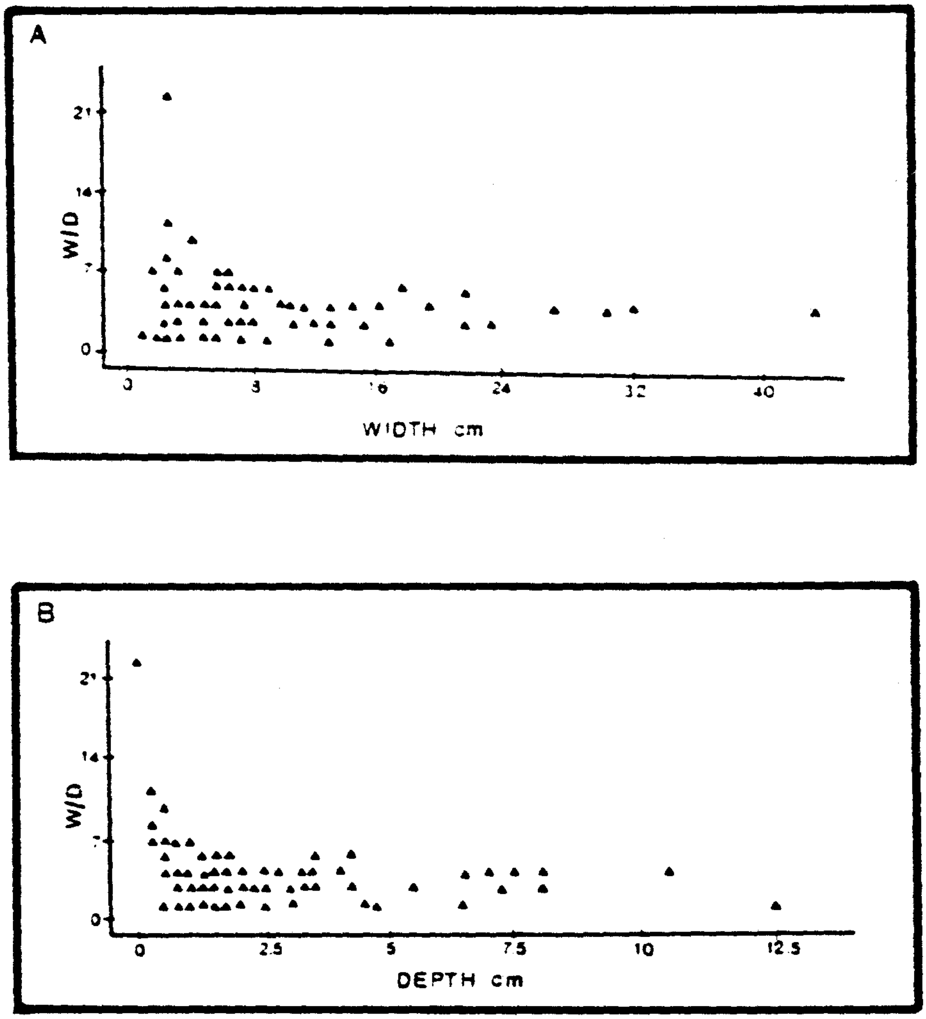


Figure 3.12 A, B Width and Depth vs W/D Ratios For Bed 1

the range of 1-6. Therefore the similarity between width and depth ratios indicates that there is no change in shape from bed to bed. The pits along each individual bed have the same general shape. Pit shape is essentially constant throughout the entire study area if pits are present at all. Therefore no zonal patterns can be distinguished on the basis of change in pit form.

The actual form of the pits is shown by a comparison of their width and depth (Fig. 3.11). Width of a pit is on average three times greater than the depth (Fig. 3.15) but, has concave walls giving the pits a rounded bowl shape.

The range of widths and depths increases from Bed 1 to Bed 3. The widths lie between 1-8 cm for Bed 1, 1-10 cm for Bed 2; and 1-12 cm for Bed 3. The depths ranged from 2.5 cm for Bed 1 to 4.0 cm for Bed 3.

3.4.3 RELATIVE RELIEF

When examining the relative relief of the quadrats with respect to height above low water mark there are no distinct trends present (Table 3.2 in Appendix A) but, there is some indication that the area of greatest relative relief varies from Bed 1 to Bed 4: on Bed 1, it is around mean tide level (1.2-2.0 m), but at high tide level (3.4-4.4 m) on Bed 4. Finally, on Bed 2 there is no dominant zone which exhibits the greatest relief. The fact that the relative relief is

Figure 3.15 An Example of Pit Form and Biota Present

greatest at mean tide level for Bed 1 can be explained by the cyclic changes in tides as explained above. Bed 4 undergoes these same processes but receives the direct energy of the waves whereas those reaching Bed 1 have been slightly refracted. Thus the rate of solution is probably greatest at mid tide level but with greater mechanical energy. Therefore, the zone of greatest relief is closer to high water mark on Bed 4.

The effect of these small differences in energy level are apparent when examing the three beds with respect to one another. The relative relief increases as one moves from Bed 1 to Bed 4. The average relative relief on Bed 1 is 23.6 cm, 24.3 cm on Bed 2 and 29.2 cm on Bed 4.

3.4.4 BIOLOGICAL ZONATION

Examination of the biota present reveals an imbalance between the pit formations found and the biota. For example, limpet home scars were found which had barnacles living in them instead of limpets. In reality this would never happen unless some other factor influenced the removal of the limpets. Another example of a biotic imbalance is the density of barnacles found on the rock surface. On most rock coasts the barnacles are so closely packed together that there exists no space between them through which bare rock can be seen. This is however not the case on Neroutsos Inlet. Great quantities of rock are visible through the sparse barnacle cover. It is believed that the pollutants produced from the pulp mill, located a few kilometres south, are killing or driving away the biota which would normally be found on a rock coast such as this.

There are some minor trends present in the marine organisms with respect to height above low water mark. In general, there are three zones present: i) a zone of no biology (high water line), ii) animals and plants and iii) large plants (low water line). All three beds exhibit these zones with variations in length of each zone (Fig. 3.16). The zone of no marine biota decreases dramatically from Bed 1 to Bed 4 (from 16m-4 m). Bed 1 is the farthest away from the water, thereby making it a harsh environment for marine organisms. There are prolonged periods of dryness during low tide through which the organisma are unable to survive. Bed 4 is much closer to a source of water thereby enabling marine organisms to survive through the shorter periods of dryness. Therefore, marine organisms are able to colonize beds 2 and 4 sooner and at a higher level than bed 1 as a result of the lack of water for life.

There are distinct areas within and around the pits where certain marine animals exist. Mussels are found along and in fractures or around and under broken pieces of rock. Barnacles dominate the entire study area but are concentrated around the exposed surfaces of the pits. Sea snails are found inside water filled pits on the floors,

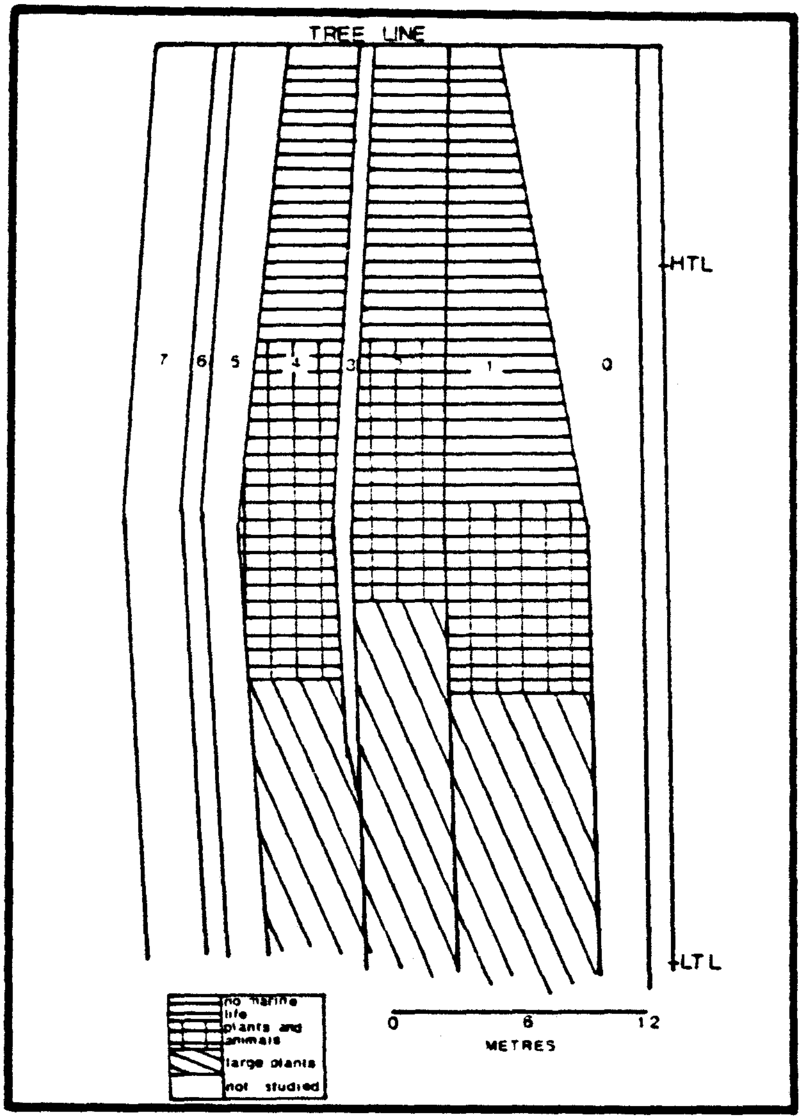


Figure 3.16 Biological Zonation

while limpets are located on all surfaces especially the walls and floors of the pits.

3.4.5 THE RILLENSTEIN ZONE

Rillenstein are rocks with microscaled solution features (Fig. 3.17). These microrills were found on Beds 1, 2 and 4. On Bed 1 rillenstein was found for 16 m extending from high water mark to tree line, 4 m on Bed 2 and 6 m on Bed 4. Rillenstein zones have not been described on other limestone coasts either in Ireland or in the tropics. Even in the interior the exposed limestone has no rillenstein formation on it. This results from the fact that the liemstone had a vegetation cover and has only been recently exposed (1970) as a result of deforestation and soil erosion on the Island. Rillenstein is able to develop on the exposed limestone of Neroutsos Inlet due to the fabric of the rock. The every fine grained homogeneity of the rock makes it well suited to the formation of rillenstein if the rock can be kept bare. Storm wash keeps the rock surface bare, but there is little abrasion to mechanically erode the rills away. Therefore, rillenstein can be formed on this bare surface by rain or spray or rain onto a salty surface.

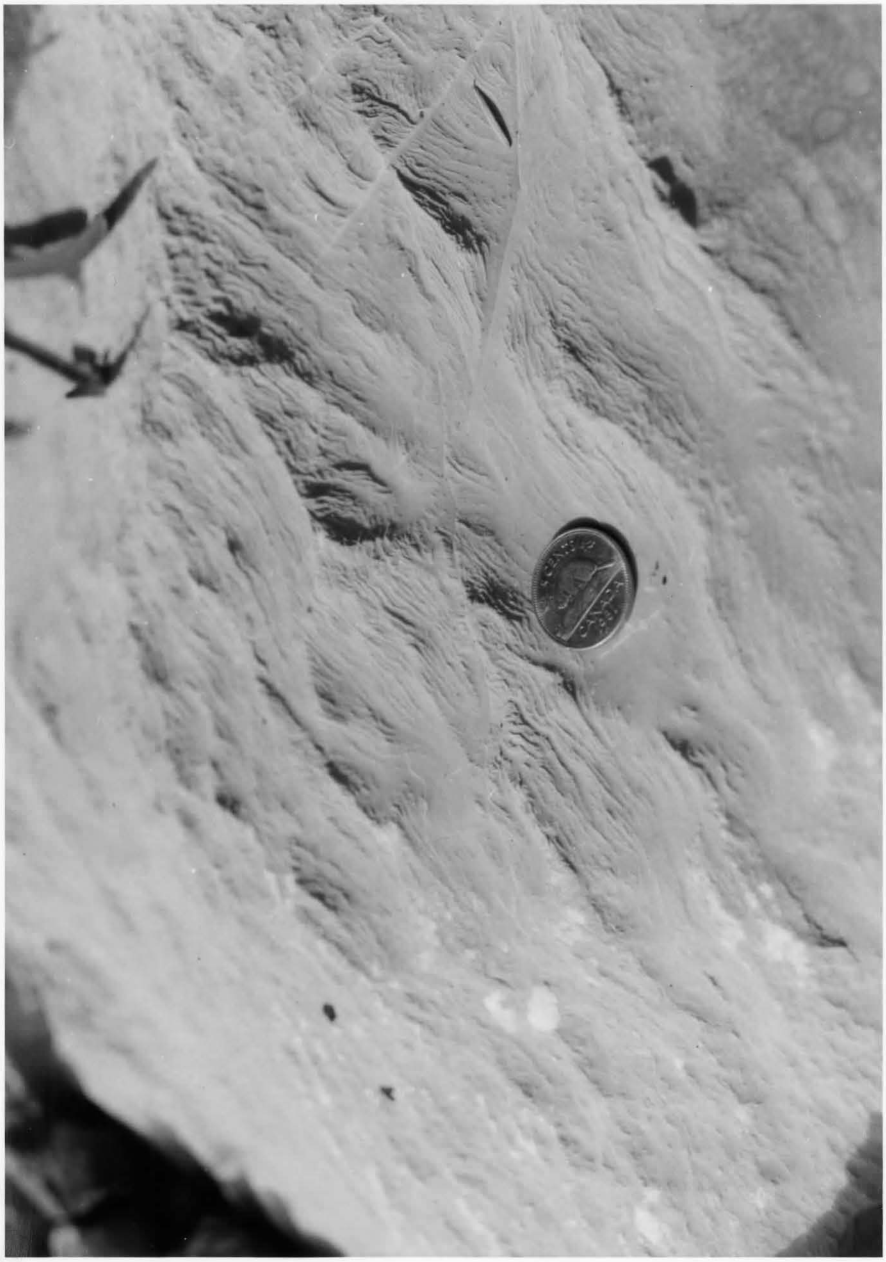


Figure 3.17 Rillenstein of the High Tide Zone

CHAPTER FOUR

CONCLUSIONS AND FUTURE RESEARCH

4.1 CONCLUSION

After careful inspection of the pit morphometry in the littoral zone we can conclude that there is little clear zonation in the pitting. A clear and sharp change in pit form is absent as one moves from low low tide to high tide as well as from bed to bed. The width of a pit is approximately three times greater than the depth throughout the entire study area. This contrasts with the findings of Williams (1971) and Lundberg (1977) in Ireland on horizontally beded shores. Both Williams (1971) and Lundberg (1977) identified distinct changes in pit form from high to low water mark (Fig.). The pits become deeper and begin to undercut their walls towards low tide with the deepest dissection occurring in the echinoid (sea urchin) zone (Lundberg, 1977).

This area, however, does resemble the karren of the more sheltered Bristol Channel area described by Ley (1977; 1979). The greatest diversity in pit size occurs at mean tide level.

Zonation is evident in the biology but not in the pitting. Where beds will support pits, there is little or no correlation between pit size, frequency and morphrometry on the one hand and the marine biotic zonation present.

There is strong lithological control with no pits developing on densely fractured beds. As well, the rock will support the finest scale of karren-rillenstein. The general size and shape of the forms is quite limited and constant throughout the entire area.

Therefore, at this site, the eastern shore of Neroutsos Inlet, there is little marine karst zonation. There is a narrow rillenstein zone with few pits, then a wide pit zone with no rillenstein. The pit zone shows that the most varied pits occur at the mean tide line, but this is not a strong trend. The pit form remains constant throughout the entire study area which results from the limemstone being of all the same bulk chemical composition and texture and undergoing the same physical processes.

4.2 FUTURE RESEARCH

Further research could be done on Northern Vancouver Island with respect to the littoral karren. Other limestone outcrops could be examined in order to determine if what was found at Neroutsos Inlet is the norm for the Island. A site which is affected by the same environmental and physical processes but where a pulp mill is absent would be ideal. This would allow one to determine if the mill has any affect upon the exposed strata. Chemical analyses of the water should also be carried out during both day and night on any future research in this area. This will allow one to determine how aggressive the water is and therefore perhaps provided a device with which erosion rates could be predicted. There are numerous aspects of littoral karren which could be studied within this area which could not be covered within this thesis

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APPENDIX A

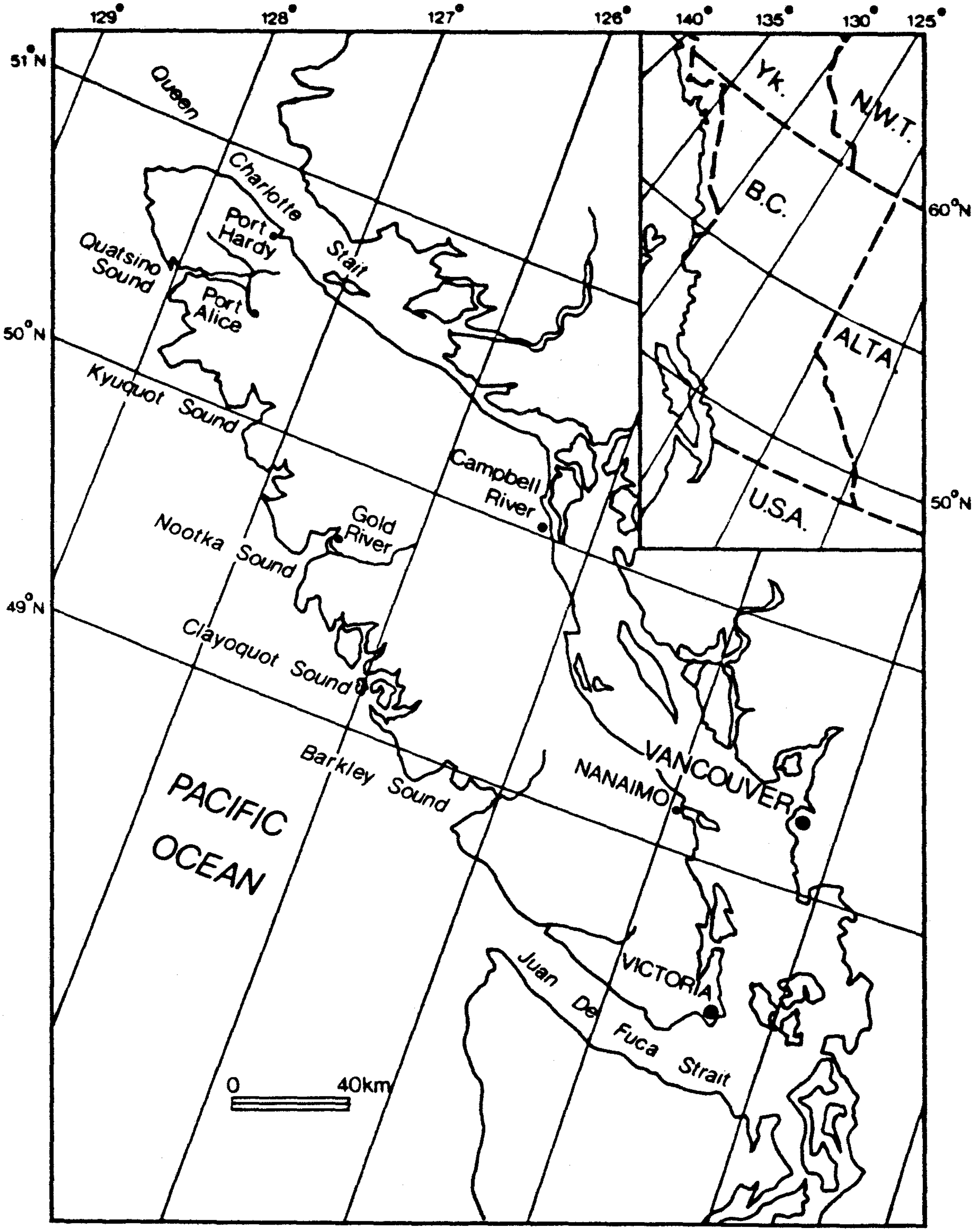


Figure 2.1a Study Area: Northern Vancouver Island

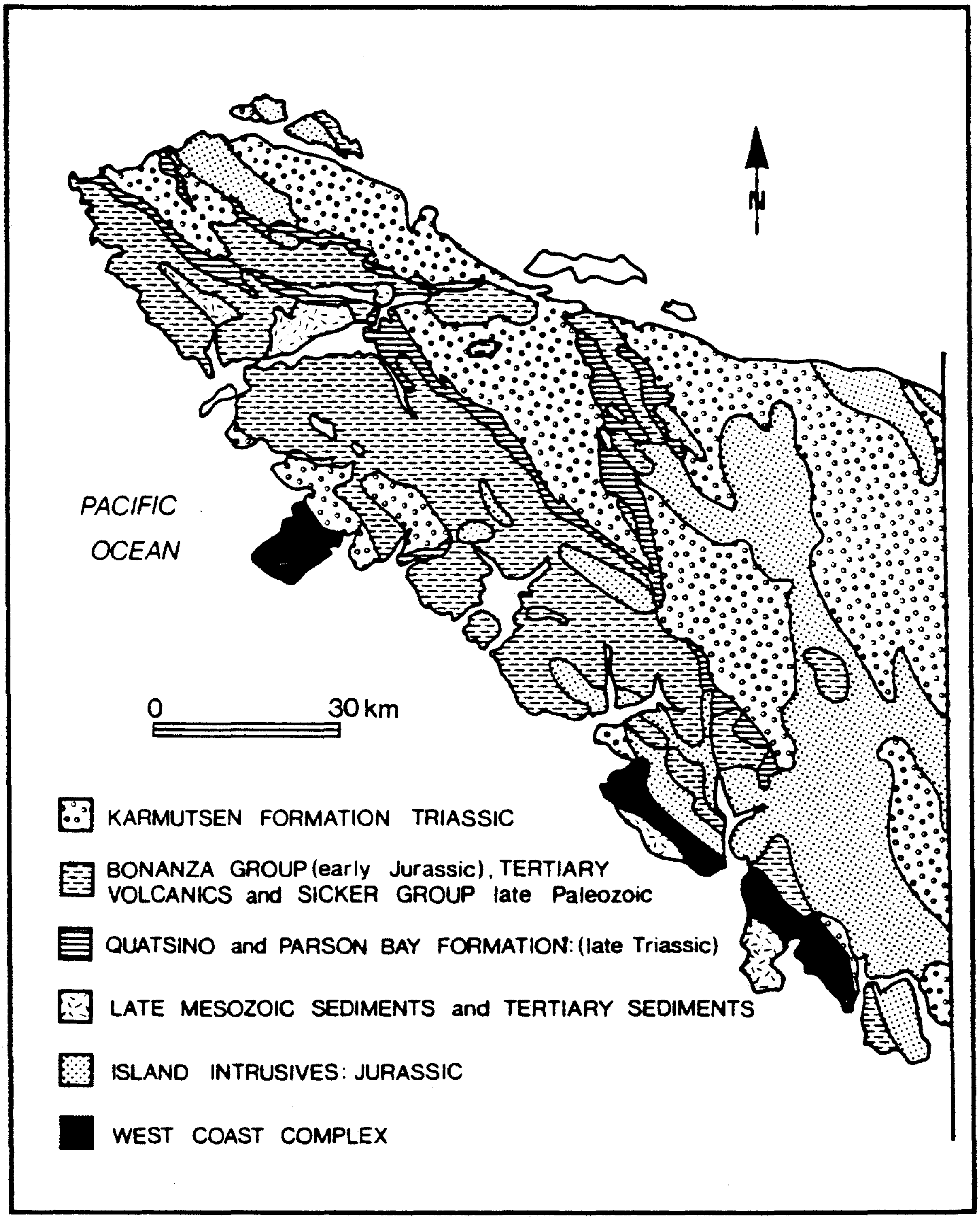


Figure 2.2 The Geology of Northern Vancouver Island

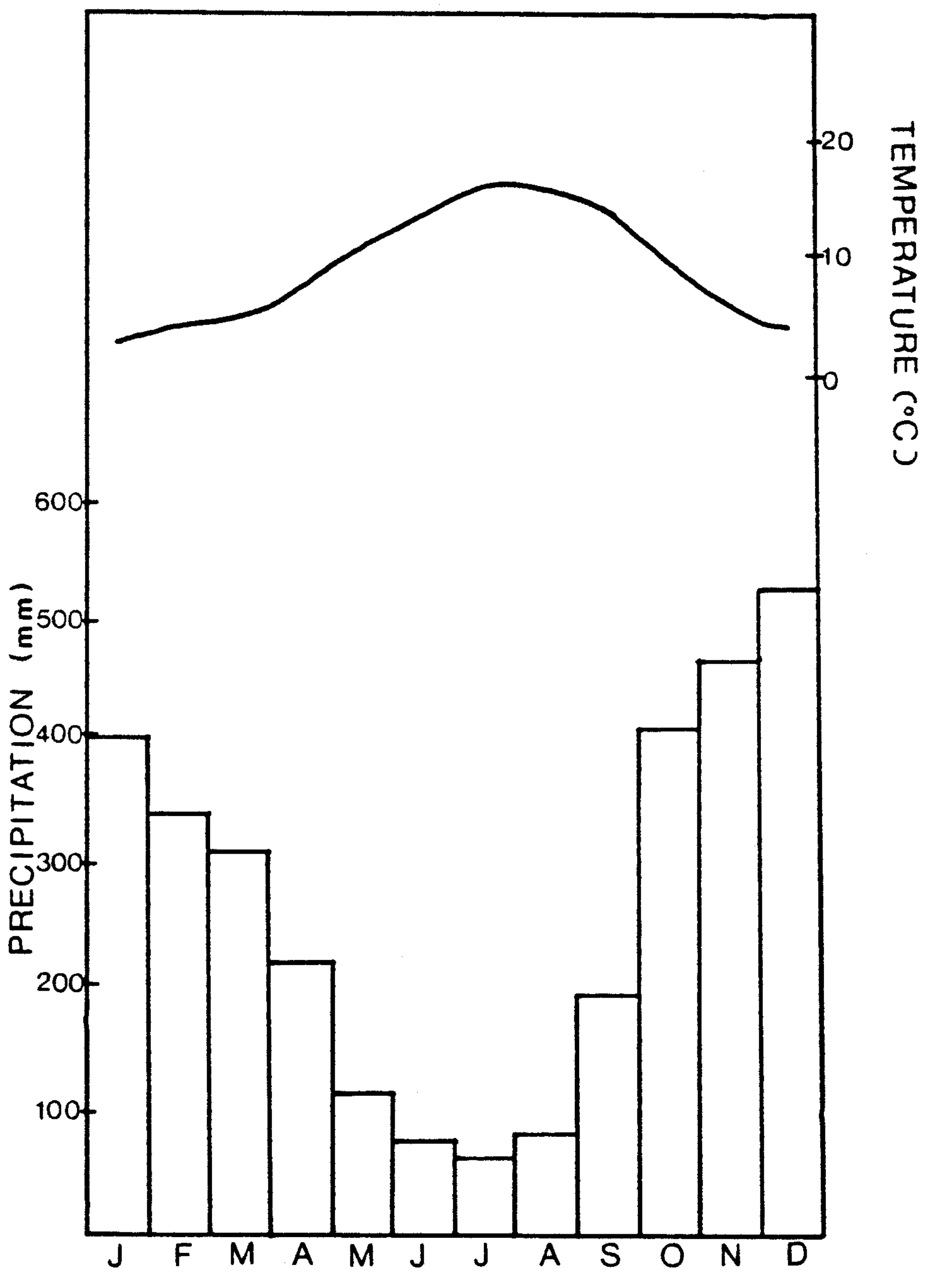


Figure 2.3: Total Monthly Precipitation and Mean Temperature For Port Alice 50 23'N 127 27'W

TABLE 2.1

TOTAL MONTHLY PRECIPITATION AND MEAN TEMPERATURE
FOR
PORT ALICE 50° 23'N 127° 27'W

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY TEMP (°C)	3.1	4.9	5.5	7.8	10.9	13.5	15.9	15.9	13.7	10.0	6.1	4.6
TOTAL PPT. (mm)	405.4	340.2	310.5	221.6	114.4	76.9	63.8	81.3	196.9	417.4	474.9	532.5
RAIN (mm)	381.1	330.6	302.4	221.3	114.3	76.9	63.8	82.4	196.9	417.4	472.4	521.5
SNOW (mm)	27.9	9.3	7.8	0.4	TRACE	0.0	0.0	0.0	0.0	TRACE	2.5	10.5

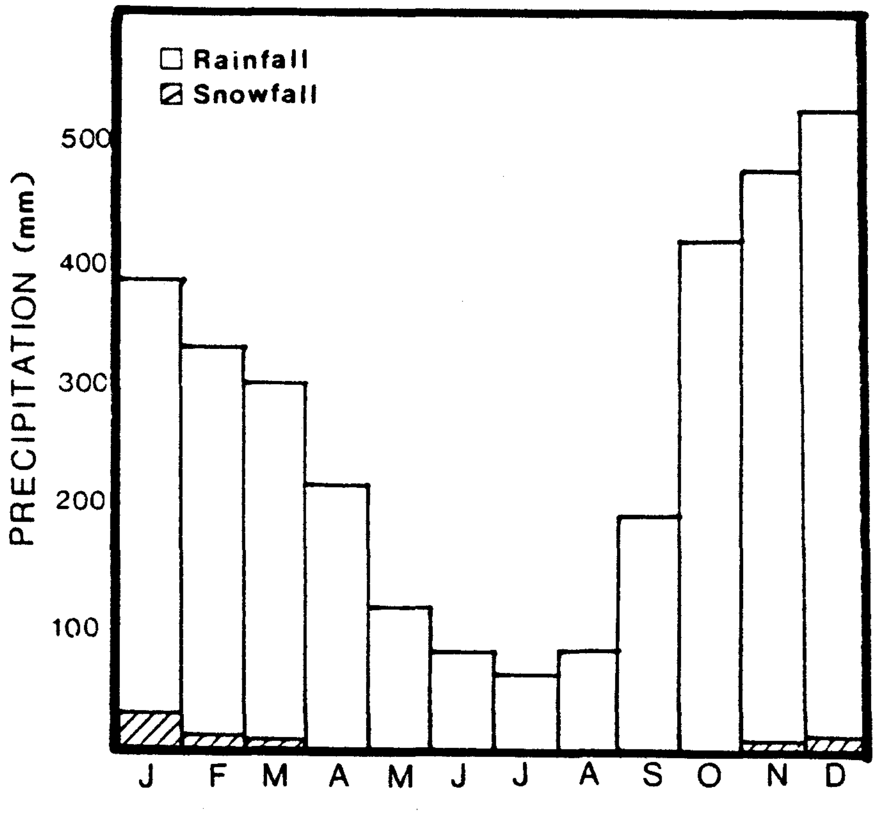


Figure 2.4: Total Monthly Snow and Rain accumulation For Port Alice 50 23'N 127 27'W

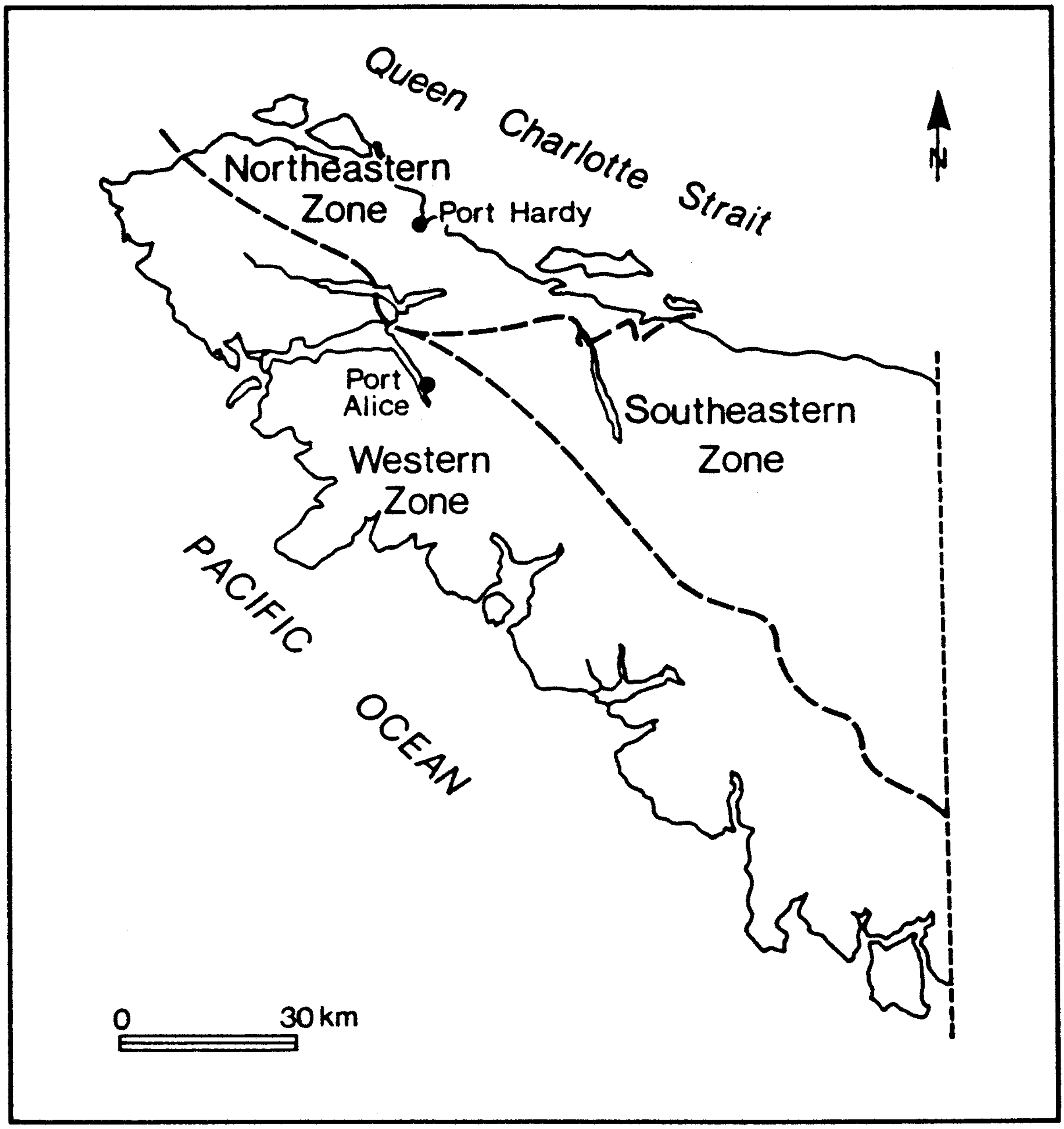


Figure 2.5 Precipitation Zones of Northern Vancouver Island

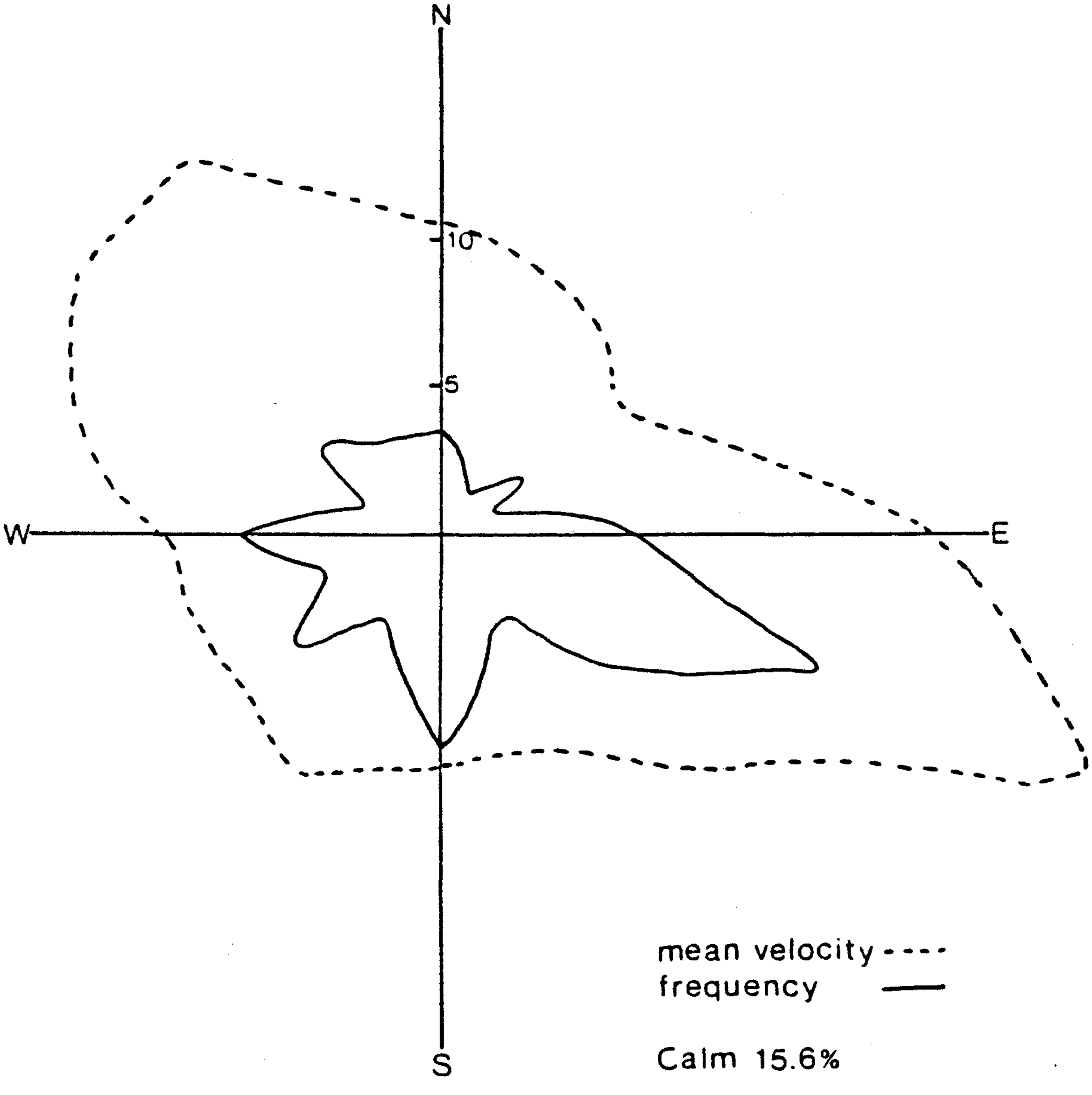


Figure 2.6: MEAN WIND VELOCITY (kmh^{-1}) AND FREQUENCY
FOR
PORT HARDY 50 41'N, 127 30'W

TABLE 2.2

MEAN WIND SPEED (Kmh^{-1}) AND PREVAILING DIRECTION
FOR
PORT HARDY 50° 41'N 127° 30'W

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SPEED (Kmh^{-1})	16.6	15.4	14.2	12.2	10.8	10.5	9.5	7.8	8.0	11.7	15.6	17.0
DIRECTION	ESE	ESE	ESE	ESE	NW	NW	NNW	NW	ESE	ESE	ESE	ESE

TABLE 2.3

FREQUENCY AND MEAN WIND VELOCITY
FOR
PORT HARDY 50° 41'N 127° 30'W

	N	NNE	NE	ENE	E	SES	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
FREQUENCY	3.3	1.8	3.3	1.9	7.0	14.4	8.3	3.6	7.5	3.7	6.6	4.3	6.9	2.9	5.0	3.9
MEAN VELOCITY (km^{-1})	9.5	7.9	10.2	17.9	24.2	14.0	9.7	8.3	10.0	9.0	9.3	9.9	13.9	15.5	16.0	11.0

CALM 15.6% OF THE TIME

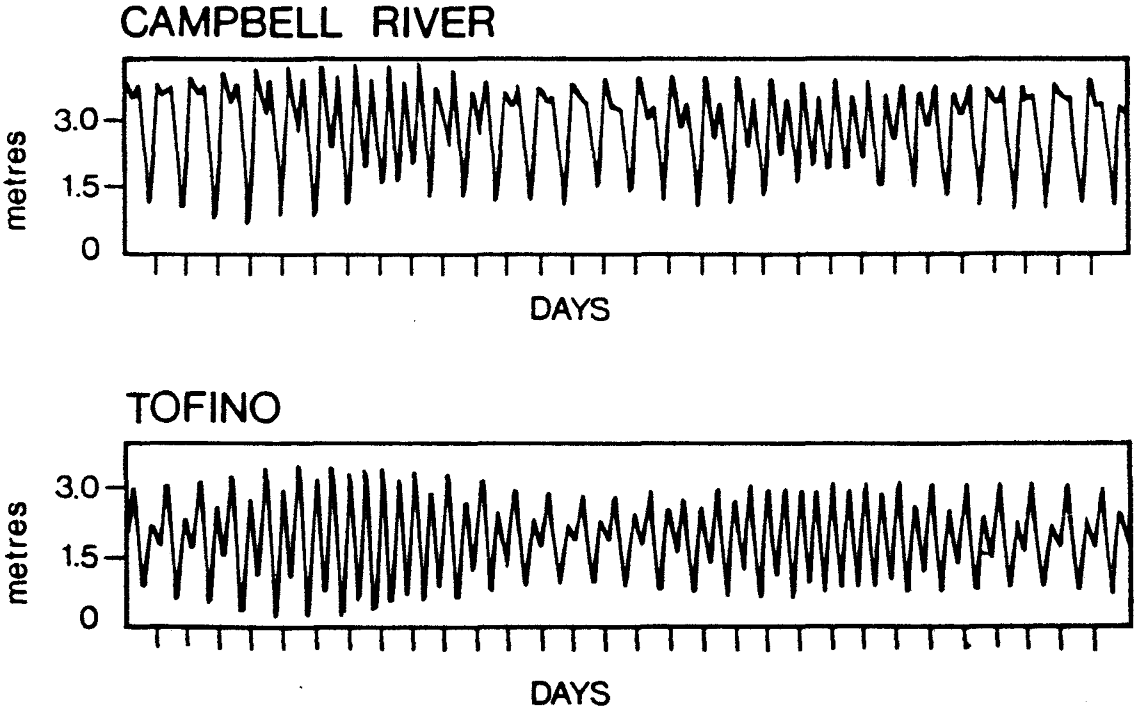


Figure 2.7 Tidal Regime of Tofino and Campbell River

TABLE 2.4

TIDAL DATA

LOCATION		MEAN TIDAL RANGE (m)	LARGE TIDAL RANGE (m)	TYPE OF TIDE
Prince Rupert	54°19'N 130°20'W	4.9	7.6	Mixed Semidiurnal
Bella Bella	52°10'N 128°08'W	3.4	5.3	Mixed Semidiurnal
Alert Bay	50°35'N 126°56'W	3.5	5.3	Mixed Semidiurnal
Vancouver	49°17'N 123°07'W	3.3	4.9	Mixed Diurnal
Tofino	40°09'N 125°55'W	2.7	3.9	Mixed Semidiurnal
Victoria	48°25'N 123°22'W	1.8	3.1	Mixed Diurnal
Sooke	48°22'N 123°44'W	2.0	3.2	Mixed Diurnal

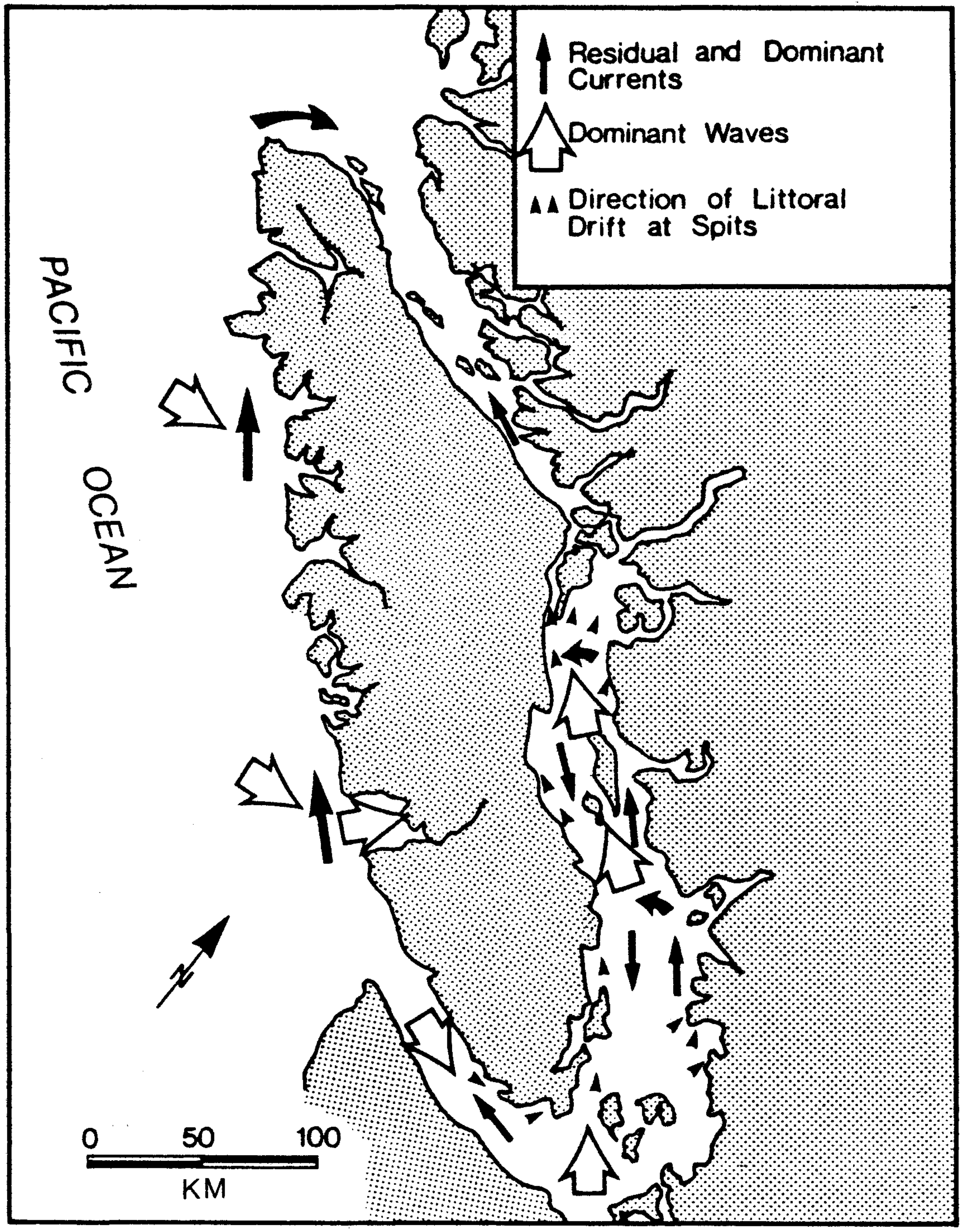
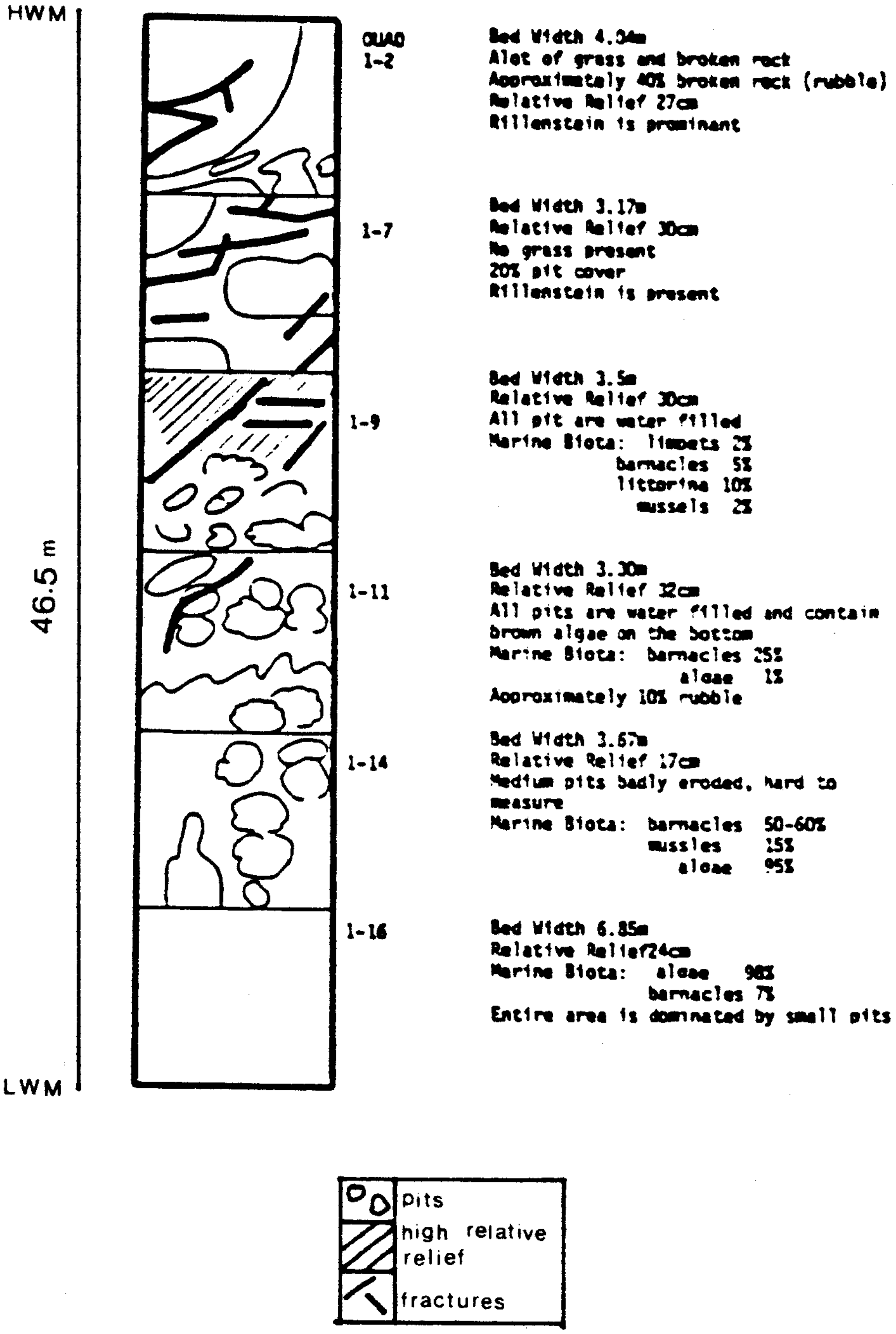


Figure 2.8 Tidal Currents of Vancouver Island

TABLE 2.5

HEIGHT, SLOPE AND LENGTH OF SAMPLING QUADRATS

BED	QUADRATE	SLOPE	LENGTH FROM LOW (m)	HEIGHT ABOVE LOW LOW TIDE (m)
1	1	6	35.7	3.7
	2		33.3	3.5
	3		30.9	3.2
	4		28.5	3.0
	5		26.1	2.8
	6		23.7	2.5
	7		21.3	2.2
	8		18.9	2.0
	9		16.5	1.7
	10		14.1	1.5
	11		11.7	1.2
	12		9.3	1.0
	13		6.9	0.7
	14		4.5	0.5
	15		2.1	0.2
	16		0.0	0.0
2	1	6.5	40.0	4.5
	2		37.5	4.2
	3		35.0	4.0
	4		32.5	3.7
	5		30.0	3.4
	6		27.5	3.1
	7		25.0	2.8
	8		22.5	2.6
	9		20.0	2.3
	10		17.5	2.0
	11		15.0	1.7
	12		12.5	1.4
	13		10.0	1.1
	14		7.5	0.9
	15		5.0	0.6
	16		2.5	0.3
	17		0.0	0.0
4	1	7	39.5	4.8
	2		36.3	4.4
	3		34.1	4.2
	4		31.9	3.9
	5		29.7	3.6
	6		27.5	3.4
	7		25.3	3.1
	8		23.1	2.8
	9		20.9	2.5
	10		18.7	2.3
	11		16.5	2.0
	12		14.3	1.7
	13		12.1	1.5
	14		9.9	1.2



Bed Width 4.34m
Alot of grass and broken rock
Approximately 40% broken rock (rubble)
Relative Relief 27cm
Rillenstein is prominant

Bed Width 3.17m
Relative Relief 30cm
No grass present
20% pit cover
Rillenstein is present

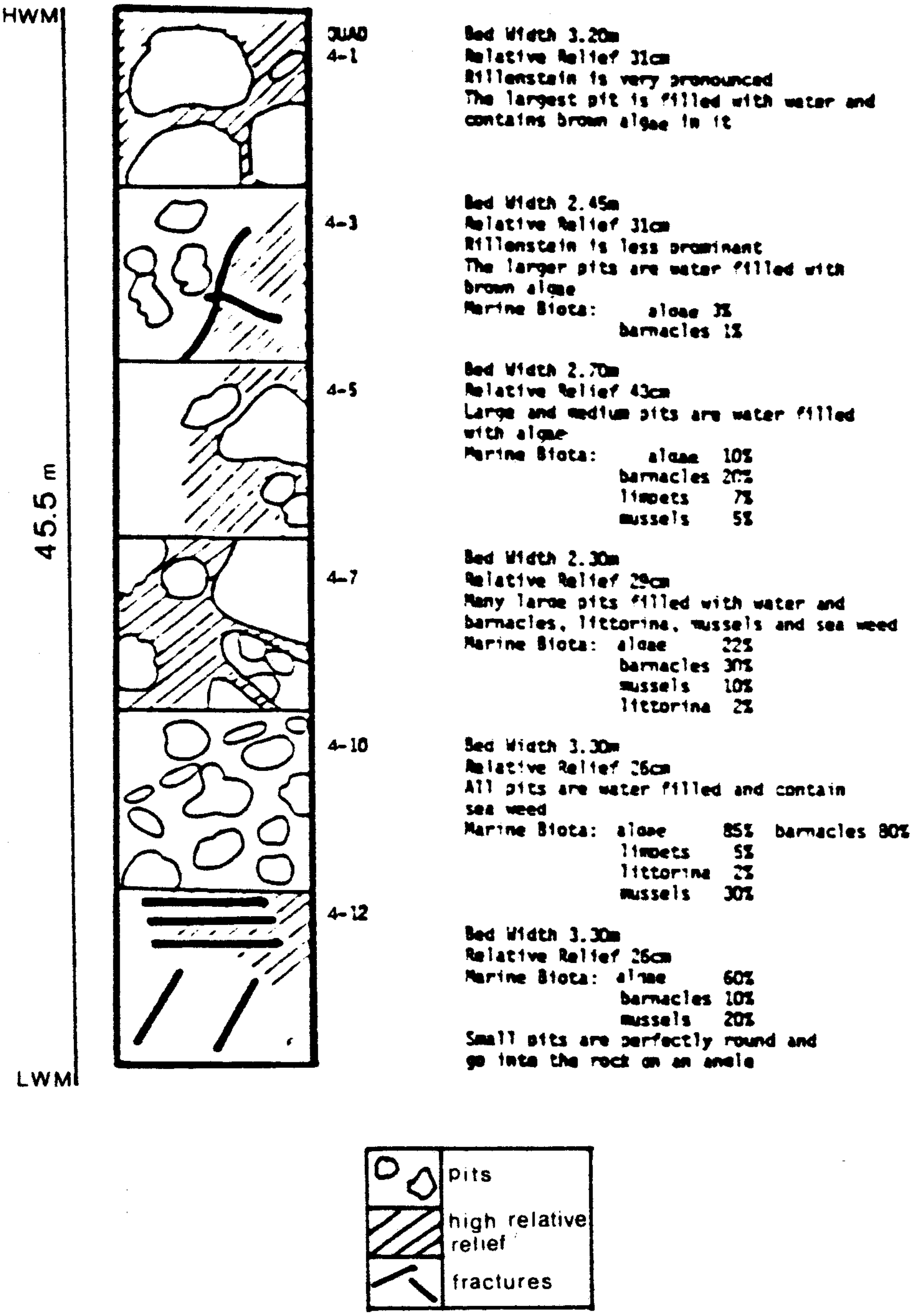
Bed Width 3.5m
Relative Relief 30cm
All pit are water filled
Marine Biota: limpets 2%
barnacles 5%
littorina 10%
mussels 2%

Bed Width 3.30m
Relative Relief 32cm
All pits are water filled and contain brown algae on the bottom
Marine Biota: barnacles 25%
algae 1%
Approximately 10% rubble

Bed Width 3.67m
Relative Relief 17cm
Medium pits badly eroded, hard to measure
Marine Biota: barnacles 50-60%
mussles 15%
algae 95%

Bed Width 6.85m
Relative Relief24cm
Marine Biota: algae 98%
barnacles 7%
Entire area is dominated by small pits

Figure 2.11: Examples of Sample Quadrats For Bed 1



Bed Width 3.20m
Relative Relief 31cm
Rillenstein is very pronounced
The largest pit is filled with water and
contains brown algae in it

Bed Width 2.45m
Relative Relief 31cm
Rillenstein is less prominent
The larger pits are water filled with
brown algae
Marine Biota: algae 3%
barnacles 1%

Bed Width 2.70m
Relative Relief 43cm
Large and medium pits are water filled
with algae
Marine Biota: algae 10%
barnacles 20%
limpets 7%
mussels 5%

Bed Width 2.30m
Relative Relief 29cm
Many large pits filled with water and
barnacles, littorina, mussels and sea weed
Marine Biota: algae 22%
barnacles 30%
mussels 10%
littorina 2%

Bed Width 3.30m
Relative Relief 26cm
All pits are water filled and contain
sea weed
Marine Biota: algae 85% barnacles 80%
limpets 5%
littorina 2%
mussels 30%

Bed Width 3.30m
Relative Relief 26cm
Marine Biota: algae 60%
barnacles 10%
mussels 20%
Small pits are perfectly round and
go into the rock on an angle

Figure 2.13: Examples of Sample Quadrats For Bed 4

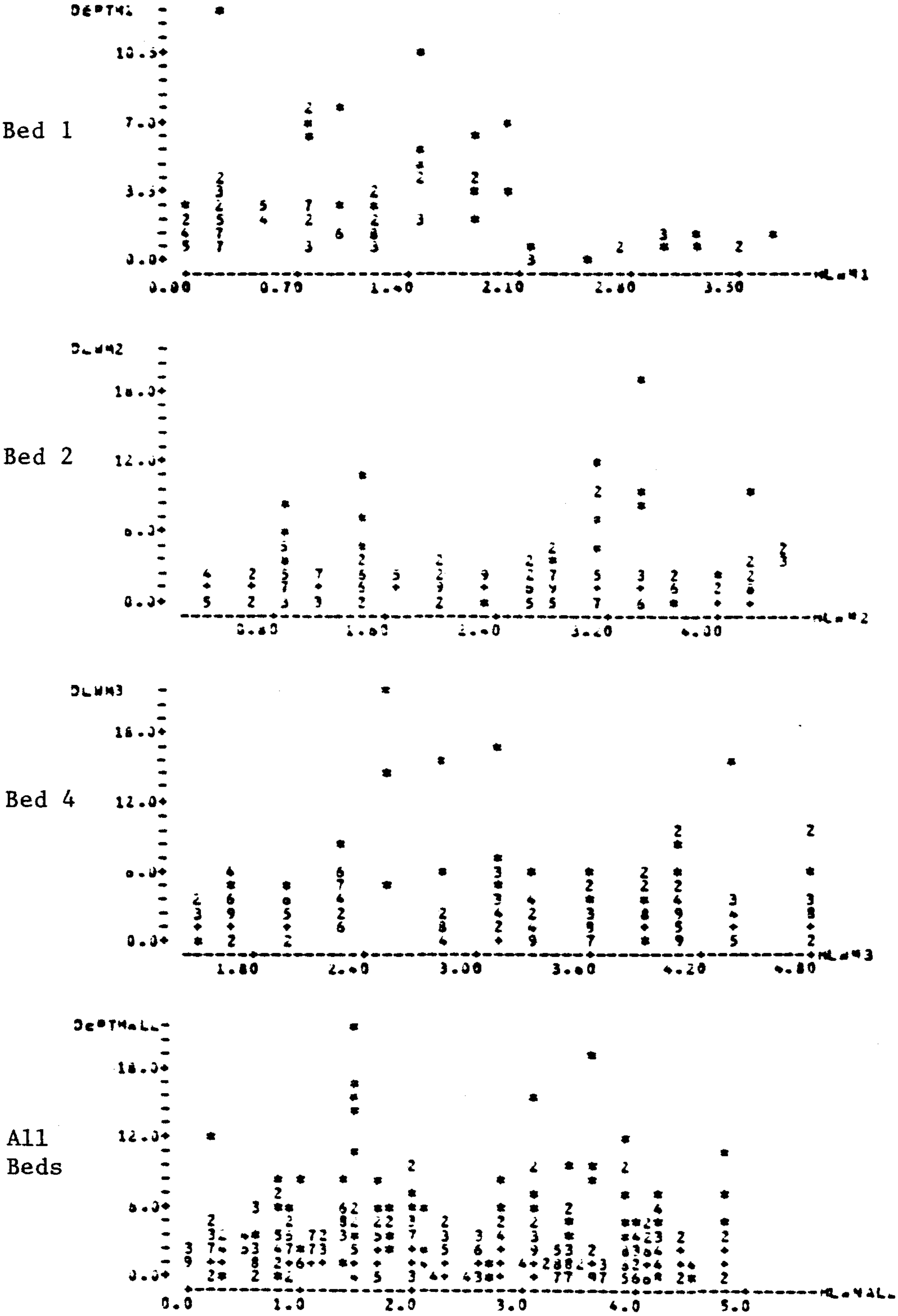


Figure 3.2 Height Above Low Low Tide vs Depth Above Low Low Tide For Beds 1, 2, 4, and all beds

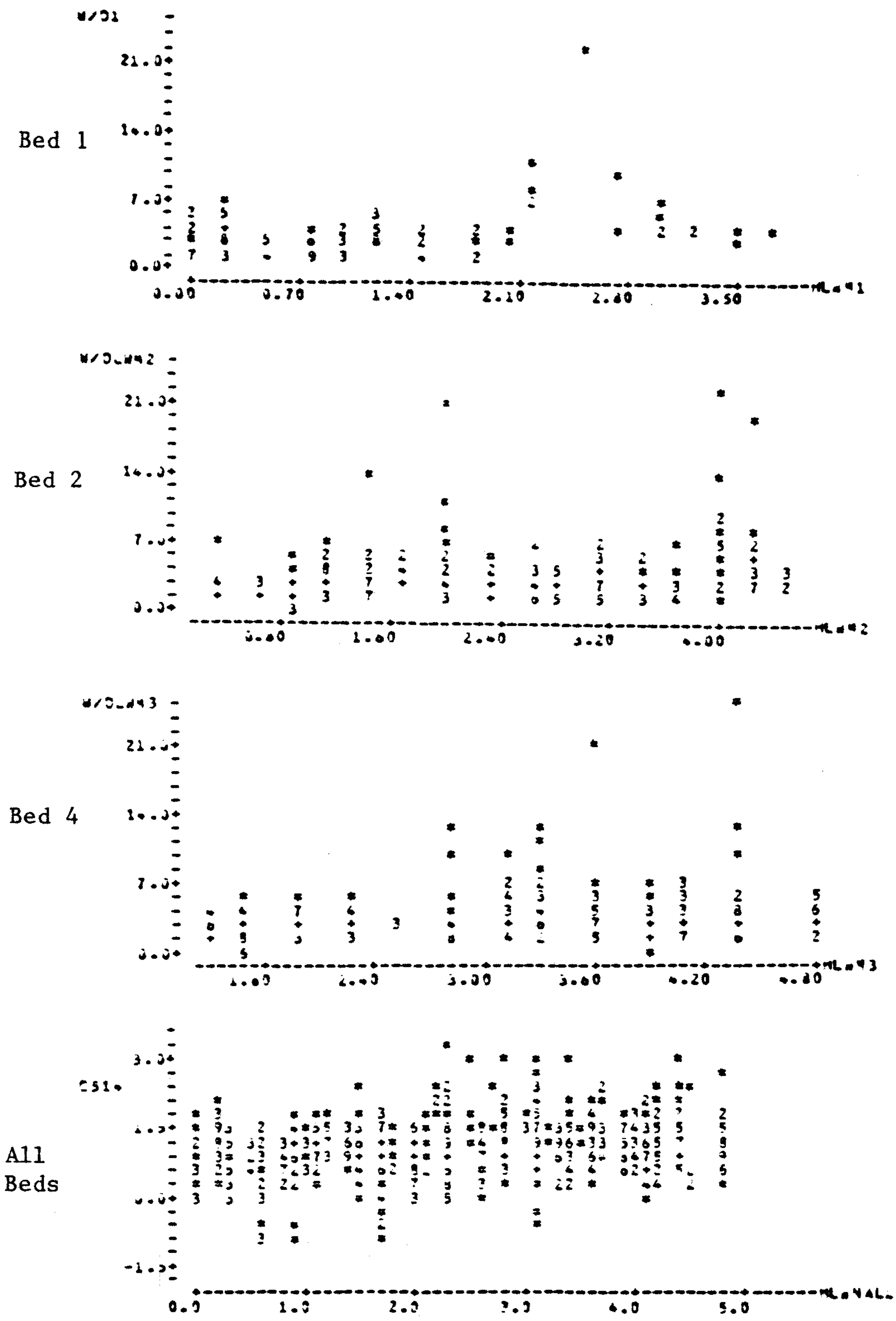


Figure 3.3 Height Above Low Low Tide vs W/D Ratios Above Low Low Tide For Beds 1, 2, 4, and all beds

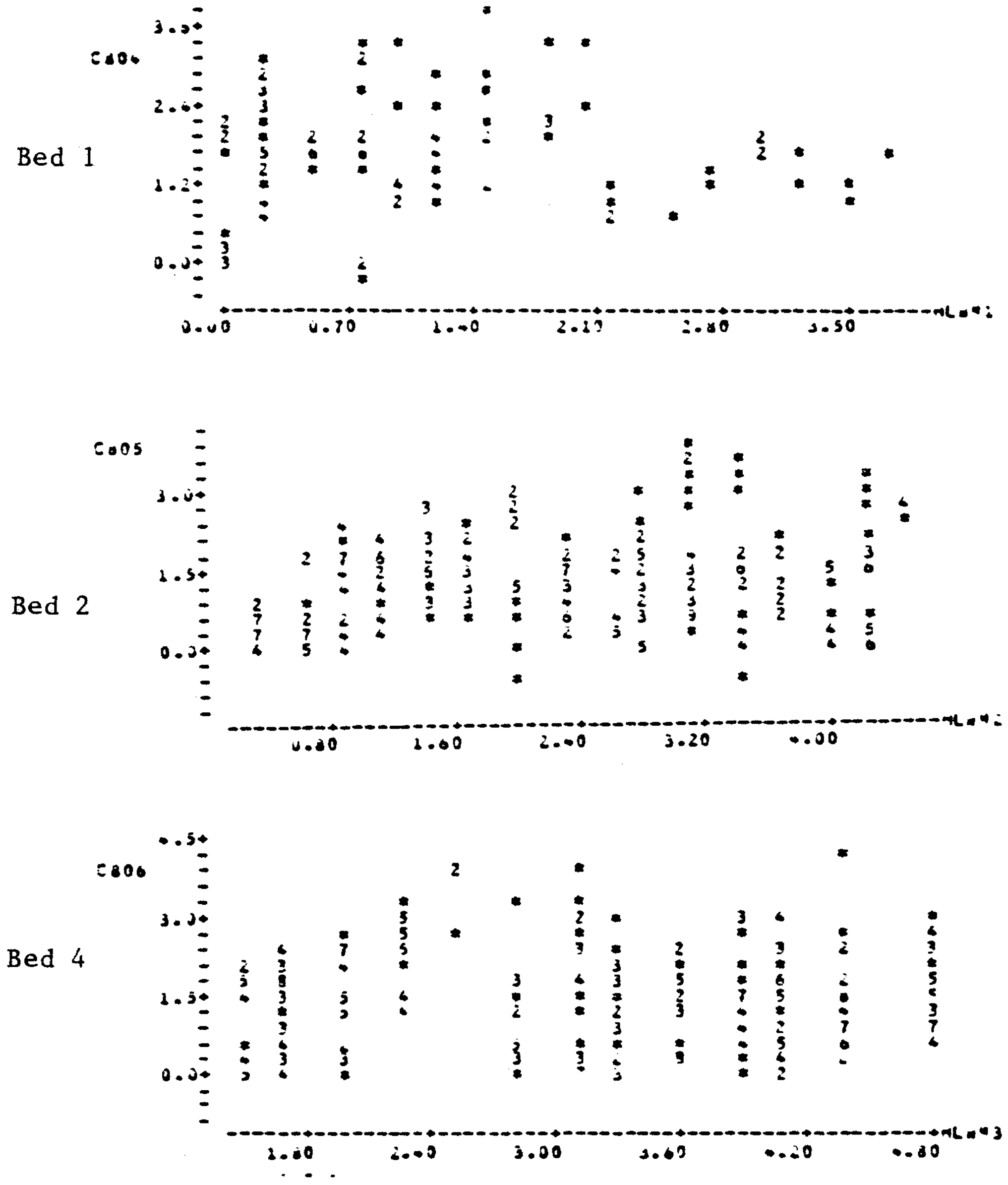
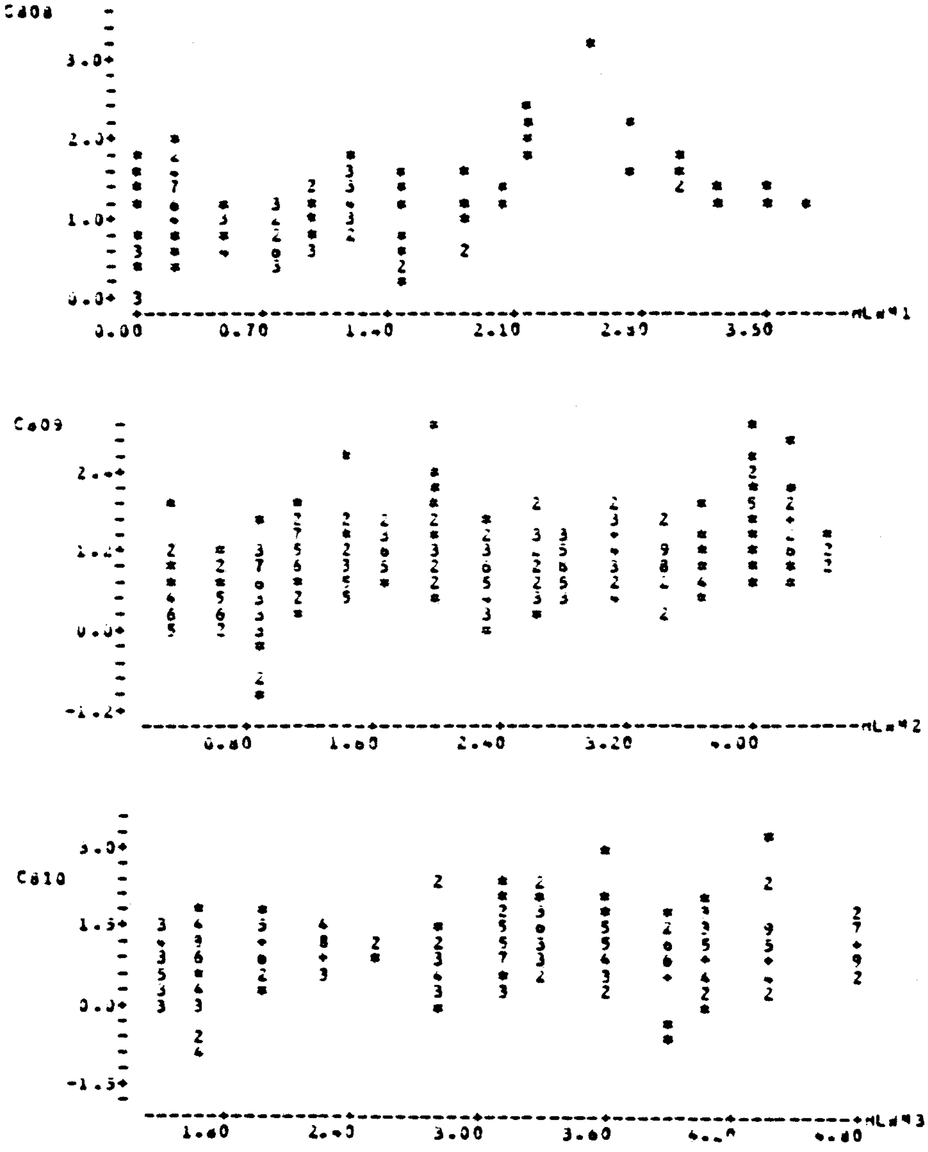


Figure 3.7 Height Above Low Low Tide vs Logarithmic Depth Above Low Low Tide For Beds 1, 2, and 4



Bed 1

Bed 2

Bed 4

Figure 3.8 Height Above Low Low Tide vs W/D Ratio Above Low Low Tide For Beds 1, 2, and 4

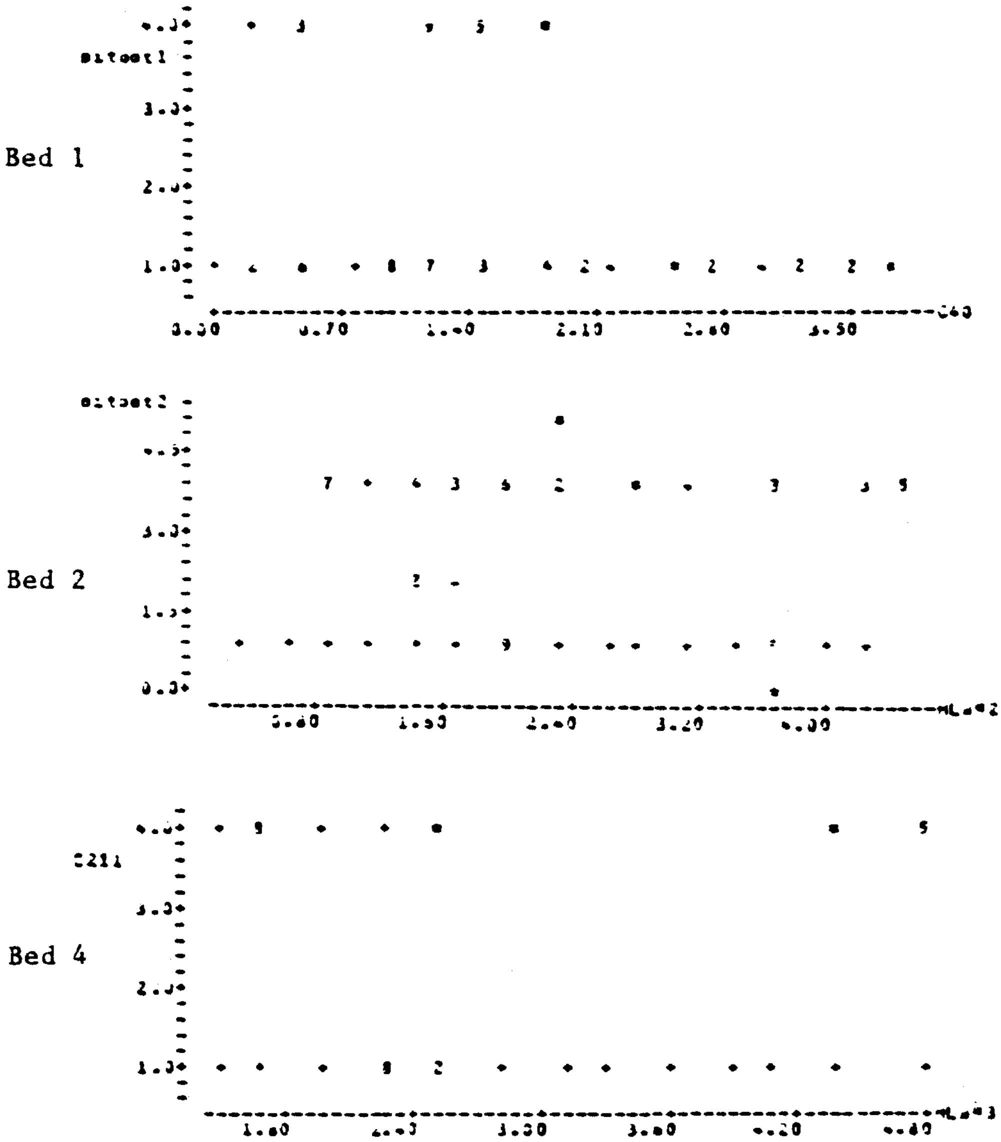


Figure 3.10 Secondary Pit Formation ; vs Height Above Low Low Tide For Beds 1, 2, and 4

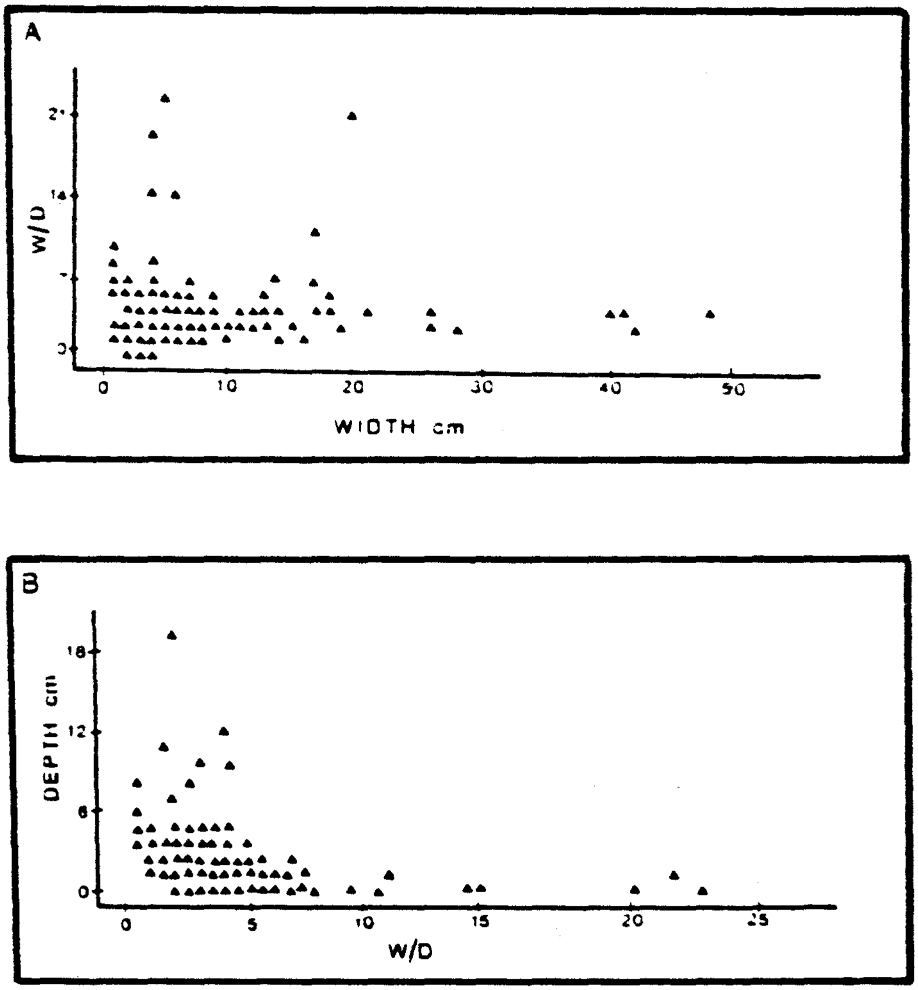


Figure 3.13 A, B Width and Depth vs W/D Ratio For Bed 2

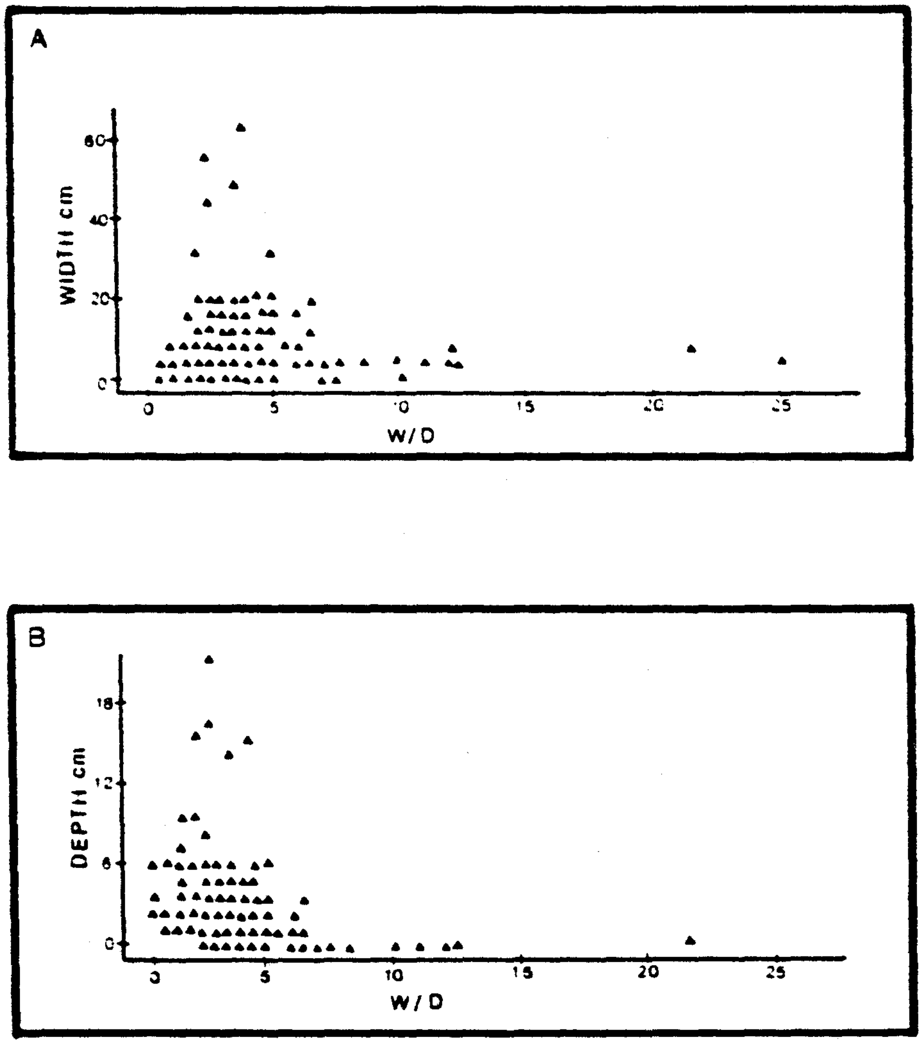


Figure 3.14 A, B Width and Depth vs W/D Ratios For Bed 4

TABLE 3.2

RELATIVE RELIEF OF SAMPLING QUADRATS

BED	SAMPLE QUADRATE	RELATIVE RELIEF (cm)
1	1	27
	2	27
	3	15
	4	17
	5	18
	6	26
	7	30
	8	23
	9	30
	10	32
	11	32
	12	29
	13	21
	14	17
	15	27
	16	24
2	1	21
	2	27
	3	27
	4	14
	5	27
	6	13
	7	29
	8	29
	9	15
	10	19
	11	27
	12	40
	13	22
	14	25
	15	29
4	1	31
	2	17
	3	31
	4	36
	5	43
	6	32
	7	29
	8	24
	9	23
	10	26
	11	35
	12	26
	13	27