Our File: P95/16 September 1995

FINAL REPORT

Broughton Archipelago Clam Terrace Survey

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During a 1995 aerial video survey of the coastline of Johnstone Strait, an unusual shoreline feature was noted and termed "*clam terraces*" (inset) because of the terrace-type morphology and the apparent association with high clam productivity on the sandflats. Typical alongshore lengths of the terrace ridges are 20-50m, and across-shore widths are typically 20-40m.

Clam Terrace Morphology

- a **boulder/cobble ridge** in the lower intertidal, extending across small embayments or indentations in the mostly rocky shoreline,
- a **sandflat** extending from the ridge into the middle intertidal zone and comprised almost entirely of biogenic sand (barnacle and shell fragments),
- a **boulder veneer over a bedrock ramp** in the upper intertidal zone.

An area with an especially high density of *clam terraces* was noted in the Broughton Archipelago, between Broughton and Gilford Islands of southeastern Queen Charlotte Strait. *Clam terraces* in this area were inventoried from the aerial video imagery to quantify their distribution. The terraces accounted for over 14 km of shoreline and 365 *clam terraces* were documented.

A three-day field survey by a coastal geomorphologist, archeologist and marine biologist was conducted to document the features and determine their origin. Nine *clam terraces* were surveyed. The field observations confirmed that: the ridges are comprised of boulder/cobble-sized material, ridge crests are typically in the range of 1-1.5m above chart datum, sandflats are comprised almost entirely of shell fragments (barnacles and clams) and sandflats have very high shellfish production. There are an abundance of shell middens in the area (over 175) suggesting that the shellfish associated with the terraces were an important food source of aboriginal peoples.

The origin of the ridges is unknown; they appear to be a relict feature in that they are not actively being modified by present-day processes. The ridges may be a relict sea-ice feature, although the mechanics of ridge formation is uncertain. Sand accumulates behind the ridge because the supply rate of the shell fragments exceeds the dispersal rate in these low energy environments.

The high density areas of *clam terraces* correspond to high density areas of shell middens, and it is probable that the *clam terraces* were subjected to some degree of modification by aboriginal shellfish gatherers over the thousands of years of occupation in the region.

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1.1 Statement of the Problem

During the summer of 1995, low-tide aerial video surveys were conducted of the shoreline in Johnstone and Queen Charlotte Straits in support of the Province's land-use planning and oil spill contingency planning initiatives. During these surveys, a unique coastal feature was observed that (a) was very common, comprising an estimated 5-10% of the coastline length and (b) had not been previously documented on the BC coast. The basic elements of the feature are sketched in Figure 1 and include:

a **boulder ridge** in the lower intertidal zone, apparently comprised of uniformly-sorted cobble/boulder-sized sediment,

a **tidal flat** in the mid-intertidal zone that consists almost entirely of sand-sized shell fragments, and

either **bedrock cliffs** or **large boulder rubble** over bedrock in the upper intertidal zone.

The features were tentatively named "*clam terraces*" to indicate their terraced-type morphology and their apparent close association with high clam production. Numerous coastal shell midden deposits were also noted in the area although not usually in direct association with the clam terraces.

Figure 1 Sketch of typical *clam terrace*.

The number and uniformity of the features was striking. The regularity of ridge height and composition suggested a common origin. The features are confined to low energy sites so oceanographic/hydraulic processes could not be responsible for their origin. They could represent relict ice features, but these type of features (e.g., boulder barricades) are typically irregular, poorly sorted and associated with higher energy environments. Because of the abundance of shell-middens in the area we postulated a *cultural origin* of the terraces as our initial working hypothesis; that is, the ridges were created by aboriginal peoples to create sand flats behind the ridges and to maximize clam productivity in sand flats.

1.2 Objectives

A field survey was planned to further investigate selected clam terraces. The objectives of the survey were to:

(a) define the spatial extent of the clam terraces.

(b) collect field data to confirm and supplement aerial interpretations of the features.

(c) test the hypothesis that the clam terraces have an aboriginal cultural origin.

1.3 Project Area

The area of the Broughton Archipelago Marine Park (Figure 2, shaded inset) was selected for an initial 3-day survey because of the apparent high density of *clam terraces* associated with the area and the relative ease of logistical access.

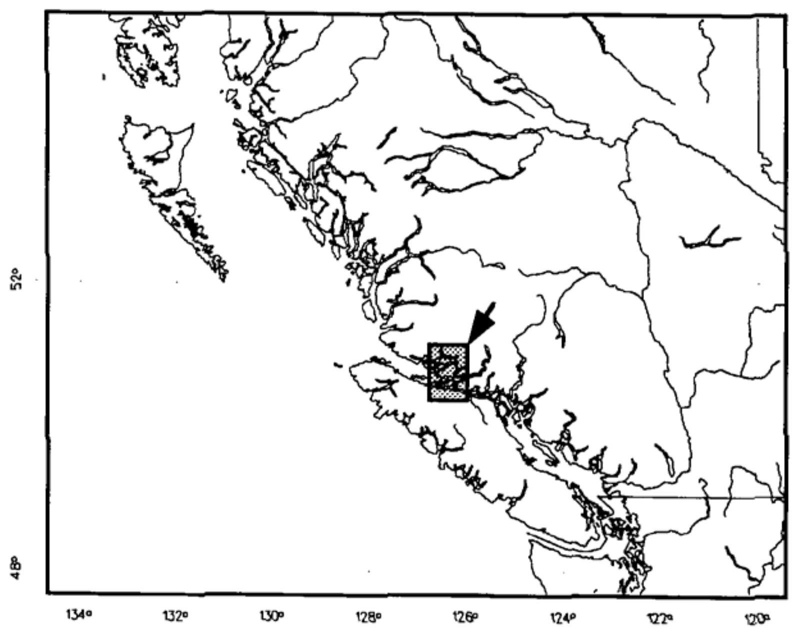

Figure 2 Location of the Broughton Archipelago and primary survey area (shaded).

2.1 Geological Features

The clam terrace features of southeast Queen Charlotte Strait are exclusively confined to low energy areas of the Strait. Wave fetch windows are generally less than 5 km at most sites and although tidal currents are moderate in some channels (1-2 knots), there does not appear to be sufficient hydraulic energy to rework the boulders (mean size ~30cm diameter). As a result, the origin of the ridges due to hydraulic processes related to either wave or current transport were ruled out.

It is possible that the features represent *relict* ice features, as the area is rarely affected by ice under present climatic conditions. However, under colder regimes, seasonal ice formation could have occurred in the area and an "ice-origin" of the features is possible. Boulder ridge ice features have been documented on the eastern Canadian seaboard, Hudson and James Bay and the Alaskan Beaufort Sea.

Rosen (1980) describes the *boulder barricades* of the Makkovik region of Labrador and notes that these ridges "flank all shorelines except high energy rocky areas . . . including seaward of most high-energy cobble beaches. They occur near the LLW line" which in the Makkovik area is about 2m below the HWL and near the maximum ice thickness of 2m (Fig. 3). Rosen (1980) suggests: that "ice blocks are grounded at this point, depositing and pushing boulder material brought ashore or alongshore by ice rafting and that shore-fast ice prevents the ice blocks from moving material farther onshore." He also notes that boulder barricades are an almost continuous shore feature in low-energy environments. Rosen (1979) suggests that the origin of the boulder barricades occur where: (a) there is a rocky coastal setting providing an adequate supply of boulders, (b) there is sufficient winter ice and water level fluctuations to entrain boulders in ice rafts, and (c) there is a distinct break in slope in the nearshore to serve a locus for grounding ice, otherwise the boulders are deposited randomly as bouldery tidal flats.

The boulder barricades described by Rosen (1980) have some similarities to the Broughton Archipelago *clam terraces* in that they are (a) a concentration of boulder-sized sediment, (b) occur near the low-water line and (c) are associated with low energy shorelines; the *clam terraces* differ in that they appear to be much better sorted than the Makkovik boulder barricades and they conform consistently to the straight or concave curvature of the LLW line.

Lauriol and Gray (1980) describe boulder barricades of Ungava Bay area (Fig. 4 & 5) and propose a different mode of origin where boulders are incrementally moved downslope by terrestrial mass-wasting processes and into the shore zone where further downslope movement is prevented by landfast ice. The authors cite the absence of boulder barricades on the emergent coastal plain as evidence to support this mechanism. While this process is viable for locations where fluvial ice flows occur (i.e., delta flats) it does not appear to be relevant to locations without strong fluvial outflow and is not applicable to the Broughton Archipelago *clam terraces*.

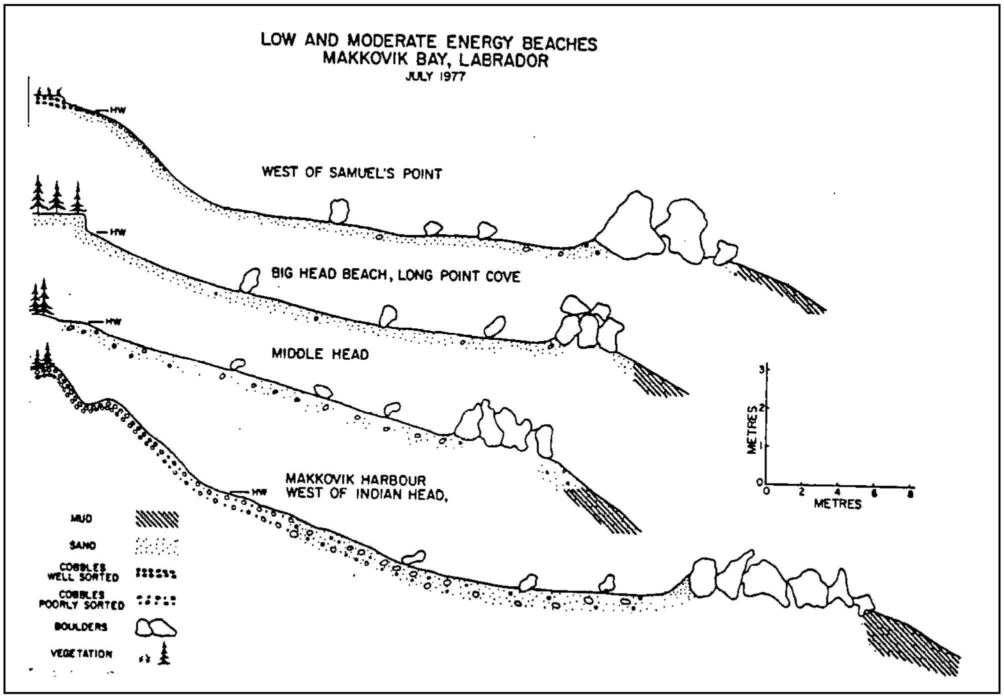

Figure 3. Across-shore profiles of boulder barricades near Makkovik (from Rosen 1980)

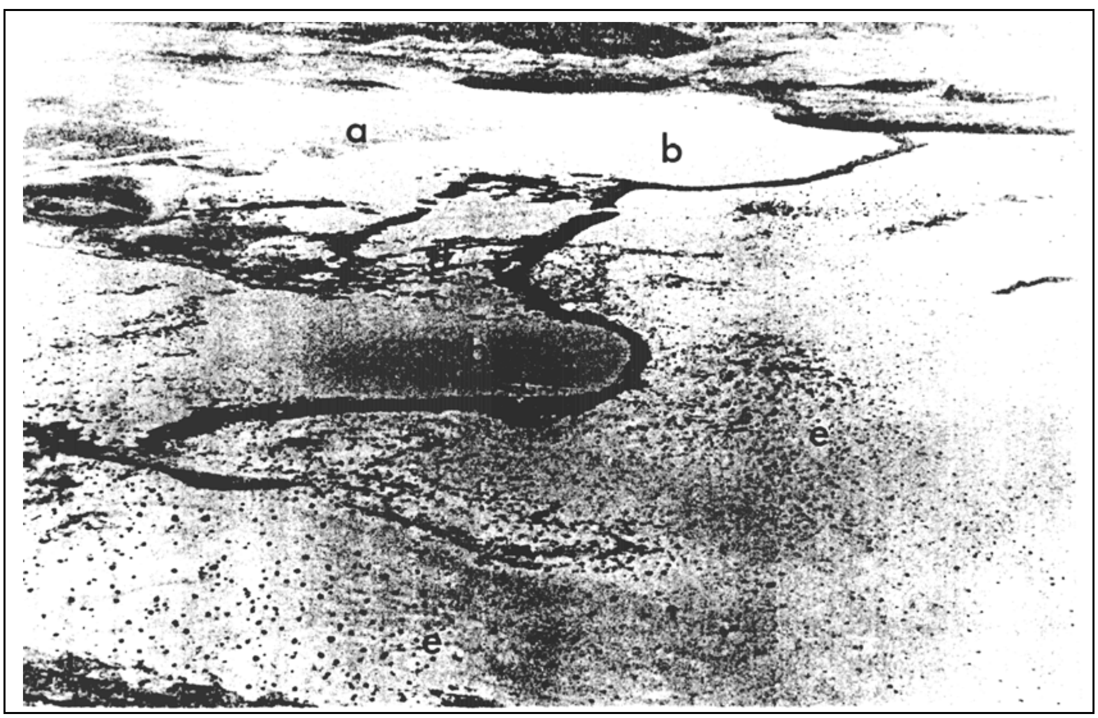

Figure 4. Aerial photo of boulder barricades in Ungava Bay (from Lauriol and Gray 1980).

Figure 5. Ground photo of the boulder barricade shown in Fig. 4 (from Lauriol and Gray 1980).

Barnes (1982) describes a marine ice-pushed boulder ridge in the Beaufort Sea of Alaska. The ridge, up to 4m in height, was formed by ice push that preferentially sorts boulder-sized material from 1-2m water depths. Ridge material is poorly sorted, angular and boulder material is concentrated in the upper intertidal zone (Fig. 6). A schematic diagram (Fig. 7) indicates the proposed origin of the ridge. The described ridge differs from Broughton Archipelago *clam terrace* ridges in that material is concentrated in the upper intertidal and is poorly sorted and angular.

Figure 6. Photos of the Camden Bay, Alaska boulder ridge (from Barnes 1982).

Overview

None of the mechanisms described in the literature appears to explain adequately the morphology of the Broughton Archipelago *clam terraces* and associated ridges.

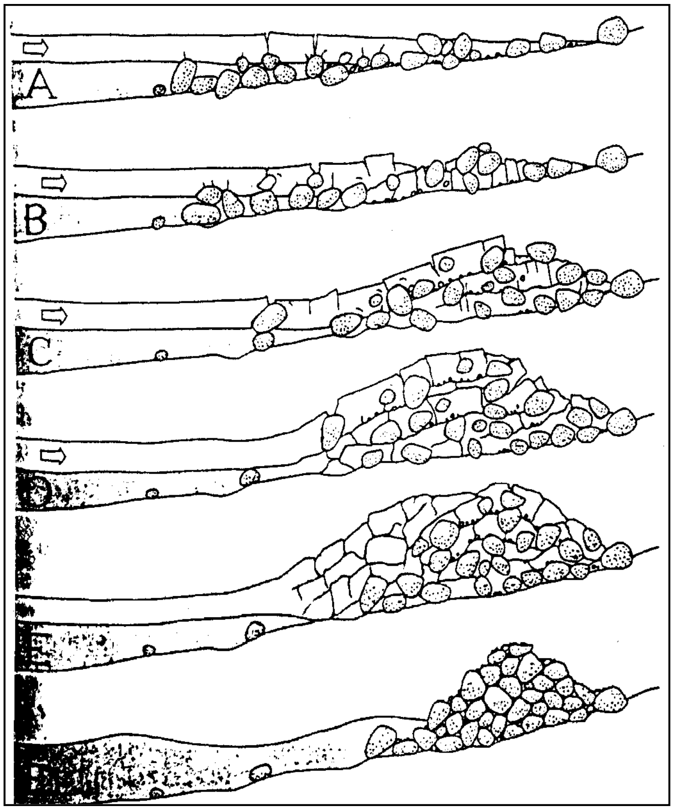

Figure 7 Schematic diagram of proposed origin of the Camden Bay, Alaska boulder ridge (from Barnes 1980).

The *clam terraces* and associated boulder ridges are much more uniformly sorted than the boulder barricades of the eastern seaboard, and the Camden Bay ridge in the Beaufort Sea appears to have a very different origin. The roundness of the *clam terrace* boulders differs also but this could be due to a much greater age and a marine-related, bio-chemical weathering of the clasts.

In summary, none of the coastal boulder ridge formation literature provides a reasonable explanation of the Broughton Archipelago *clam terrace* ridges.

2.2 Archaeological Features

Several types of intertidal stone-wall features associated with aboriginal occupation and use of the modern shoreline are well known and documented throughout western North America. Stone wall fish traps and canoe runs are the two most common types of archaeological sites located in the intertidal zone. Canoe runs or skids almost always occur directly in front of either village or camp sites. Stone alignments associated with individual canoe runs are necessarily oriented perpendicular to the adjacent shoreline to facilitate ease of access of small watercraft to the exposed portion of the intertidal zone. The *clam terrace* features observed in the Broughton archipelago typically occur at or near the zero tide level and extend across the entire openings of small embayments. Canoe runs were observed at two of the nine clam terrace locations visited during the field survey (see Section 4.4).

The second and more common type of archaeological site located in the intertidal zone is the stone wall fish trap (Haggarty and Inglis 1985; Eldridge and Acheson 1992; Moss, et al 1990). Stone wall fish traps occur in a variety of marine intertidal environments, including protected and semi-exposed shorelines, as well as deltaic environments. Stone wall traps located on deltaic sediments at or near the mouths of streams and rivers were associated primarily with trapping salmon species during the fall spawning season. These traps generally consist of a single, often long, stone wall that spans the entire delta at or near the half tide level. Most stone wall fish traps, however, occur along sections of protected or semi-exposed shoreline and are constructed to seal off small to medium-sized embayments, again at or near the half tide level. These stone wall traps can range from simple (single wall) to complex (multi-walled) and are not directly associated with streams or rivers. Instead, these traps were constructed to procure several species of small, inshore schooling fish (herring, smelt, anchovy, etc.) during the spring when these species came inshore to spawn.

All stone wall fish traps associated with the modern sea level regime and constructed to seal off small embayments exhibit several common characteristics, including: (a) location at or near the half tide level in the intertidal zone; (b) seaward and landward faces of the outer stone wall at or near the angle of repose; (c) usage of cobble size clasts in the construction of outer and interior (if present) walls; and (d) a seaward convex curvature that serves to maximise the size of the entrapment or catchment area of the trap. Frequently, the construction of both outer and interior stone walls will be altered to incorporate large, isolated boulders or bedrock outcroppings in the wall structure. As these traps utilise locally available cobbles, it is not uncommon to find areas adjacent to the outer margins of the wall devoid of cobble-sized clasts. These cobbles, as well as those located in the proposed entrapment area, would be used in the construction of the stone walls of the trap. Frequently, many traps of this type exhibit narrow openings near the middle of the outer wall. These openings served several functions: (a) assist in gathering trapped fish by helping funnel fish into an attached wicker type container as the tide level dropped; and (b) allow sediment to flow freely out of the trap during daily tidal fluctuations when the trap was not in use. Preventing excess sediment accumulation behind the outer wall greatly decreased certain tasks associated with keeping these structures functioning efficiently over time.

The ridges associated with the *clam terrace* features observed on AVI and during the field reconnaissance survey in the Broughton Island archipelago do not exhibit any of the morphological characteristics typical of stone wall fish traps associated with the modern sea level regime. The clam terrace ridges are located at or near the zero tide level, only the outer face of the ridge appears to be at or near the angle of repose, clast size ranges from gravel to boulders, and the curvature of the ridges is typically convex landward rather than seaward. Further, unlike stone wall fish traps described above, these ridges simply do not have the appearance of being purposefully constructed.

The possibility that these ridges represent the outer walls of relic stone wall fish traps associated with a lower sea level regime is remote for many of the same reasons outlined above. The fact that the clam terrace features have a landward curvature, opposite that of stone wall fish traps associated with current sea level, would seem to preclude effective utilisation of available space for trapping small, inshore schooling fish.

3.1 Aerial Video Imagery Review

Aerial video imagery (AVI) was used to delineate the location and distribution of the *clam terraces* prior to conducting the field survey. This overview was concentrated in the area of highest *clam terrace* density (Fig. 8). *Clam terraces* were identified and were classified as to distinctness (Table 1), and length of the associated boulder ridge estimated. The latitude and longitude of the *terrace* location was noted (as recorded by GPS on the aerial video image; locations actually noted aircraft position at the time the *clam terrace* was imaged.). Data were recorded in a database and plotted in ArcView 2.0.

Table 1 Classification of *Clam Terraces* on AVI

Distinctness	Properties
High	general morphology of a boulder ridge in the lower intertidal, a sandflat in the middle intertidal clearly visible and prominent; video narration not required to identify feature
Medium	morphology of boulder ridge at LWL and flat in the mid-intertidal requires experienced observer to identify; audio narration helpful in confirming interpretation but not essential
Low	general morphology of ridge at LWL and flat in mid-intertidal possible but difficult to determine from video imagery alone; audio narrative used to identify feature

3.2 Distribution of *Clam Terraces*

The classification of *clam terraces* is summarized in Table 2. Over 350 *clam terraces* were observed and they comprised over 14 km of shoreline. Forty-two percent of the *clam terraces* were classified as “distinct, accounting for 54% of the total length.

Table 2 Summary of Observations

Distinctness	Number	Length (m)	% Length
High	148	7,600	54
Medium	124	4,315	31
Low	81	2,195	16
TOTAL:	*353*	*14,125*	*100*

The distribution of *clam terraces* (Fig 8) and shows that the features are generally confined to the very protected, central portions of the Broughton Archipelago. They were not observed along Queen Charlotte Strait or along the western end of Knight Inlet. Only one terrace was observed on Midsummer Island, which lies in the middle of Knight Inlet. The distribution clearly suggests that the features are associated with low wave exposure where wave fetches are less than 5 km.

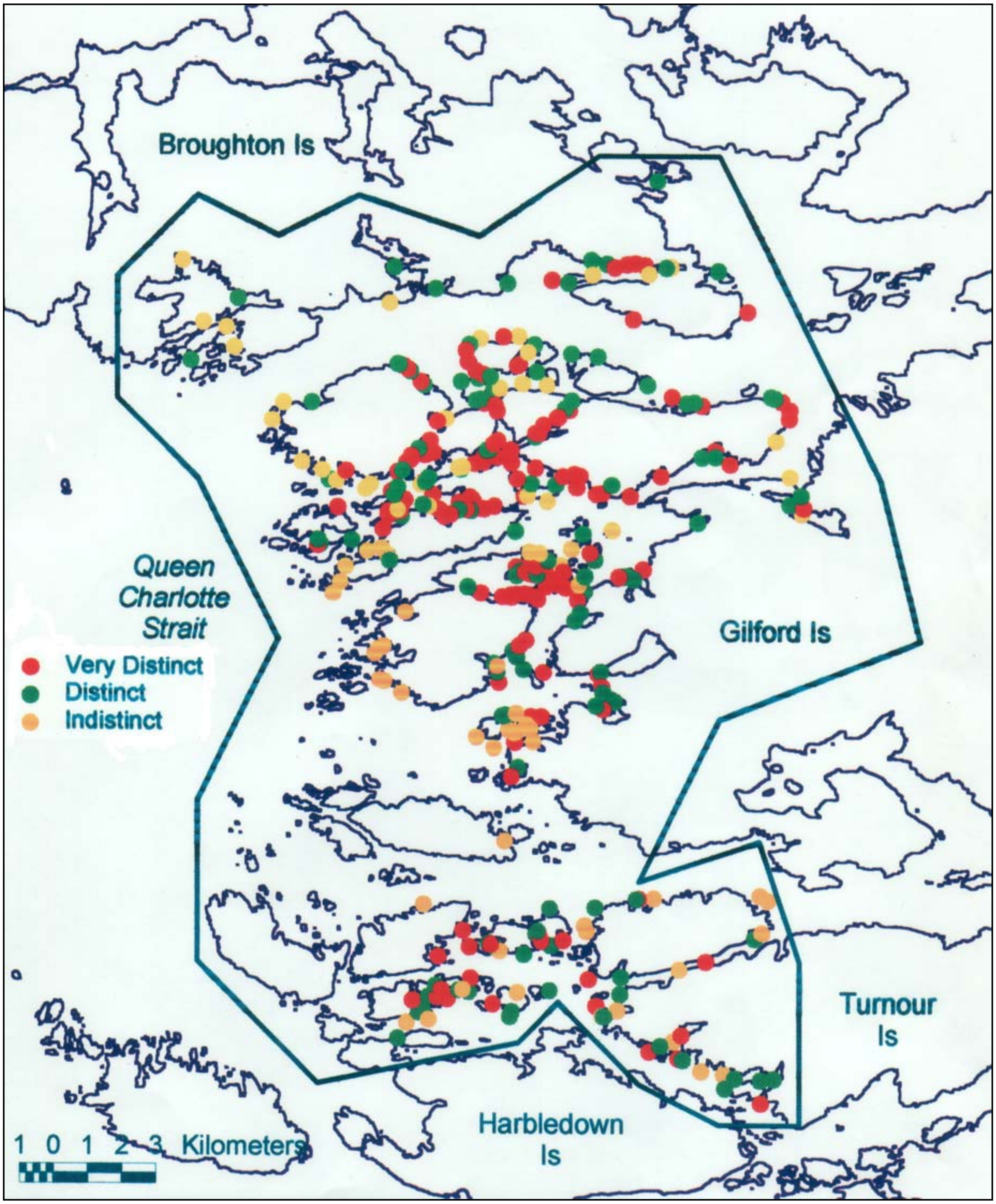

Figure 8 Boundary of AVI survey area and *clam terrace* locations.

3.3 Distribution of Archaeological Sites

Mitchell (1969) discusses the composition and distribution of archaeological sites found and recorded in the Johnstone Strait region during field surveys conducted in the late 1960's. Mitchell's discussion of the composition and distribution shell middens sites, defensive sites, and fish trap sites in the Broughton Island archipelago are of particular relevance to the present study. Addressing the distribution of archaeological sites in his study area, Mitchell (1969:207) states:

> "...there is clustering of sites. The greatest concentrations lie in the sheltered waterways of the lowland archipelago between Vancouver Island and the mainland. ...Within the low island groups there are three main site clusters: the largest on islets and channels to either side of the mouth of Knight Inlet,..."

The large cluster of sites near the mouth of Knight Inlet noted by Mitchell during his initial field work in the region (Fig. 9), is strikingly similar to the overall density and distribution of clam terraces noted during the review of AVI for this project (Fig. 8). The formation of the ridges is likely responsible for the eventual formation and emergence of the highly productive clam flats immediately landward of the ridge. As clam terraces became increasingly more productive over time, a corresponding increase in their use and exploitation of available shellfish resources would occur, particularly given a corresponding increase over time in aboriginal settlement and subsistence. It is reasonable to expect that the density and distribution of villages and camp sites would correspond generally to *clam terrace* locations in the region. However, the degree of overall correspondence is, nonetheless, striking.

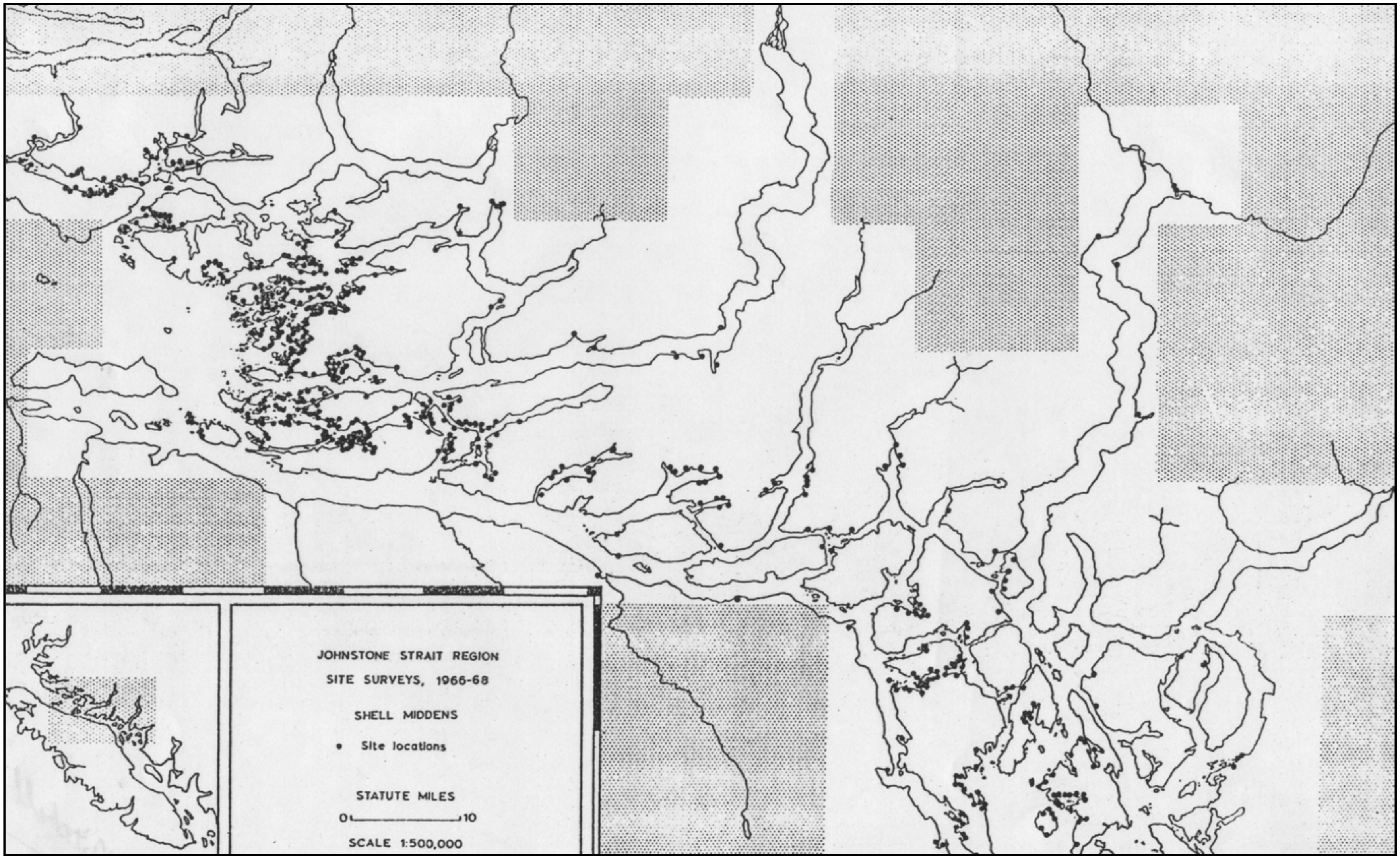

Figure 9. Shell midden sites in the Johnstone Strait area (from Mitchell 1966).

4.1 Survey Approach

A field team consisting of a coastal geologist, archeologist and marine biologist conducted a 3-day survey in the Broughton Archipelago during the low-tide window of 8-10 September 1995. Low tides reached +0.65m above chart datum (range 0.65m - 4.8m). Field observations and data recording were limited to tide levels less than 2m above chart datum.

Nine locations were visited during the survey (Appendix A) and observations on sediment distribution, morphology and associated elevations, intertidal biota and associated archeological/cultural features were noted. Specific site data is summarized in Appendix A.

4.2 Geological Observations

General field observations are listed in Table 3. Summary observations resulting from the field program are:

- the *clam terraces* are ubiquitous in this area (over 350 locations accounting for 14 km of shoreline),
- the boulder/cobble ridges associated with the *clam terraces* are surprisingly uniform, with well-sorted, well-rounded boulder/cobble sediment (~0.3m average diameter) and with bases near the zero-tide level and with crests about 1-1.5m above tide datum,
- the sand flats in the lower to middle intertidal are comprised almost entirely of biogenic sand (barnacle and shell fragments).

4.3 Biological Observations

The *clam terraces* visited were typified by **highly productive clam beds on the sandflat**. The sandflat and nearshore subtidal at the toe of the boulder/cobble ridge have a substrate of biogenic sand (shell hash). The shell hash contained a high proportion of barnacle shell, along with clam shell. Numbers of sea stars were observed at most sites: *Evasterias* were noted in the intertidal and *Pycnopodia* in the subtidal, both of which are predators to shellfish.

Historically, the large human population of the area harvested significant amounts of the shellfish and barnacles, as evidenced by extensive midden deposits in the Broughton Archipelago. Human harvest is now virtually non-existent and the sea stars are the dominant predators of the barnacles and clams, the shells remain *in situ* and the biogenic shell hash tends to accumulate at a faster rate on the terraces.

Table 3 Summary of Field Observations

Category	Observation
General	*clam terrace* features are a prominent, repeatable morphology that are sufficiently distinct to be observable from the air (Fig. 10)
	the terraces are numerous and appear to be unique to this area
	terraces are not present at stream mouths
	terraces are not present in high to moderate wave exposure areas
Ridges	distinct boulder/cobble ridges occur near the low tide line (Fig. 11)
	ridge material is well to moderately sorted boulder/cobble with a mean diameter of 0.3m (Fig, 12); boulders larger than 0.5m are very rare and where present *appear* to pre-date ridge formation
	boulder/cobble sediment is generally very-well rounded but includes some angular-type clasts (Fig. 12)
	the base of the boulder/cobble ridge appear to be at or near the "0-tide" line (Fig. 11) and the crest of most ridges is between 1-1.5m above chart datum
	ridges usually extend across embayment (Fig. 13) but it is not uncommon for them to be discontinuous; where open, we had the impression that the low part of the ridge was "up-inlet" rather than closer to the mouth
	ridges tended toward concavity across embayment (concave seaward rather than concave landward that is more typical of fish traps)
	where the ridge abuts bedrock, the boulder/cobble material overlaps onto the bedrock
	ridges are usually associated with a sandflat but not always
	ridges have the appearance of "push-type" features
Flats	flats behind the ridges are comprised almost entirely of biogenic sand (shell fragments and barnacle fragments; Fig. 15); very little mineral sand is present
	the flats typically extend from the crest of the ridge (+1-1.5m above datum) to boulder rubble or bedrock in the upper intertidal (+2.3-3m above datum)
	the flats have dense clam beds of native littlenecks (*Prototheca staminea*), butter clams (*Saxidomus giganteus)*, horse clams (*Tresus capex*) and other native species; the beds (Fig. 15) are heavily predated by starfish (but not moon snails)
	flats slope gently up from the crest of the boulder ridge; at some locations, sand is spilling through the crest of the ridge into the subtidal area whereas at other locations the ridge crest is slightly higher than the seaward edge of the flat.
	the sandflat may be free of gravel but in some locations boulder/cobble clasts may comprise up to 10-15% of the surface cover; boulders up to 2m in diameter were noted on the surface of some flats (Fig. 16)
Upper Intertidal	the upper intertidal is dominated by bedrock ramps frequently with a veneer of large boulder rubble

Figure 10. Aerial photo of Location H showing the typical morphology of a *clam terrace*. Note the apron of biogenic sand/mud in the subtidal, seaward of the

Figure 11 Ground photograph looking across the boulder/cobble ridge of Location H.

Figure 12. Close-up photograph of boulder/cobble sediment in ridge (Location C).

Figure 13. Aerial photo of ridge extending across embayment.

Figure 14 Ground photograph boulder/cobble ridge without a sandflat near Location H.

Figure 15. Close-up photograph of sandflat showing shell-hash sediment, pit and shellfish retrieved from the pit (Location C).

Figure 16.
Aerial photo of Location E, a triple ridge showing an opening to the right (interpreted as a canoe run) and scattered boulders on the associated mid-tide flat.

The boulder/cobble ridge tends to be made more obvious by the dense, dark algae cover. The lower intertidal 'band' of algae is diatom-encrusted filamentous greens or small blade reds, mixed with scattered *Fucus*. These all show-up as dark brown against the light-coloured shell hash of the terrace above or the sand apron in the subtidal. Just the coloration of the algae growing on the boulder/cobble tends to accentuate the ridge.

During the field reconnaissance, no introduced shellfish species, neither oysters or manila clams, were observed. Moon snails and *Pisaster* starfish, common shellfish predators elsewhere on the B.C. coast were not observed at any of the field locations. This observation is surprising in that both *Pisaster* and moon snails are the most common intertidal barnacle predator elsewhere on the BC coast.

4.4 Archeological Observations

Observations of the ridge formations directly associated with the *clam terraces* investigated during the field phase of the study confirmed that these features are neither contemporary nor relic stone wall fish trap sites. However, cultural modification were observed at two (Locations **D** and **H**) of the nine locations investigated in the field. At Location **D**, a single canoe run was observed at the extreme north margin of the stone ridge (Fig. 16). Evidence for the canoe run interpretation consists of the cleared pathway and adjacent small ridge formation that is roughly perpendicular to the multi-strand stone ridge formation.

At Location H, two possible canoe runs were observed, each located in the extreme lateral margins of the stone ridge formation (Fig. 10). Both pathways are clear of cobbles but there were no corresponding small ridge formations observed perpendicular to the main stone ridge formation associated with the clam terrace feature. Both pathways provide easy access to the clam flat and likely were employed by aboriginal gatherers but evidence is for this interpretation is weak.

One further observation worth noting concerns the impression that the uppermost cobbles on several of the clam terrace locations visited during the field phase appear to be the result of a "discard" activity associated with the removal of cobbles within the clam flat area and their subsequent deposition on top of the main stone ridge formation. It seems reasonable to infer that, over time, cobbles in the clam flat area would have been removed to allow easy harvesting of available shellfish resources. If cobbles were gradually removed over time, the most logical place to discard them would be on top of the existing stone ridge. Again, the evidence for this activity is weak, consisting only of perceived differences in the random-like distribution of the uppermost cobbles on the main stone ridge. This activity may have been conducted to increase the overall height of the stone wall, thereby increasing the areal extent of the most productive portion of the intertidal zone. This may have been very important if the area of the clam flat immediately adjacent to the outer ridge was productively poorer than areas higher in elevation. This is an aspect of the formation of clam terraces that should receive further study.

5.0 ORIGIN OF THE FEATURES

5.1 Geological/Oceanographic Processes

A review of existing literature on ice-related features (Section 2) does not support an "ice-origin" of the Broughton Archipelago *clam terraces*. The association of the features with low wave exposure precludes a wave-related origin. As such, there is no obvious explanation for the origin of the *clam terraces*.

Based on the observations listed in Table 3, the best explanation that is a "compound origin" involving both natural and anthropogenic processes. The natural component explains the initial origin of the features whereas the anthropogenic component explains the subsequent of the natural features. This explanation is offered as a working hypothesis, requiring further evaluation.

<u>Natural Origin - Sandflats</u>

The feature that draws our attention to the *clam terraces* is the white, shell-hash sandflat behind the ridges. Where there is a natural bench in intertidal topography, shell fragments, especially barnacle fragments, accumulate. Once sufficient material accumulates, shellfish colonize the flat, further contributing to the shell hash until the depression fills to over-flowing (Fig. 10).

Where there is no natural depression in the intertidal topography, barnacle shell fragment are deposited in the offshore near the zero tide line and are visible as a nearly continuous white "apron" in the subtidal (Fig. 10, 11). A key element in the formation of the nearly continuous apron of shell material in the offshore is low wave exposure so that the ability to re-suspend and disperse the shell hash to the "offshore" is minimal; that is, the contribution of shell material to the nearshore (immediate subtidal) exceeds the dispersal rate.

Where there is no natural depression *at the mid-tide level* there will not be any extensive accumulation of shell hash. Benches in the upper intertidal often have a bleached-white accumulation of shell but do not support a substantial infauna. Benches in the lower intertidal would be quickly filled and rarely visible.

<u>Natural Origin - Boulder Ridges</u>

Field reconnaissance included locations where low-tide boulder ridges were both very distinct and subtle. Locations were visited where a discontinuous boulder veneer covered the bedrock (Fig. 14). The significant impressions of the ridges gained from the field reconnaissance included:

- in general, the ridges seem to "crest" at the 1m to 1.5m elevation level and exhibit a steep seaward face,

- there is variation, however, with a continuum of ridge morphology with both higher and lower crest elevations; the ridge crest surveyed at Site I is up to +2m above datum (with little sand accumulation) and extends into the subtidal (Fig. 18).

- ridge morphology also varies according to "degree of closure" across small to large embayments or "catchment areas". Small embayments are typically enclosed by a continuous boulder/cobble ridge of relatively uniform height whereas larger embayments may not be completely enclosed as ridges peter out near the mid-point or near one side of the embayment.

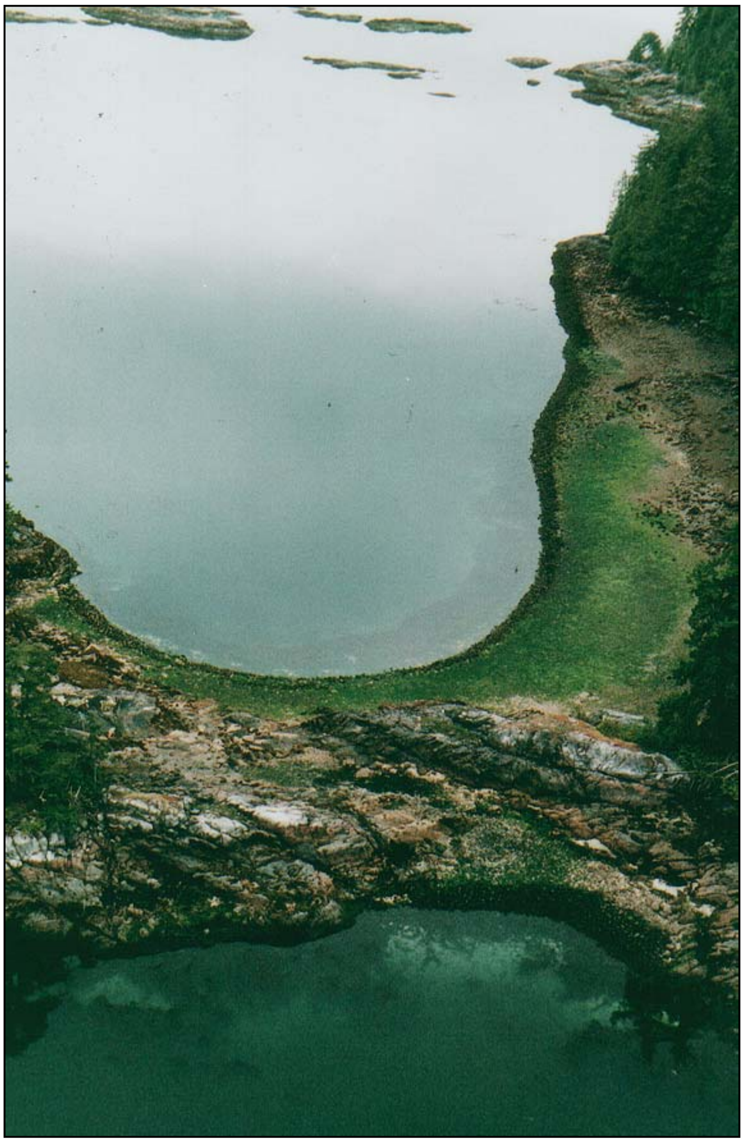

Figure 17.
Aerial photograph of Site I showing subaqueous extension of ridge.

No definitive explanation of ridge origin is offered at this point in the study. The ridges are different morphologically than ice-pushed or ice-rafted ridges. We considered a kelp-transported origin (i.e., boulder/cobble transport due to stranding of kelp holdfasts) but the size of the clasts in the ridge appears too large for being transported by kelp and we did not observe any attached, stranded holdfasts, although we did observe unattached kelp fronds on the flats.

Are the ridges in fact ridges or are they boulder/cobble veneers that appear as ridges due to the sandflat formation in the mid-intertidal? We were unable to probe through the sandflats on the landward side of the ridge so can only infer the landward slope; the protrusion of isolated boulders through the sandflat suggests the slope on the landward side of the ridge is less steep than that on the seaward side, which is near the angle of repose (Fig. 18). At some sites the crest of the ridge was higher than that of the sandflat, creating a localized depression landward of the ridge.

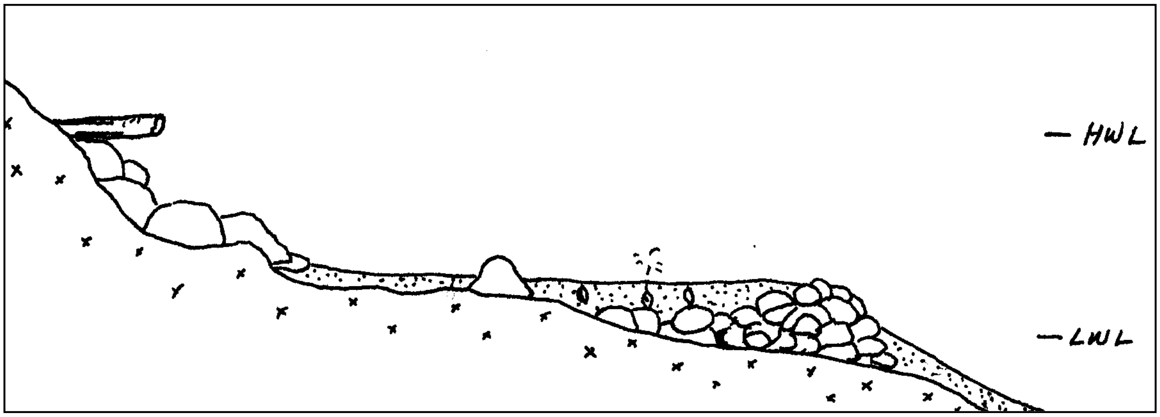

Figure 18. Hypothetical profile across *clam terrace*.

Ridge morphology at all of the sites appeared "natural" albeit of unknown origin. At several locations the ridges

appeared to have been modified in one or both areas adjacent to bedrock margins to facilitate access to the clam flat by canoes. In addition, the uppermost cobbles appear to have been the result of discard activity conducted over time by users of the clam flat. The sandflats likely were cleared of cobbles and small boulders over time as shellfish resources were exploited, and the most convenient location to discard cobbles was on top of the existing boulder/cobble ridge of the *clam terrace*. This observation has led us to the theory that (a) the ridges were originally a natural feature which created sandflats of high clam productivity and (b) ridges were likely modified by aboriginal gathers to enhance clam productivity.

5.2 Cultural Modification

Archaeological observations noted above at selected clam terrace locations do not provide any insight into the possible origin of these features. Instead, the observations noted in the field clearly take the form of modifications to existing stone ridge structures. Oral historical research is currently being conducted (but not yet complete) to probe and document, if possible, aboriginal knowledge of prior use of and modification to these structures. Initial inquiries in this area have not produced any substantive results to date.

6.0 CONCLUSIONS

1. *Clam terraces* are a common feature of the Broughton Archipelago area. Although there is variation, they are remarkably uniform in morphology with a boulder/cobble ridge in the lower intertidal, a biogenic sandflat in the lower to mid intertidal and a boulder veneer over bedrock ramp in the upper intertidal.

2. The origin of the boulder/cobble ridges in the lower intertidal zone is uncertain. The ridges do not appear to be forming at present and are considered *relict* features, possibly of sea-ice-related origin.

3. The distribution of *clam terraces* is remarkably similar to the distribution of archeological sites. However, no direct cause-effect linkage is known.

4. At present, the clam terrace features are viewed as natural in origin but may have been subjected to some degree of modification over time by aboriginal gathers.

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APPENDIX A

Field Survey Data
(Survey locations are noted in Figure A-1)

Table A-1 Summary of AVI tape Times and Slides for Survey Locations

Site	Location	Tape No., Time	Aerial Slide #	Notes
Location A	head of False Cove	Tape #2-6 17:08:47	--	--
Location B	south entrance Grebe Cove	Tape #2-11 15:49:56	roll III 18 #26	just north of Site B
Location C	inside south entrance Grebe Cove	Tape #2-11 15:50:22	--	two profiles measured
Location D	south entrance Waddington Bay	Tape #2-11 15:53:26	roll III 18 #29 & 30	'triple berm'
Location E	near head Waddington Bay	Tape #2-11 15:53:53	--	--
Location F	inside Site C in Grebe Cove	Tape #2-11 15:50:35	--	midden site
Location G	south of entrance to Waddington Bay	Tape #2-11 15:53:10	roll III 18 #28	profile measured
Location H	islet south side of Tracey Island	Tape #2-11 16:52:48	roll III 20 #1 thru 4	profile measured
Location I	north side Mars Island	Tape #2-11 16:56:20	--	two profiles measured

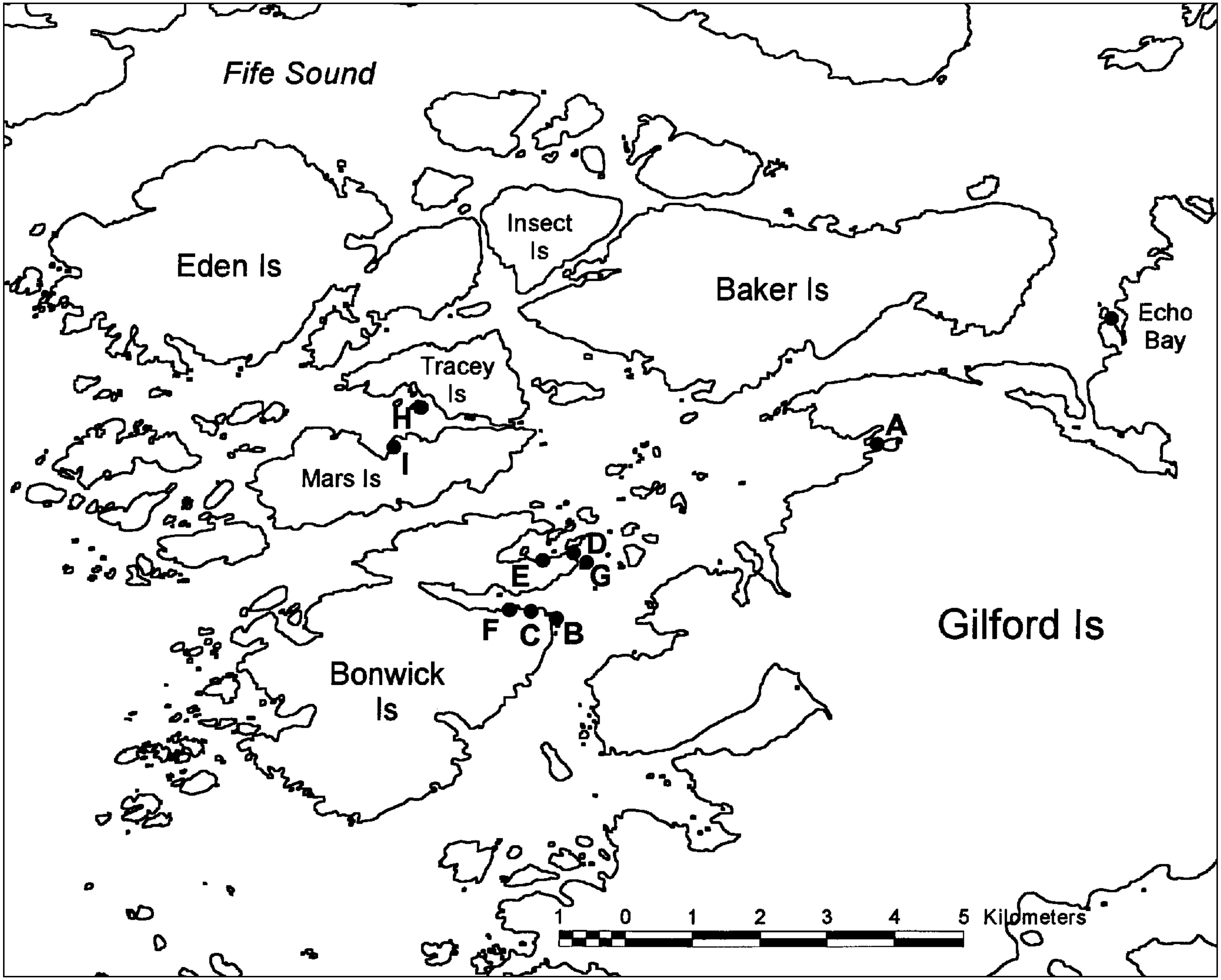


Figure A-1. Map of locations visited during the 3-day field survey.

Location A (AVI Site 6)
False Bay, Gilford Is (50° 44.00’N, 126° 32.68’W)

Geological Description

- small “bench” or clam terrace feature on the central finger of False Cove
- ridge has steep seaward face
- numerous boulder/cobbles on flat
- boulder/cobble rubble along upper intertidal
- numerous, large, whole shells on flat surface

Biological Description

- incredible number of clams: horse, butter, native littleneck
- hash of huge-shelled barnacle, clams. Eelgrass flats at head of the bay
- photos of predator stars (MM1-11) and pan across boulder ridge (MM1-12&13)
- stars seem to be all *Evasterias*, not *Pisaster*

Location B (AVI Site 55)
South Entrance to Grebe Cove, Bonwick Is (50° 42.41’N, 126° 36.55’W)

Geological Description (JRH1 - 1,2)

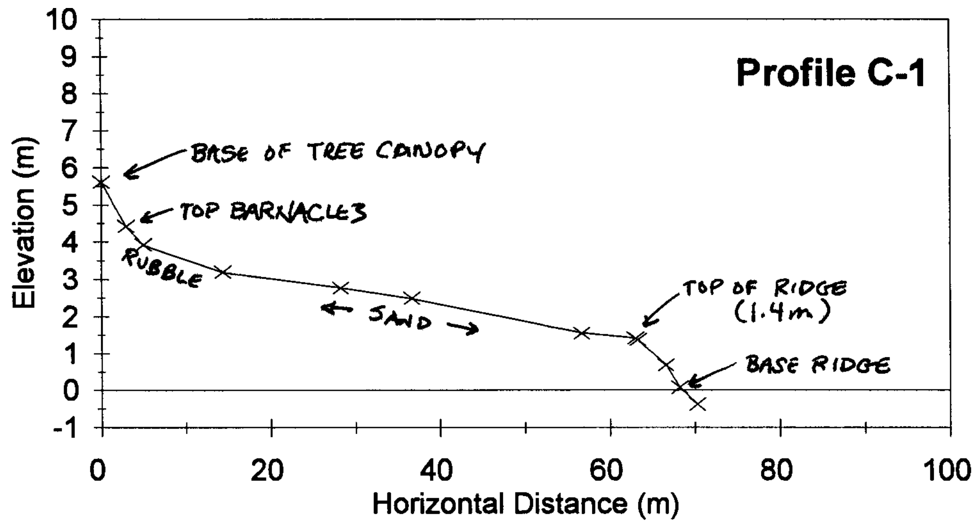
- bedrock outcrop breaks embayment into north and south components
- ridge does not have steep seaward face
- very narrow flat to south (~5m)

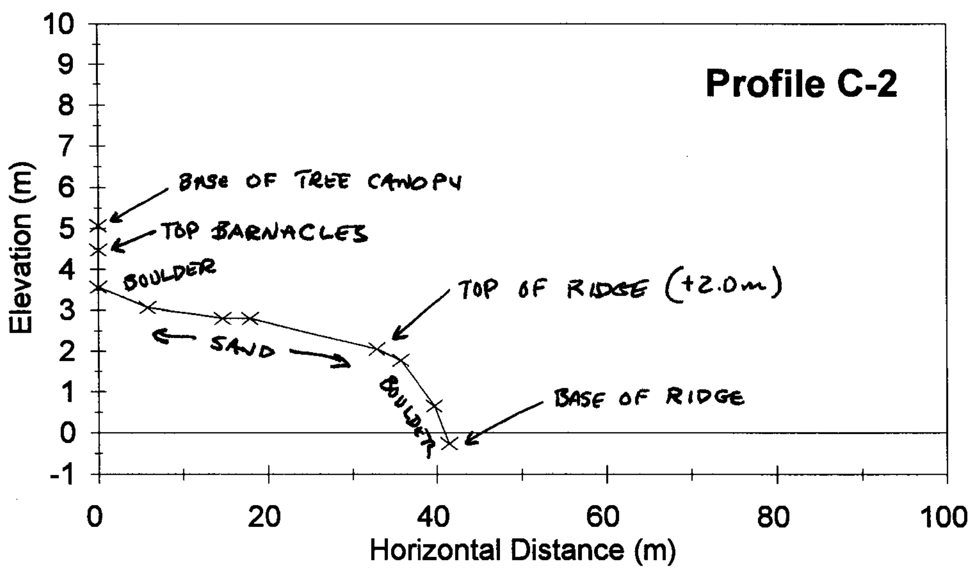
Biological Description

- photo MM1-14: detail at waterline, ULVA/REDS band, red *Mastocarpus*, dark mat of diatom on filamentous greens dominates the band, *Agarum* submerged in water, on biogenic sand, also gumboot chiton, *Cucumaria miniata*
- photo MM1-15: view across berm
- photo MM1-16: detail of transition of ULVA to FUCUS band: on granitic bedrock outcrop, large *Semibalanus cariosus* (>2cm tall), *Ulva, Fucus, Cryptosiphonia, Katharina*

Location C (AVI Site 58)

South Side of Grebe Cove, Bonwick Is (50° 42.55'N, 126° 36.95'W)





Geological Description (JRH1 - 3 to 6,31 to 36; JRH2 - 1 to17)

- very protected tidal flat with large bedrock outcrop dividing into west-facing (C-1) and north-facing (C-2)
- granitic bedrock and gravel

- mean boulder size 30cm; maximum boulder size 40-50cm
- ridges comprised of sub-rounded boulder/cobble
- flat entirely shell hash

Biological Description

- photo MM1-17: view at waterline and below: shell hash, dozens of *Pycnopodia*, Laminarins
- photo MM1-18: detail, on boulder ridge, green filamentous with covering of diatoms: not *Enteromorpha*-type, appears to be a type of *Cladophora* (separate strands, branched, tufted, wiry texture-but grows as flat mat over boulder. Not tufted clumps as *Cladophora* of higher intertidal)
- zillions of clams on the terrace, no sand: it's all shell hash
- photo JRH 1-31: at waterline and base of berm: laminate browns, *Ulva*, *Pycnopodia*, shrimps
- photo JRH 1-32 view up profile C-1, from waterline to high water
- photo JRH 1- 33 & 34: views across berm from rock outcrop
- photo JRH 1-35: view from mid-terrace towards waterline
- photo JRH 1-36: bioturbations, shell hash and shell at top of berm, lower platform elevation

On Line C-2
- photo JRH 2-1: On Line C-2: view down profile from HHW towards the waterline
- photo JRH 2-2: platform above the ridge: more boulder and *Fucus*, also narrower than on Line C-1
- photo JRH 2-3: shell hash, pit, near crest of boulder berm
- photo JRH 2-4: view of boulder ridge and waterline
- photo JRH 2-5: view across berm from outcrop at one end
- photo JRH 2-6 to 9: views of Line C-1, #9 is incipient ridge near Line C-1
- photo JRH 2-10: Pit detail. well-drained shell hash granular, mostly native littleneck clams, one butter clam, several small *Macoma*. 2m upslope from top of berm. ?*Upogebia*? tunnels, few worms
- photo JRH 2-11: Pit in mid-section, ~7m upslope from berm. seepage, blacker, muddier substrate: 20 butter clams, 20 littlenecks
- photo JRH 2-12: Pit near top of shell-hash section, wet pit, dark black mud, about 20 little necks, 4 live butter clams, 4 dead horse clams in situ
- photo JRH 2-13: uppermost pit on Line C-1: very wet, anoxic, near intersection of Line C-1 & C-2, one large and one small ?*Mya arenaria*?, 2 littlenecks
- photo JRH 2-14: dry pit on Line C-2, mostly dead shells in shell hash, 2 or 3 live littlenecks, about 5m upslope from top of berm
- photo JRH 2-15&16: kelp on HHW swash, bulbs and holdfasts. Mechanism for transport?

Cultural Description

Site D (AVI Site 66)

South Side of Waddington Bay, Bonwick Is (50° 43.00'N, 126° 36.45'W)

Geological Description (JRH 1 - 14 &15)

- triple ridge evident in aerial video and aerial slide
- ridges not very distinct on ground
- ridge open at north end (canoe run?)
- seaward face of ridges not steep
- large scattered boulders on flat
- algae cover on flat gives dark appearance
- granitic bedrock

Biological Description

- photo MM1-19: view across berm, towards SE
- photo MM1-20: detail of Fucus-barnacle band, (upper intertidal) huge *Semibalanus carriosus*, much of the shell hash at base of rock outcrop looks like barnacle, lots of live limpets
- photo MM1-21: detail of Fucus band near the waterline, Ulva greens, diatom-encrusted filamentous greens *Cladophora*-type. Lots of interstitial spaces under boulder with black-tipped shore crabs, shell hash
- photo MM1-22: detail of odd-looking *Halosaccion*
- photos MM1-23 & 24: views across berm. On upper flats: diatom threads/mats look like brown filaments, *Ulva*. Collected other *Cladophora* from upper intertidal, on bedrock outcrop and confirmed ID.

Cultural Description

- ridge cleared of boulder/cobble at northern end to allow canoe access

Location E (AVI Site 67 or 68)

South side of Waddington Bay, Bonwick Is (50° 43.93'N, 126° 36.88'W)

Geological Description (photos JRH1 - 17,18)

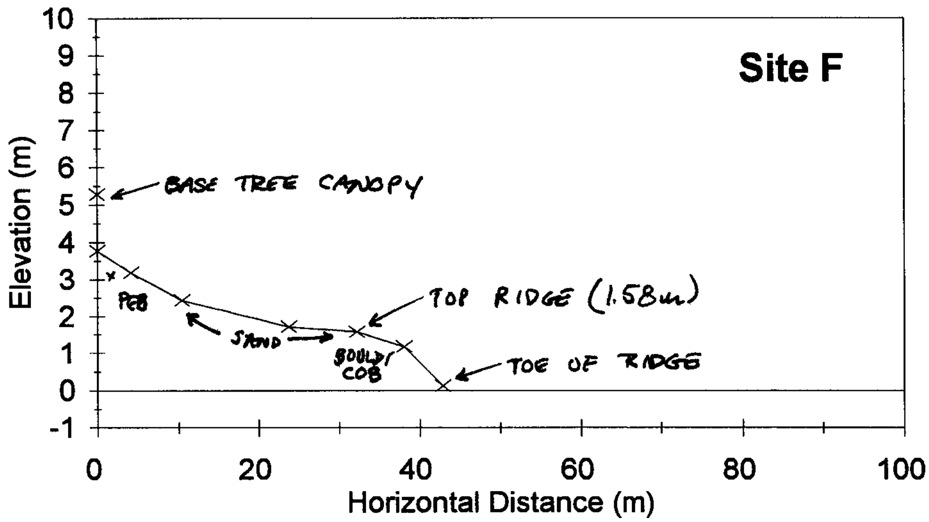
- small pocket beach, 20m long; flat <5m wide
- steep seaward side to boulder ridge

Biological Description

- photo MM1-25: many *Pycnopodia* on subtidal slope, biogenic shell hash. In subtidal: *Agarum, Tealia* anemone
- Fucus/barnacle band is sparse, lots of diatom mat on stringy, filamentous greens

Location F (AVI Site 60)

South Side of Grebe Cove, Bonwick Is (50° 42.51'N, 126° 37.28'W)



Geological Description (photos JRH2 - 20 to 23)

- small, 30m long pocket beach
- ridge not steep on seaward side
- shell hash spilling through crest of ridge

Biological Description

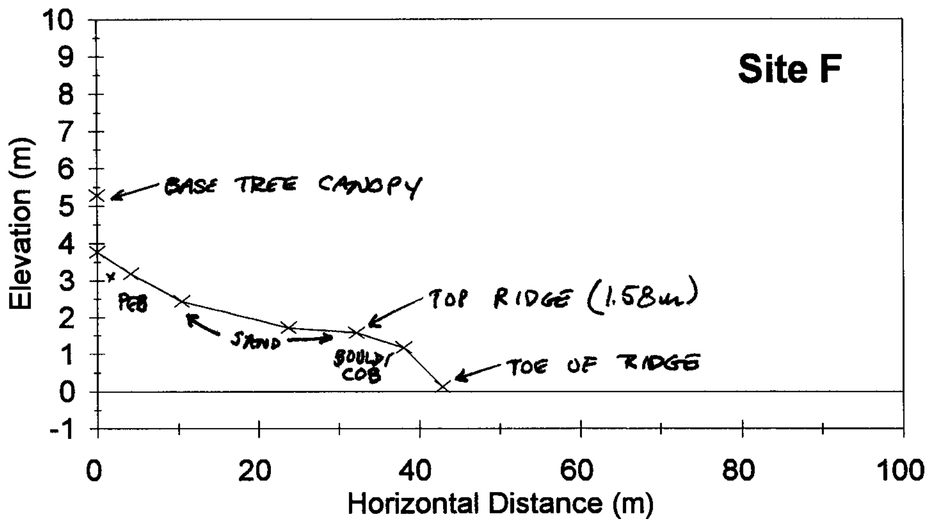
- platform fine silt, ridge more rounded stones and less slope than at Stop C
- sandflat covered with diatom mat

Cultural Description

- shell midden in backshore suggest location was a shellfish processing site

Location G (AVI Site 65)

South Entrance to Waddington Bay, Bonwick Is (50° 43.90'N, 126° 36.45'W)



Geological Description (photos JRH2-24 to 34)

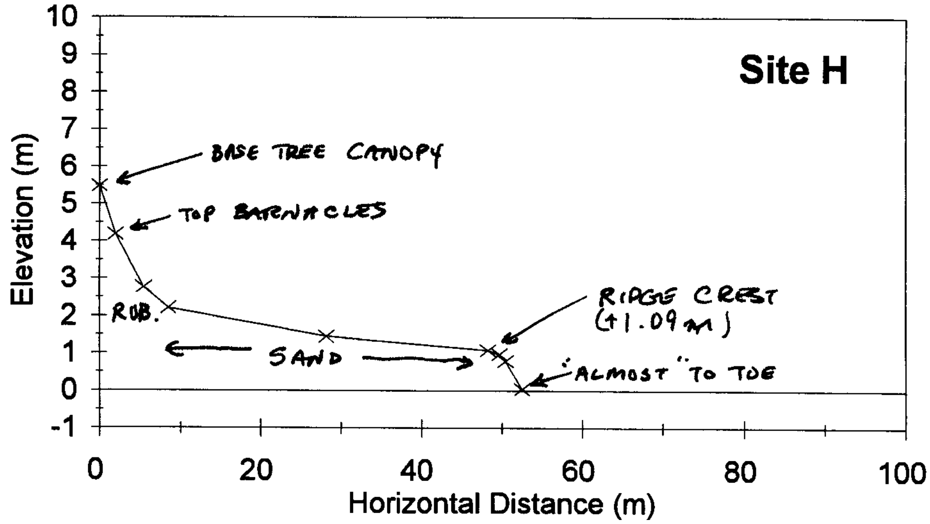
- long ridge (~60m) but higher at south end (~+0.5m)
- mean diameter of boulder 20-25cm
- granite with intrusive dykes
- sandflat is 75% covered w peb/cob that are barnacle encrusted
- more boulder/cobble on flat than at other sites

Biological Observations

- photo JRH2-24: view across platform
- photo JRH2-25: boulder and cobble at waterline
- photo JRH2-26: another view across platform
- photo JRH2-27: *Fucus* to waterline on boulder ridge, with *Balanus glandula*
- photo JRH2-28: on platform, *Enteromorpha* encrusted with diatoms, also Ulva. Overall looks dark brown , same colour as the *Fucus* which goes to the waterline
- Ulva band shows filamentous greens also
- photo JRH2-29: at time 1013 waterline of incoming tide crosses the north half of the berm. sough end is still 20-30cm above WL
- photo JRH2- 30 to 33: showing incoming tide flooding the berm
- after two days of observations, no evidence of any evidence of moon snails: no shells, no drilled clams, no collars.

Location H (AVI Site 126)

Small islet on South Side of Tracey Is (50° 44.10’N, 126° 38.40’W)



Geological Description (photos JRH3-15 to 36)

- very prominent ridge, flat system; surveyed closely during aerial overflight
- ridge about 30-40m long
- very steep seaward side
- very prominent, “white” sandflat
- few boulders of cobbles on flat
- site has the appearance of being “well-tended”, neat and organized
- boulder ridge on seaward side has no associated flat and is higher elevation (photo JRH3-27)

Biological Description

- have aerial close-up of this site
- dropping tide (0705) exposes open canoe run-like feature at each end of the ridge
- large *Pycnopodia* at waterline and below
- ridge appears to be smaller boulder than Site C, ridge covered with diatom-hair
- stars on vertical rock, on bedrock ramp are not *Pisaster*, are orange or green long-armed *Evasterias(?);* No *Pisaster* seen.
- the shell has on terrace: barnacle, lots of littleneck shells, some butter clams
- evidence of animal digging in upper (?raccoon?) and seastar digging in lower (print photo MM2-8)
- no moon snails
- the waterline band: toe of the berm, *Agarum* with diatoms, *Ulva*
- red rock crab, juv. dungeness, no *Pisaster, Cucumaria*, a few tufts of *Mastocarpus*-type, terebellid worms. (Note this is very different substrate than on the terrace)

- the clam flats: only scattered few boulders, seeping water in lower quarter,
- surface shells are horse clams, butter clams, littlenecks (more littlenecks up higher), mounds of shell hash from bioturbation.
- Hardly any algae on flats - scattered Ulva only and diatom mat/scum
- a few Upogebia moults

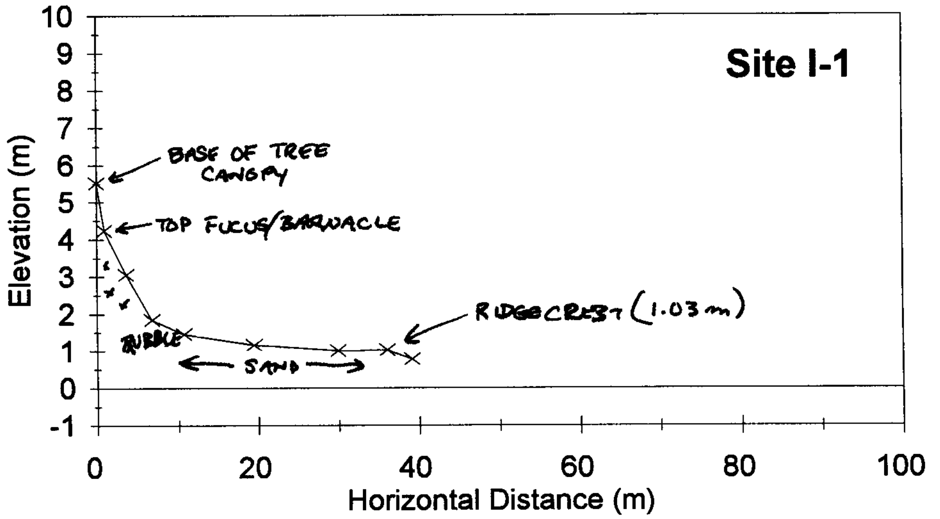
- photo JRH 3-15: view across berm
- photo JRH 3-16: *Cucumaria* and scum on berm, near waterline
- photo JRH 3-17: *Pycnopodia* and its excavated pit, lower terrace near top of the berm
- photo JRH 3-18: waterlogged lower terrace
- photo JRH 3-19: view from waterline up, across the terrace
- photo JRH 3-20 & 21: detail of the Fucus/barnacle band. Includes *Mytilus*, patchy *Fucus*, large *Semibalanus cariosus*, lots *Balanus glandula*, mat of *Enteromorpha*-type filamentous greens, diatom brown on filaments, *Cladophora* in upper, some Ulva
- boulder on shell hash and bedrock in this upper band
- photo JRH 3-22: pit in lower terrace, very wet. 3 littlenecks, 2 juv. dungeness, fine shell hash, butter clam shells, lots of worms, 2 shrimp holes
- photo JRH 3-23: another wet pit, 5m up from berm, 12 littlenecks, 1 small ?Mya?, 1 cockle, 2 butter clams. Lots tube worms and other worms
- photo JRH 3-24 & 25: view of berm
- photo JRH 3-26 to 28: nearby incipient and other boulder beach forms
- photo JRH 3-31: pit in mid-terrace, wet, large *Nereis* worm, *Upogeba* (live), 1 large butter clam and 2 smaller butter clams, 8 littleneck clams. Sediment is darker than previous lower pits - looks like less shell and more sediment
- photo JRH 4-1: pit at toe of upper bedrock/boulder scree: base of Fucus band. Lots of small littlenecks (about a dozen), well drained (not water-filled) but much more clay

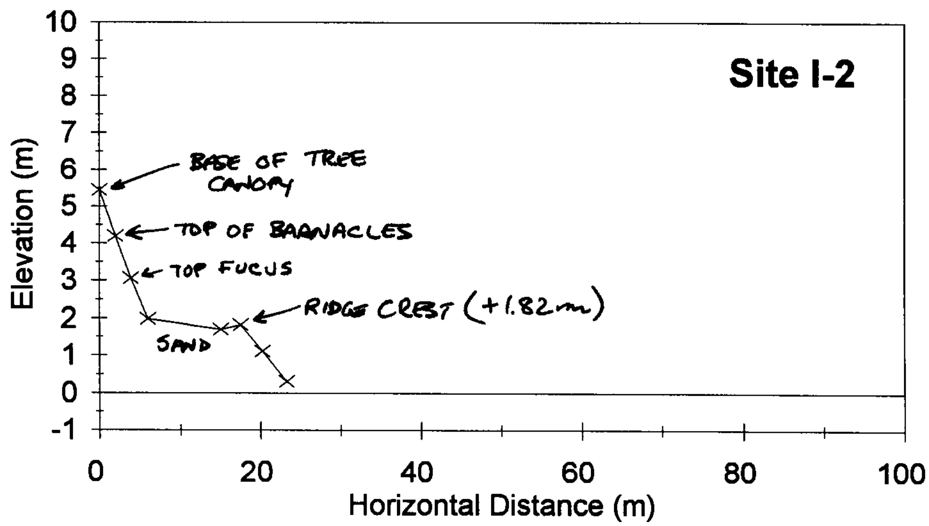
Cultural Notes

- both ends of the ridge at this site may have been modified to permit canoe access; boulder/cobble ridge does not lie against the bedrock outcrops.

Location I (AVI Site 136)

Large embayment on north shore of Mars Is (50° 43.75'N, 126° 38.80'W)





Geological Description (photos JRH4-7 to 13)

- very long ridge the extends from mid-intertidal into subtidal and possible extends across embayment
- clearly related to bedrock bench (i.e., natural not cultural)
- granitic bedrock
- ridge is steep on seaward face but not steep on landward side
- mean diameter of boulder 30-40cm

Biological Description

- looking for the very large berm from the AVI mapping; we find a high-elevation berm which is broad and strongly dipping at one end. (photo MM2-11)
- photo JRH 4-9 & 10: looking across the berm
- photo JRH 4-11 & 12: upper berm edge detail, diatoms encrusted brown on *Enteromorpha*-type, over mineral clay and shell hash with burrows
- photo JRH 4-13: in Fucus/barnacle band detail, lots of limpets, *Semibalanus cariosus, B. glandula*, scattered *Fucus*, large rubble and blocks, lots of Thais
- photo JRH 4-14: across berm at lower elevation-end-of-berm: eelgrass at this end, tide looking in by large boulder & blocks.
- photo JRH 4-15: Near first profile at 1000 the tide spills onto flats
- photo JRH 4-17: near line I-2: top of berm pit-sandy and dry, huge tunnel-holes (like shrimps) and a few tiny clams a.k.a.: not clam habitat
- photo JRH 4-18: pit near top of terrace, between the two profile lines, muddy sediment between large shell fragments (barnacle & clam) - not a shell hash as seen at last sites-bigger pieces. Still lots of large tunnels and a few littlenecks