THE QUATERNARY GEOLOGIC HISTORY OF LADY FRANKLIN BANK, SOUTHEASTERN BAFFIN SHELF, N. W. T.

by

Daniel Brian Praeg

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B.Sc. HONOURS THESIS

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ABSTRACT

The Lady Franklin Sand and Gravel is an informal term for a compositionally sand and/or gravel surficial sediment unit of the southeastern Baffin Shelf, delineated on the basis of grab samples and acoustic data by Praeg and MacLean (in preparation). The unit tends to occur above a bathymetric depth of about 200 m below which there is often surficial till of the Baffin Shelf Drift, and above which there is either (1) thin sand and gravel over thick tills, (2) thin sand and gravel over bedrock, or (3) an intermediate thickness cover for which it is uncertain whether there is thin sand and gravel over thin till, or solely thick sand and gravel. The Lady Franklin Bank area is an example of the latter case. In this area, the sand and gravel is overlain or grades into the silty/clayey sediments of the restricted Monumental Basin.

Twenty-five randomly distributed surficial van Veen grab samples are available from the unit in the Lady Franklin Bank area. These had undergone grain size analysis prior to inception of the thesis, and were subsequently submitted to detailed lithologic and textural analysis of three selected grain size intervals: gravel (-5Ø to -3Ø), coarse sand (-2Ø to 0Ø), and fine sand, (2Ø to 3Ø).

Grain size distributions indicate assemblages dominantly bimodal between gravel and fine sand, with a silt/clay mode of variable importance. Grain size parameters across the study area indicate a general coarsening with increasing depths, except for two coarse grained medium depth samples off Loks Land. Hydraulic interpretation indicates currents of ~ 20 to 35 cm/s are required to mobilize the fine sand modes, values in the range of existing oceanographic currents.

Lithology of the three selected intervals of the sediments are dominated by crystalline siliclastic material and limestone, with minor uncertain brown siltstones and very minor quartz sandstones, largely reflecting the underlying Pre-Cambrian granites and gneisses and Ordovician limestones of the Lady Franklin Bank/Monumental Basin bedrock. Lithologic distributions of all three selected intervals are non-random, and similar, showing a relation to the bedrock adjacent to bathymetrically shallow areas, (< 150 m) and no relation to the bedrock over deeper areas.

Textural study of the three grain intervals delineates the presence of a distinct grain surface history comprised of an older, rounded, low relief surface, broken by a younger, angular high relief surface, which has been subsequently slightly modified by rounding. Entirely young surface grains are most common, followed by grains exhibiting both the old and new surfaces and entirely old surface grains. Scanning Electron Microscope study of - 20 to 00 quartz grains also recognizes the surface history, although it is confused by silica precipitation/solution features. Environmental discrimination indicates that the old surface is of the aeolian, subaqueous, and possibly source material environments, while the new surface is of the glacial environment. The new surface has been modified by rounding and surface forms of the subaqueous environment.

Roundness distributions for the new surface are non-random, and show a noticeable increase in roundness modification with increasing depth.

The evidence indicates a probable relative sea level low of 100 to < 150 m to produce the old surface, followed by ice advance (glaciation) to produce the new surface, and the observed lithologic distribution. The resulting till was modified and is probably still being modified by oceanographic bottom currents, which have decreasing strength to the west (decreasing depths), thus producing the existing grain size and roundness distributions.

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Dr. P. Hill provided appreciated direction and assistance in calculation of the sedimentary parameters, as well as an illuminating afternoon of opinions on the SEM work.

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ESTIMATE OF TIME SPENT ON FACETS OF THE THESIS

Data Collection	0 (already done)
Sieving	25
Visual Observation (texture, lithology)	50
SEM Observation (texture)	25
Calculations, Plotting Rough Figures	15
Writing	75
Drafting	15
TOTAL	205 hours

I. INTRODUCTION

(1) Purpose and Methods

Recent mapping on the southeastern Baffin Shelf (Figure 1) (Praeg and MacLean, in preparation) has delineated several surficial sediment units, among them a sand and/or gravel unit informally termed the Lady Franklin Sand and Gravel after the area in which it is most extensively developed, the Lady Franklin Bank. Several van Veen clamshell grab samples are available from the unit in this area. This thesis aims to determine the origin of the sand and gravel unit in the Lady Franklin Bank area, and hence examine the Quaternary geologic history of part of the southeastern Baffin Shelf, through lithologic and textural studies on the sediments as made available from the grab samples.

(2) Location of Study Area

The area of study of this thesis is shown in Figure 1, and is hereinafter referred to as the Lady Franklin Bank area. The Lady Franklin Bank area was chosen for this study for three main reasons. Firstly, it represents the most areally extensive development of the Lady Franklin Sand and Gravel on the southeastern Baffin Shelf. Secondly, it has the most samples per unit area of any development of the sand and gravel on the shelf. Thirdly, it is underlain by at least two distinctive bedrock lithologies, allowing evaluation of sediment lithology with respect to bedrock lithology.

(3) Data

The data used in this thesis was generously made available by the Bedford Institute of Oceanography (BIO), Atlantic Geoscience Centre, Regional Reconnaissance division, at the onus of Mr. Brian MacLean. The data consists of twenty-

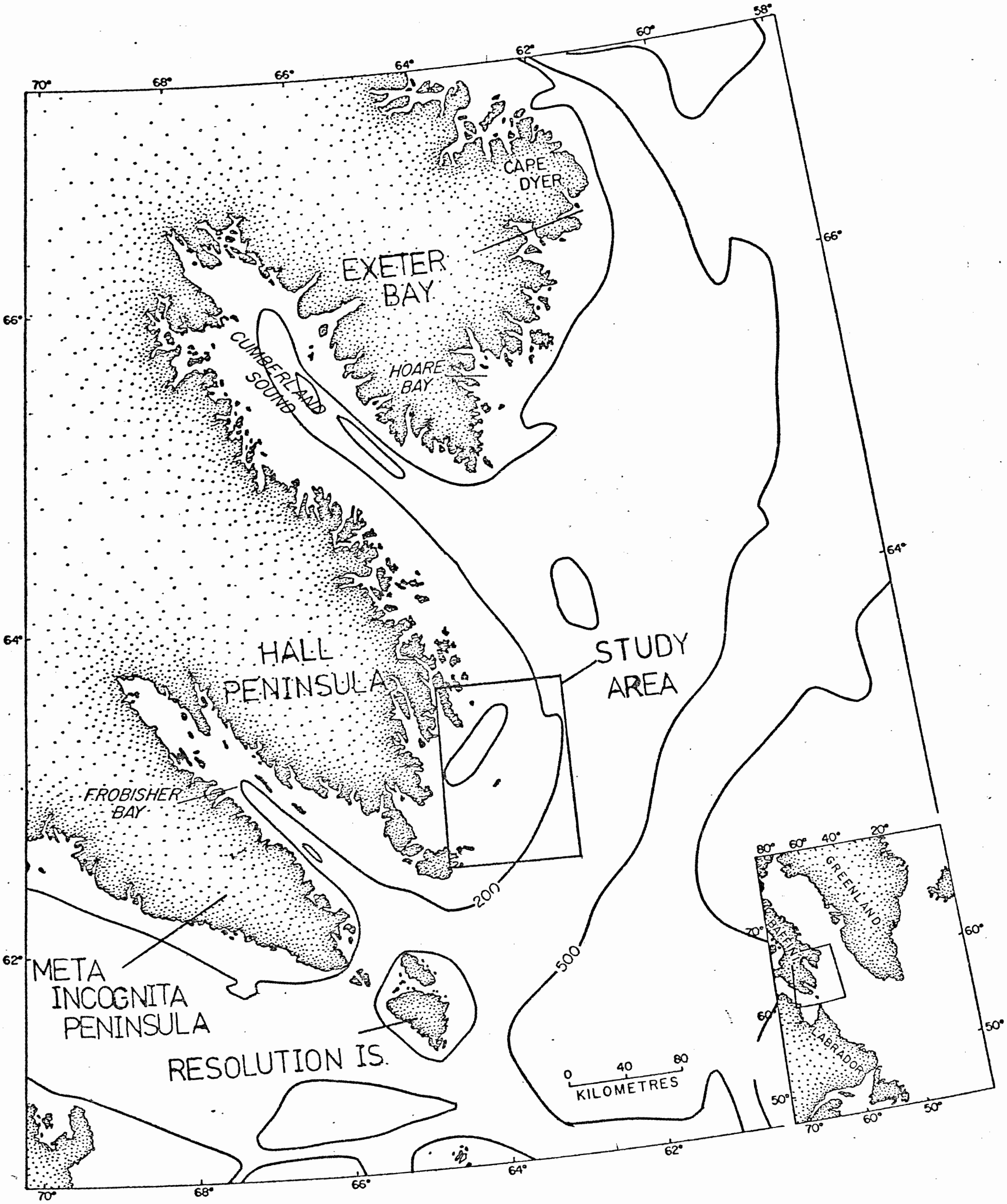


FIGURE 1 - Map of the southeastern Baffin shelf, showing the location of the shelf in the Canadian eastern Arctic, general bathymetry of the shelf, location of places mentioned in the text, and the location of the study area.

three van Veen (clamshell) grab samples collected on various BIO cruises from 1975 to 1981. These samples are shown with regard to location in Figure 2, and listed along with depth, cruise number, unit, and location in Table 1.

Prior to the undertaking of this thesis, the samples had all been subjected to grain size analysis, either in the sediments laboratory at BIO or by consulting firms. The resulting grain size data has also been utilized in this thesis.

All other data presented or used in this thesis is the result of work done by myself during the course of the thesis, except where otherwise indicated. In completing the Scanning Electron Microscope (SEM) studies, I gratefully acknowledge the advice and occasional guidance of B. Deonarine of BIO; however, the interpretation presented is my own.

II. BACKGROUND

(1) Bathymetry

Between Cape Dyer in the north and Resolution Island in the south, the Baffin Island continental shelf margin sweeps seaward to produce the broad crescentic platform of the southeastern Baffin shelf (Figure 1). This southeastern shelf is in distinct contrast to the characteristically narrow (< 50 km), shallow (< 200 m), trough-dissected shelves to the north along northeastern Baffin Island and to the south along eastern Labrador. It can be roughly physiographically divided into a narrow (usually < 50 km), shallow (< 200 m) inner shelf (outlined by the 200 m contour on Figure 1) and a wide (up to 180 km), deep (> 250 m to < 600 m) outer shelf (outlined by the 500 m contour on Figure 1), which are separated by a 'steep' slope (sometimes referred to as the continental slope, e.g. Kranck, 1966). Both the inner and the outer shelf possess a relatively subdued topography, lacking the characteristic bank and saddle topography of shelves to the north and south. The prominent marginal trough of the Labrador Shelf is also

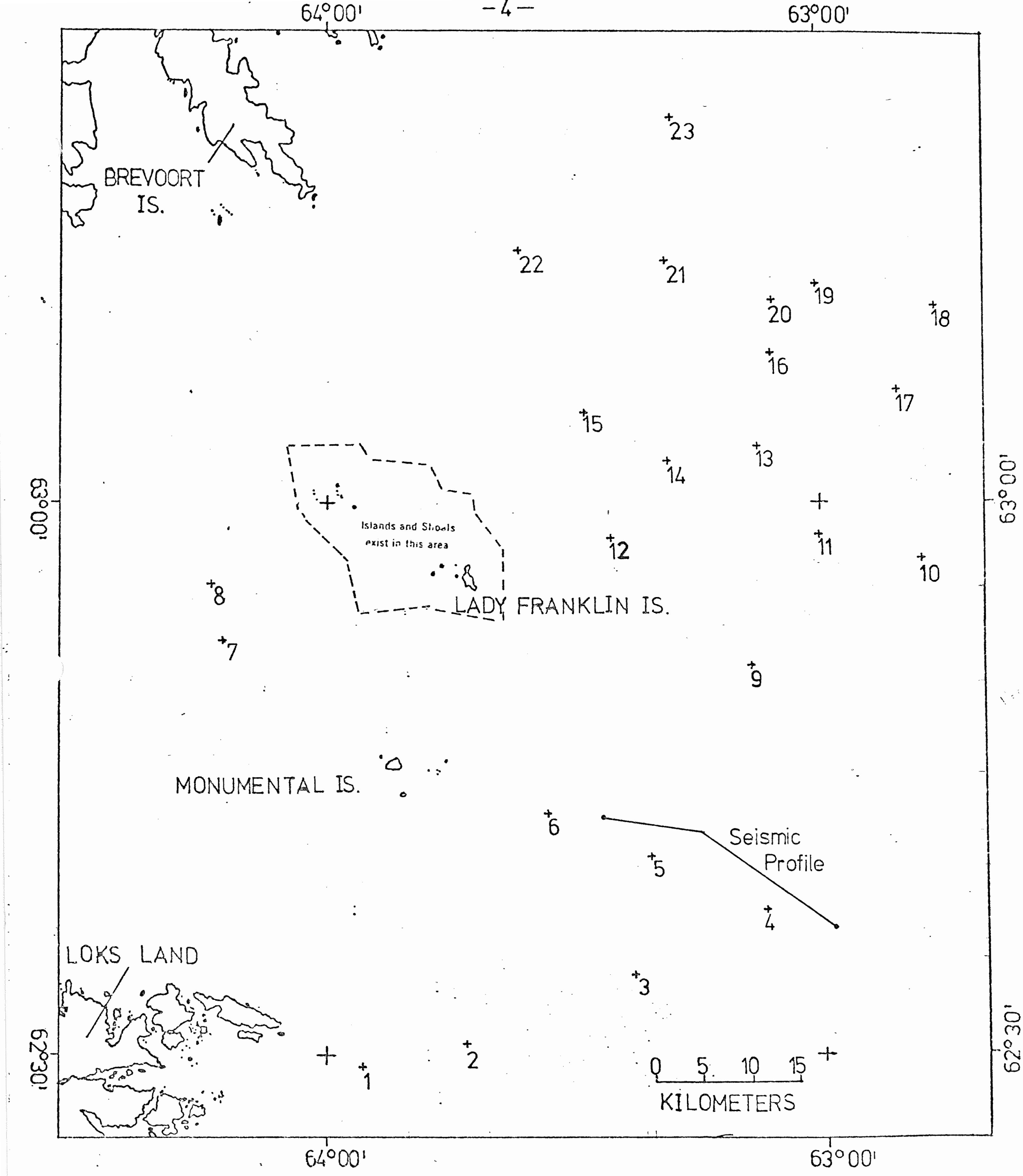


FIGURE 2 - Study area (see Figure 1 for location), showing the location of the surficial grab samples used in the thesis. See Table 1 for latitude/longitude positioning. The seismic profile line is that of Figure 7.

SAMPLE	BIO NUMBER		WATER	LOCATION		GRAIN SIZE ANALYSIS				UNIT
	Cruise	#	DEPTH	Latitude	Longitude	Gravel	Sand	Silt	Clay	
1	81-045	42	@140m	62 29.3'N	63 55.7'W	35%	65%	0%	0%	S&G
2	81-045	43B	@160m	62 30.6'N	63 43.6'W	13%	87%	0%	0%	S&G
3	76-029	13	201m	62 34.5N	63 23.5'W	14%	86%	0.1%	0%	S&G
4	81-055	28	220m	62 38.0'N	63 06.0'W	62%	37%	0.4%	0.7%	S&G
5	75-009	3	206m	62 40.9'N	63 20.3'W	--	--	--	--	S&G
6	81-055	44	@160m	62 43.2'N	63 33.2'W	--	--	--	--	S&G
7	81-055	42	100m	62 52.3'N	64 13.8'W	1.5%	78%	13%	8%	MBS
8	81-055	41	150m	62 55.4'N	64 14.4'W	7%	78%	10%	5%	MBS
9	81-055	32	150m	62 50.8'N	63 08.0'W	50%	49%	1%	0%	S&G
10	81-055	31	205m	62 56.8'N	62 47.7'W	0%	96%	2%	2%	S&G
11	77-027	29	183m	62 58.3'N	63 00.8'W	0.4%	88%	6%	5%	S&G
12	75-009	4	157m	62 58.2'N	63 26.1'W	1%	90%	7%	2%	S&G
13	81-055	34	150m	63 03.0'N	63 07.8'W	--	--	--	--	S&G
14	81-055	33	146m	63 02.2'N	63 18.8'W	76%	23%	0.6%	0.6%	S&G
15	81-055	51	160m	63 04.8'N	63 29.0'W	3%	93%	2%	3%	S&G
16	81-055	35	137m	63 08.0'N	63 05.8'W	0%	83%	10%	7%	S&G
17	81-055	50	190m	63 06.0'N	62 50.0'W	17%	70%	8%	6%	S&G
18	76-029	49	218m	63 10.5'N	62 46.2'W	70%	29%	0.2%	0%	S&G
19	77-028	28	179m	63 11.9'N	63 01.0'W	0.4%	83%	11%	5%	S&G
20	75-009	9	176m	63 11.1'N	63 06.2'W	77%	20%	2%	1%	S&G
21	81-055	36	@180m	63 03.0'N	63 19.0'W	0.3%	92%	4%	3%	S&G
22	75-009	7	216m	63 13.8'N	63 37.5'W	19%	29%	28%	24%	T
23	81-055	38	190m	63 21.5'N	63 18.0'W	65%	15%	14%	7%	TNS

TABLE 1 - Grab samples used in this thesis (see Figure 2 for location). @ indicates an estimated depths; all other depths were taken from field sheets. -- indicates no grain size analysis done; samples in these cases were mostly gravel. Units: S&G=Lady Franklin Sand and Gravel, MBS= Monumental Basin Sediments, T=Baffin Shelf Drift, TNS= transitional between the Lady Franklin Sand and Gravel and the Cumberland Sand.

largely absent, save in the area between Frobisher Bay and Cumberland Sound (McMillan, 1971).

The bathymetry of the Lady Franklin Bank area is shown in Figure 3. As can be seen, the bank is really a seaward extension of the normally narrow inner shelf to the south and north. It achieves tutelary bank status due to its separation from the mainland to the west by an enclosed basin (part of the marginal trough mentioned above, informally referred to herein as the Monumental Basin), and from the inner shelf directly to the north by a shallow trough. The concept of the inner shelf/outer shelf dichotomy discussed above is valid to the north and south, but directly to the east of the area the concept fails as the seabottom falls gently away. The bank margin here is considered to be outlined by the 100-fathom contour through extension from northern and southern areas, but the associated surficial sediment units of the 'bank' surface extend slightly farther east than this (see Figure 6). On the bank itself the water depth decreases gradually towards the southwest corner, reaching an abrupt minimum in the two sets of islands (Lady Franklin Island in the north and Monumental Island in the south).

(2) Oceanography

The Baffin Bay-Davis Strait area is dominated by a counterclockwise isogyre, composed of the relatively warm, saline waters of the Greenland Current flowing north through Davis Strait and along the western Greenland coast to northern Baffin Bay, where they are joined by and mixed with cold, less saline waters of the Arctic Archipelago; this mixture of waters then flows south along the eastern Baffin Island coast as the Baffin Current (or Canadian Current), exiting the Baffin Bay area through western Davis Strait and flowing over the southeastern Baffin shelf, including the thesis area (Collin and Dunbar, 1964). As is evident from Figure 1, Davis Strait represents the most horizontally and vertically

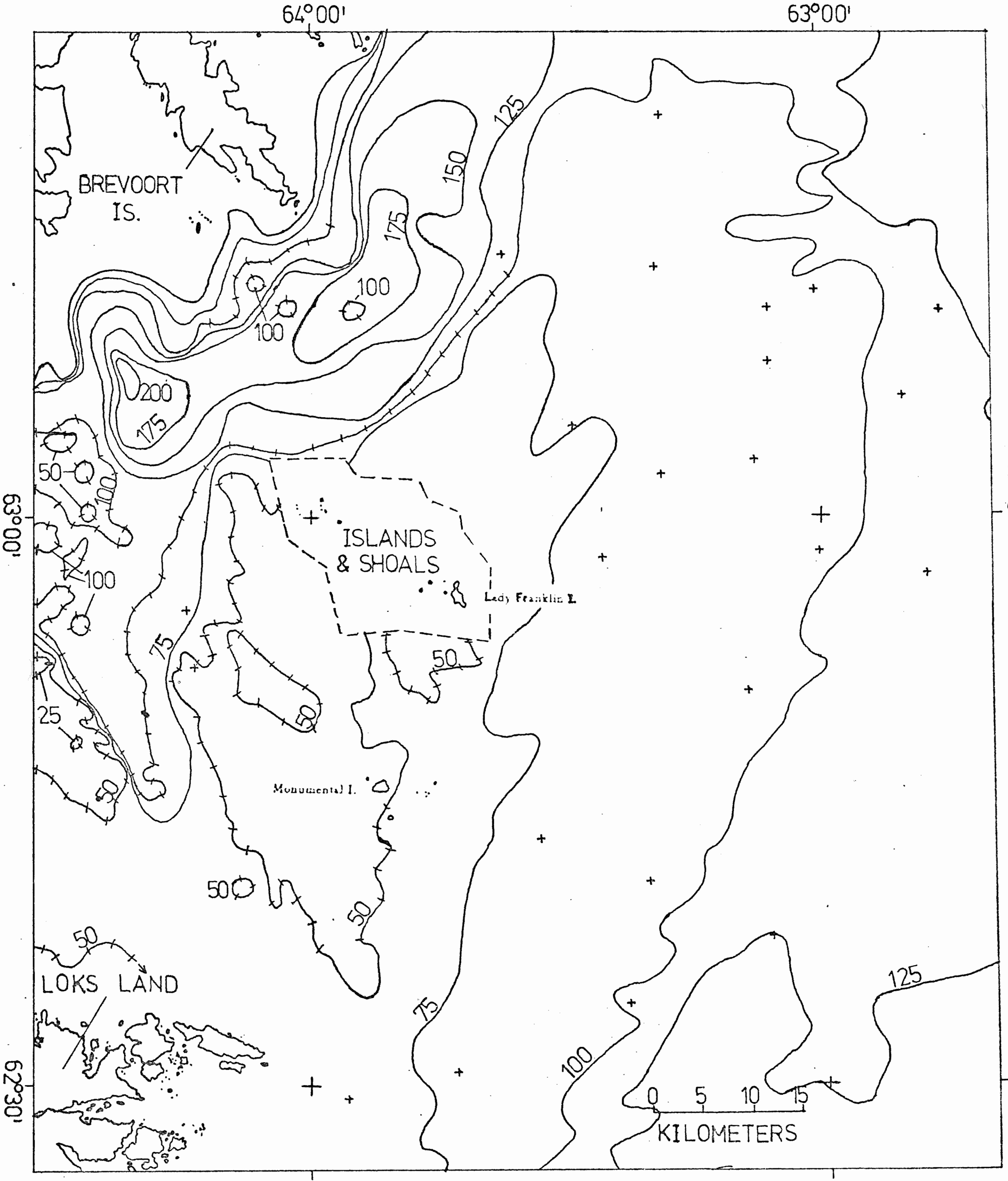


FIGURE 3 - Bathymetric map of the study area, with sample locations inset. Contours in fathoms; contour interval 25 fathoms. Hatched intervals indicate countours taken from Canadian Hydrographic Services (CHS) Chart 7050; unhatched intervals indicate contours hand drawn from soundings on CHS Chart 7050.

restricted region of the Baffin Bay-Labrador Sea curculation system; hence currents in this area can be expected to be very energetic (Pelletier, 1974), and decreasingly energetic to the south as the Baffin Current emerges onto the less restricted southeastern shelf.

Actual current measurements are scarce for the southeastern shelf. Pilot of Arctic Canada (1961) reports surface currents of 5 to 20 cm/s for the shelf in the thesis area, while Anonymous (1965) reports summer surface currents in the range of 50 to 70 cm/s. MacLean (personal communication, 1983) estimates surface currents in late summer of 50 to 100 cm/s in the general thesis area, based on ship travel time. Tidal currents may be more significant than the Baffin Current in some areas; tidal currents of up to 350 cm/s are reported in the mouth of Frobisher Bay (Pilot of Arctic Canada, 1978), between Resolution Island and Loks Land, and of up to 500 cm/s in the Gabriel Straits between Resolution Island and Meta Incoguita Peninsula (Canadian Hydrographic Services Map 7050). Further currents are reported by the latter source on the shallow shelf on the north side of Frobisher Bay, and such currents could be important on the shallow shelf and among the shallow islands bordering Loks Land.

Subsurface current measurements on the southeastern shelf are unavailable in the literature. However, Anonymous (1965) reported subsurface values for the Canadian Current north of Cape Dyer and east of Hudson Strait. These profiles show surface currents of 0.4 knots and 1 knot respectively, decreasing to 0.2 knots and 0.3 knots respectively at 200 m and to <0.1 knots and 0.2 knots respectively at 400 m. The surface currents are in the range noted above for the Canadian Current in the thesis area, and hence these values can be expected to broadly reflect the range within which southeastern shelf subsurface currents will fall.

(3) Bedrock Geology

The bedrock geology of the southeastern shelf has been presented in a series of papers by Grant (1975), MacLean et al. (1977), MacLean et al. (1978), MacLean and Falconer (1979), and MacLean et al. (in press) on the basis of acoustic and shallow drillhole data. A simple summary is shown in Figure 4. Pre-Cambrian bedrock extends offshore a short distance in most areas of the shelf, and is overlain in Frobisher Bay, Cumberland Sound, and along the coast north and south of Cumberland Sound by Ordovician limestone. The bulk of the offshore is underlain by flanking Tertiary sediments and Tertiary volcanics (basalts), the volcanics actually coming onshore in one area of Cape Dyer (Clarke and Upton, 1971). The Tertiary sediments are in places disrupted by sedimentary/volcanic diapirs of pre-Tertiary original age, which are associated with gas (MacLean et al., in press). The bedrock geology underlying the Lady Franklin Bank area is shown in Figure 5. The bank is underlain by the Pre-Cambrian material of the Baffin Island mainland in the south, which is overlain in the north, in three small pockets in the south, and in the Monumental Basin by Ordovician limestone. These two units are in turn overlain to the east by the flanking fine-grained, semi-consolidated Tertiary sediment. In combination with the bathymetry (Figure 3) it can be seen that Pre-Cambrian/Ordovician material of the bank represents an arched basement high relative to the onlapping Tertiary sediments and the Monumental Basin (MacLean et al., 1977, p. 1935).

(4) Surficial Geology

The surficial sediments of the southeastern shelf have recently been mapped by Praeg and MacLean (in preparation), using 40 in^3 airgun and Huntec high resolution seismic data in conjunction with about 120 van Veen grab samples. They distinguished several units pertinent to the study area (Figure 6):

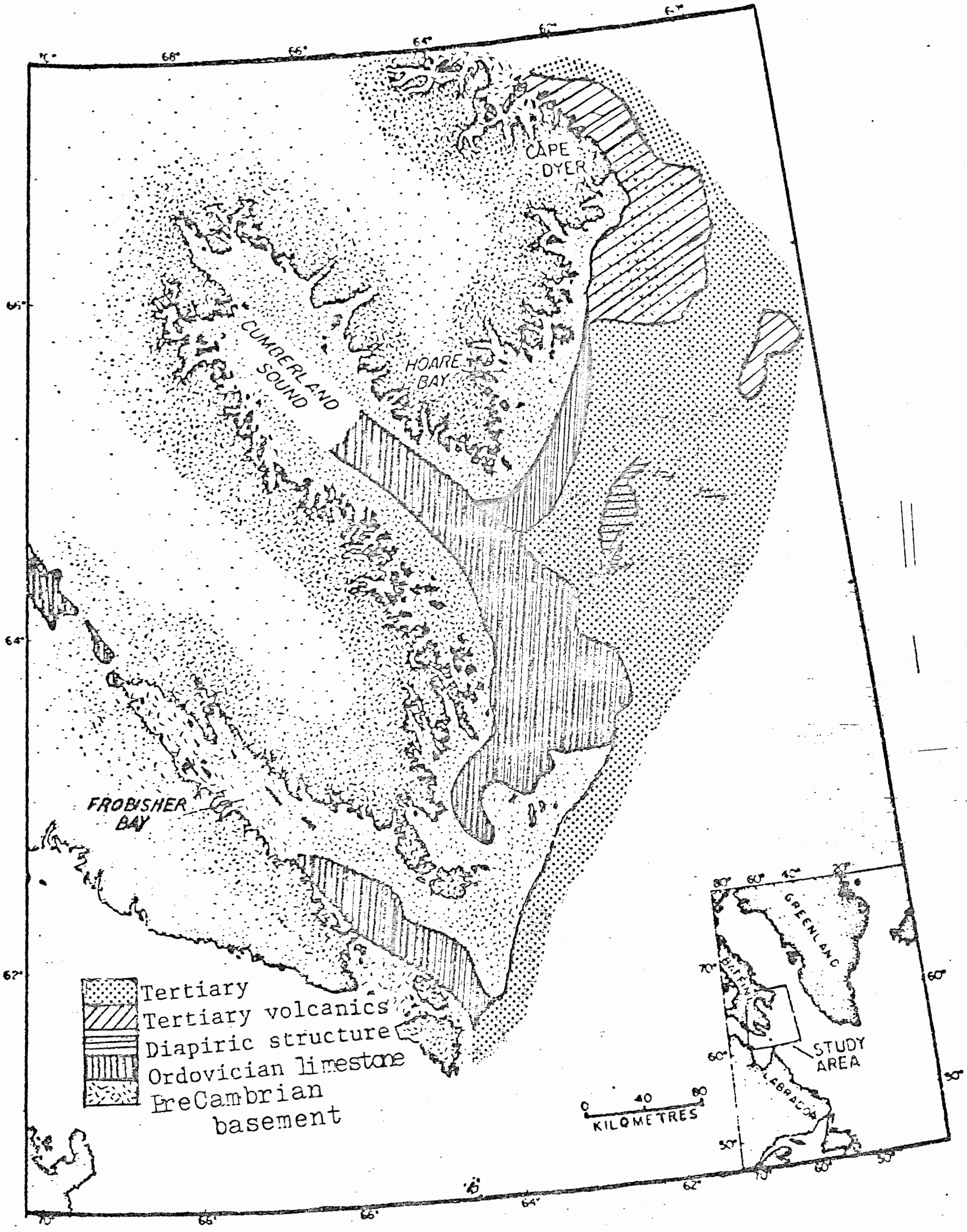


FIGURE 4 - Simplified bedrock geology map of the south-eastern Baffin shelf. After MacLean and Falconer(1979).

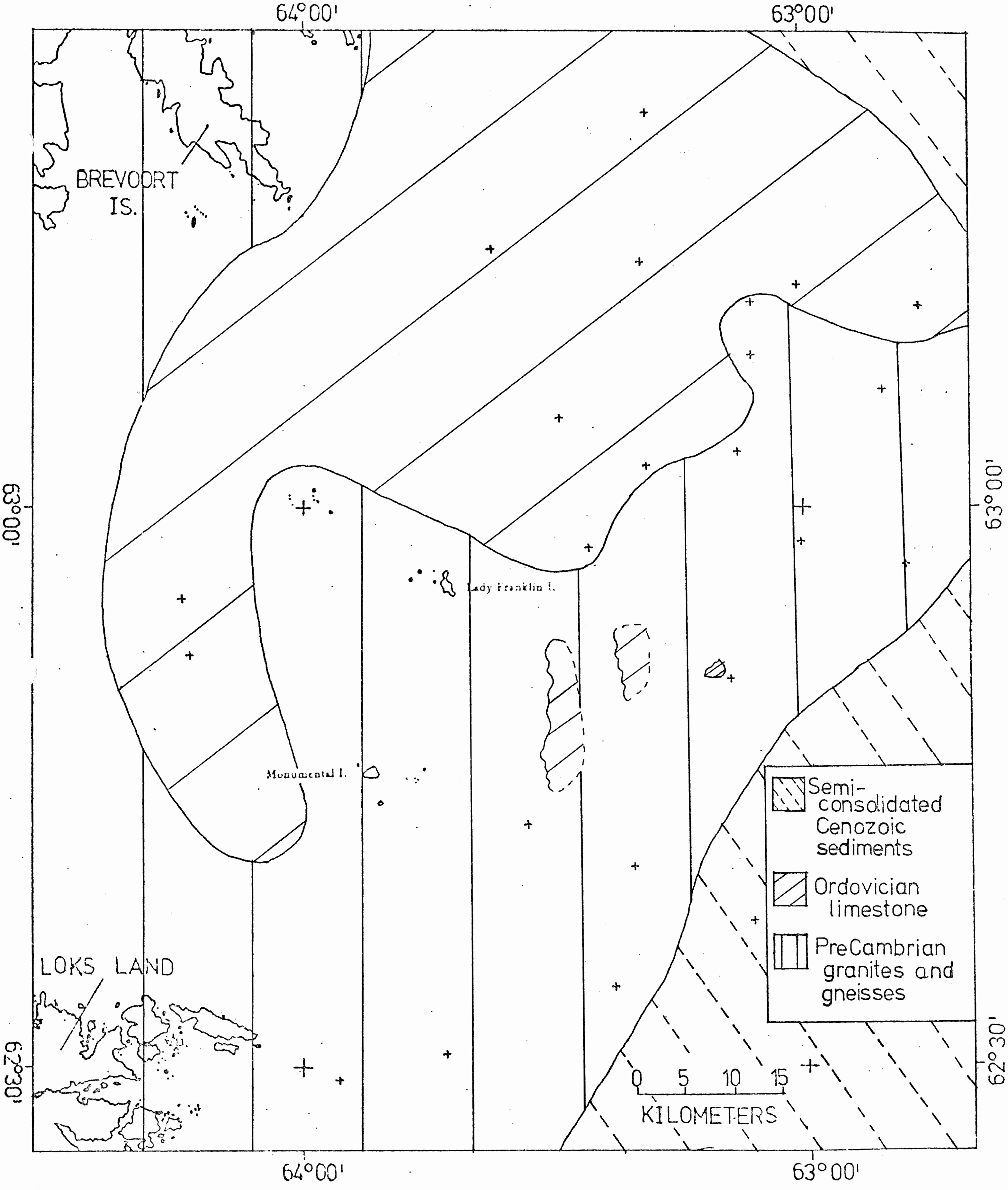


FIGURE 5 - Geologic map of the bedrock geology of the study area, with sample locations inset (crosses). After MacLean and Falconer(1979).

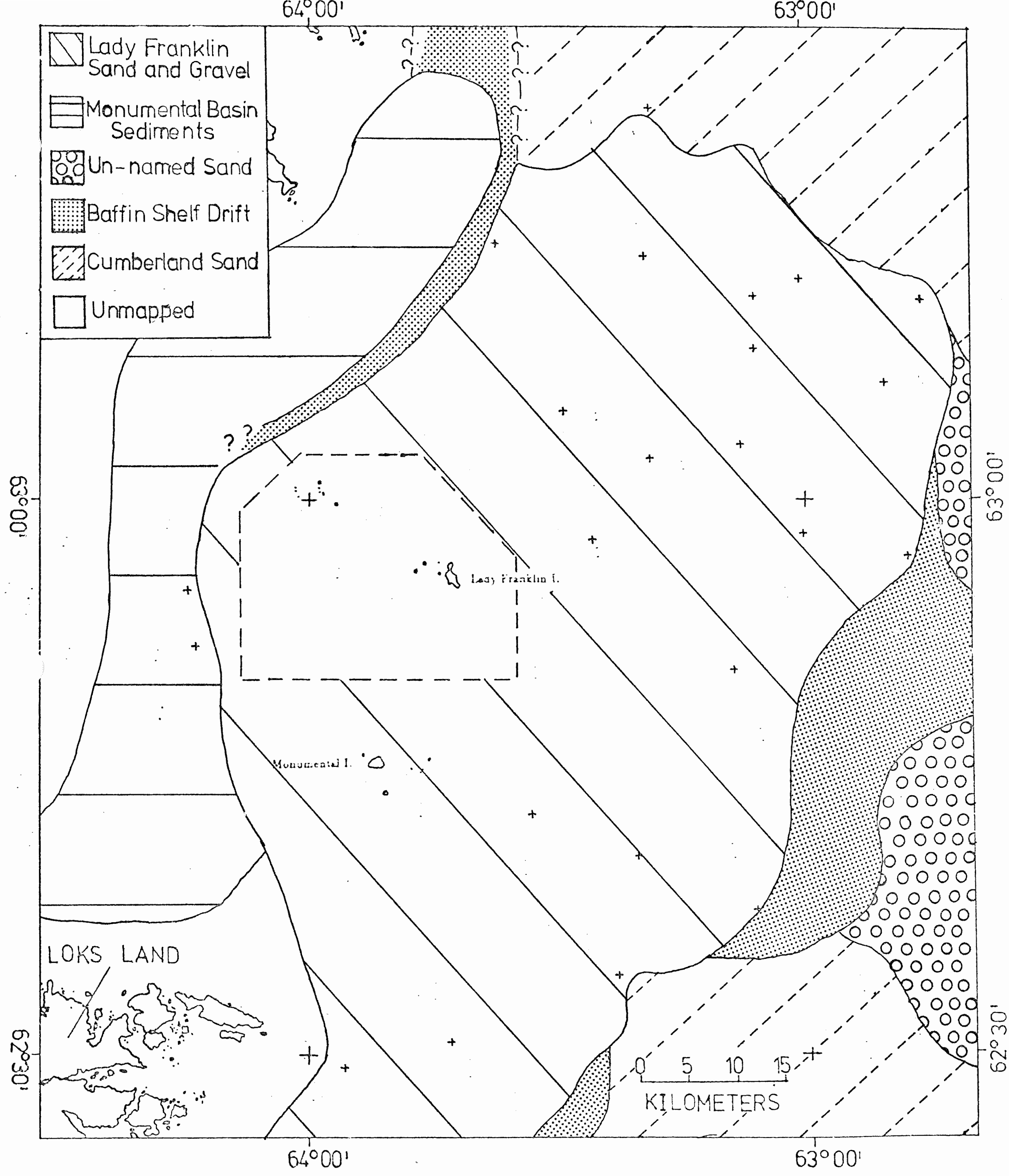


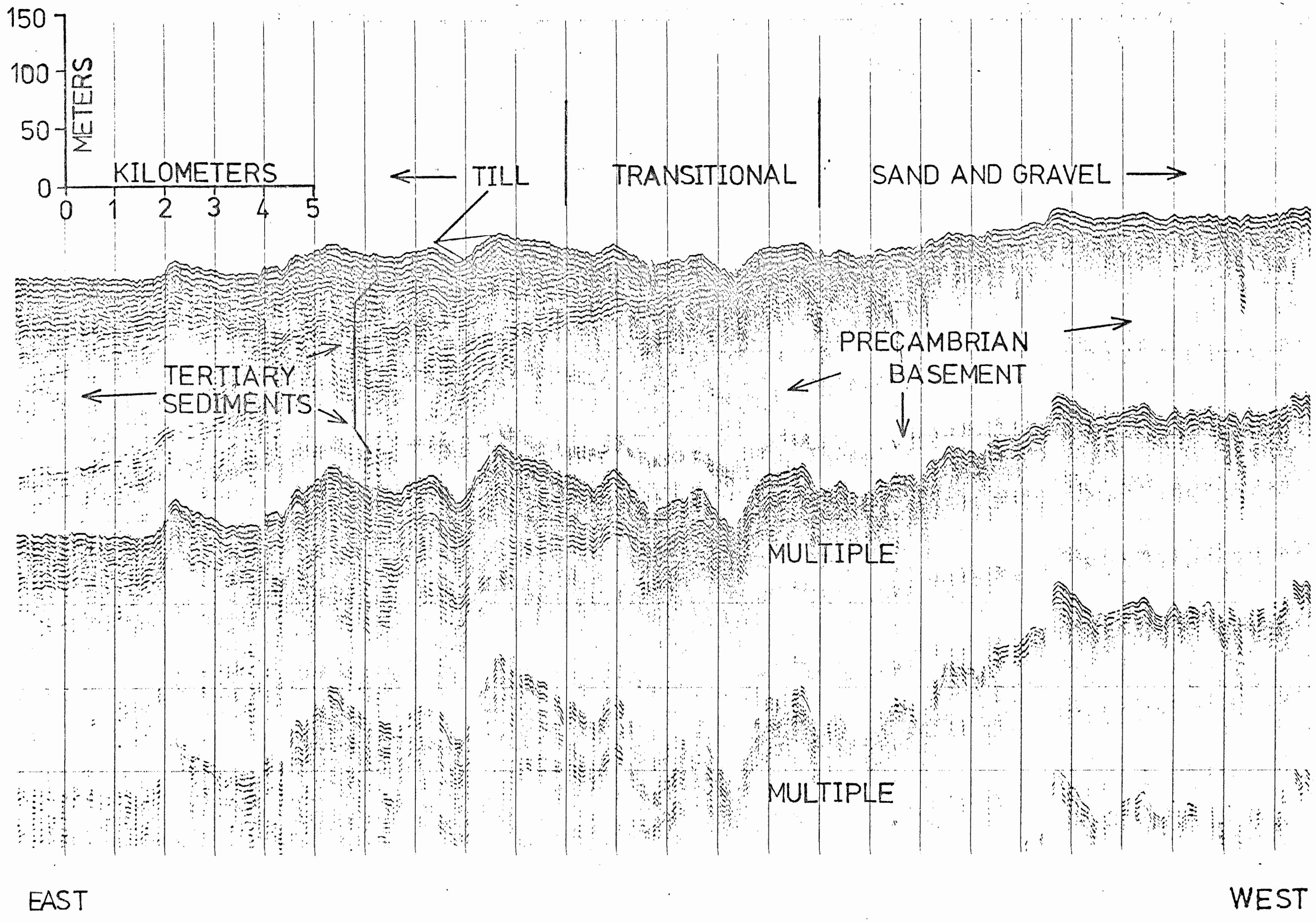
FIGURE 6 - Geologic map of the surficial sediments of the study area, with sample locations inset (crosses). Unit nomenclature is informal and tentative. After Praeg and MacLean(in preparation).

1. Baffin Shelf Drift - an informal term for an acoustically unstratified, texturally poorly sorted, morphologically irregular deposit of interpreted glacial origin. In the study area, to the immediate east of the bank the Drift is represented by a series of 20 to 40 m elongate ridges (lateral continuity uncertain) with a combined maximum width of 18 to 20 km (Figure 7). The Drift decreases in number of ridges, height of ridges, and combined width of ridges to the north and the south, eventually disappearing from surficial view (although Drift is suspected in the subsurface); this decrease in extent is crudely shown by the surficial representation on Figure 6. The till increases in extent in the subsurface to the north, east of the shallow trough of the north of the bank, though this is not shown. A narrow wedge of till, with little associated relief, was also mapped on the northwest corner of the bank, but its lateral extent as depicted is speculative. As the till (in any area) is followed bathymetrically 'up' onto the bank surface it thins, and undergoes an uncertain transition to the (surficial) sand and gravel unit (see Figure 7).

2. Cumberland Sand - an informal term for a widespread muddy sand (sandy mud unit with several surficial subunits which is thin (always < 40 m) but variable and confined to depths generally > 200 m. It is acoustically stratified where unfurrowed and acoustically unstratified where furrowed by iceberg grounding (a feature common on the southeastern shelf). It is tentatively ascribed as a partial time correlative of the Drift due to an interfingering till tongue in the mouth of Frobisher Bay. Its relation to the sand and gravel is uncertain; the contact between the two units is marked by transitional samples (e.g., sample 23).

3. Unnamed Sand - an informal term for an acoustically broadly stratified

FIGURE 7 - 40 in^3 airgun seismic profile running west to east across the eastern margin of the Lady Franklin Bank (see Figure 2 for location). In subsurface, the profile shows the edge of the Precambrian basement high and the flanking Tertiary sediments. Surficially, the profile shows the transition from the irregular, thick Baffin Shelf Drift to the west, to the thin Lady Franklin Sand and Gravel to the east. Note the close correlation between the thick offshore Drift and the underlying Tertiary strata. The vertical scale is for the velocity of sound in water.


150
100
50
0
METERS
KILOMETERS
0
1
2
3
4
5
TILL
TRANSITIONAL
SAND AND GRAVEL
TERTIARY SEDIMENTS
PRECAMBRIAN BASEMENT
MULTIPLE
MULTIPLE
EAST
WEST

(2 to 3 m between reflectors), texturally slightly muddy fine sand, which is most distinctive for possessing a very smooth, even surface despite iceberg furrowing evident on sidescan sonar records. It is of uncertain relation to other units, and is of uncertain origin. In the zone marginal to the Baffin Shelf Drift to the direct east of the study area, acoustic data indicate that the unnamed sand overlies the till, but it is uncertain to how much of the acoustic unit over the southeastern shelf this relation can be extended.

4. The Monumental Basin Sediments - this is the only occurrence of this unit on the southeastern shelf. Acoustic data is limited, indicating only that there is a thin, light tone cover over bedrock; however, the textural data are distinct. Five samples on the unit from depths of 100 m to 300 m all consist of a trimodal assemblage of, in varying degrees, silt, fine sand, and coarse sand to gravel, the amount of silt generally increasing with depth.

   Two samples used in this thesis (7 and 8) are mapped as being in the unit due to their high silt/clay content (15 to 20 %) and consequent trimodal assemblage; however, it was suspected, largely due to the shallow depth, that the sand and gravel components were genetically related to the rest of the bank surface, a supposition borne out by the results. The unit bears an uncertain relation to the Cumberland Sand and the Drift, and appears to grade into the sand and gravel. Its origin is uncertain.

5. Lady Franklin Sand and Gravel - an informal term for a thin (< 5 m to < 1 m), fine to medium sand and/or gravel unit. It always occurs above 180 to 220 m (100 fathoms), is moderately but not intensely furrowed, and appears to stratigraphically directly overlie the Baffin Shelf Drift. Acoustically

it manifests itself as either (a) a thin lag over bedrock, (b) a thin cover over a thicker cover recognisable as till, or (c) an intermediate thickness poorly to unstratified deposit over bedrock for which it is uncertain whether there is sand and gravel over the entire thickness or a thin (< 1 m) sand and gravel lag over thin till beneath. In any case, it is usually associated with reflectivity values higher than those of any other unit on the shelf.

The Lady Franklin Bank is an example of case (c), an intermediate thickness deposit of uncertain vertical consistency. The unit here is represented by a moderate tone, acoustically poorly to unstratified deposit which varies in thickness over the bedrock, ponding slightly in topographic lows (up to 5 m) and occasionally thinning to become acoustically unresolvable from bedrock (< 50 cm). Grab samples consistently show sand and/or gravel with minor (< 10% to < 1% to 0%) silt and clay. However, such grab samples (van Veen) effectively only sample the top 10 to 20 cm of sediment; thus as noted it is uncertain whether the unit is sand and gravel throughout its thickness or thin sand and gravel over a thicker unstratified deposit (likely till).

The unit is also in contact with the Cumberland Sand in some areas, but as noted the relation is uncertain. Samples (#23) suggest a transitional relationship. Origin of the unit is uncertain, a fact this thesis hopes to remedy.

(5) Previous Work

Kranck (1966) studied the sediments of Exeter Bay (Figure 1), an area dominantly surficially represented by the Lady Franklin Sand and Gravel unit (Praeg and MacLean, in preparation). She divided the study area, which extended from the nearshore islands of the bay to the edge of the inner shelf, into an inner, nearshore fine-medium sand and local gravel area, and an outer, offshore gravel with local sand and/or bedrock area. Subsequent acoustic data have shown the outer area to consist of a thin (< 1 m) lag over bedrock and the inner area to consist of a broadly stratified 10 to 20 m deposit. On the basis of gravel lithology, heavy mineral distributions, and gravel texture, she concluded that the inner sediments could be derived from reworking of till by tidal currents among the nearshore islands, but that the outer sediments more likely represented deposition by ice rafting, kept free of fines by the transporting power of the Canadian Current. This latter conclusion was largely due to the presence of 'foreign' lithologies, particularly limestone, among the offshore gravel.

McMillan (1971) disagreed with Kranck (1966) and others in attributing foreign lithogies, particularly limestone, to ice rafting deposition, due to the relative abundance of limestone clasts in submarine (shelf) gravels throughout the eastern Arctic, yet the lack of a reasonable limestone bedrock source for ice (berg) erosion. He suggested that the limestone represented reworked glacial gravel derived from ice erosion of submarine (shelf) carbonate outcrops. He then attempted to use their distribution to map the extent of the hitherto unknown submarine bedrock.

Kranck (1966) presented brief textural evidence indicating the gravel was not glacial in origin, but her evidence was hardly conclusive. However, MacLean _et_ _al_. (1978) mapped the submarine geology of Kranck's (1966) study area and showed it to be underlain by Tertiary volcanics (see Figure 4), hence invalidating McMillan's (1971) hypothesis of carbonate bedrock.

Andrews and Miller (1979) investigated the distribution of limestone erratics in Baffin Island drift, and found a three-fold abundance zonation west to east across Baffin Island which they explained in terms of Laurentide ice being composed of a complex of ice divides, rather than a single ice sheet over Hudson Bay as was popularly thought. Their third zone of abundance lies generally along the eastern coast, and in particular, includes Cape Dyer near Exeter Bay. Since drift is noted in the offshore here, bathymetrically below the sand and gravel (Praeg and MacLean, in preparation), the carbonate gravel of Kranck's (1966) study area could indeed be derived from erosion of till as suggested by McMillan (1971), although not of submarine bedrock derivation, and need not be explained by ice rafting deposition. However, the evidence either way is not conclusive.

(6) Sea Level History

Evidence exists for a relative sea level (RSL) lowstand in the Canadian Arctic area. Pelletier (1961), Horn (1963), and others working with the Polar Continental Shelf Project (PCSP) reported conclusive core evidence for a post-Pleistocene RSL low of 200 m in the western Arctic Archipelago. Marlowe (1968) suggested an extension of this RSL low to the Baffin Bay area on the basis of decreases in grain size toward the top of Baffin Bay cores, suggesting a rising base level. Baker and Friedman (1973) suggested that the Davis Strait sill was only 300 m deep in the Pleistocene, thus producing the alternating dark/light bands they saw in Baffin Bay cores; this amounts to a RSL low of approximately 300 m.

Working just north of Cape Dyer, England and Andrews (1973) suggested a possible sea level low of uncertain amount from ca. 50,000 B.P. to ca. 35,000 B.P. on the basis of land and submarine evidence around Broughton Island; the

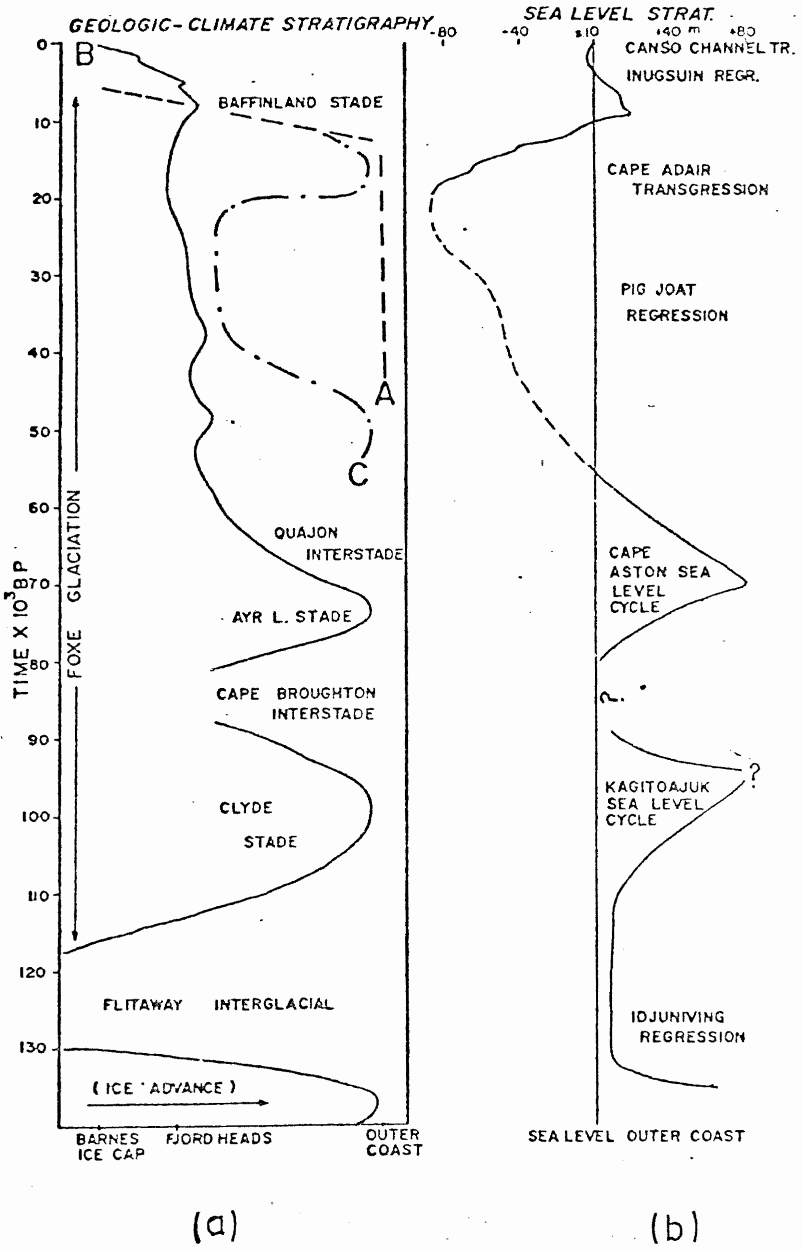


FIGURE 8 - Canadian eastern Arctic Wisconsin glacial and sea level histories.

(a)Alternative Wisconsin glacial histories for the Canadian eastern Arctic. Alternative B is that of Andrews(1980); alternatives A and C are those of other workers (see text).

(b)Wisconsin relative sea level curve for the Canadian eastern Arctic, assuming glacial history B above.

From: Andrews(1980)

alternative was slow ice retreat. The most recent and comprehensive statement on sea level is that of Andrews (1980); on the basis of a prominent land stratigraphic unconformity, a C^{14} dating gap, numerous coastal sections, and echosounding off Broughton Island, he proposed a sea level low he termed the Pigjoat Regression from ca. 55,000 B.P. to ca. 12,000 B.P. (Figure 8). The evidence was not conclusive, but he suggested the conflict between a sea level low or the slow ice retreat alternative of England and Andrews (1973) (Figure 8) would be resolved by investigation of the continental shelf; finds of till beneath Holocene marine sediments would demonstrate that late Pleistocene ice extended to the coast, but the absence of such tills would serve to substantiate the Pigjoat Regression.

III. PROCEDURE

Subsamples or, where the sample was small, whole samples were taken from the samples available on store at BIO. The subsamples were washed of any fines (< 40) by wet sieving, and then hand sieved (dry) to 1 0 intervals; this was done in the sediments labaratory at BIO. A shaking machine was not used in the sieving, both to save time and to avoid damage to the samples. On the basis of size fraction abundance and thesis objectives, three intervals for study were selected: the -50 to -30 for gravel, the -20 to 00 for coarse sand, and the 20 to 30 interval for fine sand; the latter was chosen as it represents the modal size of the sand component (see below). The grains were then examined either visually or using a binocular microscope (maximum 50X magnification).

Selected samples were chosen for Scanning Electron Microscope (SEM) analysis of quartz grains of the -20 to 00 fractions. Small subsamples were taken from the original sample to avoid any effect of sieving. These samples were decanted of fines, then boiled in concentrated HCl for fifteen minutes to remove carbonates, rinsed in distilled water, boiled in a saturated stannous chloride solution for twenty minutes to remove oxides, rinsed in distilled water, boiled in concentrated H_2O_2 for fifteen minutes to remove organics, and rinsed in distilled water. They were then coated with a layer of palladium-gold using an Edwards High Vacuum Evaporator, and observed on the BIO Cambridge Stereoscan SEM.

IV. RESULTS

(1) Grain Size Analysis

Grain size analyses were performed on all twenty-three samples used in this thesis by BIO, either 'in house' or on a contractual basis. With the exception of a few of the older samples for which the analysis encompassed the whole grain size range (the 75-, 76-, and 77- series in Table 1), the analyses took the form of a detailed full 1/4 ø analysis of the -2ø to 8ø fractions and a brief gravel-sand-silt-clay % breakdown of the whole sample (Table 1).

Such treatment renders parameters such as mean size or standard deviation, which evolved from the analyses, meaningless for the samples as a whole. However, as will be seen below, there is usually a modal relation between the sand and the gravel in these sediments such that the two grain size groups form almost separate modes. Hence it is valid as a first approximation to treat the two separately. To this end the grain size parameters which evolved from the analyses (mean size, standard deviation) for the -2ø to 8ø fractions have been utilized in a relative sense in the following discussion. The older samples mentioned above which had whole grain size range analyses performed were recalculated to the -2ø to 8ø interval for consistency; this was done using the statistical method of moments outlined in Folk (1968).

The gravel in this study has not been differentiated as to grain size, but merely grouped as 'gravel.' This is in part due to the lack of analytical data on the gravel (above), and in part due to the inability of a small van Veen grab sampler to obtain representative samples. Most (90%) of the gravel examined was finer than 60 in size. The largest grain examined was a 20 cm boulder from sample 22 (till).

The grain size relations of the sediments of the study area are characterized in Figure 9, a plot of mean size versus standard deviation for the sand-silt fractions. As is shown, the sediments fall into three major groups along an approximately linear trend, numbered Groups 1, 2, and 3; three samples form a minor separate group (Group 4).

Each of the three groups is distinct with respect to their grain size distributions. Group 1 is a bimodal assemblage, with a dominant mode of very well sorted sand (modal value = 0.6 - 1.10) and a secondary (< 30%) mode of gravel; the two modes do not overlap. Group 2 is essentially trimodal, with two slightly overlapping dominant modes of well sorted sand (modal value = 2.3 - 3.00) and gravel which vary in relative importance, and a very minor (< 15% to < 1%) silt clay mode which does not overlap with the sand mode. Group 3 is essentially quadramodal, with a separate gravel mode of variable importance, and three overlapping modes of coarse sand (0.30), fine sand ~ 3.50), and silt/clay, of which coarse sand is always minor and the other two vary in importance. Group 4 is similar to Group 2 in being trimodal, but the sand mode is coarser.

The three major groups represent samples not only texturally related, but areally related. This point is illustrated in Figure 10, where the mean

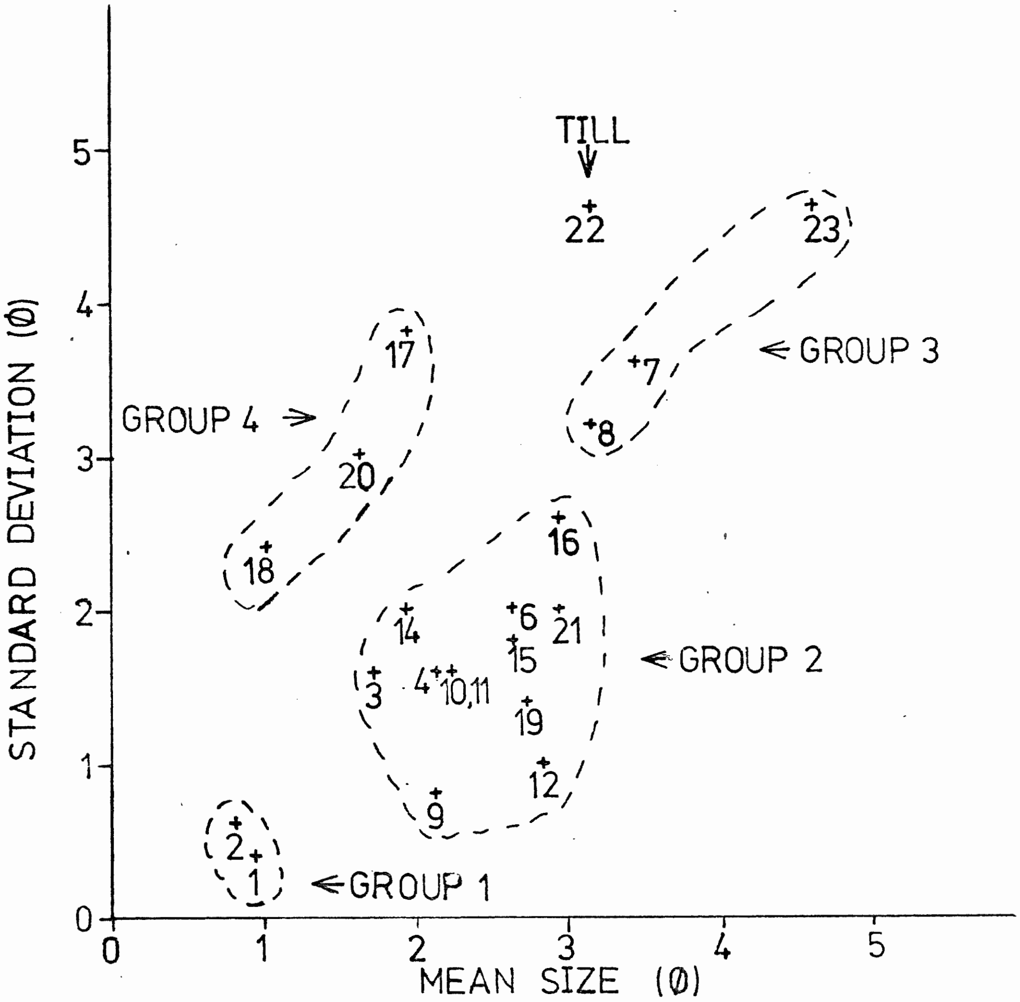


FIGURE 9 - Plot of mean grain size versus standard deviation for the artificially terminated -2Ø to 8Ø fractions. Four textural groups are defined, and the position of the till sample is shown. Sample 23 is as close to the till sample as it is to the rest of Group 3; however it is classed with Group 3 because (a) it is not a till (Table 1), and (b) it is generally fine grained and poorly sorted like samples 7 and 8.

grain size of Figure 9 is plotted over the area. Group 1 corresponds to the samples off Loks Land, which are much more well-sorted and coarser grained. Group 3 corresponds to the two finer grained samples on the Monumental Basin Sediments plus one sample of sediments transitional to the Cumberland Sand. Group 2 corresponds to the rest of the samples on the bank, which are generally similar; however, an important feature of variability of Group 2 is noted in Figure 10, where it can be seen that in general the mean grain size increases to the east, or into deeper water. This trend culminates in the group 4 samples, which all occur on the northeast corner of the bank area, and two of them, samples 17 and 18, represent the deepest samples available.

It was the original intent of this thesis to perform dissection of cumulative frequency curve analysis on the samples to delineate grain groups. However, the tendency of the samples to be composed of distinct modes possessing only slight overlap has made this unnecessary. Each of the distinct modal groups can be treated as a grain size population.

For reasons which will become apparent in the discussion, the primary interest at this point is in the sand modes. The silt/clay modes are in most cases minor (except for Group 3 which will be considered), and the gravel modes are not relevant to the following analysis.

The variations in the maximum modal value of the (fine) sand mode over the bank was investigated; it was not presented in a figure, however, as it was found to be almost identical to the variations in mean size seen in Figure 10. The coarsest modal values occur in the northeast corner of the area, and off Loks Land; the modal value becomes progressively finer over the bank, culminating in samples 7 and 8 (Group 3).

It is of interest to calculate the approximate velocity of water required

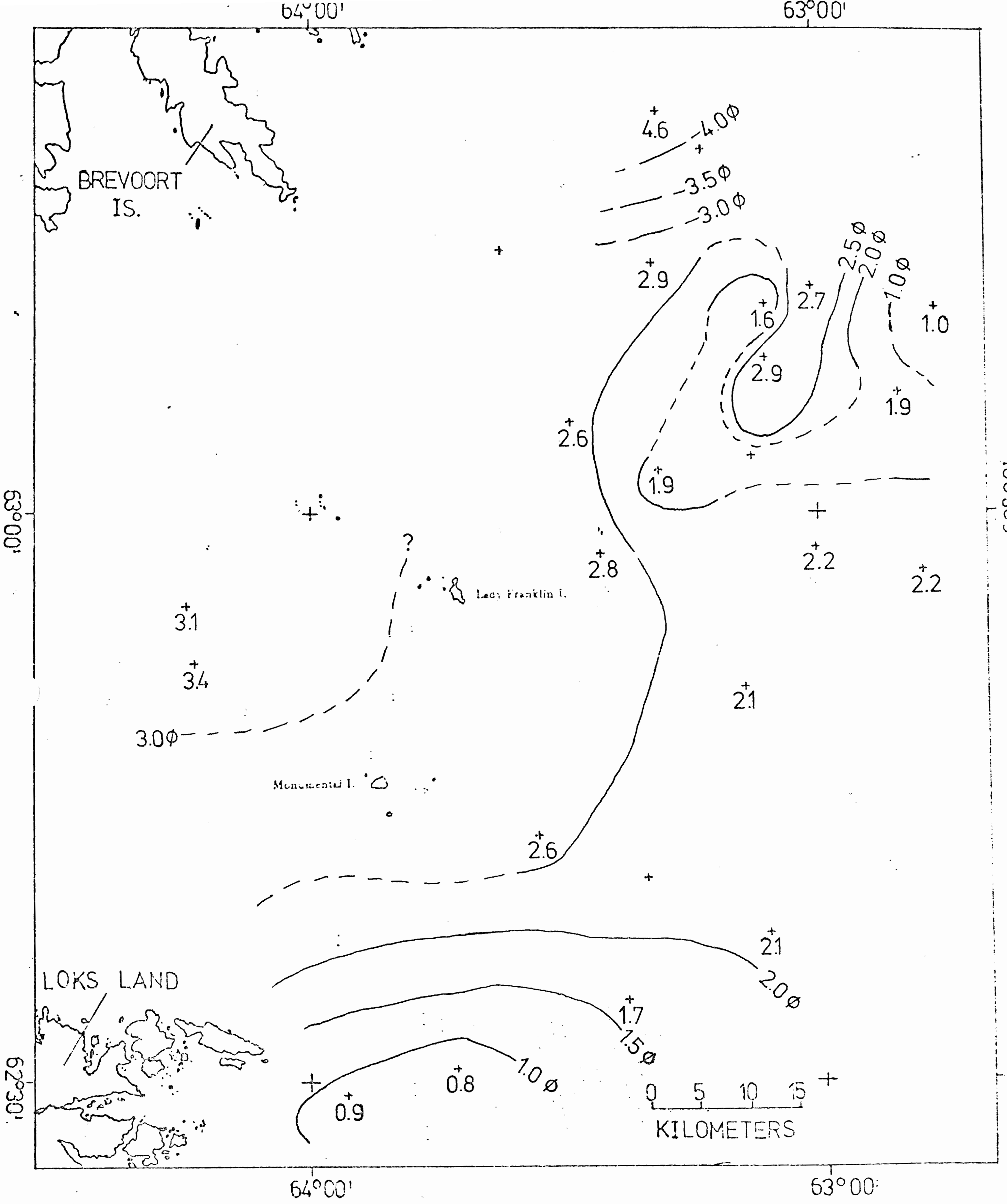


FIGURE 10 - Map of the variation in mean grain size of the artificially terminated -2ϕ to 8ϕ fractions of grab samples. Contour interval = 0.5ϕ. Solid lines indicate well defined contours, dashed lines indicate less certain contours.

to move the fine sand mode. This can be most easily accomplished by using the diagram of Blatt et al. (1980), p 103, which summarizes the criteria for movement of quartz sand grains in water at 20°C. For material of 2Ø to 3Ø, the criteria of motion are the Shields parameter curve (initial motion) and the curve $U* = W$ (suspension) where for $U*$ above the Shields curve there is bedload motion and for $U* > W$ there is suspension. For material coarser than 2Ø the criteria of motion are the Shields parameters, with little suspension. The water velocity can then be calculated from $U* = Cf\ U$, where U is the shear velocity, assuming a suitable drag coefficient Cf. Hill (1979) used a drag coefficient of 0.003 for samples as shallow as 200 m, so this value will be assumed.

Using this calculation, we can determine the following velocities. For Group 1, the modal value is 0.6 - 1.1Ø or ~0.8Ø. There will be bedload motion of this population for $U* > 1.8$ cm/s, or $U > 33$ cm/s, but there will be no suspension for $U* < 6.0$ cm/s, or $U < 110$ cm/s. For Group 2 the modal value varies. For the lower values, 2.3Ø, there will be bedload motion for $U* > 1.3$ cm/s, or $U > 24$ cm/s, and suspension for $U* > 2.0$ cm/s, or $U > 37$ cm/s. For the higher values, 3.0Ø, there will be a direct transition from non-motion to suspension for $U* > 1.0$ cm/s, or $U > 18$ cm/s. For Group 3, the presence of significant amounts of silt/clay indicates either sheltered subsurface sediments, or currents of < 5 cm/s. For Group 4, the deepest samples, the modal values vary from 0.3 to 1.0Ø, or basically within the range of values for Group 1.

The absolute validity of these values depends on the suitability of the drag coefficient. However, the relative differences of the samples are significant, and even the absolute values give some idea of the order of magnitude of currents required.

(2) Lithology

(a) Lithologic Groups

Each of the three selected grain size intervals were examined with regard to lithology. For the gravel fraction, the grains (always less than 30) were simply counted; for the coarse sand fraction, at least 200 grains were counted in each sample (except sample 13, where only 12 grains were obtained in the sample); for the fine sand the percentages were estimated. Over all the samples, a total of four lithologic groups were recognized.

1. Siliclastic material - for the gravel this could usually be distinguished as either Pre-Cambrian granite, gneiss, or gneissic fragments, but for the sand fractions it was usually only recognizable as polycrystalline to monocrystalline aggregates (or crystals) of quartz, feldspar, blacks, horneblende, pyroxene, magnetite, occasional garnet and green diopside, although gneissic or granitic fragments could sometimes be recognized. In the coarse sand fractions of all samples examined, quartz and feldspar in varying proportions were the dominant minerals, followed by blacks, garnet and diopside. In the fine sand fractions, monocrystalline quartz dominated, comprising 80 to 90 per cent, with the rest being blacks and feldspars.

2. Limestone - this material varied from mudstones to wackestones to dolostones to chalks, but was always fine grained and polycrystalline. In the gravel fractions features such as bedding could often be observed, but in the sand fractions the lithology was always represented by homogenous, apparently isotropic, golden-brown to white to occasionally red

grains. Acid testing indicated the presence of dolomitization in many grains.

3. Brown siltstone - this distinctive but minor lithology was recognized in the sand fractions as well-consolidated medium to dark brown coarse siltstone, finely laminated, often with lenticular forms to the laminae reminiscent of bird's eye texture or fenestrae in carbonate rocks. In the gravel fractions larger scale bedding could sometimes be recognized. Thin section examination showed the brown colour to be derived largely from very fine-grained reddish brown oxides, which often occurred in elongate bands parallelling the laminae. Most of the rock consisted of either of these oxides, or of yellowish fine-grained material; however also present were larger euhedral calcite or dolomite crystals. The euhedral nature of these crystals suggest that they have grown from the groundmass, and suggest that the yellowish material is carbonate mud.

   The relation of this lithologic group to the surrounding bedrock lithologies is not directly evident. However, the well-consolidated nature indicates that the siltstones are much older than the semi-consolidated Tertiary sediments, probably of Paleozoic age (G. Williams, personal communication, 1983). This and the presence of carbonate mud in the groundmass strongly suggests association with the Ordovician bedrock. However, because there is room for uncertainty, and because the siltstones occur in very minor amounts, they have been neglected in the discussion below.

4. Quartz or quartz-rich grey sandstones - this very rare lithologic group was recognized in only a few samples as a fine-grained, laminated, grey quartz-rich sandstone. A thin section of the one gravel fragment noted

showed it to be an equigranular aggregate of 95% quartz; however, this may not be the case for all such fragments. Because of its rare nature, it could have originated from minor siliclastic sandstone components in the Pre-Cambrian or Ordovician bedrock; it will be neglected below.

(b) Lithologic Variability

The % limestone in the gravel fractions, the % limestone in the coarse sand fractions, and the % limestone in the fine sand fractions are shown in Figures 11 to 13. The % brown siltstone and % quartz siltstone are neglected for the reasons given above. The % siliclastics (group 1 above) is not shown, as it essentially the inflection of the % limestone in all fractions.

The % limestone in the coarse sand is a very accurate measure, due to the large number (> 200) of grains counted; the % limestone in the fine sand fractions is accurate enough to indicate the presence or absence of limestone. The % limestone in the gravel is not very accurate, however, due to (1) the low number of grains counted, and (2) the low number of samples with gravel (see Figure 11).

The % limestone in coarse sand fractions show a well-defined pattern. The maximum percentage of limestone occurs in the two samples (7 and 8) taken from sediment overlying limestone bedrock (Figure 5) at the head of the Monumental Basin (Figure 3); and decreases more or less radially to the southeast and northeast over both the Pre-Cambrian and limestone bedrock; in the north of the area the % of limestone rises again. The intervening area over the limestone bedrock is notably deficient in limestone. (The uncertain contour connecting these two areas is based on sample 75-7, a till, which had only six pieces of gravel available for study; however three of these were limestone. Such high proportions of limestone in so few pieces of gravel have been observed in other samples, and have almost always reflected high limestone % in the coarse sand fractions; however, as noted the contour is tenuous.)

The % limestone in the gravel fractions is less-well defined than that for the coarse sand fractions. Nevertheless the same general pattern as that described above is evident. The percentage of limestone shows a maximum in the south over the limestone bedrock at the head of the Monumental Basin and the Pre-Cambrian bedrock to the east shows a notable decrease over the limestone bedrock to the north, and increases again in the far north.

The % limestone in the fine sand fractions follows the general pattern of the coarser fractions above, although the low % allows only contouring of presence/absence. Limestone is present in the south and far north, and absent in the intervening areas.

(4) Staining and Bryozoans

Surface staining and encrusting bryozoans are ubiquitous surface features of the gravel fractions of the samples examined.

(a) Staining - the gravel examined can be classified into three groups with respect to staining: grains stained over their whole surface, grains unstained, or only lightly stained in random areas, and grains clearly stained on one side or end but not on the other side or end. (In the latter case, the boundary between the stained and unstained sides is often sharply outlined by an encircling band of darker stain.) Stain varies in colour from yellowish- to reddish-brown. The relative abundance of the types of stained grains above varies, but usually (1) all are present, and (2) grains with one side stained strongly predominated.

(b) Bryozoans - Encrusting bryozoans are present on > 95% of all gravel

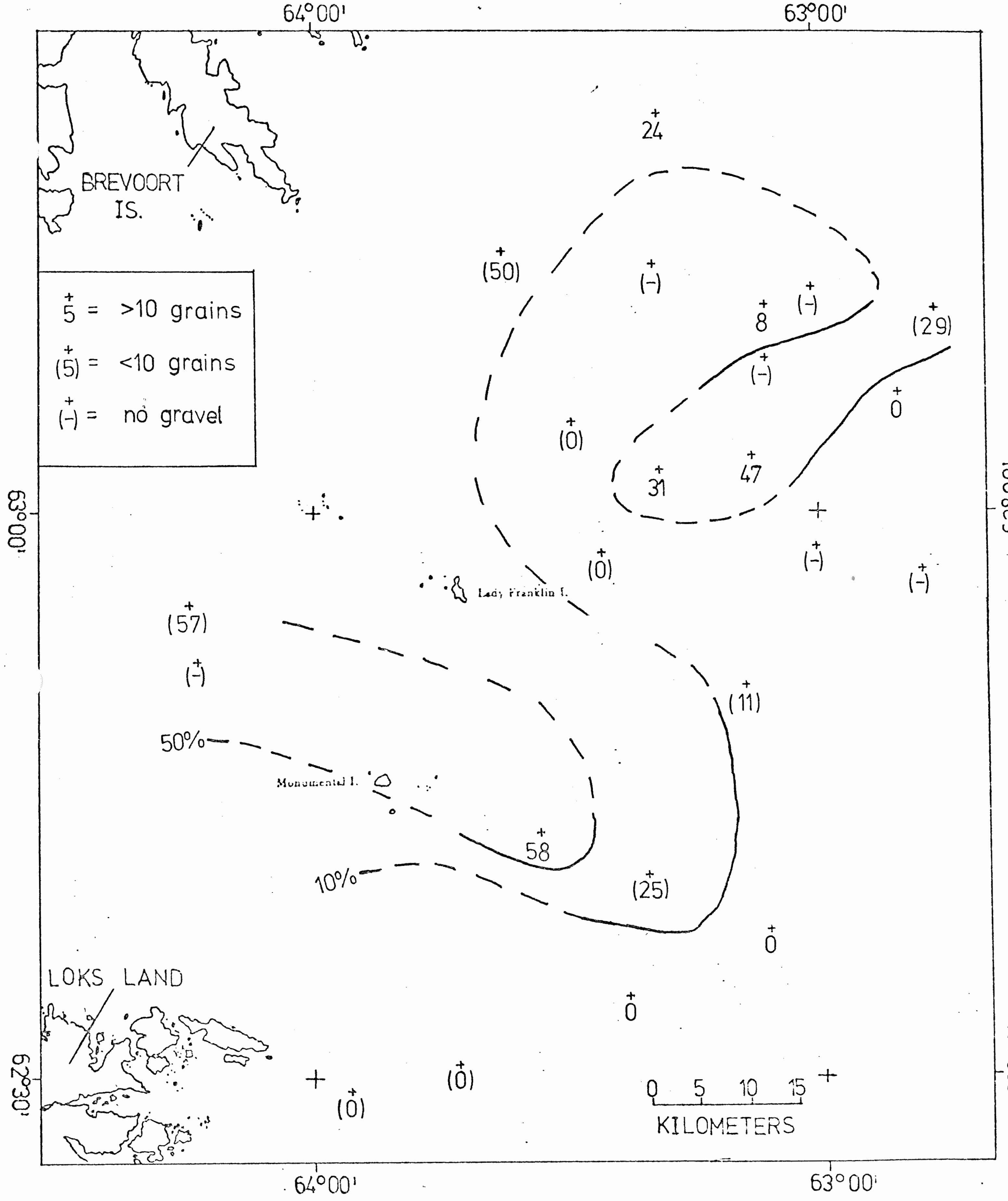


FIGURE 11 - Map of abundance of limestone grains in the -50 to -30 (gravel) fractions of grab samples, based on grain counts. Contours = 10%, 50%. Solid lines indicate well-defined contours, dashed lines indicate less certain contours.

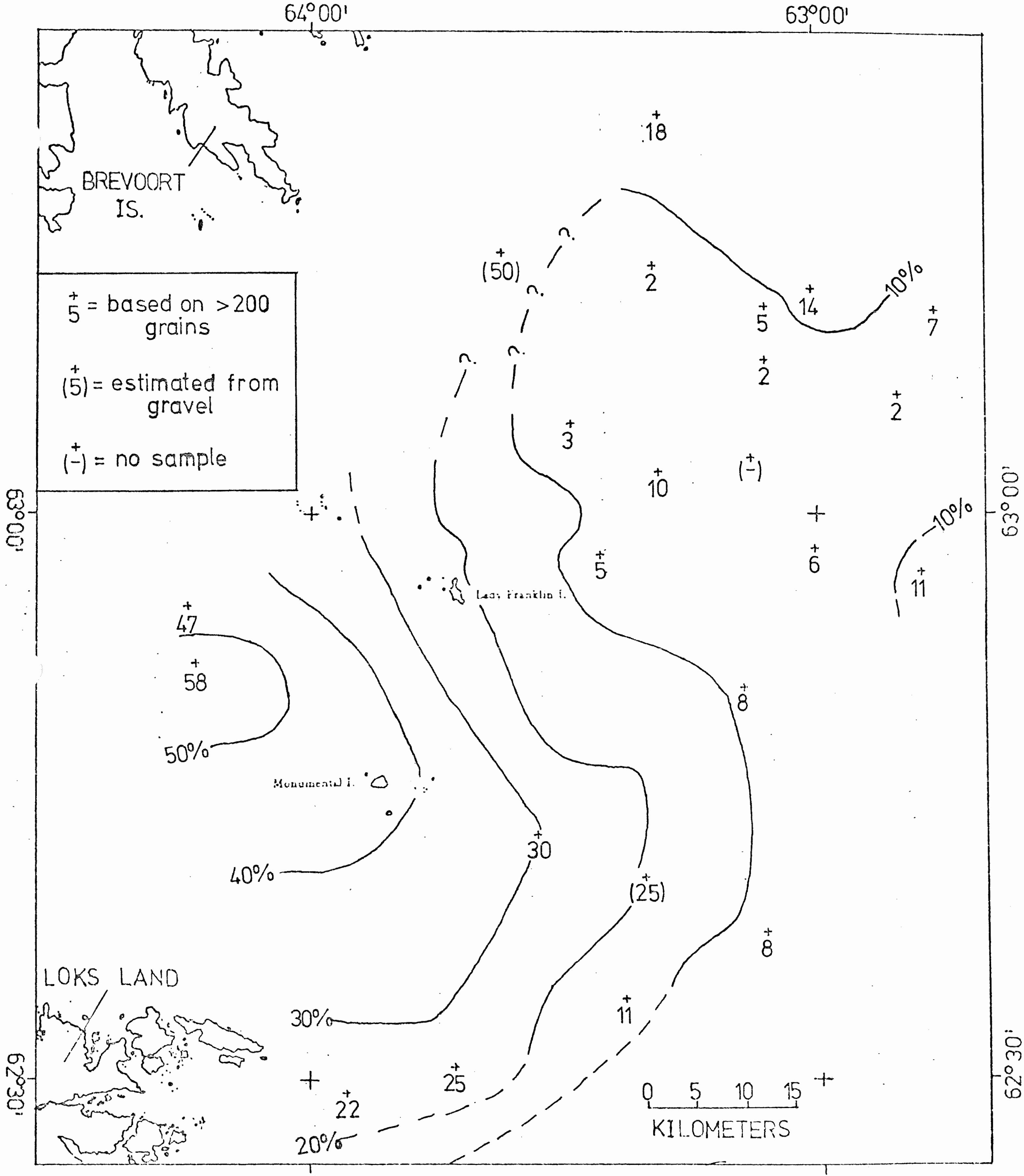


FIGURE 12 - Map of abundance of limestone grains in the -20 to 00 (coarse sand) fractions of grab samples, based on grain counts. Contour interval = 10%. Solid lines indicate well-defined contours, dashed lines indicate less certain contours.

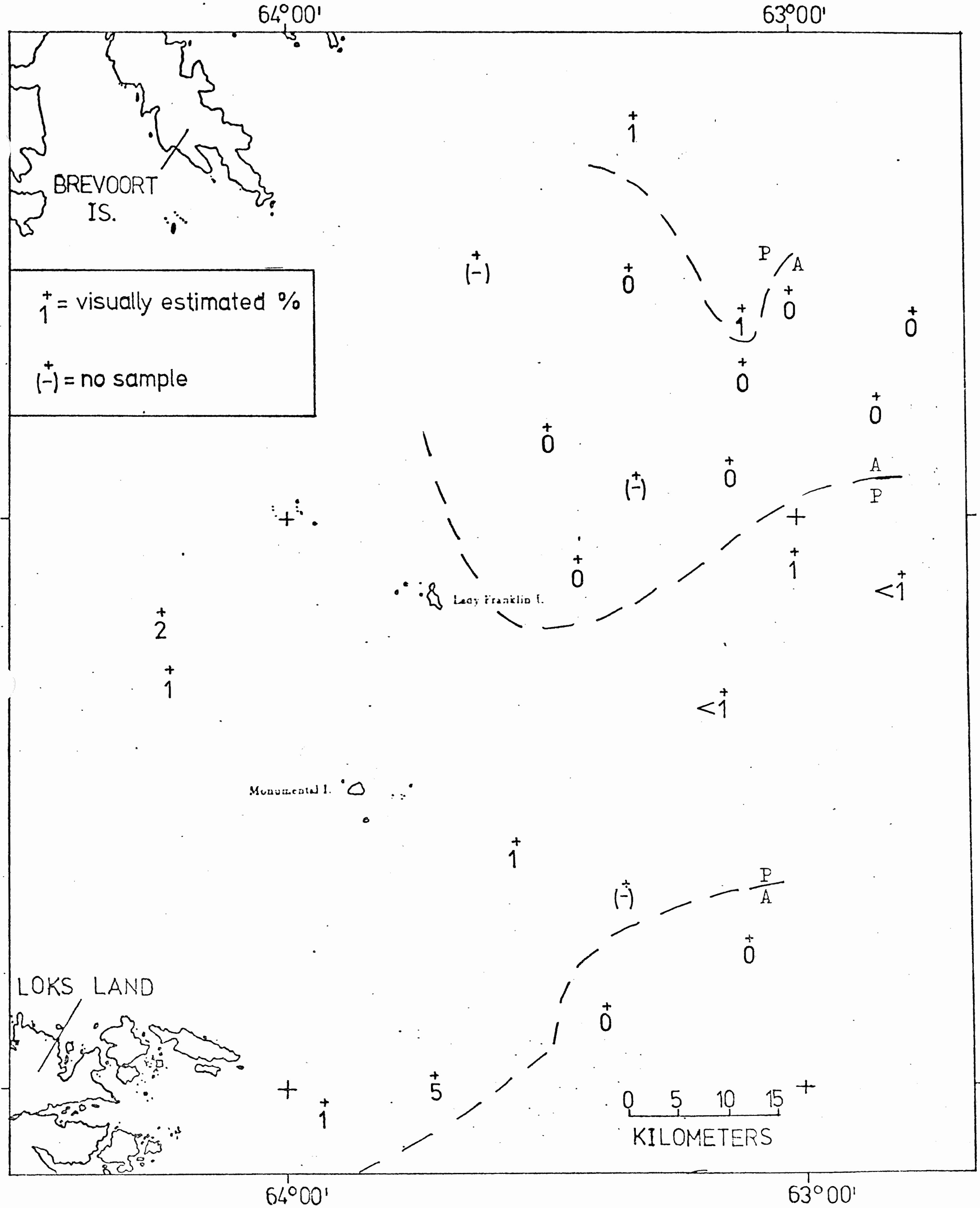


FIGURE 13 - Map of abundance of limestone grains in the 2Ø to 3Ø (fine sand) fractions of grab samples, based on estimation from binocular microscope examination. The dashed line is dimensionless, and is intended to separate areas with no observed limestone from areas where limestone is present. P=present, A=absent.

examined, to degrees varying from 1% to 50% of surface area. They occur either (1) randomly distributed across the grain surface or (2) on one side or end of the grain only. The latter occurrence is by far the dominant one. Where the latter occurs, the bryozoans characteristically are found in association with staining on one side or end of the grain; they almost always are situated on the stained side or end. The reasons for this will be examined in the discussion.

(4) Surface Texture

For each sample, all of the available gravel (always < 30 grains) and 15 grains from each of the -2Ø to -1Ø and -1Ø to 0Ø intervals were carefully visually examined for surface texture information. An estimate of surface texture criteria was made for the 2Ø to 3Ø interval. In addition, 16 grains from the -2Ø to 0Ø interval (usually mostly in the -1Ø to 0Ø interval) of nine selected samples were examined separately using the SEM. The results of this textural study are significant and are given below.

(a) Visual Examination - The three grain size intervals selected for study were all examined with respect to their surface textures. For the gravel and coarse sand fractions, this was done by careful examination of a number of randomly selected grains (thirty for the coarse sand; as many as possible for the gravel). For the fine sand and fractions, a brief visual estimation was made. The surface characteristics utilized in the examination were those of roundness, reflectivity or 'polish,' microrelief, and in the specific case of quartz, conchoidal fracture and cleavage plates. The gravel was merely observed visually under bright light, while the coarse and fine sand fractions were observed with a reflecting light binocular microscope.

On the basis of the surface criteria above, the grains observed could be classified into three surface groups:

(1) grains with an entirely old surface - This surface is referred to as 'old' because it is observed to be broken by the younger surface below. The old surface is recognized primarily by its high roundness, but also by its low reflectivity, and smoothness (low microrelief), on all lithologies; on quartz grains it is also recognized by a lack of conchoidal fracture or visible cleavage plates.

(2) grains with an entirely new surface - This surface is observed to break the above surface, and hence is referred to as 'new.' The new surface is recognized primarily by its angular nature, but also by its high reflectivity and roughness (high microrelief) on all lithologies; on quartz grains it is also recognized by the presence of conchoidal fracture and visible cleavage plates. The new surface is usually observed to be slightly modified due to rounding, typically to angular or subangular (Powers, 1953) from a presumed original very angular; however, the contrast with the well-rounded old surface is maintained.

(3) grains displaying both the old and the new surface - These grains form the basis for the discrimination of the relative ages of the surfaces, and will hereinafter be referred to as old/new surface grains. On these grains the old surface is visible on one or several faces (by the above criteria), at the edges of which it is broken by the new surface (by the above criteria). The new surface is, again, slightly modified.

This grain surface categorization was recognized in all the grain size fractions examined. It was particularly convincingly displayed in the gravel fractions, where the greater size of the grains permitted greater resolution. However, it was also distinctly noted in the coarse and fine sand fractions.

The abundance of the three surface types observed was quantified. It was found that the new surface grains were the dominant components of all the grain size intervals (always > 60%), followed by the old/new surface grains (usually < 25%), and the old surface grains (always < 10%). However, for the -2Ø to 0Ø fractions an estimate was also made of the per cent of surface area of the old/new surface grains with > 50% new surface. It was found that the value for all samples was low, generally < 20 to 30%. This indicates that most of the surface area of the old/new surface grains is the old surface. The significance of this will be elaborated below in the SEM section.

These observations imply two significant features of the sand and gravel deposit.

(1) A distinct grain surface history is discerned, with an older rounded surface broken by a younger angular surface which has been subsequently modified. The roundness of the old surface indicates some high energy environment, while the slightly modified angular nature of the new surface indicates either a low energy environment or a very brief time in a high energy environment.

(2) The grain surface history is recognized in all grain size intervals examined and in all lithologies, implying a homogenous environmental history, or origin, for the deposit as a whole.

(b) Scanning Electron Microscope Examination

Nine samples were selected for SEM examination to provide adequate areal coverage; these were samples 1, 2, 6, 7, 9, 10, 14, 15, and 23, (see Figure 2 for location). Sixteen grains were taken from each sample, a number recommended by Krinsley and Doornkamp (1973) to provide adequate coverage of the possible variability of textures in any given sample.

General features - The SEM study noted the presence of a distinct grain surface history, present to varying degrees in every sample examined. It consisted of an older, rounded surface, with characteristic surface features, broken by a newer 'fresh' angular surface, with characteristic surface features, which has been modified to some extent by rounding and specific surface features. This is in excellent accord with the results of visual observation given above. The characteristic surface features of the older surface, newer surface, and the new surface modification are listed in Table 2, along with an estimate of their overall abundance. The characteristic surface features of several environments according to Krinsley and Doornkamp (1973) are listed in Table 3.

Old surface - The characteristic textural features of the old surface tend to be rather complex. In general, they can be grouped into three sets:

(1) Solution/Precipitation surface - solution/precipitation features of the old surface vary, but are dominated by irregular solution/precipitation, and occasional smooth precipitation surfaces. These features can be seen throughout Figures 14 and 15 below, and are listed in Table 2. These features are to be compared with columns 1 and 2 of Table 3 which list the solution/precipitation features of the aeolian and subaqueous environments according to Krinsley and Doornkamp (1973) and comparison can be made with their photomicrographs (p 53-72).

(2) This set is dominated by mechanically formed upturned plates, dish-shaped concavities, and high roundness, shown in Figure 14 and listed in Table 2. These features are to be compared with column 1 of Table 3 which lists the characteristic surface features of the aeolian environment

SURFACE FEATURES	OLD SURFACE				NEW SURFACE		MODIFICATION	
	SET I		SET II					
	P/A	Abundance	P/A	Abundance	P/A	Abundance	P/A	Abundance
conchoidal fracture					X	A		
mechanical V-forms			X	A			X	B
slightly curved grooves			X	C			X	C
dish shaped concavities	X	B						
mechanically formed upturned plates	X	A	X	B	X	A		
flat cleavage faces					X	B		
cleavage planes					X	B		
rounding	X	A	X	B			X	B,C
angularity					X	A		
irregular precipitation/solution	X	B	X	B	X	C	?	
deep surface solution	X	C	X	C				
smooth precipitation surface			X	C	X	C		

TABLE 2 - Surface features of the surface groups recognized in SEM study of -2Ø to 0Ø quartz grains. P/A = Presence/Absence (X means surface feature is present). Abundance: A=Abundant (always present), B=Intermediate (often present), C=Rare (occasionally present).

SURFACE FEATURES	AEOLIAN		SUBAQUEOUS		GLACIAL		SOURCE MATERIAL	
	P/A	Abundance	P/A	Abundance	P/A	Abundance	P/A	Abundance
conchoidal fracture			X	C	X	A	X	B
chemical V-forms			X	B				
mechanical V-forms			X	A				
slightly curved grooves			X	B				
dish shaped concavities	X	B						
mechanically formed upturned plates	X	A	X	B	X	A	X	A
flat cleavage faces			X	C	X	C	X	C
cleavage planes					X	B	X	B
rounding	X	A	X	B	X	C	X	B
angularity					X	A	X	B
irregular precipitation/solution	X	B	X	B	X	B	X	A
deep surface solution								
smooth precipitation surface	X	B						
precipitated upturned plates	X	C					X	B

TABLE 3 - Characteristic surface features of coarse sand grains from four environments according to Krinsley and Doornkamp(1973). P/A = Present/Absent (X means surface feature is present). Abundance: A = Abundant (always present), B = Intermediate (often present), and C = Rare (occasionally present).

according to Krinsley and Doornkamp (1973), and comparison can be made with their photomicrographs (p 63-72).

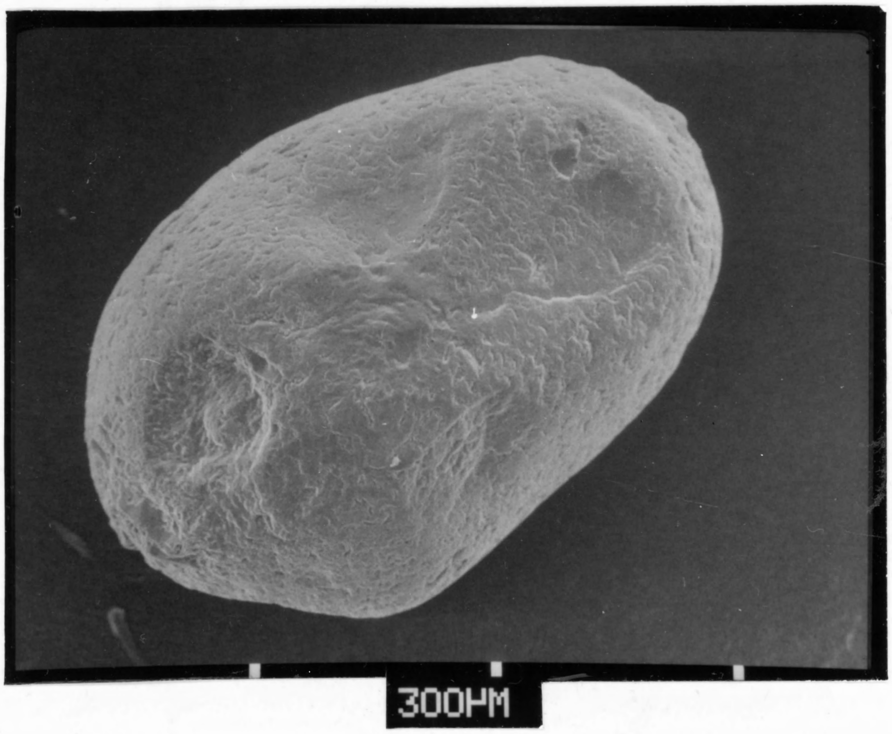
(3) This set is dominated by V-forms, medium-high roundness, and curved grooves, illustrated in Figure 15 and listed in Table 2. These features are to be compared with column 2 of Table 3 which lists the characteristic features of the subaqueous environment according to Krinsley and Doornkamp, and comparison can be made with their photomicrographs (p 53-58).

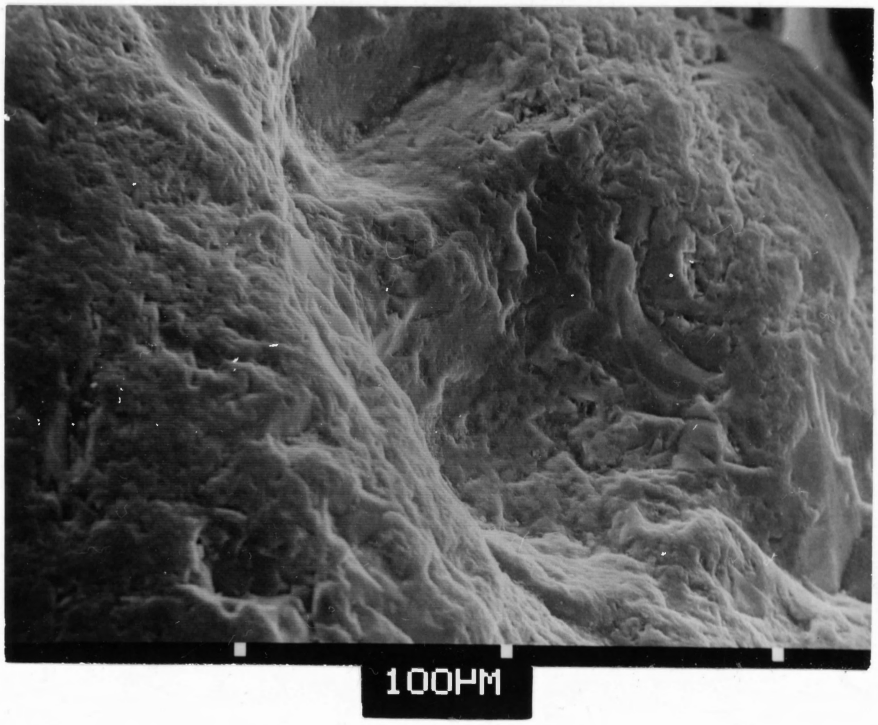
These three sets of features only rarely occur as pristine examples and old surfaces tend to be mixtures of these end-members. Thus solution/precipitation features with superimposed V-marks are often found (Figures 15d and 15e), as are rounded aeolian surfaces with irregular solution/precipitation surfaces (Figure 14c), or aeolian features with superimposed V-forms (Figure 14b). Of any surface, the solution/precipitation surface tends to occur most frequently nearly pristine (though almost never without some V-forms), but this is mostly due to its capacity to modify or conceal. The surface exhibited by the grains undoubtedly represents only the last stage of a process of modification with a long and varied history--the outer skin of an onion, as it were.

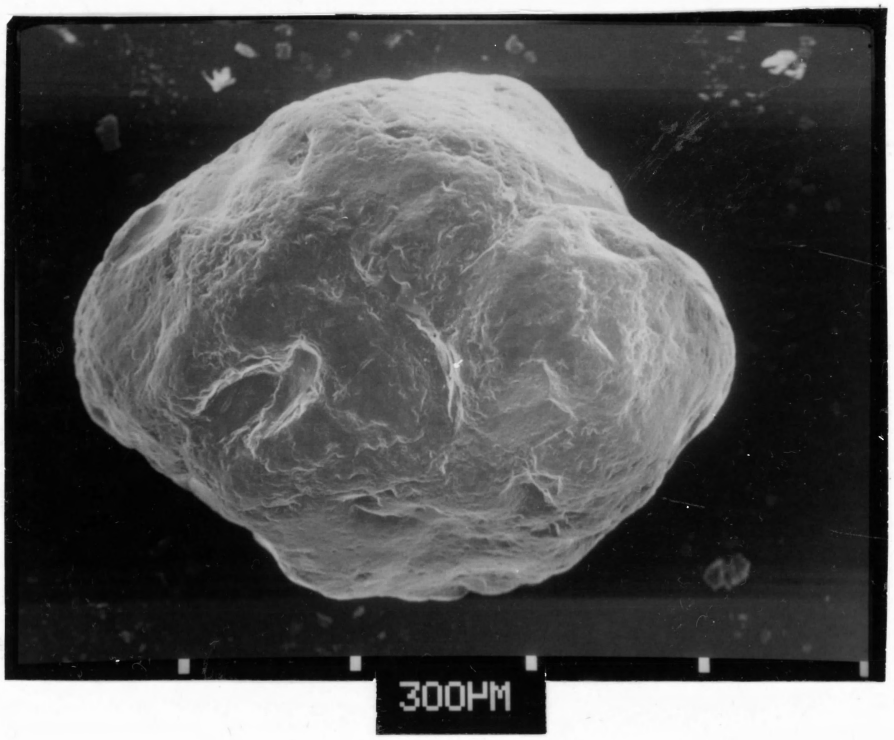
This renders difficult the task of determining the environment(s) of formation of the old surface in any highly specific sense; for example, the prominent effects of repeated solution/precipitation in destroying the subaqueous V-forms, combined with the difficulty of recognizing V-forms as an irregular solution/precipitation surface, make it impossible to count V-forms and compare with the subaqeuous environmental discrimination diagram of Krinsley and Doornkamp (1973, Figure 1).

FIGURE 14 - SEM photomicrographs of surface features of the old surface (set I, Table 2).

Scale - the distance between two white squares on the lower margin equals the distance in microns given below the margin.


300UM


100UM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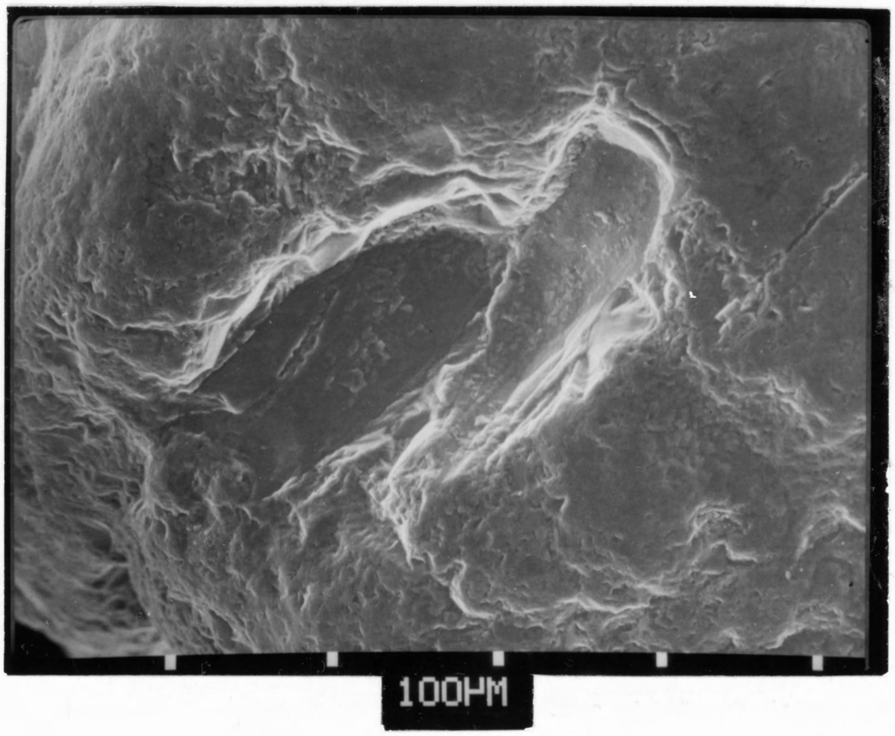

100µM

(a) Sample 2

Grain with an entirely old surface in view, displaying good roundness and mechanically formed upturned plates over most of the surface, and a prominent dish-shaped concavity at lower left. The grain is slightly smaller than 0Ø.

Magnification - 103X.

(b) Sample 10

Close-up of a dish-shaped concavity on an entirely old surface grain. The surface displays good rounding, mechanically formed upturned plates, and likely precipitation/solution. Superimposed are abundant mechanical V-forms.

Magnification - 320X.

(c) Sample 15

Grain with an entirely old surface in view, displaying good roundness, mechanically formed upturned plates, and moderately intense solution/precipitation over most of the grain surface. Several prominent cavities tentatively termed dish-shaped concavities are also present, as are scattered V-forms.

Magnification - 81X.

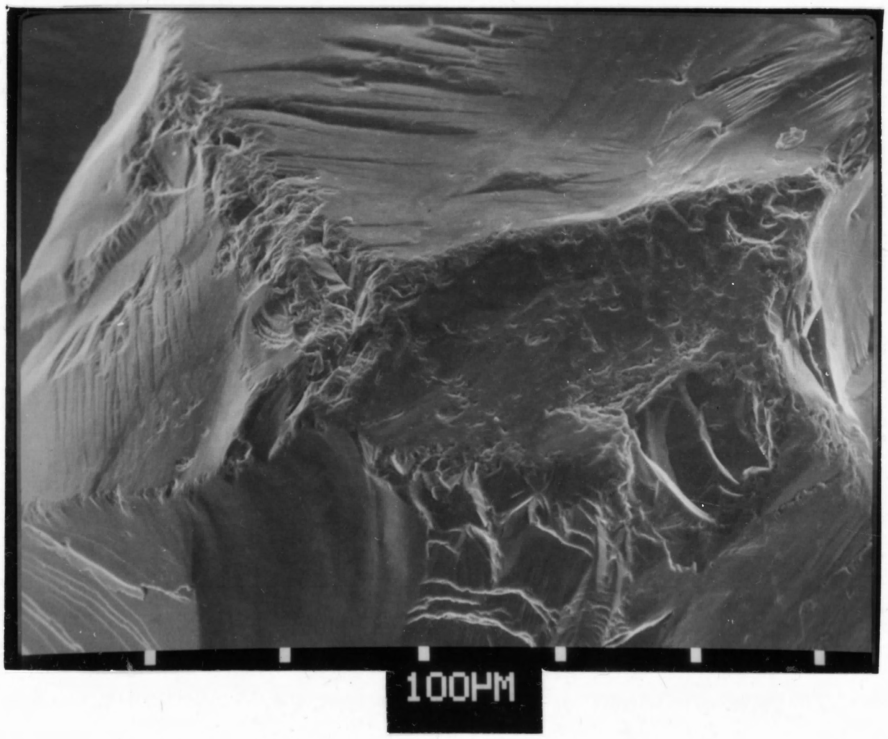
(d) Sample 51

Closeup of one of the cavities on the above grain. Note the steep-sided nature, distinct from the other more dish-shaped cavities. Also note mechanically formed upturned plates, precipitation/solution, and scattered V-forms.

Magnification - 208X.

FIGURE 15 - SEM photomicrgraphs of surface features of the old surface (set II, Table 2).

Scale - the distance between two white squares on the lower margin of the photomicrographs equals the distance in microns given below the margin.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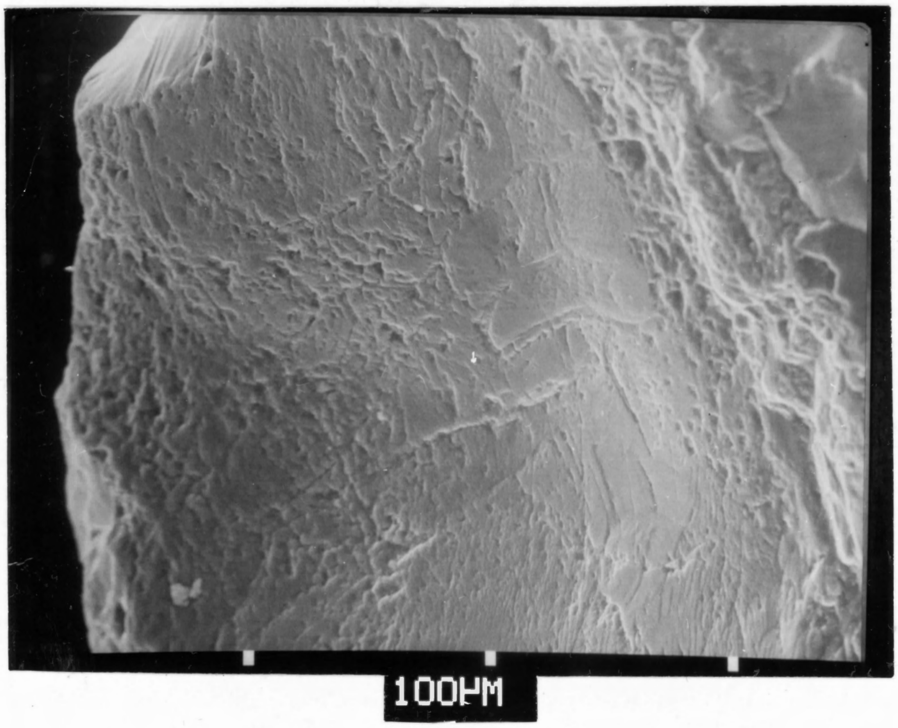
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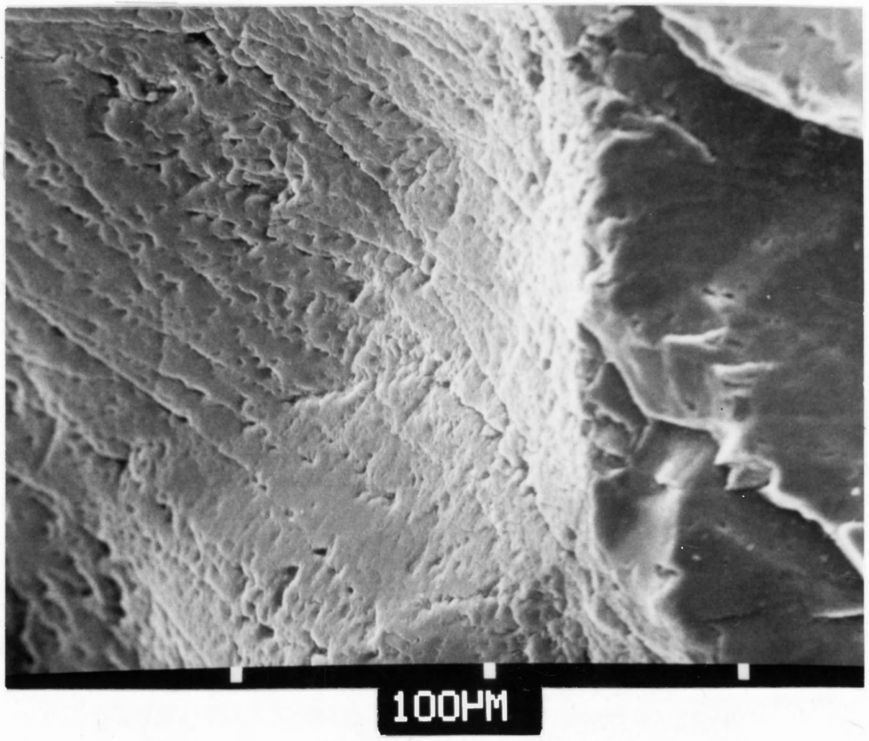
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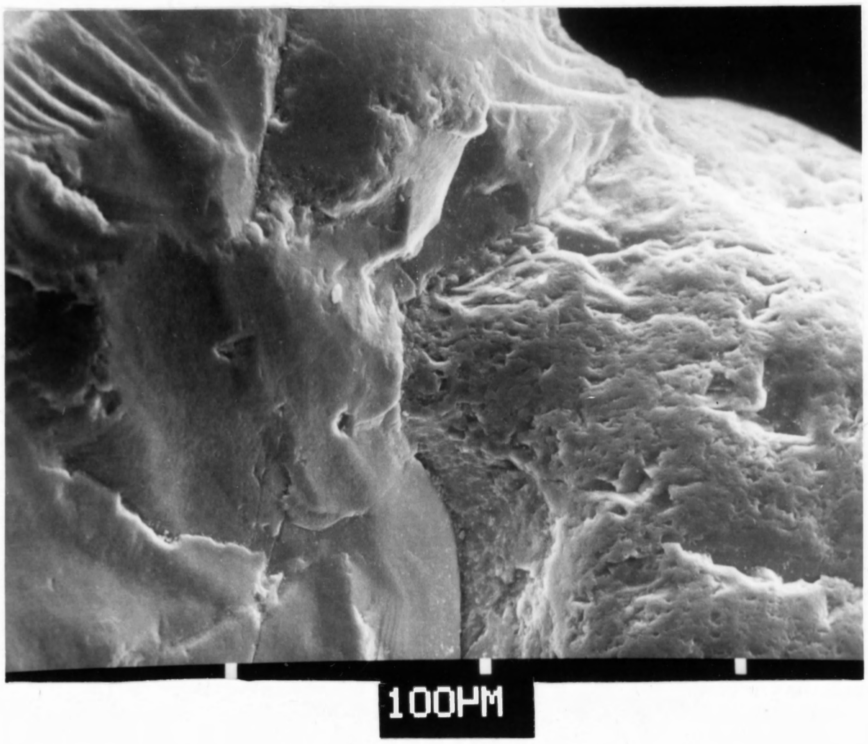
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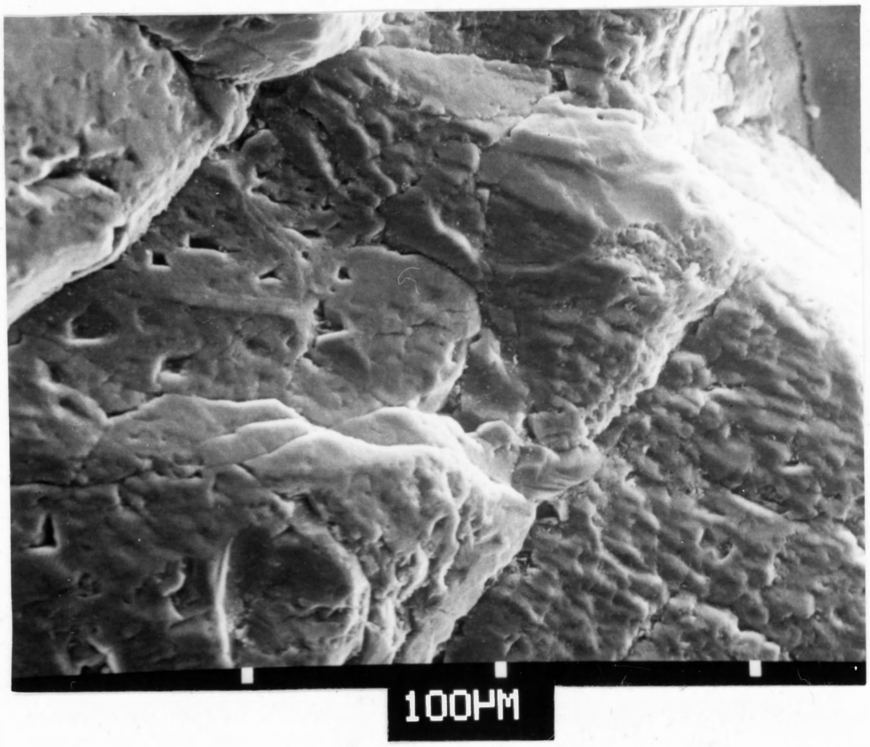
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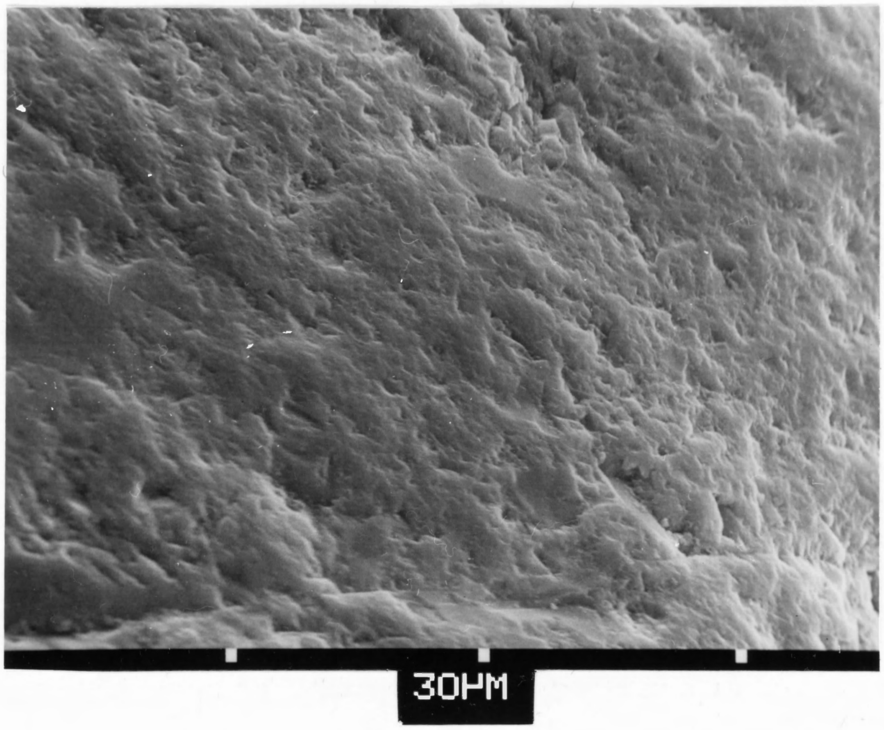

30PM

(a) Sample 14

Grain with an old/new surface. The triangular portion of old surface just to right of centre displays abundant prominent mechanical V-forms and occasional curved grooves. It is broken at the deges by the new surface, displaying cleavage planes, mechanically formed upturned plates, angularity, and scattered, less abundant V-forms.

Magnification - about 200X.

(b) Sample 51

Old/new surface grain, with the old surface in a bowl shaped depression broken at the edges by the new surface, visible in the foreground at right and in the background in the upper left. The old surface displays scattered V-forms superimposed on a solution/precipitation surface consistingg of grooves and lines of dubious origin.

Magnification - 308X.

(c) Sample 9

Old/new surface grain, with the old surface in bowl shaped depression broken at the edges by the new surface, which is visible at right in the foreground. The old surface displays prominent, abundant, slightly oriented V-forms, and long lines which may be curved grooves. Some solution/precipitation features may also be present.

Magnification - 305X.

(d) Sample 9

Old/new surface grain, with the old surface at right broken by the new surface at left. The old surface displays rounding, mechanically formed upturned plates, and prominent solution/precipitation features, with superimposed V-forms of variable size. The new surface displays mechanically formed upturned plates, angularity, and surface pits (rare). The geometry of the breakage appears awkward at this angle.

Magnification - 304X.

(e) Sample 9

Portion of the old surface, displaying mechanically formed upturned plates rounded by precipitation/ solution, with superimposed large V-forms; smaller V-forms are also present throughout.

Magnification - 304X.

(f) Sample 10

Portion of the old surface, displaying rounding, prominent mechanically formed upturned plates, and abundant small V-forms.

Magnification - 1010X.

However, in general the following picture of the 'old' environment can be discerned:

(1) Both the aeolian and subaqueous environments can be recognized, and the solution/precipitation textures noted are also ascribable to these environments (see Table 2, but also see new surface discussion below).

(2) The association of aeolian with subaqueous grains suggests either a shoreline deposit, or wind transport of aeolian grains to offshore subaqueous deposits.

(3) The high rounding of many of the grains with dominantly subaqueous textures (Figure 15e), along with local high concentrations of V-forms (Figure 15c), tend to support a high energy source for the subaqueous texture, and hence the shoreline deposit hypothesis. However, this is speculative. The problem of provenance of the old surface will be discussed more later, in light of other data.

An idea of the abundance of the old surface in the sediments can be derived from the last column in Table 4. In general there are relatively few--though present--entirely old surface grains, and anywhere up to half the grains can have an old surface as part of the grain. Thus while it is not omnipresent, it is an important feature of the grains. This parallels the pattern observed visually.

New surface - The surface features characteristic of the new surface are listed in column 3 of Table 2. As can be seen, it is dominated by angularity, cleavage plates, conchoidal fracture, and flat cleavage faces. These features are illustrated in Figure 16, and are to be compared with columns 3 and 4 of Table 3 which lists the characteristic features of the source material and glacial environments according to Krinsley and Doornkamp (1973). Comparison can be made with their

SAMPLE #	NUMBER OF MECHANICAL V-FORMS PER $20,000u^2$ (AVERAGE)	# GRAINS WITH THE INDICATED ROUNDNESS			# OLD/NEW SURFACE GRAINS WITH THE INDICATED % SURFACE AREA OF NEW SURFACE		# GRAINS WITH THE INDICATED SURFACE TYPE		
		6	5	4	$>50\%$	$<50\%$	Old	New	Old/New
1	7	0	10	4	9	1	2	8	6
2	8	2	14	0	8	1	1	6	9
6	4	0	8	6	6	0	0	11	5
7	0	12	2	0	4	0	2	10	4
9	4	1	14	1	6	3	0	6	10
10	4	0	8	7	8	5	2	5	9
14	8	1	12	2	8	1	0	7	9
15	7	0	7	8	8	4	1	9	6
23	15	1	6	8	4	0	0	12	4

TABLE 4 - Abundance of V-forms, roundness types, and surface types, measured on the new surface of -20 to 00 quartz grains using the SEM. The abundance of V-forms was determined by counting a standard area ($20,000u^2$). The values for roundness and surface type refer to the number of grains out of the total (16 grains). Roundness is as given in the text: 6 = very angular, 5 = angular, 4 = subangular.

photomicrographs (p 30-35 and 44-50).

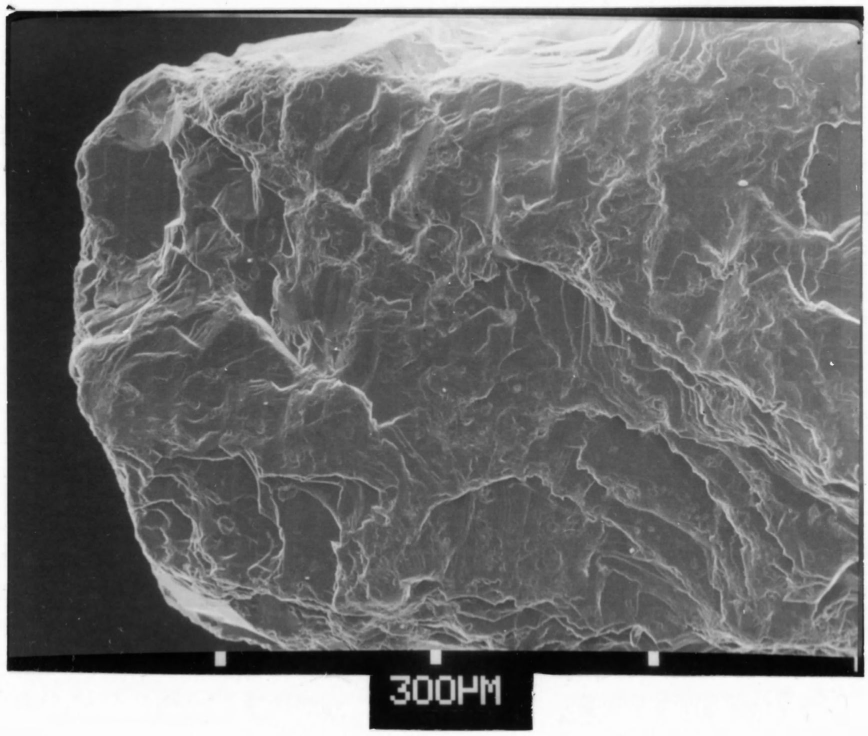
There is difficulty in differentiating the glacial and source material environments, although together they are distinctive, a fact noted by Krinsley and Doornkamp (1973) and Whalley (1978). Krinsley and Doornkamp (1973) suggest that the source material environment can be readily distinguished by the much greater variability in size and occurrence of surface features, and by the more common occurrence of solution / precipitation features. In particular, they note that in the source material environment subaerial weathering of bedrock outcrops can result in selective precipitation/solution along exposed grain surfaces, while surfaces exposed later are fresh--a very similar situation to the old/new surface dichotomy recognized. However, they also note that this will only occur where the grains are freshly broken and subsequently unbroken, a very rare occurrence; in all other cases, there will be extremely complex precipitation/solution phenomenon over all grain surfaces.

As can be seen in Table 2, solution/precipitation textures do occur in association with the new surface (see below). However, (1) they are not very common, and (2) it is uncertain whether they are part of the glacial environment or the environment of modification of the new surface (see below). In most cases, solution/precipitation textures are associated with the old surface, and are separated from the new surface by a distinct boundary.

The environment represented by the new surface is determined by the following argument. On many grains the new surface is observed to break an older surface clearly associated with the aeolian or subaqueous environment; in these cases the new surface obviously cannot represent the source material environment, and must be glacial in origin. However, on grains for which the old surface is dominantly a solution/precipitation texture, or for grains which have an entirely

FIGURE 16 - SEM photomicrographs of the new surface (Table 2).

Scale - the distance between two white squares on the lower margin equals the distance in microns given below the margin.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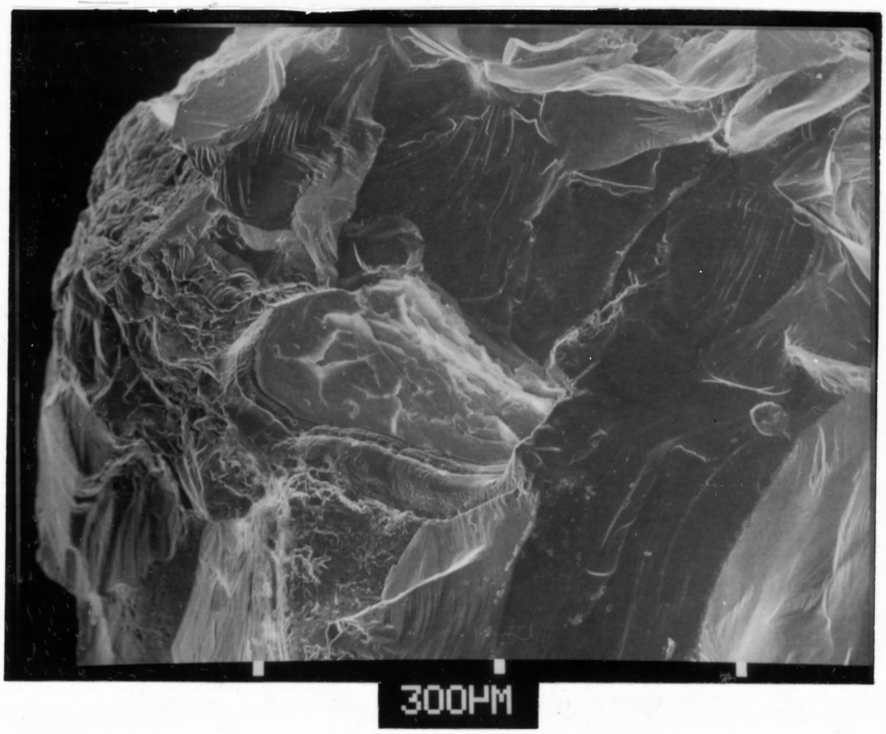
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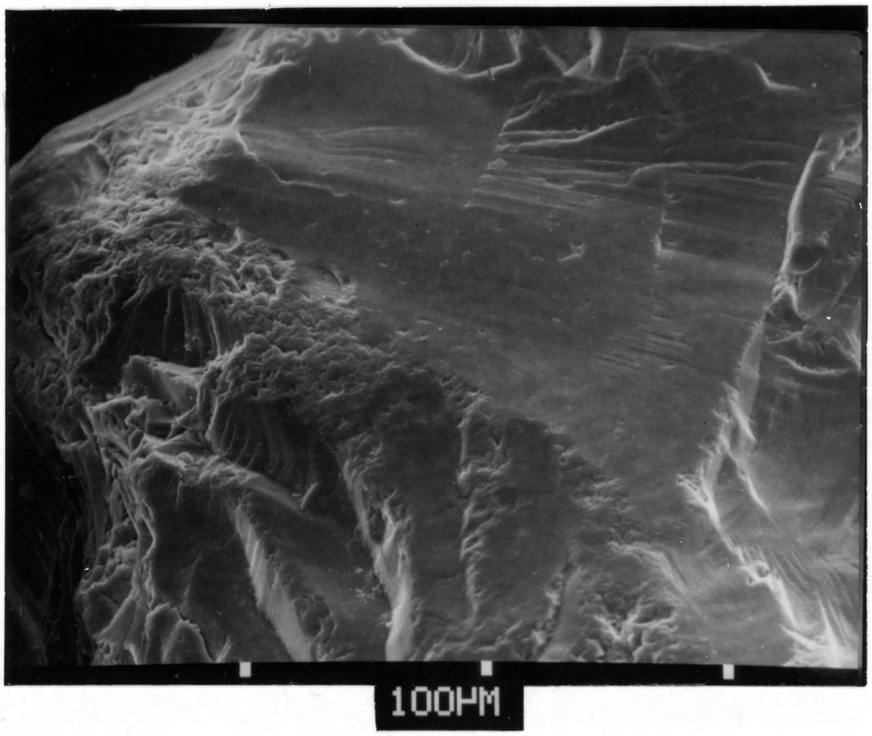
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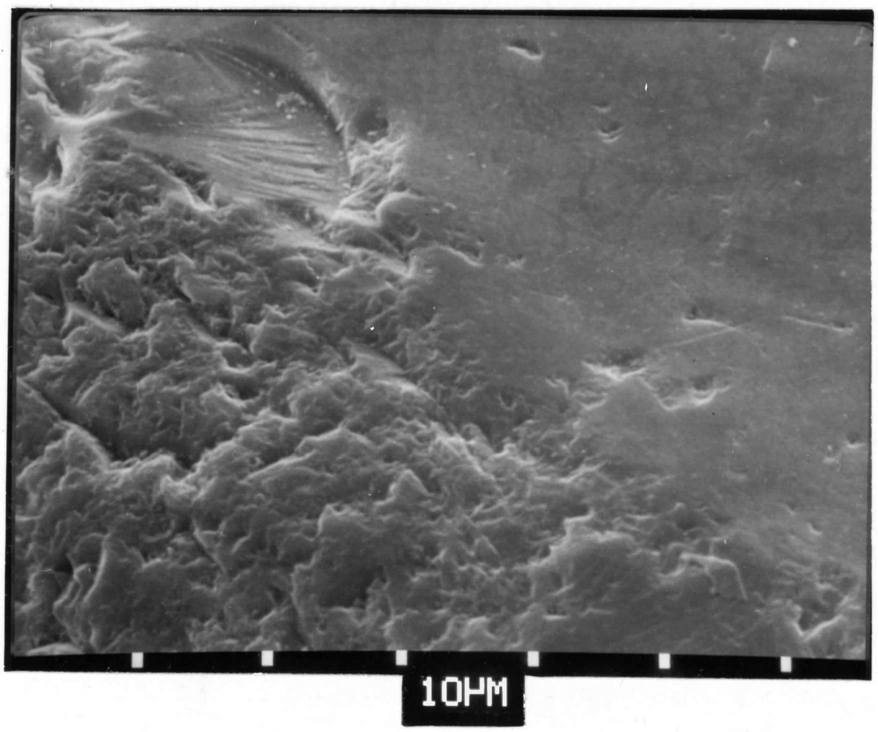
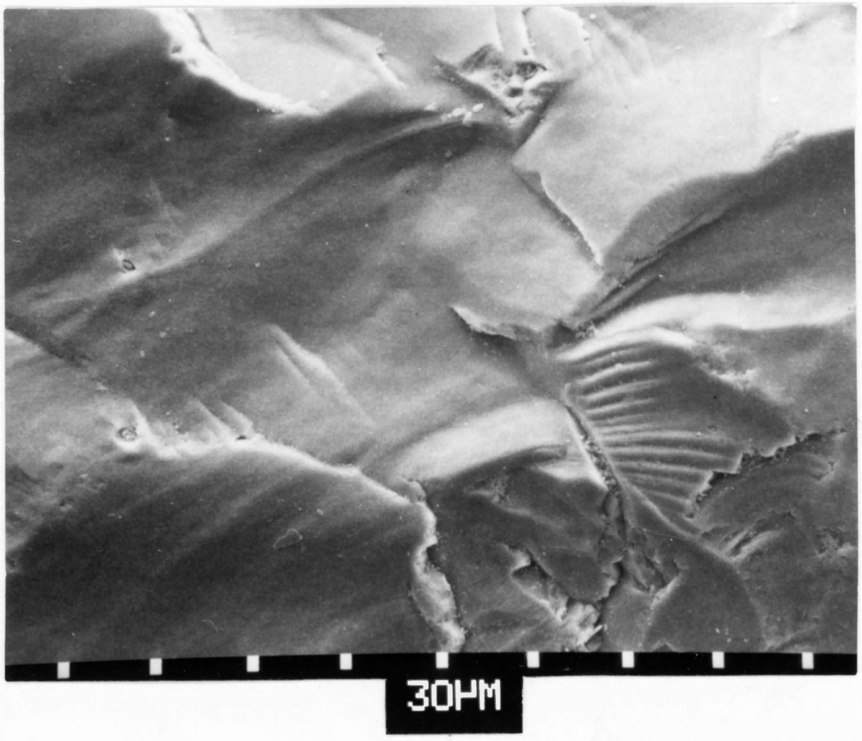

10µM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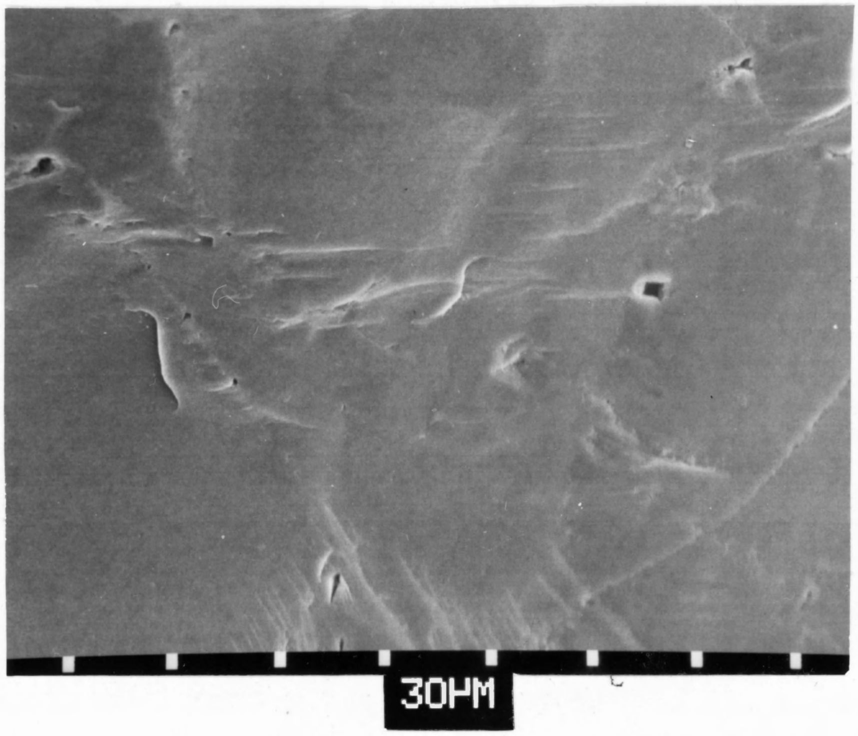

30µM

(a) Sample 14

Portion of the new surface, displaying angularity, mechanically formed upturned plates, and cleavage planes throughout. Conchoidal fracture is present in some areas. Modification is visible as slight rounding of the edges, and scattered V-forms.

Magnification - 92X.

(b) Sample 6

Portion of the new surface, displaying angularity, conchoidal fracture, mechanically formed upturned plates, and cleavage planes. Modification is visible as scattered V-forms.

Magnification - about 100X.

(c) Sample 2

Old/new surface grain, with the new surface in the upper right breaking the old surface in the lower left. The new surface displays angularity, mechanically formed upturned plates, and prominent modification in the form of scattered V-forms and other surface pits. The old surface displays roundness, solution/precipitation features, V-forms, mechanically formed upturned plates.

Magnification - about 300X.

(d) Sample 2

Closeup of the above grain, showing the contact between the old and new surfaces. Note the conchoidal fracture in upper left clearly demonstrating the breakage of the old surface.

Magnification - 1670X.

(e) Sample 9

Portion of the new surface, showing angularity, mechanically formed upturned plates, and conchoidal fracture. Possible very mild modification can be seen as a few surface pits.

Magnification - 390X.

(f) Sample 9

Portion of the new surface, displaying mechanically formed upturned plates and smoothness. Modification is visible as a few surface pits and V-forms.

Magnification - 510X.

new surface, this argument cannot apply. For these grains, (1) the lack of complex solution/precipitation phenomenon over all the grain, and (2) the lack of extreme variability in surface textures strongly suggest that the texture is glacial in origin. However, it is a distinct possibility that some of the grains are from the source material environment *via* the glacial environment, which would explain the abundance of solution/precipitation phenomenon; this will be considered more in the discussion.

An idea of the abundance of the new surface can be derived from the last column in Table 4. Over half of the grains can have an entirely new surface, and up to half of the grains can have a new surface as part of the grain. It is thus an important feature.

Old Surface/New Surface Distinction

The postulate that one set of surface features is distinct from and older than the other is examined here. In the absence of diagenetic textures, the distinction and age relationships are clear: the two surfaces possess completely different textural features (see Table 2) and where a sufficient portion of both surfaces are visible there is a noticeable difference in angularity; the older surface is confined to discrete faces or areas of the grain, and is broken at its edges by the newer surface (Figures 14, 15, 16).

However, where diagenetic features are present, as they frequently are, it can be very difficult to extend the old surface/new surface distinction above, due to the difficulty of separating diagenetic features of the old surface from similar diagenetic features of the new surface. The surface dichotomy of diagenetic (old) features against fresh (new) features alone is insufficient, due to the possibility of selective solution/precipitation; Krinsley and Doornkamp (1973) show several photomicrographs where some faces of the grain have undergone extensive diagenesis while others are relatively pristine (p 30, 32). My own investigation revealed several grains where selective precipitation/solution has occurred, e.g., Figure 16. In distinguishing a surface as an older rather than later surface, therefore, great care has been exercised. The following features have been utilized:

(1) relief - Where solution/precipitation occurs after formation of the new surface, the new surface is generally raised slightly relative to the adjacent diagenetic surface; however, where the diagenetic surface has been broken by the new surface, it is generally raised.

(2) geometry - Where solution/precipitation occurs after the new surface, it can be rather patchy in extent, occurring on parts of one face as discrete patches, or on several faces; however, where the diagenetic surface came first, it must by necessity be confined to one face or series of faces.

(3) boundary - Where the diagenetic texture occurs after the new surface it often has an irregular border; however, where the diagenetic texture occurs first the boundary is sharp, and well defined.

Since exceptions can occur to each of these rules, they must be used in combination and with great care.

Preservation

The old surface is preserved relative to the new surface in several ways: (1) as whole grains (unbroken) (Figures 14a, 14c); (2) as faces or numbers of faces, broken at the edges by the new surface (Figures 15a, 15d); (3) in bowl or dish-shaped depressions, some clearly formed due to breakage at the edges (Figures 15b, 15c) but others reminiscent of the dish-shaped concavities of the aeolian environment.

There is in this line an interesting geometrical problem associated with some manifestations of the old surface, for bowl-shaped depressions are indeed fairly common; yet it seems that the most likely preservation of the old surface would be on convex outward surfaces, rather than convex inward 'bowls.' Some of these could be explained as selective diagenesis but not all of them (e.g., Figure 15c). Why these bowls occur so frequently as preservational mechanisms is an interesting, unanswered question.

An estimate of the per cent surface area of the grain occupied by the new surface was made as it was for the visual observation of grains, by counting the per cent grains with > 50% surface area composed of the new surface; the values for the SEM study are listed in Table 4. As can be seen, the most important forms of preservation are those which result in a minimum per cent of old surface per grain. This corresponds with mechanisms of preservation (3) and depending on extent (2), above.

This result should be compared with that presented in the visual observation section, where it was shown that for the same grain size the reverse was true--the per cent of grains with > 50% surface area new was always low, rather than high. This change is a reflection of the method of study--SEM study allows resolution of very small grain surface areas, and hence small patches of old surface can be seen, while for visual observation only those grains with a significant per cent area of old surface--usually ≥ 50%--can be observed with confidence. The conclusion is that old/new surface grains are much more prevalent than the visual examination results would seem to indicate. Note, however, that even the high SEM study results represent a minimum estimate, for with the fixing of grains on studs only one side of a grain can be seen.

This result is important, because it reduces the problem of distinguishing grains derived from the unconsolidated source represented by the old surface, from grains freshly derived from bedrock. Clearly this point must be considered, however, for it can be seen in Table 4 even with SEM magnification a maximum of only 50% or more of the sample possesses an old/new surface dichotomy; this leaves 50% or more of the sample uncertain. However, (a) it is expected that a significant proportion of grains derived from an unconsolidated source would be broken to an entirely new surface, and (b) some contribution from bedrock erosion is certainly possible, and may not present a problem to interpretation. This will be discussed further under the problem of provenance.

Modification

The new, or glacial, surface exhibits forms of modification, illustrated in Figure 17. These are:

(1) roundness - Roundness was estimated from the Powers (1953) comparison charts, using the simple numerical equivalency 1 = very angular, 2 = angular, 3 = subangular, 4 = subrounded, 5 = rounded, and 6 = very rounded. Krinsley and Doornkamp (1973), among others, note that fresh glacial grains are very angular. They outline a test for angularity by focussing on a grain edge and going to progressively higher magnification--if the edge remains angular in appearance, it really is. In most cases in this study it was not necessary to go to very high magnification to see modification, and often it could be seen with little magnification at all. The number of grains having a given roundness 4,5, or 6 is listed in Table 4; as can be seen, only rarely does a grain have an unmodified new surface, i.e., roundness of 6 (see below for exception). Whalley (1978) noted that glacial grains can undergo primary (i.e., glacial) rounding on their edges due to edge-grinding, or abrasion beneath the ice. However, he noted that (a)

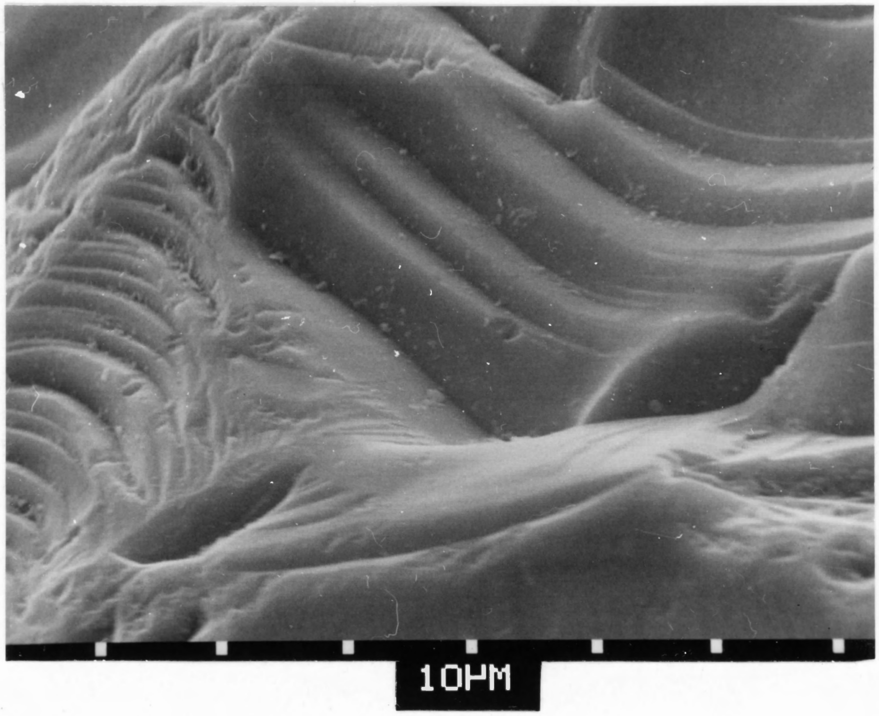
the edge-grinding was absent from many grains, and (b) it did not usually affect every corner and edge on the grain. This is in contrast to the rounding on grains in this study which (a) affects almost every grain, and (b) affects every corner and edge of a given grain. I conclude that the rounding observed here is due to secondary modification, i.e., post-glacial, and not edge-grinding. Rounding will be discussed in a later section. The average roundness of the new surface as observed on SEM is plotted in Figure 18. The highest roundness occurs in sample 23, and decreases to the southwest reaching a lowest point (high angularity) in the essentially unmodified sample 7. This will be discussed more below.

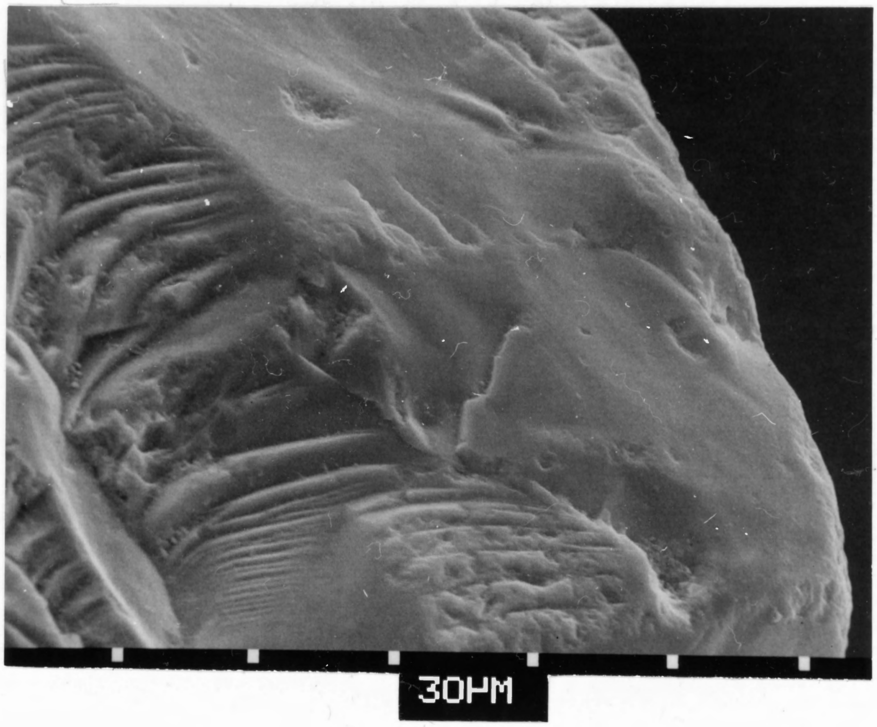
(2) mechanical pits - These include, to varying degrees, V-shaped pits. As discussed above, these are indicative of motion in water. Although the number of pits per unit area was generally very low--often less than one pit per 1000 μ^2--they were with one exception (see below) ubiquitous. Estimates of V-form abundance on the new surface were made, and the results are listed in Table 4. It should be noted that these values may represent minimum estimates, as in some cases there were a variety of smaller (< 1 μ) surface pits which it was difficult to count accurately or know the value of. However, in cases where there was an abundance of these smaller features (e.g., sample 27), there was a commensurate increase in the larger pits (2 - 10μ) which were primarily counted, thus ensuring that the values in Table 4 bear relative significance, even if absolute values are low.

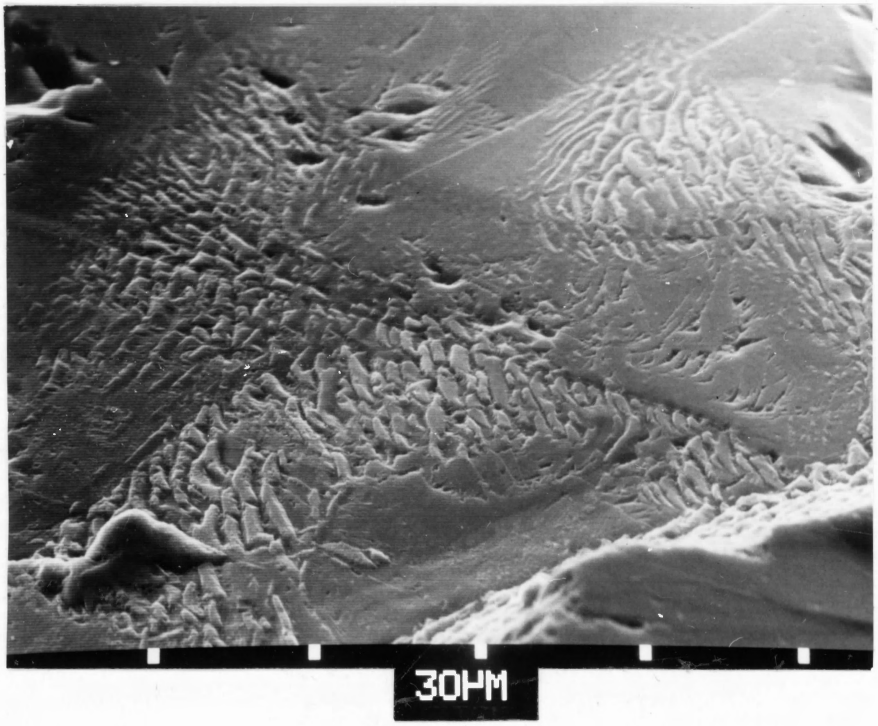
The number of pits/μ^2 were far too low to register on Figure I of Krinsley and Doornkamp (1973). This is true even despite the fact that absolute values may be low, for the values would have to be several orders of magnitude higher to register. However, since the values bear relative

FIGURE 17 - SEM photomicrographs of surface features of the modification of the new surface (Table 2).

Scale - the distance between two white squares on the lower margin equals the distance in microns given below the margin.


10ΜΜ


30ΜΜ


30μM

(a) Sample 10

Portion of the new surface, displaying conchoidal fracture and/or mechanically formed upturned plates. Note the prominent modification in the form of abrasion of the edges of the plates.

Magnification - 1490X.

(b) Sample 10

Portion of the new surface, displaying angularity, conchoidal fracture, and mechanically formed upturned plates. Note the modification in the form of abrasion and rounding of plate edges, and rounding of the grain edge. Some rounding may be assisted by precipitation/solution. Also note scattered V-forms.

Magnification - 550X.

(c) Sample 6

Portion of the new surface, displaying prominent modification in the form of selective precipitation/solution and mechanical V-forms.

Magnification - 670X.

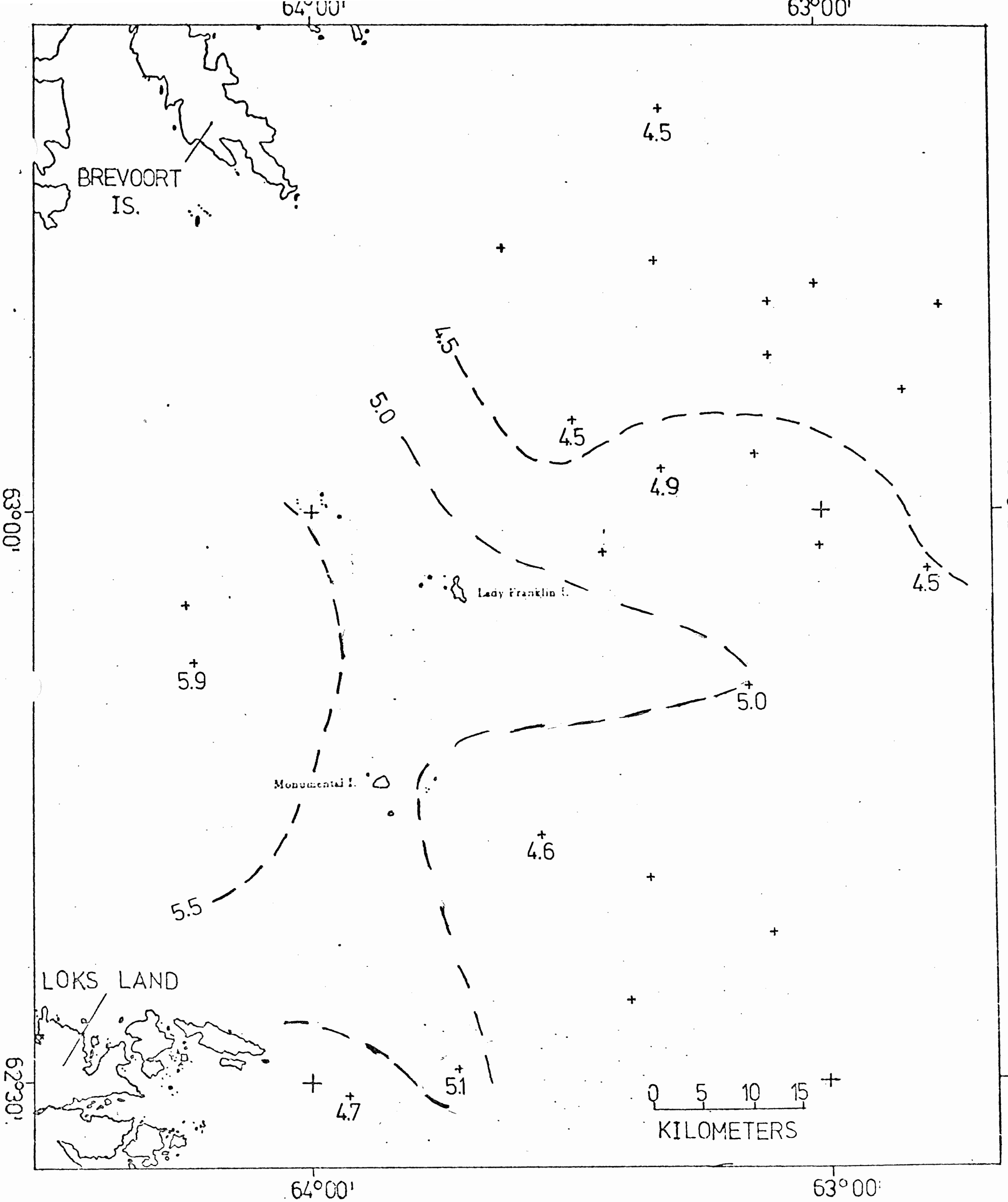


FIGURE 18 - Map of the variability in average angularity of the new surface (see text) of -2Ø to 0Ø quartz grains from the 9 samples studied under the SEM. Angularity estimated using the Powers(1953) comparison chart. Contour interval = 0.5.

significance, they were plotted on a figure. This is not shown, for the distribution is essentially similar to that of the roundness in Figure 18. The highest pit concentration occurs on sample 23, and pit concentrations decrease to the south west increasing again only in the shallow samples off Loks Land. The lowest pit concentration (zero) occurs on sample 7 in the west (see below). The generally low pit concentrations indicate either low energy conditions, or a very brief episode of higher energy transport.

(3) precipitation/solution textures - As discussed above, it is unknown whether the precipitation/solution textures observed superimposed on the glacial texture are primary, secondary, or both. They are compatible with either environment. Examples can be seen in Figure 17.

The exception to both the rounding and the mechanical pits is sample 7, which occurs in the Monumental Basin Sediments. Such lack of modification is commensurate with the high silt and clay content of the sample (21%) which indicates a sheltered environment at present. This will be discussed more later.

(c) Roundness

As part of the textural examination, roundness measurements were made on the new surfaces of the grains using the Powers (1953) comparison charts.

Lithologic heterogeneity - Due to the differing hardness of the various lithologic groups in the sediments, roundness data would be meaningless if not specified for lithology. The roundness values given are those of quartz, selected due to its consistent abundance in the samples as either distinct grains or part of polycrystalline aggregates. Although not specifically quantified and presented here, it was noted that feldspar, limestone and brown siltstone were all much more rounded than quartz insofar as the new surface was concerned, a not surprising result.

Variability - The variability of the roundness of the new surface of quartz across the bank is shown in Figures 19 and 20. Roundness was estimated from the Powers (1953) comparison charts, using the simple numerical equivalency outlined above. The gravel value (Figure 19) was obtained by averaging the total number of measurements, which for all grains were either 4, 5, or 6. The fine sand value (Figure 20) was obtained by estimating the percentage of total grains in each of four roundness categories, specifically 1-2, 3, 4, and 5-6; the value shown is the percentage in the 5-6 category. The 5 and 6 categories were grouped because at the high magnification needed to observe the fine sand it was impossible to distinguish very angular and angular; the value in Figure 20 corresponds to what was visually estimable (at this scale) as angular, unmodified grains. Since the % 1-2 and % 3 roundness categories (the old surface) did not exhibit significant variance in abundance, the value in Figure 20 is essentially changing relative to the % 4 roundness category, or what approximates the modified (or very modified) surface.

Although the two figures are different, they show agreement on the following point: roundness of the new surface of quartz grains decreases overall to the west and southwest, or toward the shallower parts of the bank. This is best shown by Figure 20, which displays a well-defined trend of this value; Figure 20 is thought to be valid, as measurements were taken carefully. Figure 19 shows this trend only in a general way; however, values for the gravel are uncertain due to the generally low number of grains and the low number of samples with gravel.

These figures should be compared with Figure 18 which shows the average

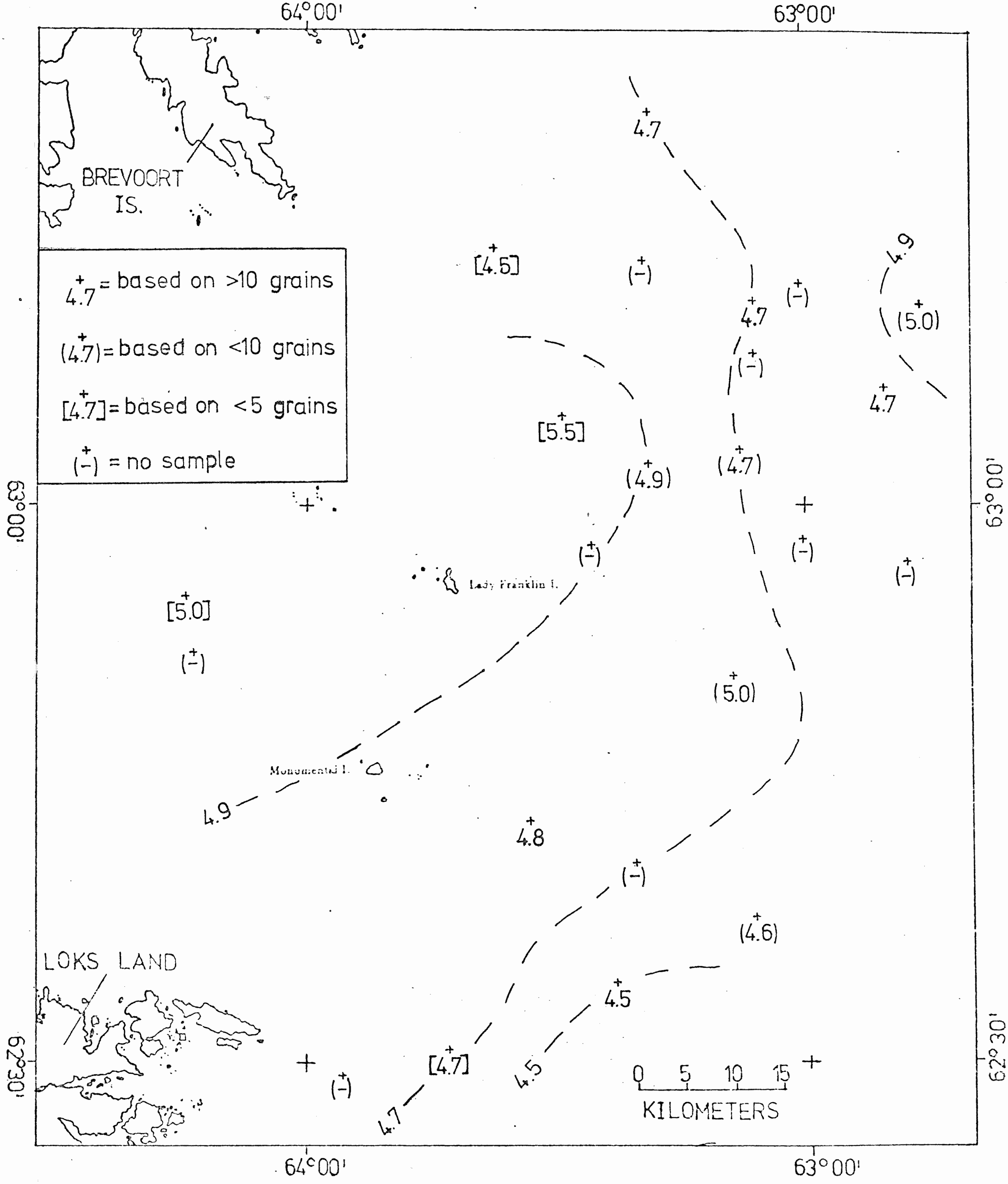


FIGURE 19 - Map of the average roundness of the new surface of -5ϕ to -3ϕ (gravel) fractions of grab samples, as observed in visual study. Roundness was estimated using the comparison charts of Powers(1953), and defined by the simple numerical equivalency outlined in the text. Contour interval = 2.0.

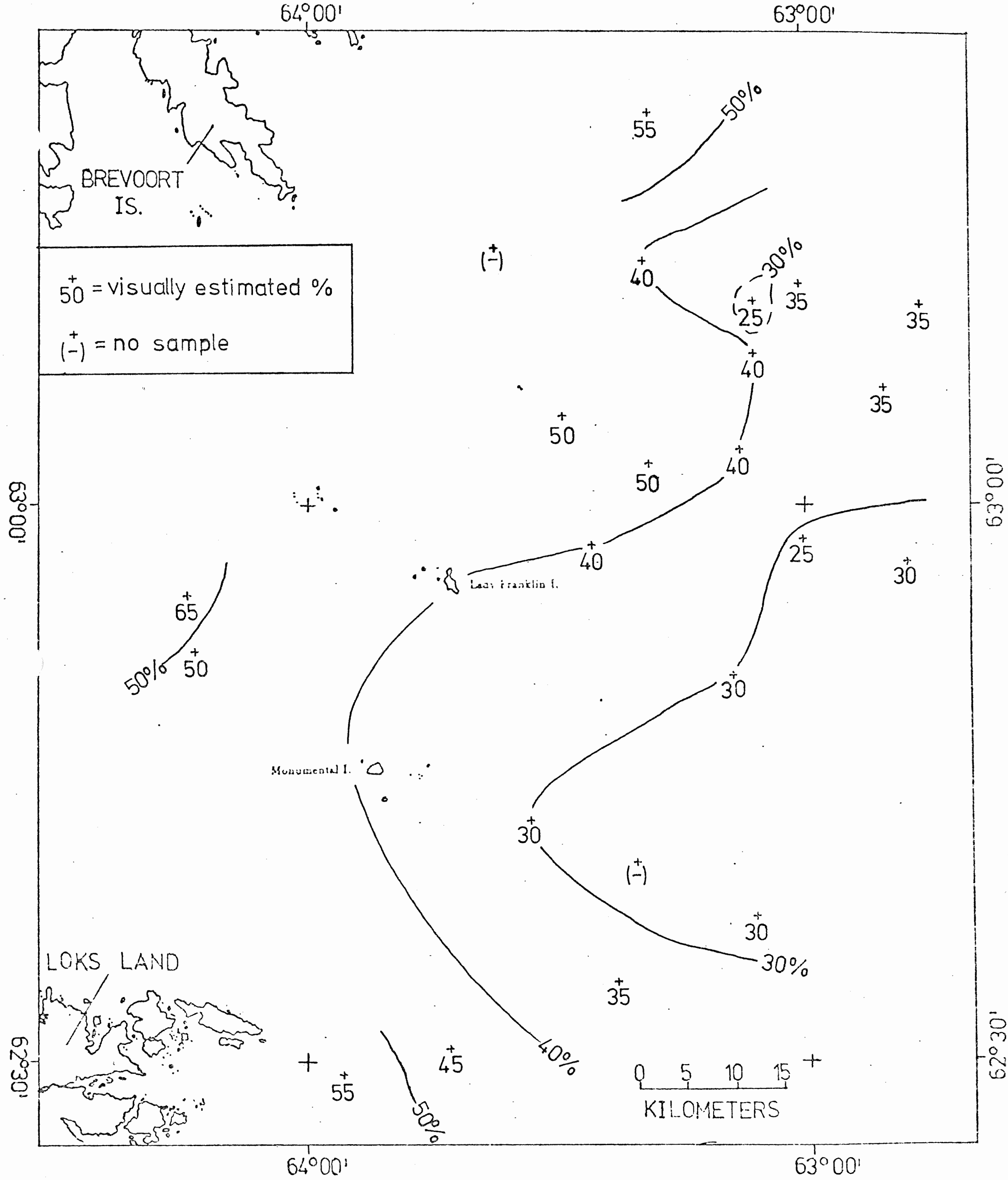


FIGURE 20 - Map of abundance of 2Ø to 3Ø quartz grains with a new surface roundness of 5-6, based on binocular microscope examination. Roundness estimated by comparison with Powers(1953). Contour interval = 10%.

angularity of the new surface of quartz for the coarse sand as observed on the SEM. SEM measurements allow very precise estimates of roundness, as discussed above; hence the values in this figure are taken to be very accurate. The pattern agrees in a general way with that of Figures 25 and 26, as the most angular sample is the westernmost and shallowest (number 9), while over the deeper parts of the bank more rounding is present. Here, however, the greatest rounding is in the north, and decreases to the south; further, the two samples off Loks Land are also rounded. Unfortunately, the relatively low number of samples studied using the SEM do not allow a very accurate delineation of areal patterns. The most important point to be drawn from Figure 18 is the lack of modification of shallow sample 7 relative to the distinctly modified surface of the other samples.

V. DISCUSSION AND CONCLUSION

(1) Interpretation

(a) Surface texture

SEM and visual examination of the surficial sediments indicate the presence of a grain surface history, which is present in all size fractions and all lithologies. This textural homogeneity implies a homogenous origin for the sediments over their whole grain size range. Environmental discrimination using the conclusions of Krinsley and Doornkamp (1973) has allowed broad environmental recognition of the surface types. The old surface encompasses both the aeolian and subaqueous environments, however diagenetic features prohibit further delineation of the subaqueous environment using Figure 1 of Krinsley and Doornkamp (1973). Occasional subaqueous surfaces free of diagenetic effects, as well as the association of aeolian with subaqueous grains, suggests a high energy shoreline environment; however, it is equally possible that the aeolian grains and occasional high energy subaqueous grains were transported to a deeper water, less energetic environment. This problem will be discussed more later. The new surface possesses features characteristic of the glacial environment, and breaks the old surface on many grains. The abundance of the old/new surface dichotomy as seen on individual grains indicates that a significant portion of the glaciated grains are derived from this older unconsolidated source; however, equally significant proportions of the grains (>50%) consist of only the new surface. It seems intuitive that any breakage of an unconsolidated source will result in significant numbers of totally fresh grains; however, the possibility of bedrock erosion cannot be eliminated. The glacial texture is modified to a varying degree by rounding and superimposed subaqueous features, the abundance of which indicates either a low level of energy or a brief interval of modification.

These results suggest two distinct possible origins for the deposit:

(1) Deposition by ice rafting, as suggested by Kranck (1966) for the gravel deposits of the sand and gravel unit off Cape Dyer. The glacial texture is produced within the glaciers which supply icebergs to the Baffin Bay area, and current motion subsequent to or concomitant with deposition modifies the glacial textures.

(2) Winnowing or modification of submarine tills by an uncertain mechanism, as suggested by Kranck (1966) for her nearshore sand deposits and by McMillan (1971) for the gravels off Cape Dyer.

Evidence for these alternatives will be considered in the next section.

(b) Lithology

Two facts are clear from Figures 11 to 13: (1) the distribution of lithologies across the bank is non-random, and (2) the pattern of distribution possesses a clear, if indirect, relationship to the underlying bedrock. In simple fashion, the % limestone in all fractions is highest over the Pre-Cambrian bedrock in the south and the % siliclastics is highest over the limestone area in the north, a rather odd distribution. However, a more detailed scrutiny shows that the % limestone decreases, in a more or less radial fashion from a bedrock source at the head of the Monumental Basin, rising again only in the sample near the <u>other</u> (north) end of the Lady Franklin Basin and remaining mysteriously low over the intervening Ordovician bedrock.

Two possible origins can be ascribed to this pattern, using the framework of ice surface texture results above. The pattern could be the result of (1) the hydrodynamics of the event which modified the glacial texture, i.e., could be the result of lithologic concentration by sediment transport, or (2) could reflect the dynamics of glacial transport, with little subsequent modification by sediment transport. That is to say, the deposit could still be either the result of deposition by ice-rafting,or as till.

The conflict between the two alternatives is resolved by the following argument. The pattern of lithologic distribution between limestone and siliclastics is seen not only in the sand fractions, but also in the gravel fractions which include particles up to -5Ø or 32 mm in size. Particles of such size are unlikely to undergo significant transport except under very high energy conditions. However, the surface texture results showed evidence for low energy conditions or, if higher energy, of very short duration, neither of which would be conducive to long distance gravel transport. Thus the gravel must be,within limits, at its site of deposition where collected. However, the coarse sand and, to a less convincing extent, the fine sand both display a similar pattern to the gravel, implying that those fractions are also, within limits, at their site of deposition. It is difficult to explain, after noting these facts, how the lithologic patterns could be the result of hydrodynamic patterns of transport, either in a modified till or in ice-rafted sediments. Since one would expect more or less random distributions from ice-rafted sediments derived from so distant a source, the till hypothesis is likely.

Another point in favour of the till hypothesis is the lithologic composition of the sediments. Both the major components of the sediments, limestone and siliclastics, are endemic to the bank area (Figure 5). The brown siltstone, as discussed previously, is felt to be essentially carbonate in character and probably belongs to the limestone bedrock. The quartz sandstones are thus the only foreign lithologies and they (a) occur in only a few samples in very minor abundances ($<<1\%$) and (b) could represent a minor lithology of the limestone or Pre-Cambrian bedrock. In any case, in the main there are very few foreign lithologies, a feature not suggestive of ice-rafting origin.

The till hypothesis is thus supported by the following facts.

(1) The consistency in presence and nature of the old surface texture. One would expect to see much more variability in sediments ice-rafted from a variety of sources.

(2) The stratigraphic relation of the sand and gravel sediments with the Baffin Shelf Drift described above, suggesting a possible derivation from till.

(3) The lack of ability of the deduced erosive event seen in SEM work to effect long distance transport, and the observed distribution patterns seen in the lithology.

(4) The indirect relation to the underlying bedrock.

(5) The lack of significant foreign lithologies.

All this evidence together strongly supports the till hypothesis, and the sediments will henceforth be referred to as modified till.

It remains to explain the distribution of lithology observed. Nielsen (1976), working in Nova Scotia tills, noted a distinct and characteristic decrease in abundance in indicator pebbles and minerals away from identifiable source bedrock outcrops, approximating a radial decrease. The % limestone in figures 11 to 13 shows a clear decrease away from a potential limestone source at the head of the Monumental Basin. However, it is difficult to explain the lithology distribution by this argument due to the low % limestone over the large areas of Ordovician limestone outcrop to the north.

In this vein there is to be considered the clear relation between the concentration of limestone (Figures 11 and 12) and the bathymetry of the Monumental Basin (Figure 3). The % limestone decreases away from a highest measured point at the southern head of the Monumental Basin, and shows a significant increase near the other (northern) end of the Basin. England and Andrews (1973), among many others, have noted the importance of topography in channeling advancing ice into ice lobes leaving thin ice elsewhere. It seems likely that when ice advanced over the Lady Franklin Bank area, it was similarly channeled through the Monumental Basin. This would result in at least two main ice paths, north and south, with ice emerging at the ends of the Monumental Basin and spreading out as lobes.

Such a pattern has clear evidence in the lithologic distribution. As noted above, the % limestone shows high values at both ends of the Monumental Basin. This could be explained by arguing that in the zones of main ice transport one would expect higher concentrations of source materials; as the ice emerged as a lobe and spread out over the bank, concentrations of limestone would decrease.

However, even accepting such an ice flow picture, there is still a great problem in explaining the lack of high limestone concentrations over the Ordovician bedrock. Surely even with thin ice one would expect a greater contribution from the underlying bedrock. Thus this hypothesis must be discarded.

(c) Surface Texture and Lithology

At this point the significance of the old surface observed on the grains must be reiterated. The presence of the old surface indicates an unconsolidated source; however its abundance leaves the possibility of some bedrock erosion open. It is an accepted fact that ice will preferentially and more easily erode unconsolidated material than it will bedrock, for example Warnke, (1970), so that such high contributions from unconsolidated material is not surprising. However, the arguments drawn up to now serve to resolve the problem posed previously concerning the relative importance of bedrock versus unconsolidated source materials. Clearly bedrock erosion alone cannot explain the lithologic distribution; yet even minimal bedrock erosion would serve to raise the limestone abundance over the northern part of the bank. Therefore it can be concluded that the primary source was unconsolidated materials, and bedrock erosion made a minimal contribution. The old/new surface dichotomy can be extended throughout the sediments.

However, up to now I have been considering the lithologic distribution in terms of bedrock. Let me now amend this, and substitute a model of sediment veneer, directly representing the underlying bedrock and covering the entire bank, in place of the bedrock.

If this is done and applied to either of the two arguments above, it is clear that the same problem exists--how does one explain the low limestone concentrations over the limestone bedrock in the north? Clearly such a model is invalid.

This suggests that perhaps the original (pre-glacial) unconsolidated sediment source may not have borne any relation to the bedrock; this leads us to an important topic of consideration, the provenance of the glacial source material. This has been alluded to previously in the discussion concerning the old surface as observed on the SEM, where it was noted that although the environment of the old surface encompassed the aeolian and subaqueous regimes, it was uncertain whether this indicated exposure and formation of shoreline deposits, or airborne supply of aeolian grains to offshore low energy subaqueous deposits. To this problem must be added the further consideration that even if a distinction could be made, how can one know whether the sediments are proximal to the bank, or derived from a distal source.

To attack the last problem first, a variety of studies have shown that in the main glacial transport tends to be a rather short distance process (e.g., Nielsen, 1976, as we have already seen). This is particularly true for ice marginal conditions, where ice is in its depositional phase; the effect of ice is largely to 'smear' the existing lithologic distribution through proximal transport, e.g., Nielsen (1976) for Nova Scotia tills. The wide expanse of moraines to the east of the bank definitely suggests that this area was relatively near an ice margin. These arguments thus support the contention that the material which acted as a source to the bank till was proximal to the bank area.

A further argument concerns the lithologic distribution; if the source material were distal, for example from central Baffin Island or Foxe Basin to the west, one might expect a considerably more chaotic lithologic distribution. One could also argue for foreign lithologies, but the source materials of Baffin Island or Foxe Basin are largely those of the bank bedrock; however, one would definitely expect a near random lithologic distribution, or if non-random, bearing little relation to the bedrock. An important point to make, however, is that there is a distinct relation to the bedrock; the highest limestone concentration on Figure 12 occurs over the limestone bedrock at the southern tip of the Lady Franklin Basin, and decreases away from this point over the Pre-Cambrian bedrock. Similarly, the higher limestone concentrations to the north have bedrock sources. It is only in the intervening area that there is a discrepancy, and this is what must be explained. Thus the lithologic distribution supports a proximal glacial source.

Thus both these lines of argument strongly support a proximal glacial source, that is the old surface environment was within the bank area. It remains to explain the lithologic distribution, and this explanation is concerned with the other problem of the old surface, the source of the aeolian grains. To repeat, it seems impossible to know whether the aeolian/subaqueous association represents a shoreline or offshore deposit. However, the following reasoning can supply an answer--if the association represents an offshore deposit, it is to be expected that it would cover a wide area, indeed the entire bank would be coated with airborne aeolian grains; if the association represents a shoreline deposit, it should be areally restricted in response to the bathymetric confines.

In this light must be added the consideration that the point of highest concentration of the limestone source occurs in the shallowest samples available on the bank, while the low limestone concentrations over the Ordovician bedrock are at greater (present) bathymetric depths (Figure 3). This suggests a simple explanation for the low % limestone in the north--there was little or no unconsolidated material for ice, even the thin ice depicted above, to pick up and redeposit as till. The unconsolidated source material, in the form of dune/beach/offshore deposits, was confined to shallow depths of at least 100 m, as the result of its deposition above a certain depth at a time of bank exposure--a RSL low. The depth of this RSL low is difficult to pinpoint with the scanty data, but must be above 150 m (the shallowest low % limestone sample in the north) and at least 100 m (the shallowest high % limestone sample at the Lady Franklin Basin). It would thus be very roughly outlined by the 50 fm contour on figure 3

The high % limestone at the north end of the Lady Franklin Basin is not adequately explained by this mechanism, as depths here are >150 m. However, comparison of the bedrock distribution in Figure 5 with the bathymetry of Figure 3 will show that some portions of the Ordovician bedrock to the west of the Monumental Basin, near Brevoort Island, are present to depths of 100 m or less. Thus there is a potential unconsolidated source for any ice which was channeled through the narrow bathymetric depression to the north of the bank.

Several incidental bits of data support this scheme. The concept of a RSL low often seems foreign to ice marginal areas; however, evidence for a sea-level low in the eastern arctic has been discussed previously. The concept of eastern Arctic Pleistocene dunes is not new either; Johnson (1967) postulated submerged Pleistocene dune deposits in Ungava Bay, formed during a Pleistocene sea-level low. Thus the concepts have precedence.

As discussed in the SEM study results, it seems possible that the source material environment may be represented in some of the old surface grains, due to the common occurrence of solution/precipitation features. This would be in accord with a RSL low which would expose bedrock to weathering and solution/precipitation.

It is interesting, though unconclusive, to note that sample 7 was taken on a well defined marine terrace at 50 fm depth. Terraces can be formed in a variety of ways, but a RSL low is a notable possibility. Unfortunately only one seismic line is available over the 50 fm contour in the area, so it is impossible to know if the feature is consistent.

As discussed in the introduction, the Baffin Shelf Drift to the east undergoes a notable increase in thickness and width relative to areas to the immediate north and south; this increase in width would be adequately explicable in terms of an ice lobe emerging from the Monumental Basin. A similar increase in width is noted in the north, east of where a northern ice lobe would emerge. Although this does not affect the explanation above, it does aid in further explaining the low limestone concentrations in the northern part of the bank. Channeled ice would emerge at the head of the Monumental Basin in the south and spread out over the bank to the east, largely bypassing the northern limestone bedrock and therefore inducing minimal supply of unconsolidated source sediments.

In summary, glacial bedrock erosion of the bank is suggested to be minimal due to (1) the lithologic distribution, and (2) the presence of the old surface suggesting an unconsolidated source. The observed lithologic distribution cannot readily be explained by glacial derivation from an extensive veneer of unconsolidated sediments over the bank, representing the underlying bedrock, due to the lithologic distribution. Nor can it be explained by glacial derivation from an extensive veneer of sediments not representing the bedrock, because there is a distinct relationship with the bedrock. Nor can it be explained by glacial derivation from outside the bank area, due to the lithologic distribution. However, it is admirably explained by glacial derivation from a restricted unconsolidated sediment veneer occupying the shallowest portion of the bank. This and the aeolian/subaqueous grains observed in SEM study suggest formation of the restricted sediment deposit during a RSL which exposed the shallow portions of the bank. Subsequent glacial overriding produced the observed lithologic distribution.

(d) Erosional Mechanism

Although we have unravelled the history of the sand and gravel deposit to this extent, an essential problem still exists: what is the nature of the erosional mechanism which modified the till?

Information on this mechanism comes from a variety of sources. The discussion in the SEM section revealed two salient points concerning the modification: (a) it is of subaqueous origin due to the occurrence of V-forms, and (b) it is of low energy and/or short duration due to the low degree of rounding. This latter point requires further consideration. Figure 19 shows the average roundness of the glacial surface of the gravel fractions; as can be seen, although modified, it is still very angular. Humbert (1968), examining the evolution of roundness with distance of transport in a circular flume found that for both limestone and chert pebbles (at water velocities of 70 cm/s) roundness increased very rapidly at first (10-15 km), and much more (decreasingly) slowly after that (15-200 km). The transition from very angular grains, such as fresh glacial grains, to angular to subangular grains, took place in the first 10 km of transport. This obviously implies that the gravel pebbles of the Monumental Basin have undergone very little transport. Certainly, it is difficult to conceive of them having undergone a transgressive event unless it was very brief.

It is difficult to make similar comments concerning the sand grains, as literature data is scarce. However, the pit counts made (Table 4) shed some light. The concentration of V-forms is in general very low, several orders of magnitude lower than the concentrations mentioned by Krinsley and Doornkamp (1973) for even low energy beaches. Again, it is difficult to conceive of the grains having undergone anything but an extremely brief transgressive event, and even this is difficult to believe.

Further, as seen above in Figures 11 to 13, the deposit is lithologically as well as texturally homogenous, which is to say that the areal lithologic distribution in all three grain size intervals is similar. This implies that even the fine sand made of textural group 2 has not undergone significant transport. However, the textural modification observed necessitates some transport; this is accomodated by the scale of the area. The large scale at which the area is being considered still allows transport of km's to tens of km's for the fine sand, without seriously altering the lithologic patterns. Thus although the modification event has certainly involved some local transport, it has not involved large scale redistributions of even the fine sand, again implying low energy conditions.

Thus, although a brief high energy event is possible, it seems very unlikely, and the evidence points to a low energy mechanism. In this light a consideration of the staining and bryozoans is in order. The staining on one half of the grain suggests that much of the gravel is resting half in, half out of the sediment, a hypothesis confirmed by field notes concerning the gravel when the samples were taken. The bryozoans occurring on the stained half further confirms this, and indicates that it is the stained half which is exposed to the water, the unstained half which rests in the sediment.

This is significant, as it indicates that the gravel exists in an erosional relationship with the sand; i.e., the sediment is or was being reworked. The sand below an uncertain threshold is transported, leaving the gravel exposed and untransported. Unfortunately, it is impossible to know whether this erosive relation of the gravel to the sand is a major feature of the erosive mechanism, or merely a recent imprint of currents. This can be resolved by examining a less transient feature of the sediments, the grain size distribution.

The sediments were previously grouped into four textural groups, each with associated grain size distributions. The grain size distributions in general support the erosive relation of the gravel and the sand as being an important feature of the sediments, not merely a last imprint. All textural groups display a marked bimodality between gravel and sand modes, as discussed. Such a well developed, consistent grain size character must be an important indicator of the origin of the deposit.

The key to 'reading' the grain size distribution lies in recognizing the inherent nature of the deposit. A variety of explanations have been forwarded to explain the origin of multiple mode deposits of depositional origin; e.g., Middleton (1976). However, the multimodal sand and gravel deposit in this thesis is of erosional origin; this has been demonstrated from the geologic history (modified till) and is supported by the erosional nature of the gravel and the sand seen in staining and bryozoans. Now, clearly any erosive event which acts on a sediment will result in the most energetic event which affects the sediment being recorded, due to the winnowing effect of the highest energy currents involved; that is, finer material which is stable at lower energies will be removed. The surficial sediments of the Lady Franklin Bank represent erosion of originally poorly sorted till (Figure 9), while the present grain size distribution is much better sorted and lacking the silt and clay characteristic of till; this evolutionary history can be seen in Figure 9. The question then arises, can the currents necessary to remove silt and clay but leave the sediments observed today be calculated? This can be most easily accomplished by calculating the velocities required to just begin moving the sand modes relative to the gravel modes, and this is why this has been previously done.

The coarser deposits at Group 1 and Group 4 will only undergo bedload transport except at very high velocities, and they will undergo such transport at velocities of $>$33 cm/s. The fine sand mode of Group 2 will undergo transport at variable water velocities across the bank from 18 cm/s to 24 cm/s. The high silt content of Group 3 indicates little if any transport. This latter contention, it should be noted, is borne out by the SEM data in Table 4; sample 7 exhibits almost no textural modification in terms of either rounding or subaqueous V-forms. As noted previously, the absolute accuracy of these values depends on the validity of the assumed drag coefficient; however, even so they indicate the order of magnitude of the requisite currents even within order of magnitude variations of the drag coefficient and this is the intent.

The oceanographic conditions of the area must now be recalled from the introduction. Although currents in the area are poorly known in specific, in general the Baffin Current flows over the area with speeds estimated at 5 to 100 cm/s. Subsurface profiles for areas north and south of the area, within the Baffin Current and with similar surface conditions, show water velocities in the order of 0.2 to 0.3 knots (10-15 cm/s) for water depths of 200 m. In general, these crudely estimated water velocities fall within the range of water velocities required for modification of the Lady Franklin Bank Sediments.

These calculations are hardly presented as conclusive evidence. However, they do serve to indicate that existing oceanographic conditions are potentially sufficient to move the sediments. Further evidence comes from a consideration of the variability across the bank of two parameters.

Firstly, it has been noted, and shown in Figure 10, that the mean grain size and maximum modal grain size of the sand fractions displays a characteristic pattern across the area. The pattern is one of increasing grain size with increasing water depth, from a low over samples 9 and 10 to a high in the northeast corner; the exception to this pattern is the median depth Group 1 samples. Such textural variations must correspond with variations in the currents required to modify the sediment. Thus the inference is one of strongest currents in the northeast corner and along the bank margins, decreasing to the west and finally almost absent in the texturally largely unmodified Monumental Basin Sediments (samples 7 and 8). Strong currents are additionally required off Loks Land.

Such a current configuration strongly suggests bottom current winnowing, likely due to the Baffin Current. Oceanographic currents tend to be deflected due to topographic obstacles. The Baffin Current, encountering the sudden eastward extension of the inner shelf which the Lady Franklin Bank represents, would tend to be deflected east into deeper water concentrating its erosive energies in the east and having progressively less current strength to the west in shallower water. Such a scheme would also explain the coarsest grain size being in the northeast corner, where the Baffin Current, first encountering the extension of the inner shelf, would have its highest energy.

To this postulate must be added a separate line of evidence, the rounding data. The variability in roundness across the bank, though variable, displays the curious general tendency of increasing with increasing water depth (Figures 19 and 20). This trend parallels that noted for the grain size (and inferred currents). The deepest samples in the area are the most rounded, while samples 7 and 8, the shallowest samples, are essentially unmodified. Group 1 samples are problematic. This indicates increasing energy with increasing depth, and hence strongly supports the above scenario.

As noted, the Group 1 samples off Loks Land represent a problem due to their anomalously coarse grain size. Indeed, the sheltering effect of the widened inner shelf would be expected to cause a <u>decrease</u> in grain size rather than an increase. However, as noted in the introduction, very high energy tidal currents (200-500 cm/s) are noted in the Frobisher Bay area. The Group 1 samples could easily be explained as to due energetic tidal currents related to the Frobisher Bay circulation system.

Thus both the grain size and roundness evidence support the hypothesis of reworking by bottom currents as the erosive mechanism which modified the till. The low degree of surface modification has already been used to suggest a low energy mechanism, and this combined with the lithologic homogeneity of the samples makes it hard to conceive of even a brief transgressive event causing the modification. The pattern of both grain size and rounding of the sediments to decrease with decreasing depth, however, provides data which is impossible to explain in terms of transgressive event, especially in light of sample 7 which SEM study shows is essentially <u>unmodified</u>; however, it is easily accomodated by bottom current erosion. The current velocities required to mobilize the existing sediment, and hence remove pre-existing finer sediment and modify a silt/clay rich till, were calculated and one of the same order of magnitude as the existing oceanographic currents. This suggests very strongly that modification of the sediments is due to current action, may continue in the present day, and that the erosive relation observed between the gravel and the sand is a modern phenomenon.

There remains to be explained the differential thickness of till on the bank ($<$ 5 m at present) and to the east of the bank (40 m). It seems intuitive that as low energy current winnowing continues, it becomes more and more ineffective as the winnowed deposit armours itself with a coarser lag; the end result must be unmodified sediments overlain by a coarsened lag, and little reduction in thickness. In particular reduction of thickness from 40 m to 5 m is unlikely. This is explicable in terms of the change in lithology at the bank margin (Figures 3 and 5); east of the bank lie the semi-consolidated Cenozoic sediments, which would erode easily under glacial attack and produce the large moraines. On the bank, however, the main sediment source was the shallow aeolian/beach sediments as demonstrated in this thesis, with ice effecting little bedrock erosion; this volume of sediment spread over the whole bank would produce a thin deposit. Thus the reduction in thickness is primary. Such a change in till thickness in response to bedrock lithology has been noted by Josenhans (1983) for the Labrador Shelf.

Further evidence in support of this erosional mechanism for the sediments will come from two sources: (1) oceanographic measurements should delineate bottom currents of 15-30 cm/s, decreasing in intensity from east to west across the bank, and (2) geologic investigations should discover the sand and gravel in this area to consist of a thin (<1 m) lag over remnant till, as is noted in some other areas of the shelf.

2. Fitting into the Regional Chronology

The lack of dates makes it difficult to speak of the events depicted above in terms of an absolute chronology. However, key events recognized make it possible to speculate on such a chronology.

The first event noted is a RSL low. Evidence for a RSL low in the eastern Arctic has been discussed previously, with regard to the Pigjoat Regression of Andrews (1980) from ca.55,000 B.P. to ca.12,000 B.P. However, the RSL low noted in this study is unlikely to be this RSL low due to the second event noted-- a glacial advance. If the RSL low were the Pigjoat Regression, the glacial advance would have had to be late-Wisconsin. Miller (1980), working on Hall Peninsula to the west of the thesis area, delineated a moraine he termed the Hall Moraine which outlines a glacial advance from which ice retreated ca. 10,000 B.P.. He found no conclusive evidence for any glacial advance more easterly than the Hall moraine event younger than ca. 42,000 B.P.. From this evidence it seems that the till deposit of the Lady Franklin Bank must be mid-Wisconsin or older, and therefore the RSL low noted must be at least early-Wisconsin or older.

However, this interpretation involves a conflict between the tentative sea level history of Andrews (1980) (Figure 8) and the history of the sand and gravel deposit determined in this thesis -- where is the Pigjoat Regression recorded? Evidence cited above indicate that the bank has not been exposed since till deposition, but a RSL low of the magnitude suggested for the Pigjoat Regression (Figure 8) would certainly have left its mark on at least the shallowest samples available on the bank.

This leads to three possibilities:

(1) the Pigjoat Regression occurred, but not (to a significant extent) in the thesis area

(2) the Pigjoat Regression never occurred, and the alternative of England and Andrews (1973) and Andrews (1980) (Figure 8) in which late-Wisconsin ice extended to the shelf is correct

(3) late-Wisconsin ice extended to the shelf in this area, <u>and</u> the Pigjoat Regression occurred

Each of these three alternatives leads to a different potential absolute chronology for the Lady Franklin Bank area. Alternative (1) supports the chronology outlined above from the evidence of Miller (1980): mid-Wisconsin or earlier till and early-Wisconsin or eadlier RSL low. Alternative (2) suggests either (a) the above chronology, except late-Wisconsin ice did not extend to the shelf in this area, or (b) late-Wisconsin till on the bank, with the RSL low some hitherto unrecorded pre-late-Wisconsin event. Alternative (3) suggests that the RSL low <u>is</u> the Pigjoat Regression, with subsequent or contemporaneous late-Wisconsin ice advance producing the till.

It is tempting to promote one or the other of these three alternatives as the more likely. However, either of the three are equally valid in terms of the data in this thesis. The answer must thus await further investigations of the southeastern shelf.

VI. <u>SUMMARY</u>

Lithologic and textural studies on the surficial sand and gravel of the Lady Franklin Bank indicate the following history for the area. The first event recognized is a RSL low, tentatively of 100m, which exposed the shallow southwest margin of the bank and produced unconsolidated aeolian/beach/source material deposits from erosion of bedrock. These deposits were overridden by eastward moving ice, which was probably channelled through the Monumental Basin into two main ice lobes with thin ice between. The ice incorporated the unconsolidated sediments and then redeposited them as it spread out across the bank, resulting in a 'smearing' of a lithologic distribution which had originally generally represented the underlying bedrock. It is uncertain whether or not the bank was still exposed at the time of ice advance. When ice retreated a till deposit was left on and to the east of the bank, with a much greater thickness to the east due to the more easily eroded Cenozoic bedrock. The till has subsequently been modified by bottom currents which acted to erode the deeper parts of the deposit more intensely than the shallower parts due to decreasing current strength with decreasing depth. The absolute chronology of these events is uncertain, but will be clarified by future regional work.

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