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Reports

Recent Marine Sediments of Lancaster Sound District of Franklin*

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Introduction

Textural and petrographic criteria are most useful in deducing the environment of deposition of marine sediments, provided appropriate consideration can be given to the mode of transportation and energy conditions of the transporting medium. In this study textural attributes of recent sediments from an Arctic marine basin have been examined to evaluate the relationships to dispersal processes. The mineralogy of the medium to fine sand has been studied to determine directions of transport and potential source areas of the clastic sediments.

The Area:

The land surfaces surrounding the basin studied (Fig. 1) include two local physiographic divisions of the Arctic Archipelago (Fortier, 1957): (1) on the east, the Baffin-Ellesmere Mountains of crystalline rock, (part of the high eastern seaboard extending from the coast of Labrador to northern Ellesmere Island); (2) the Jones - Lancaster Plateau just west of the Baffin-Ellesmere Mountains. On eastern Devon Island the mountains rise east of Dundas Harbour to a height of 3,500 feet at Cape Warender, and on northern Baffin Island and Bylot Island the elevations range from 3,000 to 5,000 feet. The plateau surfaces of unfolded Palaeozoic strata are over 2,000 feet high northwest of Dundas Harbour, but slope westerly to 1,600 feet at Cape Bullen near Cumming Inlet. The coastal areas of northern Baffin Island near Cape Charles York are characterized by high cliffs of Palaeozoic and Proterozoic sediments which rise to over 2,000 feet. On the northeastern tip of Brodeur Peninsula the flat-lying Palaeozoic sediments have somewhat lower elevations (approximately 1,400 feet), and gentler sloping coastal areas.

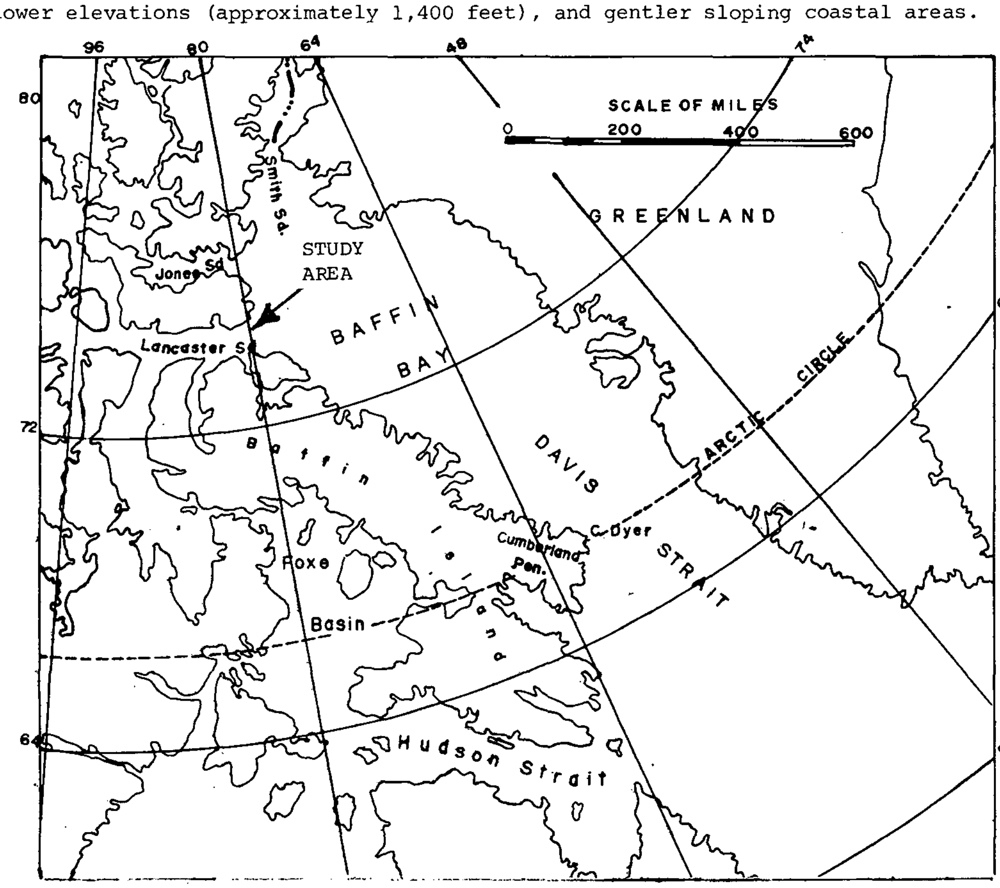

Figure 1 – Location of Study area.

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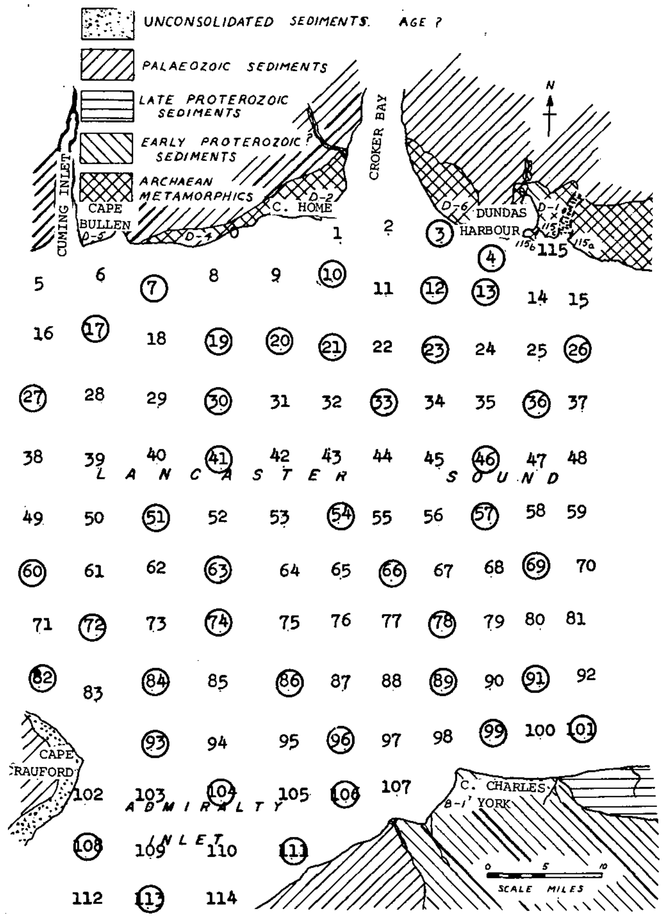


e 2 – Area geology and sample locations. Numbers in sound are station and bottom sample numbers. Circled numbers are samples analyzed hydraulically and mineralogically. Number and letter indicates shore sample for which thin section has been made and described. AA1 is profile line.

Locally there is little information available on the geology of the Lancaster Sound area, however, some regional descriptions are available (Fig. 2). On Devon Island the basement rock has been mapped as Archaean gneisses. In the Dundas Harbour area the writer has noted medium- to fine-grained garnetiferous granitic gneiss, as well as amphibolite and biotite paraschist. Rocks of similar metamorphic facies were found at Cape Home near Croker Bay. Further west exposure of the Precambrian rock is less extensive on the near shore area because of overlapping Palaeozoic strata.

Precambrian rocks of Proterozoic age have been mapped on the southern coast of Lancaster Sound from Navy Board Inlet on the east, to Cape Joy on the northeastern side of Admiralty Inlet, and further south near Arctic Bay (Geological Survey of Canada map 1045A, 1962). These rocks have been described as two groups of gently deformed Proterozoic formations; the lower composed of quartzites and volcanic members, and the upper of shale, dolomite, siltstone, and orange sandstone (Fortier, 1957).

Lower Middle Cambrian to Middle and Upper Ordovician sediments overlap the erosional surface of the Archaean on Devon Island. At Dundas Harbour these sediments have been described in some detail and comprise some 1,400 feet of Cambrian limestone, limestone conglomerate and calcareous sandstone. Lower Ordovician limestones with lesser amounts of sandstone 850 feet thick overlap the Cambrian, but further west the Ordovician sediments increase in thickness and become predominantly reddish brown limestones with larger amounts of sandstone. Thus the westerly dipping Ordovician sediments increase in thickness toward the west while the Cambrian become less extensive.

Outcrops of northwesterly dipping Ordovician and Silurian strata rest with slight angular unconformity on Proterozoic formations in the upper part of Admiralty Inlet. The lower 600 feet of cross-bedded sandstone is overlain by an additional 950 feet of sandstone, shale and silty dolomite.

The rapid breakdown of the high cliffs of sedimentary strata, giving rise to the formation of huge talus slopes and steep walled gullies, is due mainly to the lack of erosion-retarding vegetation in this area. Weathering processes do not affect the breakdown of rocks as rapidly as in more temperate latitudes.

Some fjord-type valleys on Devon Island are occupied by glaciers extending from the permanent ice field which covers most of the eastern half of the island. In contrast, only a few snow fields of limited extent are found on the land surfaces south of Lancaster Sound.

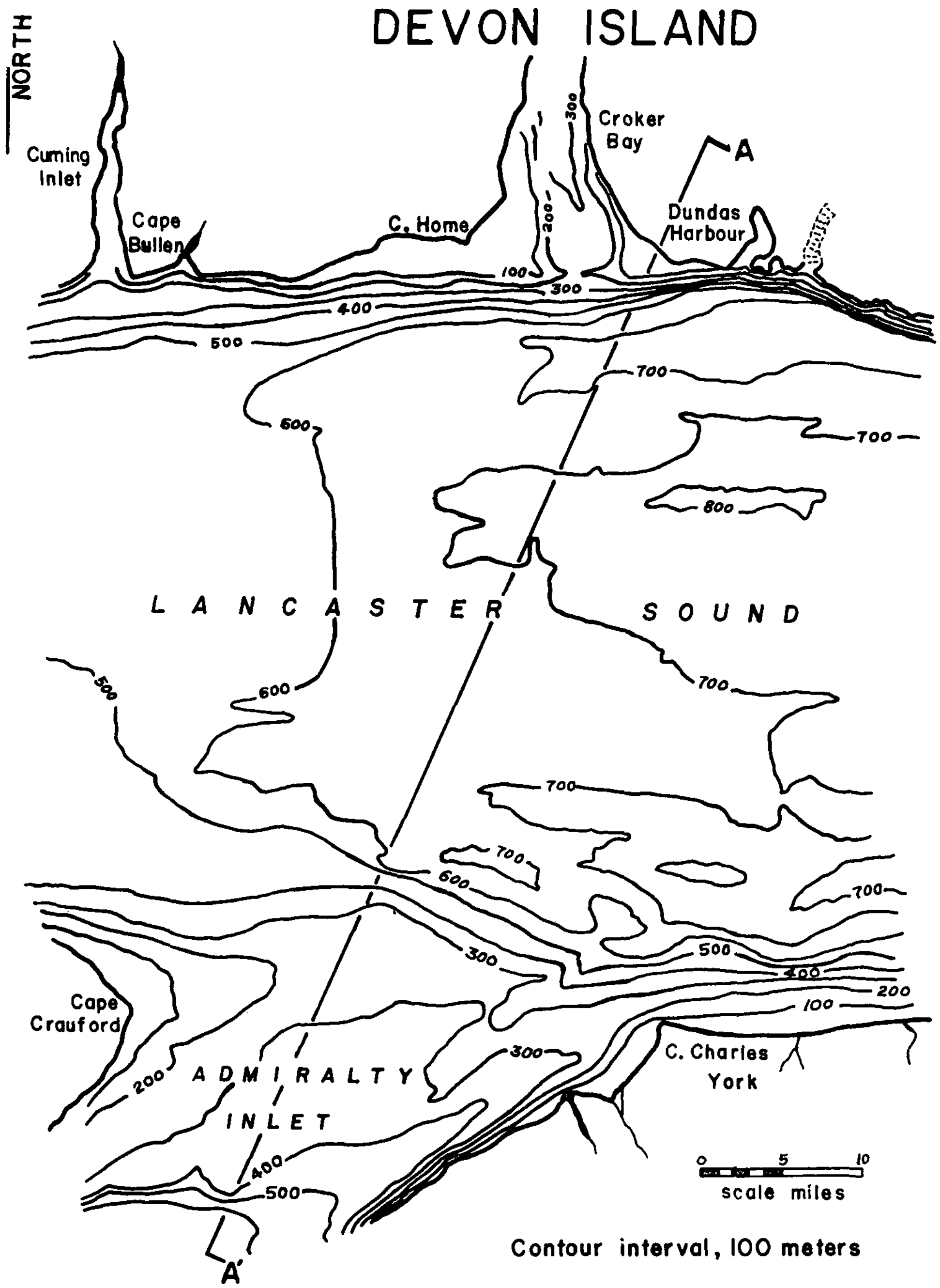


Figure 3 - Submarine topography. Contour interval, 50 metres.

The submarine topography was determined by a detailed hydrographic survey of the area in 1960 (Fig. 3). The soundings were recorded using an electronic echo-sounding device on the Canadian Scientific Ship *BAFFIN* (Department of Energy, Mines and Resources). Contours of the recorded soundings illustrate a smooth, broad, flat-bottom basin increasing in depth toward the east, to a maximum recorded depth of 950 metres. Steepest slopes of approximately 25 percent were recorded one to three miles south of the Dundas Harbour area. Progressively lesser slopes were measured west along the northern coast. The southern basin walls are similar to those on the north, but have lesser topographic gradients. This structure suggests a rift-valley basin, possibly associated with faults of Tertiary age (Thorsteinsson and Tozer, 1960), which has undergone subsequent submergence, leaving some drowned shorelines 200 to 300 metres below present sea level.

The submarine reliefs of Admiralty Inlet and Croker Bay illustrate similar features. Both possess a relatively shallow transverse sill at the junction of the inlet and the sound, a narrow slightly deeper channel through the sill, and a U-shaped deep valley behind these sills that occur respectively on the south and north boundaries of Lancaster Sound. These features are interpreted by the author as truncated glacial valleys which intersected the Lancaster Basin at a time when sea level was considerably lower.

Submarine Sampling:

Samples were collected for this investigation from the uppermost few centimetres of bottom sediments in a 2,500 square-mile area of Lancaster Sound (Fig. 1). Of the 116 sampling stations occupied on a five-mile grid (Fig. 2), 108 samples were taken, using two types of free fall grab samplers. The Dietz-LaFond clam-shell sampler with a capacity of approximately one litre was used to procure most of the samples. The loss of this device necessitated the use of the less satisfactory 0.5 litre Askania tube sampler. Sampling stations were positioned using a two range Decca radar system, but actual bottom sample locations were determined from the wire-angle method. Sample depths were recorded on the echogram profiles.

Because of the design principles of the samplers and the considerable depth of the water through which the samples were drawn, certain sampling errors were unavoidable. In particular the Dietz-LaFond sampler was most efficient in taking samples containing large amounts of pebbles and granules, but may have lost some sediment of smaller sizes. On the other hand, the Askanian samples were rather small to be considered truly representative. When available, approximately 300 grams of sample were placed in a 3.7-cm diameter plastic liner and sealed with wood or rubber stoppers.

Purpose of the Investigation:

The purpose of this investigation is focused on deducing methods of sediment transport and deposition in an Arctic inter-island marine basin.

Environmental sedimentary facies are identified in this study on the basis of total sediment grain size distributions and hydraulic settling velocities of the fine sands. Using these criteria the following dispersal influences are considered: (1) ice rafting; (2) competence and efficiency of transporting agent; (3) proximity of plausible source area; (4) physical properties of mineral assemblages of fine sand size; and (5) submarine topography.

Provenance and dispersal modes are determined by examining the residual detrital minerals with respect to the following classifications: (1) individual and total heavy mineral distributions in fine sand size; (2) hydraulic settling properties of heavy minerals; (3) hydraulic size availability of heavy minerals; and (4) carbonate minerals of silt size.

Laboratory Methods

A laboratory procedure was developed for two purposes: (1) to facilitate separation of convenient size grades for distribution studies, as well as subsequent special studies; and (2) to isolate the fine sand fraction for examination of hydraulic settling properties and heavy minerals.

In general the size grades chosen for study are based on groupings of the Wentworth grade classes as shown below:

Pebbles, granules	All material larger than 2 mm
Very coarse sand, coarse sand, medium sand	2. mm to 0.15 mm
Fine sand, very fine sand	0.15 mm to 0.06 mm
Silt	0.06 mm to 0.004 mm
Clay	Less than 0.004 mm

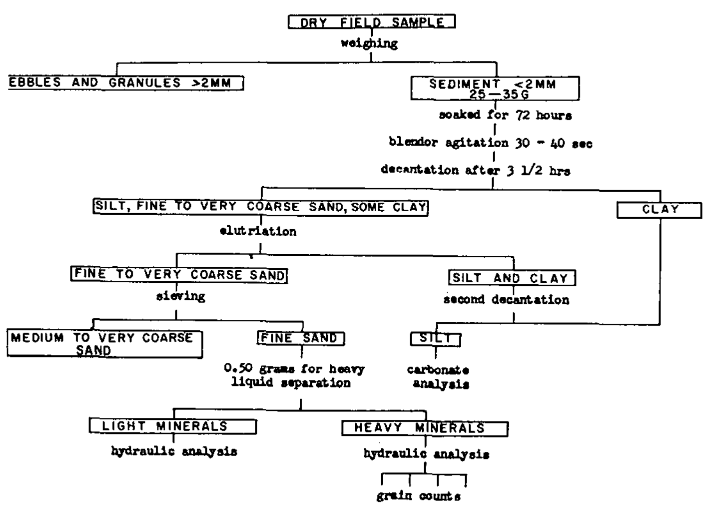


Figure 4 - Flow diagram of laboratory procedure.

The size-class grouping of fine to very fine sand was chosen to facilitate examination of the settling velocities of this size range. In addition, it was found that the upper size limit of 0.15 mm was also the approximate limit of monomineralic sand grains.

The medium to very coarse sand was not further subdivided because this grouping contained most of the faunal remains which would have been destroyed by additional separation methods.

Size Grade Separations:

The flow diagram of laboratory procedure (Fig. 4) illustrates the steps in processing the mechanical analysis. Where available a 25- to 35-gram portion of the dry grab sample was used for the analysis.

The laboratory sample was disaggregated by soaking in water for 72 hours, during which time large pebbles and granules were extracted. The partially dispersed sample was then agitated in a food blender for 30 to 40 seconds. Most of the suspended clay particles were decanted from am elutriation tube (Fig. 5) after 3.5 hours. Silts with some clay were later elutritated from the sands, using a settling time of 40 seconds in the 12.7 cm separation zone. Particles which remained in suspension, and were siphoned from the elutritation tube, were of Stoke's sizes not greater than 0.06 mm. When necessary, the complete separation of the silts and clay could be effected by additional agitation and decantations in which all suspended clay could be siphoned from the silts after the 3.5-hour settling period.

The fine sands, medium to very coarse sands, and granules were separated, first by wet sieving then by dry sieving, using acetone as a drying agent. The weights of the size grades were determined as dry weight, with the exception of clay which was found from weight differences.

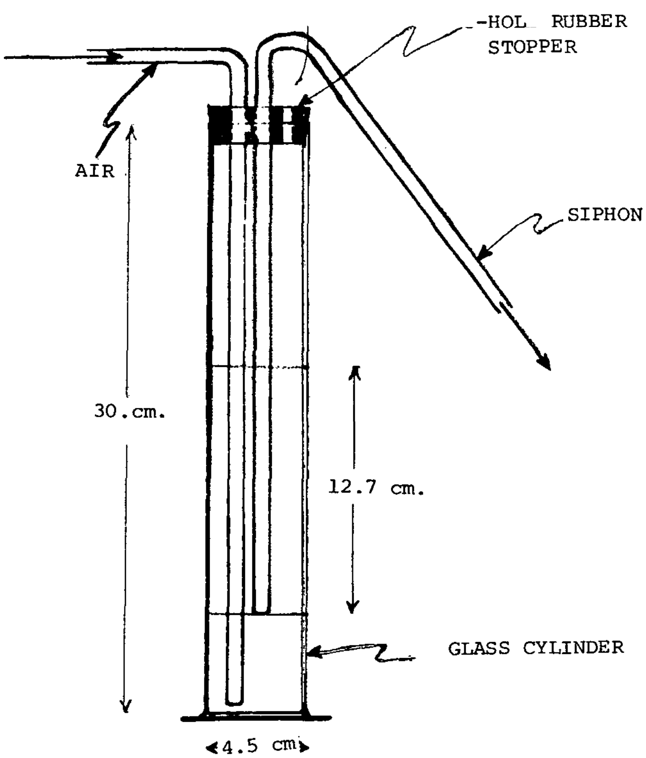


Figure 5 - Elutriation apparatus.

Heavy Mineral Separation:

Heavy and light minerals were separated from the fine sands using tetrabromoethane (s.g. 2.95). Steep-walled separatory funnels were used in processing the 41 samples weighing 0.3 to 0.5 grams. The heavy and light mineral fractions were washed and dried with acetone before being weighed in preparation for hydraulic settling analysis.

Hydraulic Settling Properties of Fine Sands:

Since it is entirely possible that all of the fine sands were at one time in hydraulic suspension before deposition, it is desirable to observe their settling properties in a controlled environment. To achieve this a settling tube was designed and used to observe fall velocities of the heavy and light minerals (Fig. 6).

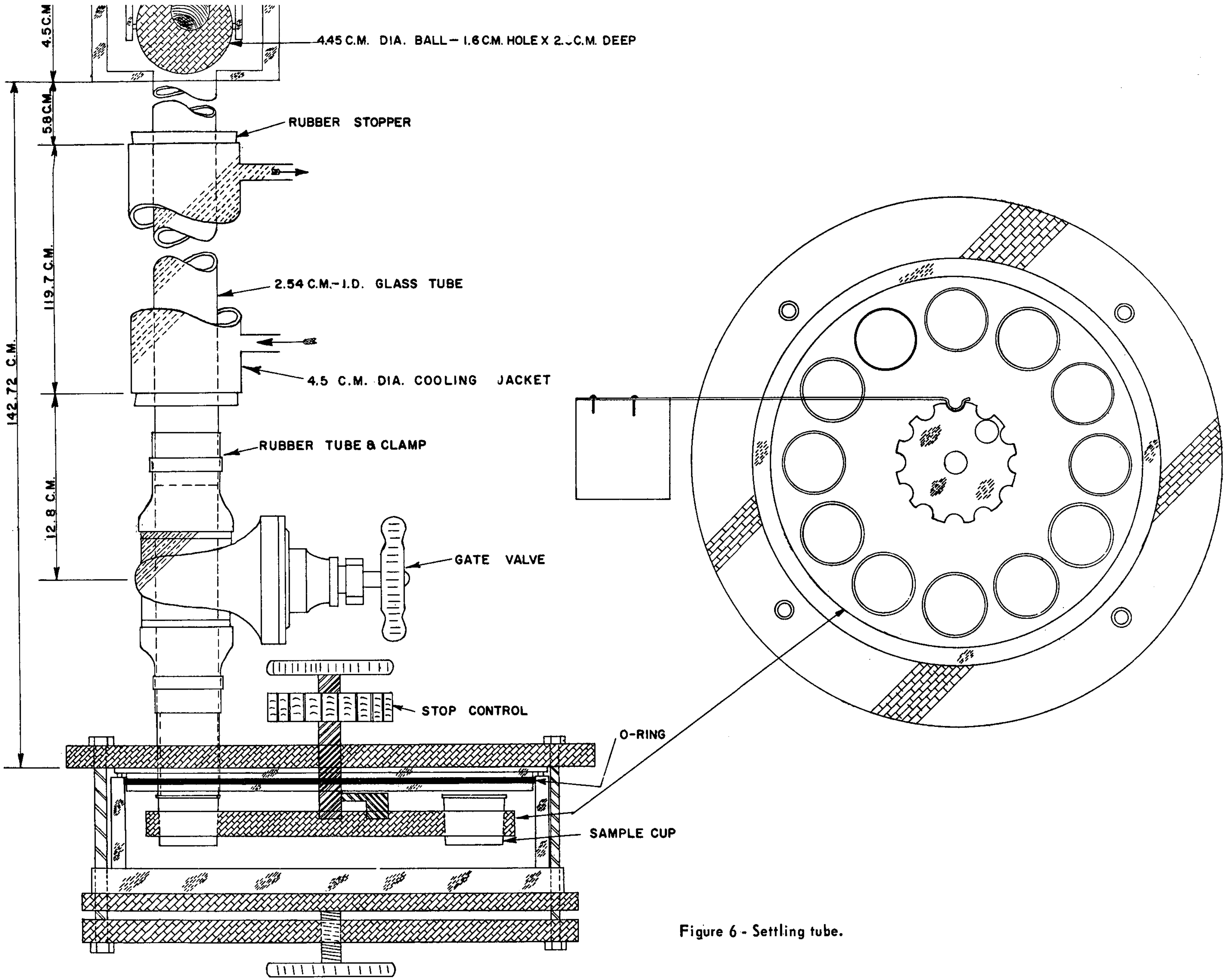


Figure 6 - Settling tube.

The design facilitates the dropping of fine-grained particles through a continuous uniform size column of water 142.7 cm long. The particles can be separated into hydraulic size fractions by rotating successive cups into position under the lower end of the tube, as the desired quantity of sample reaches the end of the tube. Since the samples are placed in the immersed loading apparatus they can be completely disaggregated before being released directly into the settling column. Settling time is measured while the grains fall from the release point to the collection cup.

Theory. The uniform settling velocity of a spherical particle less than 0.1 mm diameter is theoretically determined by using the viscous resistance formula, better known as Stokes' Equation (Rubey, 1933),

$$v = \frac{2}{9} \cdot g \cdot \frac{\rho_p - \rho_f}{\eta} r^2$$

Where
v = settling velocity of particle
r = radius of sphere
ρ_p = density of sphere
ρ_f = density of fluid
η = coefficient of viscosity of fluid
g = acceleration due to gravity.

The settling velocities of particles larger than 0.5 mm cannot be predicted by the Stokes equation, but can be determined by the impact formula,

$$v = \sqrt{\frac{4}{3} \cdot g \cdot \frac{\rho_p - \rho_f}{\rho_f} r}$$

In order to describe the settling characteristics of all sizes Rubey developed a general formula by combining the Stokes' and impact equations.

Then

$$v = \frac{\sqrt{\frac{4}{3} \cdot g \cdot \rho_f(\rho_p - \rho_f)\, r^3 + 9\eta} - 3\eta}{\rho_f \; r}$$

When units are given in cgs.

One property of natural sand grains not considered by these theoretical equations, is shape factor. Shape factor may be evaluated simply by relating the observed settling velocities of irregular shaped grains to the settling velocities of spheres of known volume and density. In this investigation no attempt is made to relate numerically the settling velocities of natural sands to hydraulically equivalent spheres; however, the settling tube was calibrated using spheres, since these values can be directly related to those theoretically determined from the above equations.

When a settling tube is used for velocity determinations, the density and viscosity of the fluid are controlled by maintaining distilled water at a constant temperature. Wall effect is minimized by the large cross section of the tube compared to the diameter of the particles (Krumbein and Pettijohn, 1938). The sample bulk must be restricted to prevent appreciable increase of the density of the fluid-sample medium and to minimize particle interference.

Settling tube calibration. Three curves were derived in the calibration of the settling tube: (1) The theoretical curve based on Rubey's general formula; (2) A curve constructed from measured settling velocities of calibrated spherical glass beads; (3) A curve constructed from settling times of natural sand grains of fine sand size.

The theoretical settling velocities were determined using Rubey's general formula as:

$$v = \frac{\sqrt{\frac{20}{3} \cdot g \cdot \rho_f(\rho_p - \rho_f)\, d^3 - 360{,}000\eta^2} - 600\eta}{\rho_f \cdot d}$$

Where g = 980.3 cm/sec^2
ρ_f = 0.997 gm/cm^3
ρ_p = density of spherical glass beads = 2.5 gm/cm^3
η = viscosity of water at 25°C = 0.0089 poise
v = mm/sec
d = diameter of particle in mm (size intervals chosen)

Velocity and settling times are converted by:

$$v = \frac{H}{t}$$

Where v = cm/sec
H = length of tube = 142.7 cm
t = time in sec

The theoretical settling curve was drawn from these data (Fig. 7).

Test samples of spherical glass beads of several measured sizes were settled in the tube and settling times recorded. From the settling velocities of the glass beads, and an adaption of Rubey's formula,

Diameter Equation. $$d = \frac{20\left(v^2 + \sqrt{v^4 + 418.781\, v}\right)}{3921.2}$$

Where v = cm/sec
t = 25°C

Theoretical sizes for the appropriate observed velocities were calculated. Observed values were plotted on Figure 7.

The error was calculated by:

Standard deviation $$\sigma = \sqrt{\frac{\Sigma\left(\frac{Dt - De}{Dt}\right)^2}{N - 1}}$$

Where Dt = diameter in mm as calculated using the diameter equation
De = microscopically measured diameter of glass beads in settling splits
N = number of observation.

Deviation was found to be 4 per cent.

Several samples of fine sand containing heavy and light minerals were also placed in the settling tube, and calibrated splits were examined for average diameter determinations. The results are plotted on Figure 7.

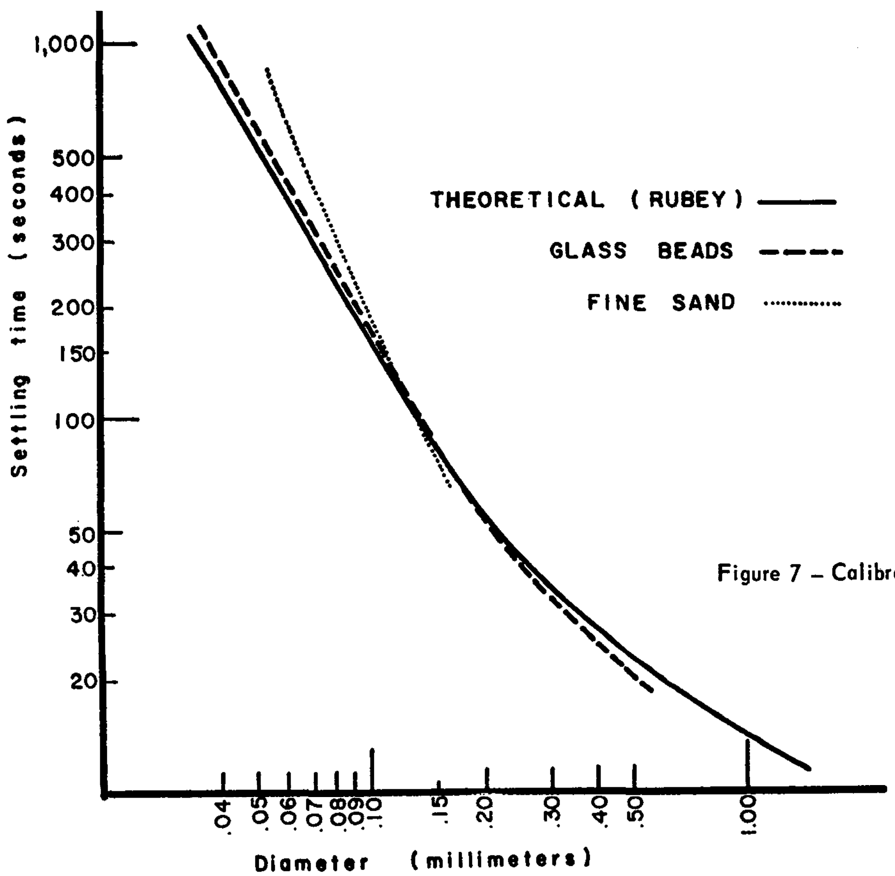


Figure 7 – Calibration curves for settling tube.

Use of the Settling Tube. The particular design of the settling tube used in this investigation was adopted to restrict some experimental errors: (1) Settling fractions were collected separately for weight determinations and microscopic examination. (2) The settling column is of uniform cross section from release point to collection cup, thus avoiding unnecessary turbulence or sample "hang-up" along the walls of the tube. (3) The temperature of the water column was held constant, to avoid convection turbulence. (4) The sample release mechanism allowed disaggregation of the sample under water before being released directly into the settling column. When samples were being removed from the retainer the gate valve was closed to prevent the water in the column from dropping into the sample cups and expelling the collected samples.

Light and heavy minerals of fine sand size were placed in the settling tube separately. Four hydraulic splits of approximately equal weight were made as the sample settled into the polyethylene cups. Collected samples were oven dried and weighed for weight per cent determinations.

Heady Mineral Grain Count:

The heavy mineral hydraulic settling splits were mounted on dry glass slides for examination under a binocular microscope. Mineral identifications were confirmed by crushing a few grains to approximately 0.03 mm size and examining with a petrographic microscope.

Grain counting was conducted using a 2.5 objective and a 25X eyepiece with cross hair. Grains intersected by the cross hair were counted, as the field was moved 0.2 mm after each identification, using a Swift automatic counter and mechanical stage. Several traverses were completed across the slide, each traverse line being 0.5 mm apart, until approximately 100 to 200 counts had been made. The resulting counts for each of the four settling splits were first computed as number per cent for each split and then combined to give the total number per cent of heavy minerals in the heavy mineral residue.

Carbonate Analysis of Silts:

The silt size fraction was chosen for analysis of the soluble carbonate minerals because the natural fine size facilitates convenient and rapid determinations.

The weighed dry silt was placed in flasks containing concentrated HCl for a period of one hour, after which it was assumed most carbonate minerals would be dissolved (Dreimanis, 1962). Constant agitation with a magnetic stirer aided in dissolution of the carbonate content. The weight loss was determined as the percentage of CO_2 in the silts.

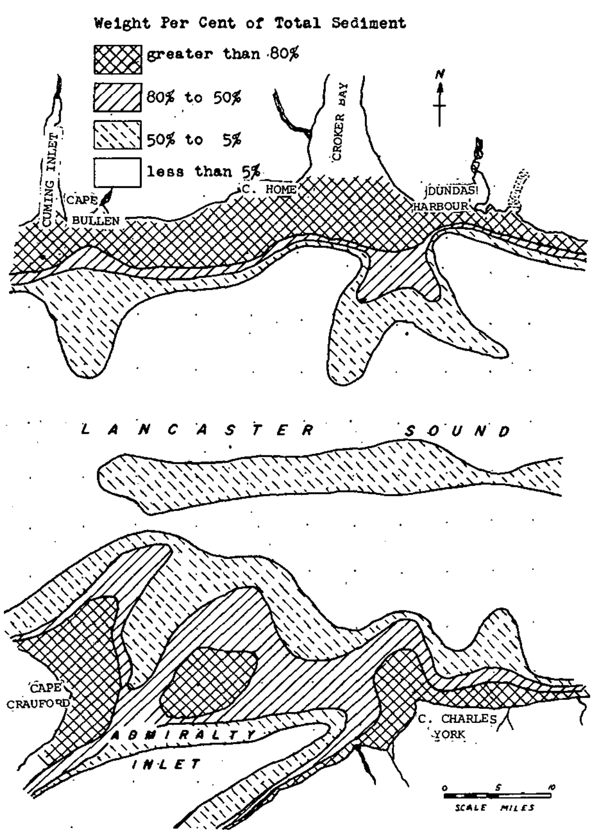


Figure 8 – Distribution of pebbles and granules.

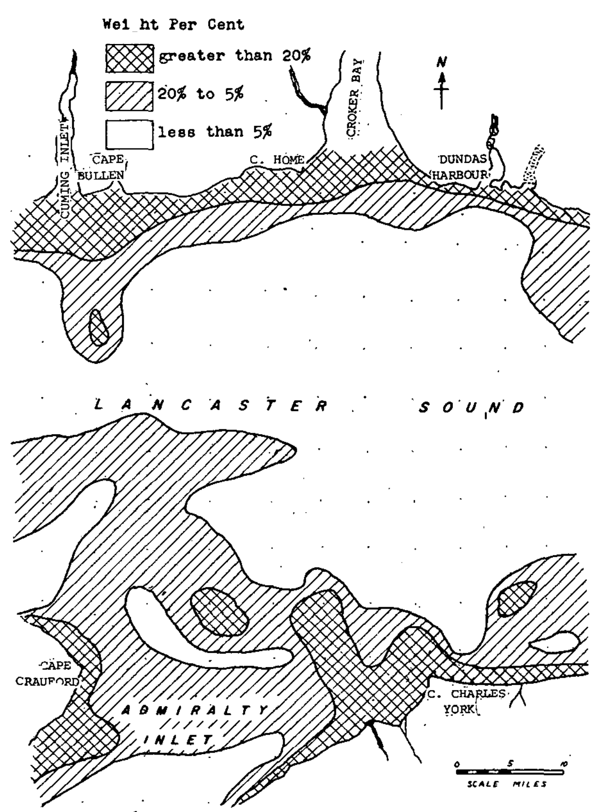


Figure 9 – Distribution of coarse to medium sand.

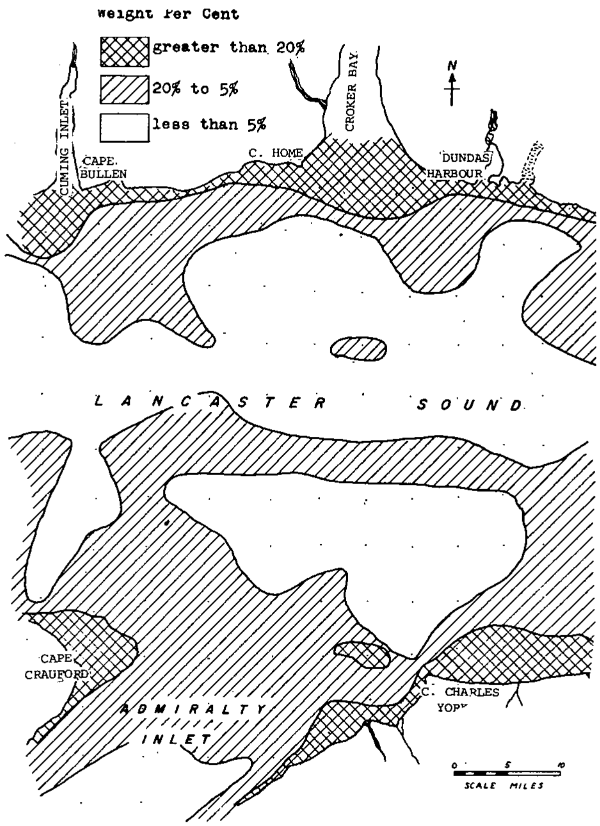


Figure 10 – Distribution of fine sand.

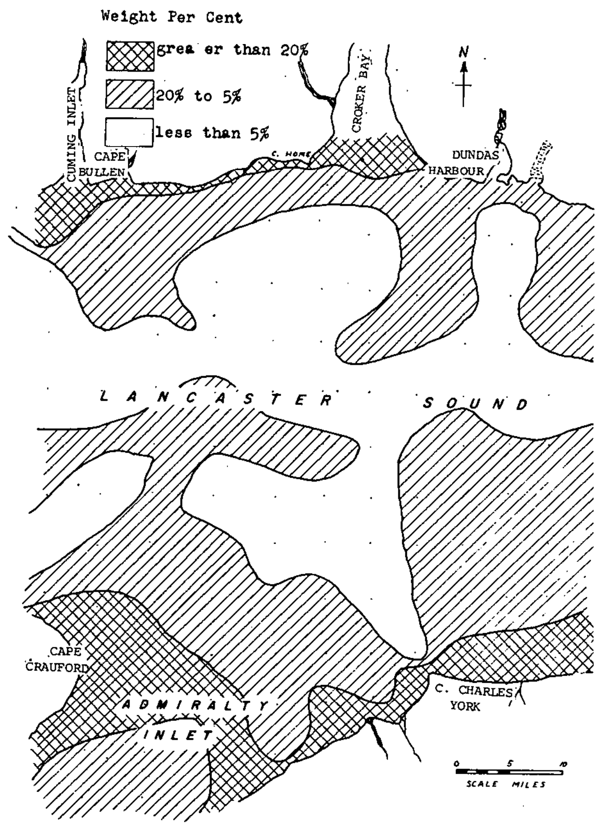


Figure 11 – Distribution of silt.

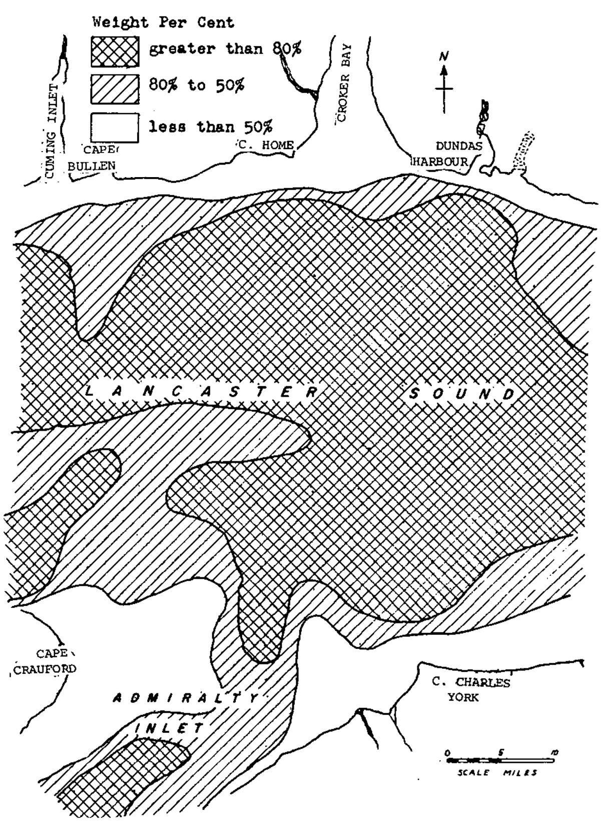


Figure 12 – Distribution of clay.

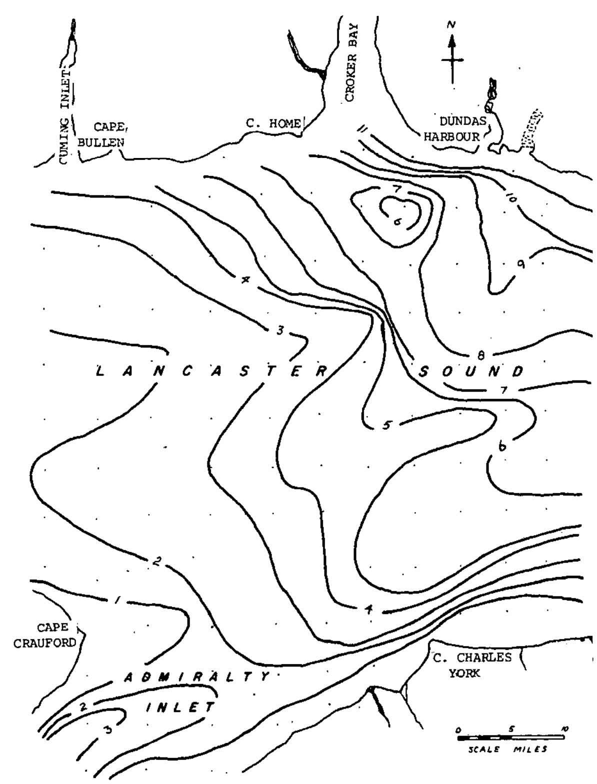


Figure – 13 Weight per cent distribution of heavy minerals in fine sand. Contour interval, one per cent.

Laboratory Results

The laboratory results are discussed briefly to emphasize the data most pertinent to this investigation.

Size Grade Distributions:

The weight of sediment in each of the size grades was used in calculating the weight per cent data. Because the weight of particles larger than 2 mm would greatly bias the per cent distribution of other sizes, it was decided to calculate the weight per cent of the pebbles and granules as a portion of the whole sample, whereas the smaller sizes were calculated as a fraction of that weight of sample with sizes smaller than 2 mm. Using the weight per cent data size-grade distribution maps were drawn (Fig. 8 to 12).

The size-grade distributions show clay to be the most important constituent of nearly all bottom sediments, with largest quantities reaching 95 per cent in the centre of the sound. All other sediment sizes appear to be more abundant in areas closer to shore. Distribution of pebbles and granules is quite random, with high percentages being found 5 to 15 miles from shore and across the mouth of Admiralty Inlet. There are no well defined distribution patterns for any of the sediment grades.

Heavy Mineral Distributions:

The weight of the heavy mineral residue from the specific gravity separations was converted to weight per cent of total heavy minerals in the fine sand. The results are shown in Figure 13.

From results of the grain count, percentage numbers were calculated for each heavy mineral in the four settling splits. An approximate weight per cent was determined for each mineral by multiplying the number of counts by a relative specific gravity factor (specific gravity of detrital minerals from Krumbein and Pettijohn, 1938). The weight per cent for the total heavy mineral fraction was then multiplied by the per cent of heavies in the fine sand size. These values for six principal heavy minerals were plotted on the area maps as shown in Figures 14 to 19.

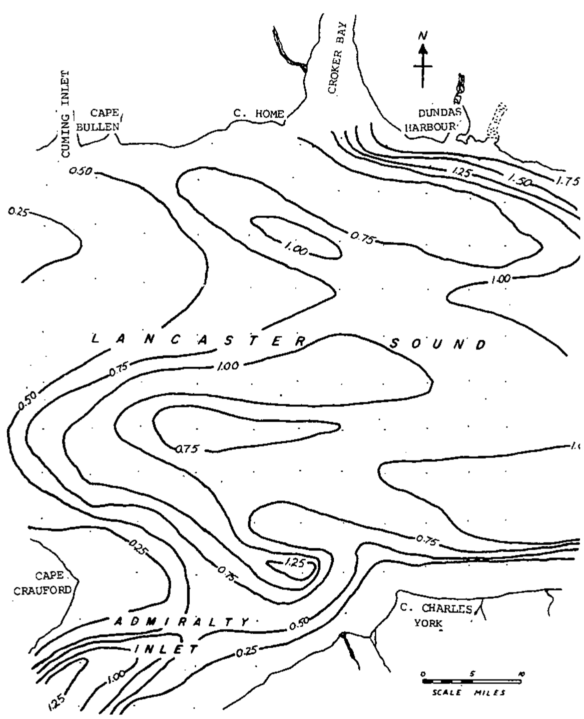


Figure 14 – Weight per cent distribution of hornblende in fine sand. Contour interval, one per cent.

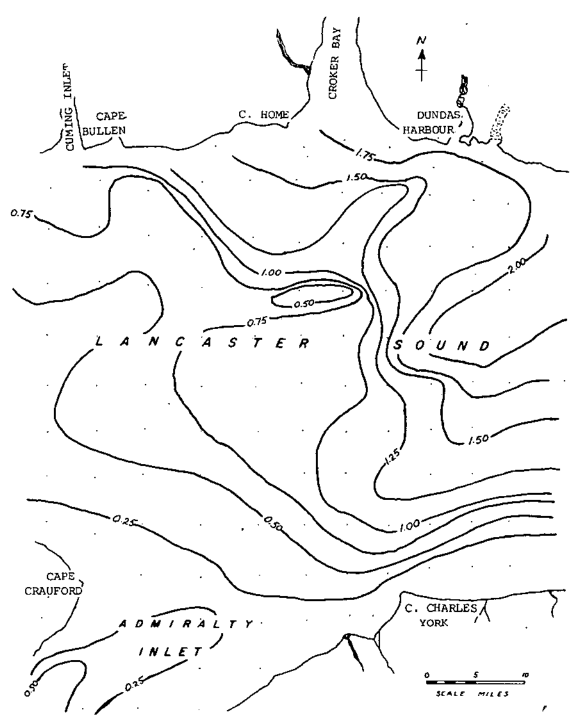


Figure 15 – Weight per cent distribution of actinolite in fine sand. Contour interval, .25 per cent.

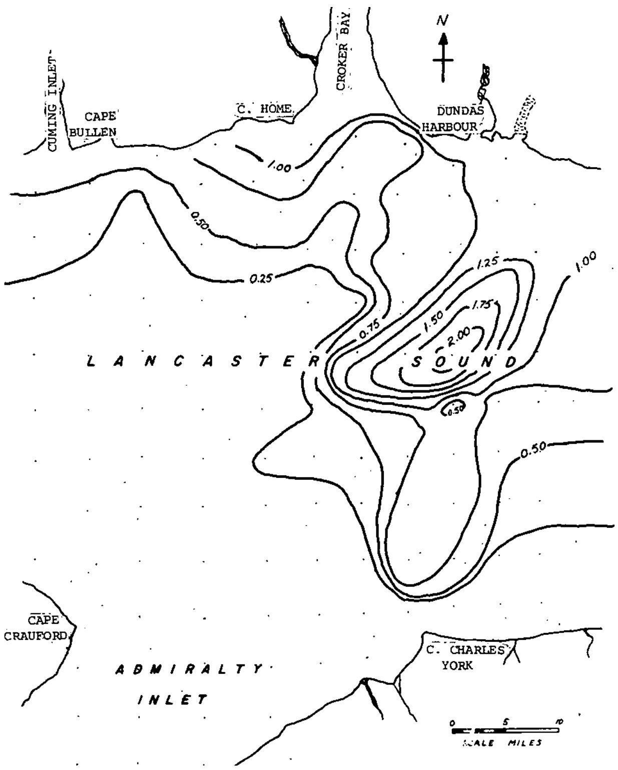


Figure - 16 Weight per cent distribution of biotite in fine sand. Contour interval, 0.25 per cent.

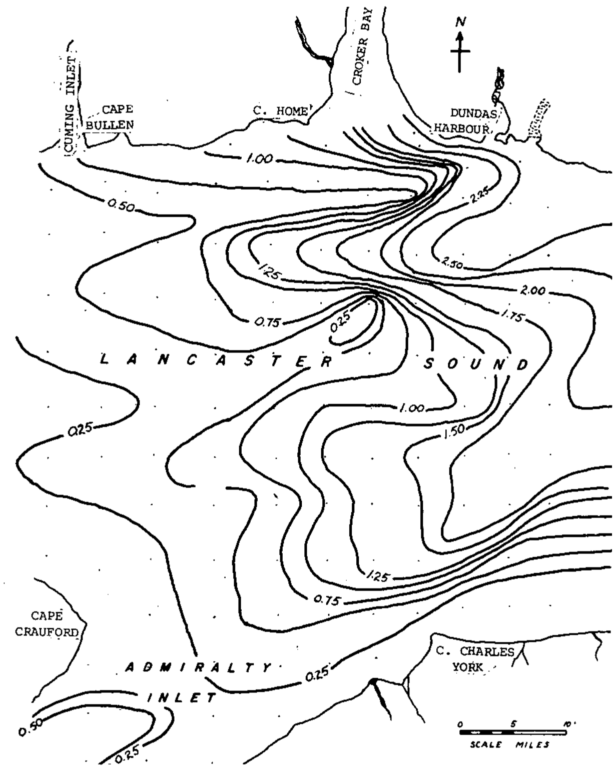


Figure 17- Weight per cent distribution of epidote in fine sand. Contour interval, 0.25 per cent.

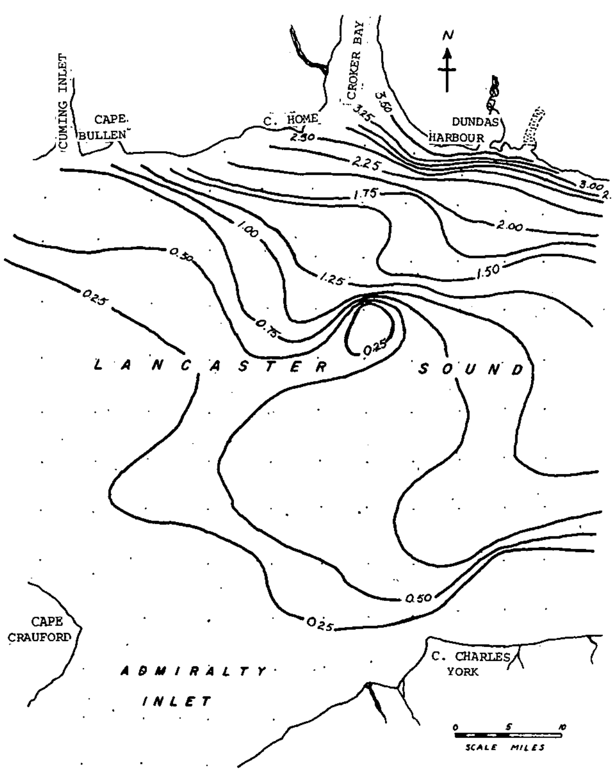


Figure 18 - Weight per cent distribution of garnet i sand. Contour interval, 0.25 per cent.

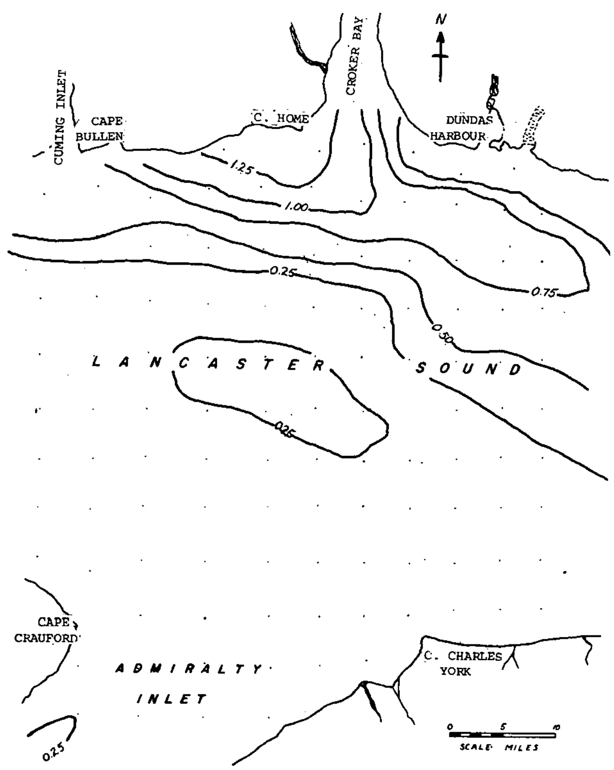


Figure 19 - Weight per cent distribution of magnetite in fine sand. Contour interval, 0.25 per cent.

In order to examine the ratios of minerals having the same hydraulic settling velocity, each weight per cent value within a settling split was multiplied by the weight per cent of heavy minerals collected in that split. Thus a proportionate weight per cent for each mineral at a given average settling velocity was determined. A proportionate weight per cent ratio was then calculated at each of four average settling velocity intervals for three sets of heavy minerals.

This weight per cent ratio is then an index of the hydraulic "sizes" availability at a particular settling velocity. For example, in sample number 4 the garnet/magnetite ratio shows an increase as the settling velocity decreases, indicating a greater abundance of garnet relative to magnetite in the slower settling velocity ranges. Similarly, the epidote/biotite ratios indicate most of the biotites possess hydraulic settling properties equivalent to smaller and/or less dense particles. As well as the variations within any one sample, it is apparent that there are profound differences in the ratios of one sample when compared with another.

Although the weight per cent ratios of the heavy minerals show few regional trends, there are well defined concentration patterns for the weight percentages of six heavy minerals in the fine sands. Light green amphibole (actinolite), garnet (almandite), epidote, magnetite, and biotite have highest concentrations in the northern portions of the sound and decrease toward the southeast. Greenish-black amphibole (hornblende) illustrates two areas of significantly high concentration; one in the northeast near Dundas Harbour and the other in the south central portion of the study area.

A few less abundant heavy minerals were significant in denoting specific provinces. A small quantity of pyroxene was found in samples close to the northern sources. Limonite or hematite was found to be important in samples of the southern shore and in Admiralty Inlet. Occasionally detrital pyrite, with fresh untarnished surfaces was encountered in samples from Admiralty Inlet. Siderite was erratic in concentration, but was present in greatest abundance in samples from the southern regions.

Detrital grains of gold and silver, usually considered very rare, were counted in several scattered samples from the southern part of the sound. One sample (No. 78) contained 47 parts per million gold.

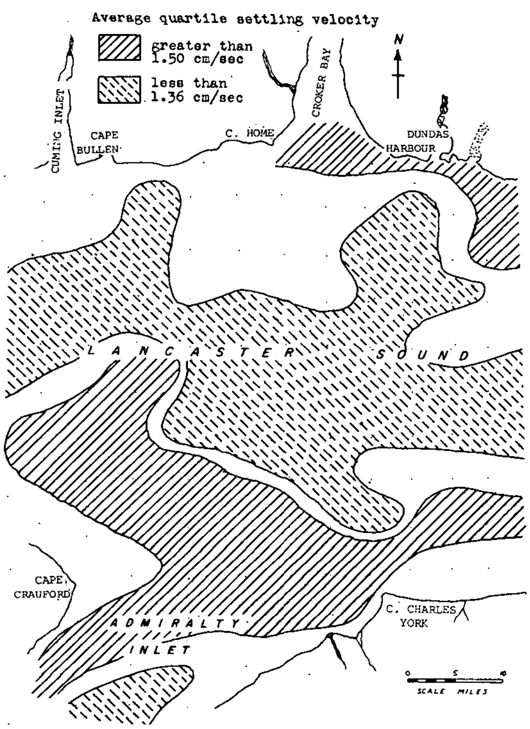


Figure 20 - Distribution of average quartile settling velocities for light minerals of fine sand size.

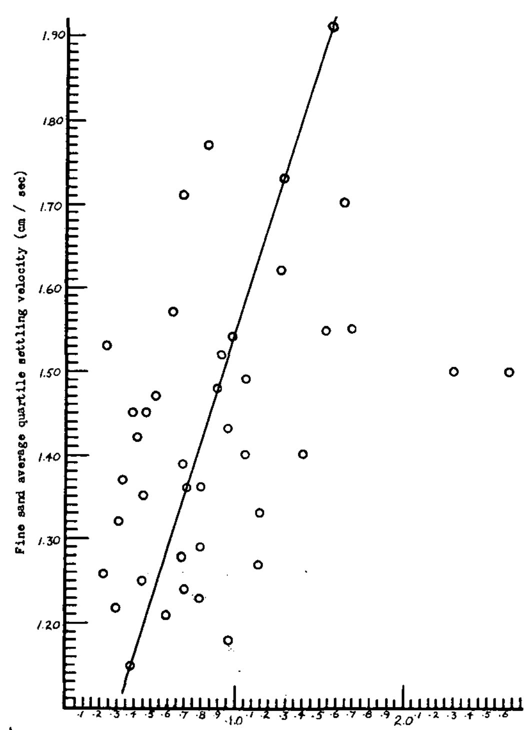


Figure 21 - Settling velocity of fine sand versus sediment grade distribution.

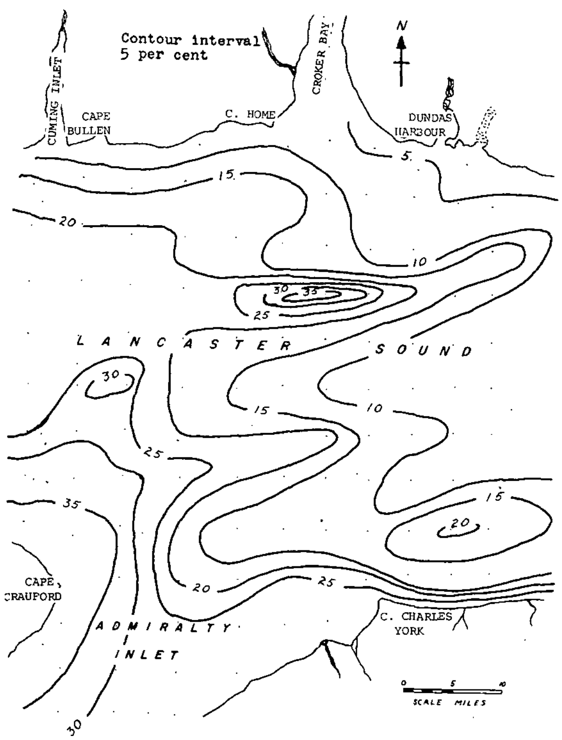


Figure 22 - Distribution of CO_2 per cent in silt.

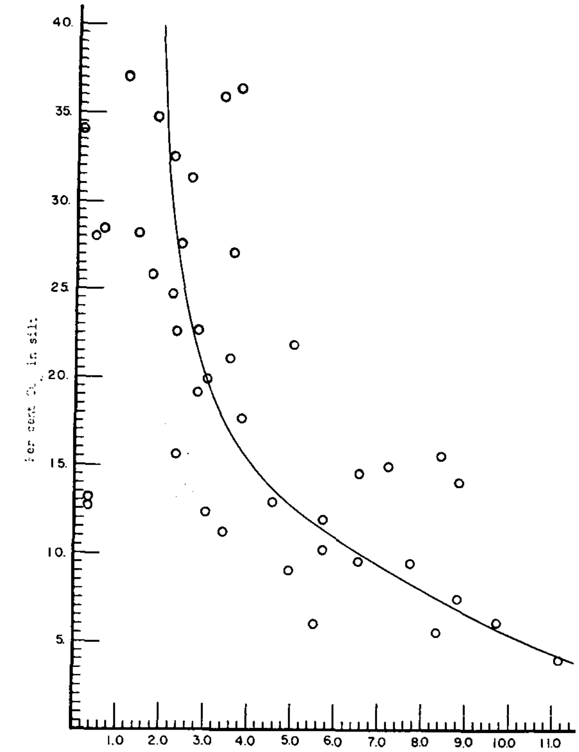


Figure 23 - Carbonate - heavy mineral concentrations.

Hydraulic Settling Properties of Fine Sand:

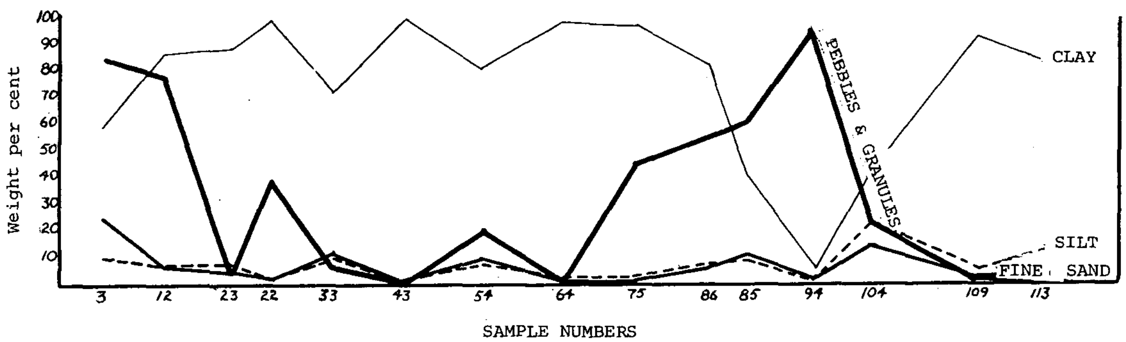
Using the sedimentation tube it was possible to collect four hydraulic settling splits from each of 41 light mineral samples and 36 heavy mineral separations. Average settling times were recorded for each split as it was collected, and weight per cents computed from the dry weight of each sample.

Distribution curves were drawn by plotting cumulative weight per cent against log of average settling time. From these curves the first to fourth moments of arithmetic quartile statistics were determined (Krumbein and Pettijohn, 1938), and expressed in terms of settling velocities.

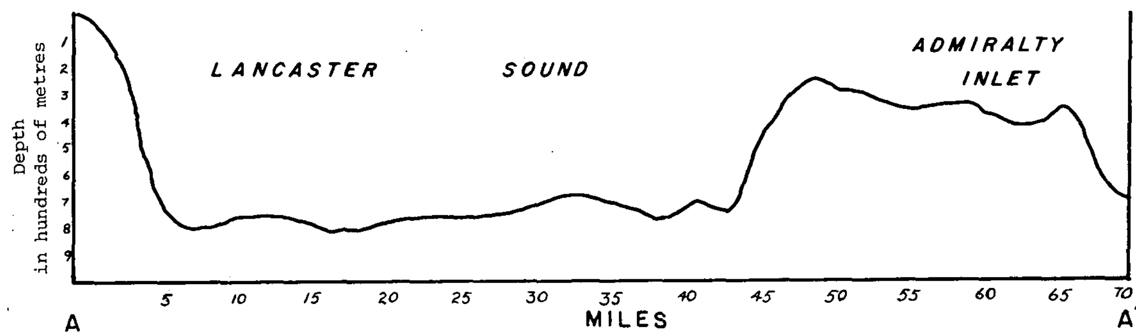
The characteristic distribution of the settling velocities for the light and heavy minerals indicate marked differences between these two mineral groupings. The average median settling velocity of the light minerals is 15 per cent less than the heavy minerals. Both light and heavy minerals tend to show positive skewing toward the higher settling velocities, but the heavy mineral skew is much less, with individual sample variations between positive and negative. A plot of the average quartile settling velocities of light minerals on the area map (Fig. 20), indicates some regional trends, with high settling velocities corresponding to high percentages of coarse sand (Fig. 9), or pebbles and granules (Fig. 8), and low settling velocities indicating abundance of clay (Fig. 12). An illustration of the correlation of settling velocities of fine sand with the weight per cent distribution of the sediment grades is given by Figure 21, in which the average quartile settling velocities of the light minerals of fine sand size have been plotted against the weight per cent ratio of fine sand and silt.

Carbonate Analysis:

The weight per cent of CO_2 given off by the dissolution of the carbonate minerals in the silt fraction was calculated. Figure 22 shows the variation of the weight per cent CO_2. The considerable increase in the CO_2 weight per cent near Cape Crauford indicates a striking increase in the carbonate minerals, and in comparison the trends of Figure 13 indicate an inverse relationship with the heavy mineral content of the fine sands. A graphical representation of this relationship is given in Figure 23.

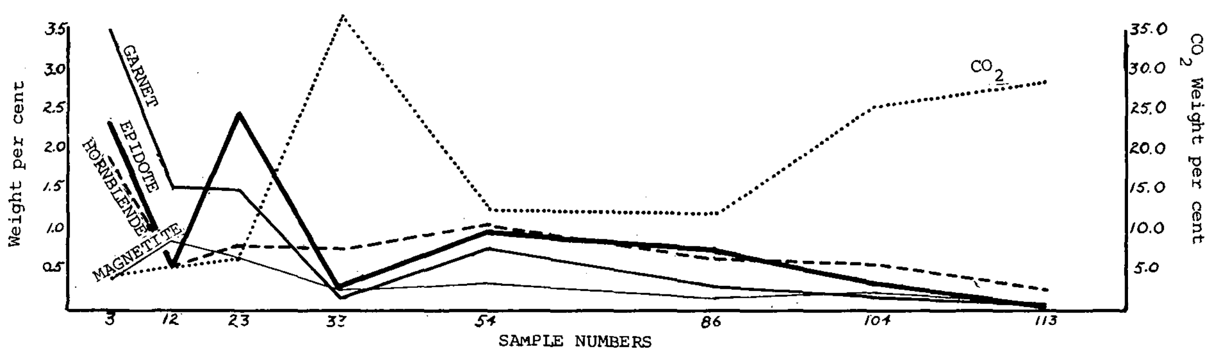


Size grade distributions

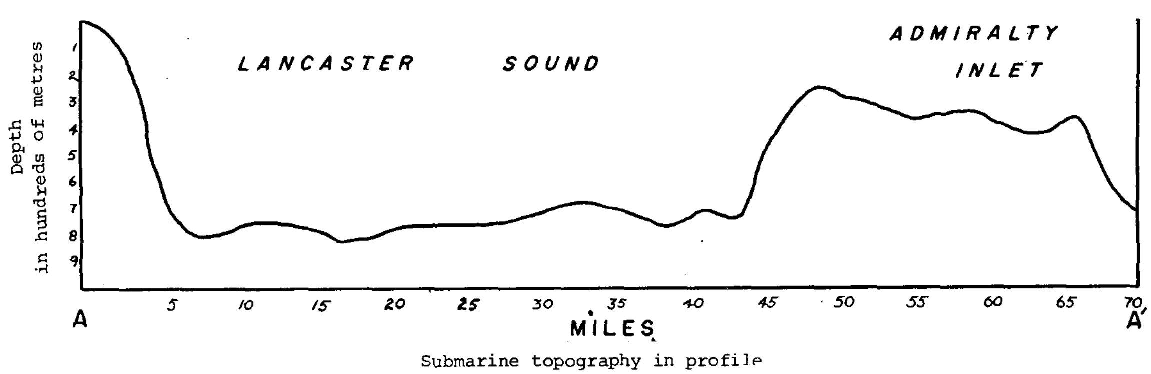


Submarine topography in profile

Figure 24 a - Profile summary of results. See Fig. 3 for location of Profile AA[1].



Heavy mineral and carbonate distributions



Submarine topography in profile

Figure 24 b - Profile summary of results.

Summary of Laboratory Results:

Size grade distributions (Fig. 23a):

1. Clay is the most abundant sediment class except in near shore areas. Clay percentages are highest in the central basin area, and decrease to some extent as a function of distance from shore. 2. Silts are nearly uniformly distributed in the sound but have highest percentages near shore. 3. Fine sand distributions are quite erratic, but show minor variations with distance from shore. 4. Medium to coarse sands are widespread; percentages decrease with distance from shore, to some extent, but show little relationship to depth. 5. Pebbles and granules are randomly distributed in relation to depth of water or distance from shore. Highest percentages of this largest of the sediment classes, are found in two broad areas; one extends across Admiralty Inlet along the south shore, and the other parallels the north shore.

Heavy mineral distribution (Fig. 23b):

1. Heavy mineral content ranges from 11.1 to 0.1 per cent of the fine sand; highest percentages being found in the northeastern section and decreasing toward the southwest. 2. Indicated source areas of garnet, magnetite and light green amphibole (actinolite) lie wholly or partly within a section of the study area on Devon Island. Transport vectors are generally from northeast or southwest. 3. Weight per cent ratios serve as an index of the relative availability of hydraulically equivalent minerals in a particular sample. 4. Nearly all heavy and light minerals show fresh fracture surfaces with little or no rounding.

Hydraulic settling properties of fine sand:

1. Settling velocities of light mineral fractions reflect the textural distributions of coarser sediments in the sample. Higher than average settling velocities indicate rapid sedimentation from a high energy transporting medium which could be responsible for deposition of coarse sands, or pebbles and granules. 2. Positive skewing, in the settling velocity curves is contrary to negative skew found in size distributions of fine sands from offshore regions along continental margins. 3. Heavy minerals have higher settling velocities than light minerals. Variations in the median settling velocity and skewness of the settling distribution curves are not readily understood. 4. Kurtosis coefficients of light and heavy minerals indicate poor sorting.

Carbonate analysis:

1. Carbonate minerals are most abundant in silts of the southeastern section of the study area. 2. Carbonate minerals appear to have dispersal vectors opposite to the trends of heavy minerals.

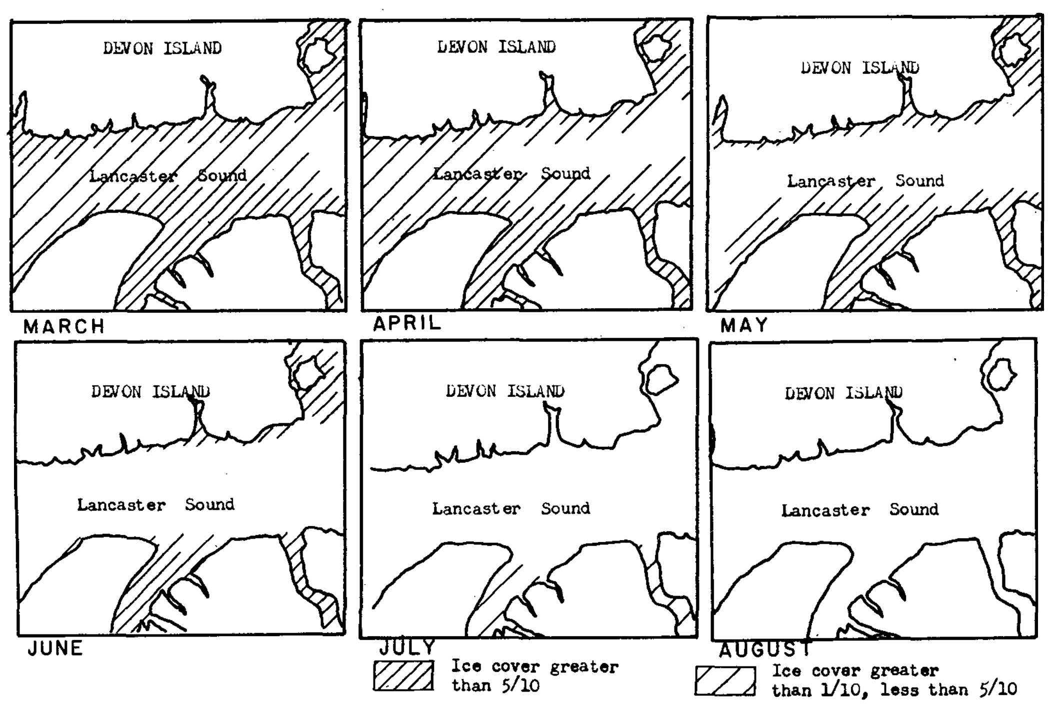


Figure 25 - Ice cover in Lancaster Sound, March to August.

Conclusions

Conclusions based on the laboratory results are considered with respect to available information on the physical parameters of the depositional environment of Lancaster Sound. Since modes of sediment transport and deposition are of prime concern, two such parameters shall be discussed, namely, ice-rafting and current transport.

From late October to early March each year, Lancaster Sound is 80 to 100 per cent covered with ice (Swithinbank, 1960). From April through July the ice breaks up in the centre of the sound and moves out into Baffin Bay, leaving a rim of shore and drift ice along both shores (Fig. 25). By August the sound is largely free of ice except for occasional bergs drifting in the predominantly easterly flowing currents.

A current survey conducted in Lancaster Sound in 1960 revealed that all current velocities were variable and of low magnitude, ranging from less than 0.5 knots at the surface to less than 0.1 knot at depth. A summary of the results of the survey are given in a report on a tidal and oceanographic survey of Lancaster Sound (Farquharson, 1962): "No tidal movement apparent anywhere across Lancaster Sound, streams weak and indefinite for the most part, slightly stronger on the northern side and decreasing with depth... Directions, coupled with ice observations, indicated a predominantly easterly flow with meterological conditions the most deciding factor. Indication of a counter flow in a westerly direction, at a depth of 300m on the south side and 600m on the north may be verified..." (see Figs. 27a and 28b).

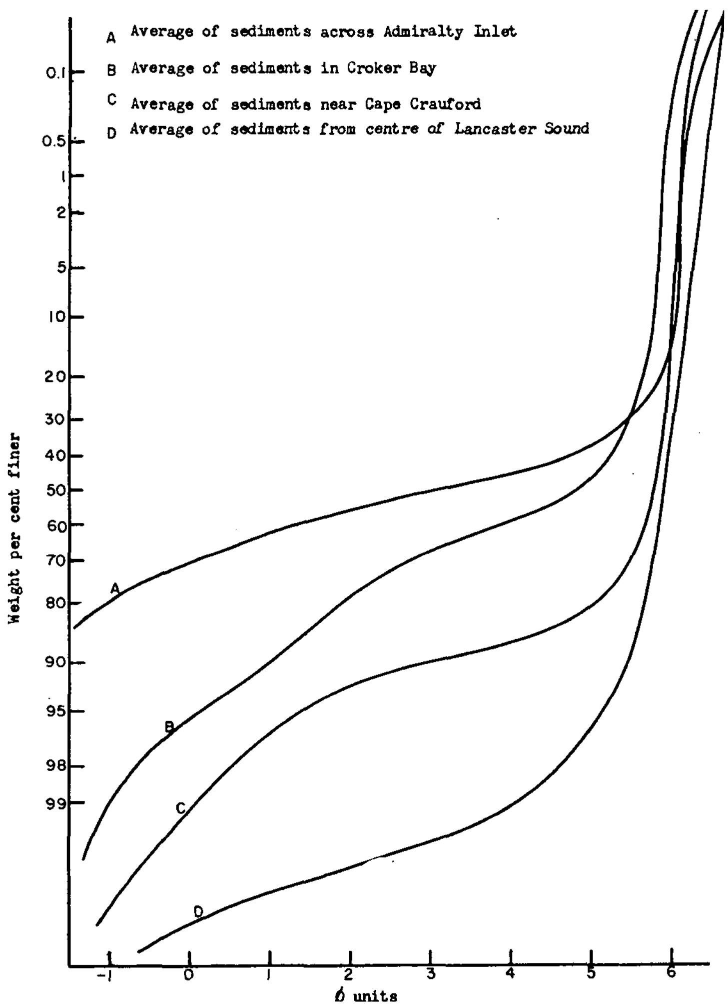


Figure 26 - Cumulative frequency distributions of sediment grades.

Environmental Sedimentary Facies:

Grain size distribution:

A plot of cumulative weight per cent frequency against size grades on arithmetic probability paper (Fig. 26), illustrates the extreme bimodal or possibly trimodal distribution of the sediment.

size grade populations (Spencer, 1963). In general the three fundamental populations are: (1) Gravel with sizes larger than -2Ø; (2) Sand with a median of 2.5Ø units; (3) Clay smaller than 6Ø. Two dominant parent populations can be recognized in most samples; one is the coarsest grades, the other is the clay. The sediment size-frequency curve indicates the energy conditions of the transporting and depositional medium. The high clay content indicates weak currents, while conversely large amounts of gravel indicate deposition from a highly competent transporting medium.

Submarine geographic distribution of the sediment size grades (Figs. 8 to 12), indicates the dominance of clay in the central sound area, and the fact that coarser sediments are more abundant in areas adjacent to the shore.

In order to examine two factors which might influence these sediment distributions a test was conducted to determine if the percentages in each size grade were dependent on the distance of the sample from the nearest likely source (map scale distance from sample position to nearest land), and depth of sample (water depth as recorded on echogram profile). Two scatter diagrams, in which the weight per cent of the size grade was plotted first against the distance from shore, and then depth of sample, indicated that a function of log of size weight per cent when related to the distance plus depth factors would give the best linear correlation.

$$\text{Log } y = a_0 + a_1X_1 + a_2X_2$$

where y = weight per cent of size grade

a_0, a_1, a_2 = constants

x_1 = depth of sample in metres

x_2 = distance of sample location from nearest potential source, in miles.

This function was applied to all size grades and a multiple correlation test for each variable was computed using the I.B.M. 650 computer. The results of the test giving "R" correlation values for each relationship, values of the constants, and estimated error of the dependent variable are given in Table I.

Table I - Correlation Coefficients for Text Equation

	Clay	Silt	Fine Sand	Medium to Coarse Sand	Pebbles and Granules
Constant A_0	1.505	1.467	1.471	1.618	1.389
Unbiased standard error of estimate of variable "Y" (weight per cent of size grade)	0.120	0.291	0.422	0.544	3.980
Correlation coefficient for depth variable X_1	(neg.) 0.206	(neg.) 0.327	(neg.) 0.246	(neg.) 0.164	(neg.) 0.135
Correlation coefficient for distance from potential source X_2	(pos.) 0.559	(neg.) 0.411	(neg.) 0.376	(neg.) 0.436	(neg.) 0.074
Total correlation coefficient R	0.667	0.609	0.540	0.547	0.201
Total correlation coefficient squared R^2	0.445	0.371	0.291	0.299	0.041

The correlation factors show an inverse linear relationship exists between all variables, with the exception of the relationship involving clay. In other words all percentages for each sediment size except clay decrease with increased distance from shore and depth of water, but clay content increases with distance from shore. The magnitude of the correlation factor indicates that the exponential relationship of weight per cent to distance and depth is only partially satisfied by the log linear equation, and that the largest particles (larger than 2 mm), appear to be randomly distributed. Although none of the correlation coefficients indicates a good statistical fit with the test equation there is ample evidence to show that distance from source is a more important factor than depth of sample. Generally the distribution of the finer sizes is effected to a greater extent by distance from shore than larger particles.

<u>Ice rafting</u>:

In a sedimentary region where pebbles and granules are found to be contemporaneous with a major clay constituent it is essential that dispersal processes of comparable efficiency and competence be active simultaneously.

The near-random distribution of coarse sediments (larger than 0.15mm) in Lancaster Sound (Fig. 8 and 9, Table I) is best explained by ice-rafting processes. Ice is competent for coarse sediments and is not selective for sediment grade. Because ice-rafted materials are not restricted to particular size ranges it can be estimated that all sizes of sediment would be available in proportions comparable to the source.

Debris carried in floating ice may have four important sources: (1) Nearshore or beach sediments picked up in the bottom surface of grounded icebergs or annual shore ice. (2) Alluvial deposits from fast flowing spring streams which carry debris onto the surfaces of shore ice. (3) Debris of glacial origin in icebergs. (4) Wind-blown deposits carried over the ice in the sound. From personal observation the first two above-named sources are believed to be of greatest importance in contributing to the bulk of the ice rafted material in Lancaster Sound.

As debris-laden ice begins to melt the sediment load is released and falls to the bottom. The relatively high concentrations of ice-rafted material near the northern and southern shores can best be accounted for by the distribution of the lingering fringe ice during the melting and break-up periods (April through July, Fig. 25). Ice rafting of a lesser magnitude in the centre of the sound is accounted for by the fact that annual surface ice in the centre of the sound does not carry a large sediment load, also the central ice drifts away early in the melting season.

When the shore ice breaks away from the shallow water it is caught in the shore currents, and is carried to and fro as the wind directions fluctuate. This ice is sometimes driven back into bays and inlets, continually melting and dropping sediments. Since Admiralty Inlet is covered with annual ice for most of the melting season, drifting shore ice from Lancaster Sound is prevented from entering the inlet, and thus rafted material is less prevalent in the inlet.

On the basis of present information it is impossible to state the per cent of the total sediment which is transported and deposited by ice rafting. It is possible, however, on the basis of the hydraulic analysis, to infer that a significant amount of the fine sands in the area were deposited from floating ice. Most of the fine sands show positive skewing (toward the higher velocities) in the settling velocity distributions, a characteristic which has been commonly observed in near-shore continental sands. Because most of the ice-rafted sands would be derived from continental or near-shore environments it might be expected that the characteristic skew would be maintained in ice-rafted deposits.

High average settling velocities in the fine sands are associated with high percentages of coarse sediments larger than 2mm (Fig. 8 and 20), and with high weight percent ratios of fine sand to silt (Fig. 21). Since percentages of coarse sediments are not related to distance from shore (Table I), then the associated anomalously high settling velocities are likewise not correlatable with distance from shore. It is therefore intuitively obvious that high average settling velocities in areas far from shore are related to the same mode of sediment transport and deposition as that which carried the coarse sediments.

<u>Current deposition</u>: The presence of coarse sediment far from shore cannot be feasibly explained by current transport, as the measured velocities are much too feeble to maintain even moderately large grains in suspension over long distances. For example, a sand grain having a settling velocity of only 4 cm per sec (lower size limit of medium sand) would be deposited on a bottom 800 metres deep, about 10 miles from shore, if the transporting current was moving at the optimum measured velocity of 0.5 knot.

In general the low-magnitude current velocities recorded by the 1960 survey seem to be verified for most areas in the sound as considerable clay deposition has taken place in all areas. Clay is a major constituent even in areas with appreciable amounts of sand and pebbles, thus the competency of the currents is below that required to keep even very fine particles in suspension over long travel distances.

In summary, there are two major environments of deposition which account for the distribution of sediments in Lancaster Sound: (1) Ice rafting, a seasonal, erratic process capable of depositing sediments of all size grades at any distance from shore, but contributing largest amounts to areas adjacent to the shore where melting shore ice is most prevalent. This process probably accounts for all sediments larger than fine sand, which are found at distances greater than 10 miles from shore. (2) "Normal" current deposition, which is a continuous process throughout the sound, transporting sediments in suspension and depositing them according to the rates of settling velocity. This process is restricted to the sizes (less than 0.15mm), which the competence of the current can maintain in suspension. The greatest influence of this environmental process is in the distribution of some fine sands, silts, and probably most of the clays. X-ray analysis of some Arctic clays has shown that they may be considered as detrital (Pelletier, 1963). The clays in Lancaster Sound would remain in suspension for the longest time and thus be deposited chiefly in the central basin area. Submarine topography appears to be an unimportant factor in grain size distribution for either of these agents.

Sedimentary Petrologic Provinces:

Delineation of petrologic provinces in this study are based on results of the heavy mineral studies of fine sand size and carbonate minerals in the silts. The distribution and indicated genetic vector of these provinces is influenced chiefly by the current environment.

Mineral distributions:

The distribution of three heavy minerals (actinolite, garnet, and magnetite) in particular indicate a source from the exposed rocks near Croker Bay (Fig. 15, 18 and 19). Biotite does not show such a clearly defined dispersal pattern (Fig. 16), but the relative concentrations in the northern and eastern sections suggest sources in the metamorphic rocks along the coast from Cape Bullen east, with highest amounts being derived from the eastern section.

The percentage of detrital epidote increases very rapidly toward the east indicating a source near or east of Dundas Harbour. The epidote province gives some indication of a northern transport of sediments toward the west.

Hornblende is the only major mineral which gives an indication of two widely separated sources, one in the northeast, and a less definite source in Admiralty Inlet.

In addition to the above named minerals, several minor species were significant in denoting a specific provenance. A small quantity of pyroxene was found in samples close to the northern sources. Limonite, or hematite was found to be important in samples off the southern shore and in Admiralty Inlet, indicating a possible source in the iron-rich rock near Arctic Bay. Occasionally pyrite, with fresh untarnished surfaces was encountered in samples from Admiralty Inlet, indicating rapid sedimentation, and (or) slow rates of oxidation at low temperatures. Siderite was erratic in concentration, but was present most frequently in samples from the southern regions.

The gold and silver occurrences in unusually high concentrations in scattered samples along the southern part of the basin are quite significant. The detrital grains of gold and silver are for the most part thin tabular flakes showing little or no tarnishing. In spite of the high density of these minerals their shape may have afforded current transport for considerable distances. In some instances where detrital gold was observed to have high settling velocities, there can be

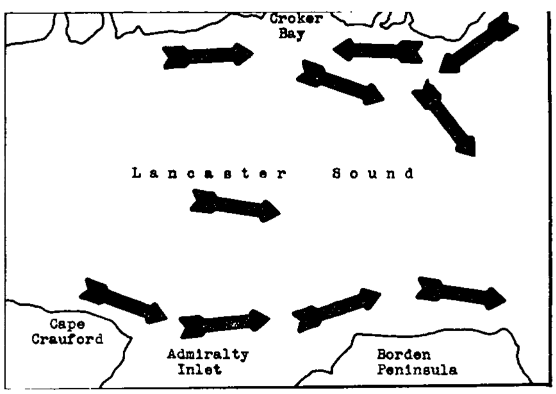


Figure 27 a - Predominant flow of drifting ice.

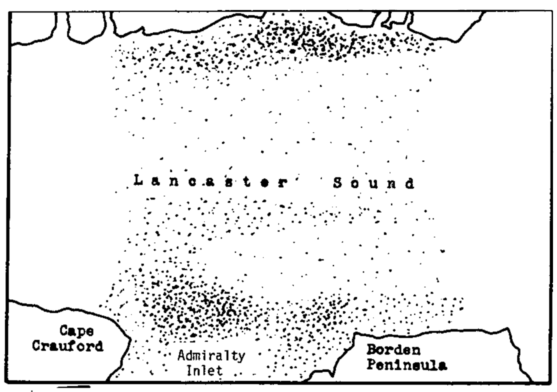


Figure 27 b - Relative concentration of ice rafted debris.

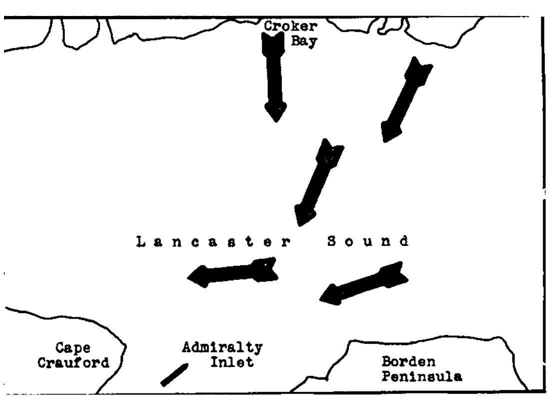


Figure 28 a - Dispersal vectors of heavy minerals.

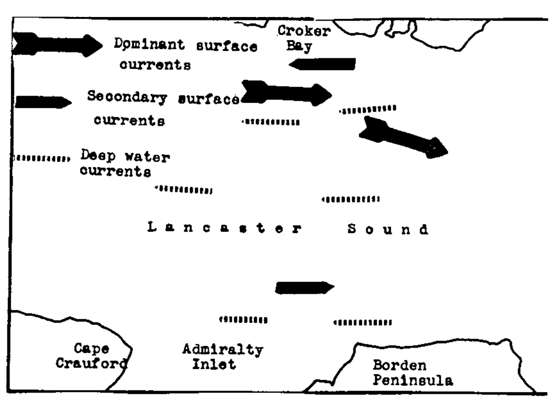


Figure 28 b - Current directions.

little doubt that the means of transport was by ice rafting. It is assumed that the primary source of the gold and silver is in the Proterozoic rocks on the Borden Peninsula, and more specifically those rocks which are exposed in Admiralty Inlet. Occurrences of native silver have been reported at Arctic Bay, on the east central side of Admiralty Inlet (Fortier, 1957).

The index of relative hydraulic availability for the heavy minerals (weight per cent ratio of 3 mineral species), showed lack of consistency from sample to sample, as well as within the hydraulic splits. Assuming minimum experimental error, these ratios indicate frequent changes in the energies and vectors of the transporting medium. It is possible, however, to denote expected tendencies in isolated samples, as in sample number 3 near the indicated garnet source, where the availability of garnet is high compared to magnetite. It can also be noted that the actinolite/hornblende ratio decreases slightly in samples from the southern area, indicating a new source of hornblende. The sharp decrease in the epidote/biotite ratio in the slower settling velocities denoted the tendency for flakes of biotite to be hydraulically equivalent to much finer particles.

Most transport vectors appear to be southerly from Devon Island for approximately 15 to 20 miles, but tend to alter to the southwest in the central sound area. It would seem plausible that this vectorial alteration may be caused by the settling of minerals from the upper easterly flowing current into the lower westerly flowing strata, (Fig. 27a and 28b).

Provenance:

Confirmation of the genetic inferences of the sedimentary petrologic provinces must be attempted with tempered enthusiasm, as it must be remembered that geologic information is regional and incomplete. Examination of a few widely scattered samples from Devon Island was undertaken in conjunction with this study (sample locations in Fig. 2).

The mineral assemblages of the Archaeozoic rock of Devon Island included all those found as detrital minerals in the fine sands. Relative percentages of garnet, amphibole and magnetite in the regional metamorphic rocks, show some correlation with the adjacent sedimentary petrologic province. Biotite and epidote appear to be less abundant in the rocks than in the sedimentary heavy minerals.

In general the Precambrian samples indicate a regional metamorphic grade ranging from low to high intermediate. The mineralogic relationships are suggestive of the Kyanite-Sillimanite type described by Miyashiro (1961) in other areas. The metamorphic facies would be principally epidote-amphibolite with slight regional variations.

In summary, the principal sedimentary petrologic province is genetically related to the Precambrian provenance of the coastal areas on Devon Island. The increased percentages of most heavy minerals in the northeast are probably due to the greater exposure of the source rocks to erosional processes. Garnet, magnetite and actinolite can be directly related to exposed metamorphic rocks at Croker Bay and Dundas Harbour. Biotite and epidote probably have their chief sources further east on Devon Island. Transporting vectors indicate slow-moving currents carry the heavy minerals east, south and then west. Some minerals of secondary importance indicate a southern source, possibly in Admiralty Inlet.

The enriched carbonate content in marine sediments near Cape Crauford and along other areas of the southern coast indicate that the sediments in the adjacent source areas contain larger amounts of carbonate minerals. The friable Paleozoic sediments on Cape Crauford, being composed of sandstones and limestones, appear to be the most important source of the detrital marine carbonates.

The distribution of the carbonate minerals in the sound appears to be opposite to the dispersal of the heavy minerals from the northern sources. This decrease in carbonate content and subsequent increase in heavy minerals may be accounted for by progressive dilution (Pettijohn, 1957), in which case the heavy minerals would be masked near the southern source of the more abundant carbonate minerals. In addition some carbonate minerals would tend to be dissolved in the cold water after some time, thus a progressive decrease in carbonate content away from the source may be accounted for.

There is, however, some indication of an easterly transport of carbonate minerals which is opposed to the apparent westerly transport of the heavy minerals. This may be accounted for by considering the differing current strata in the depths of the water of the sound. Since the heavy minerals of fine sand size would have much higher settling velocities than the carbonate minerals of silt size, it can be expected that the heavy minerals would pass through the easterly flowing currents of the upper water zone much more quickly than the carbonate minerals. The heavy minerals would then be influenced by the westerly flowing bottom currents (300m to 600m) before being deposited. On the other hand the slower settling carbonates would be carried by the predominately easterly flowing currents (also ice rafted) for a longer period of time before reaching the weaker bottom currents of opposite direction.

References cited

CREAGER, J.S., McMANUS, D.A., and COLLIAS, E.E., 1962, Electronic data processing in sedimentary size analysis: Jour. Sed. Petrology, v. 32, no. 4, p. 833-839.

DREIMANIS, Aleksis, 1962, Quantitative gasometric determination of calcite and dolomite by using chittic apparatus: Jour. Sed. Petrology, v. 32, no. 3, p. 520-529.

EMERY, K.O., 1936, Rapid method of mechanical analysis of sands: Jour. Sed. Petrology, v. 8, p. 105-111.

FARQUHARSON, W.I., 1962, Lancaster Sound, tidal and oceanographic survey: report, personal communication.

FORTIER, Y.O., 1957, The Arctic Archipelago, *in* Geol. Survey, Canada (1957), Geology and economic minerals of Canada (fourth ed.): Econ. Geology Ser. no. 1, p. 393-442.

GEOLOGICAL SURVEY, CANADA, 1962, Geological map of Canada, map 1045a.

HARRIS, S.A., 1958, Probability curves and recognition of adjustment to depositional environment: Jour. Sed. Petrology, v. 28, no. 2, p. 151-163.

HJULSTROM, Filip, 1938, Transportation of detritus by moving water, *in* Trask, P.D. (1955), Recent marine sediments, a symposium, Tulsa, Oklahoma. Soc. Econ. Paleontologists and Mineralogists, p. 5-31.

KRUMBEIN, W.C., 1937, Sediments and exponential curves: Jour. Geology, v. 45, no. 6, p. 577-601.

____________ and PETTIJOHN, F.J., 1938, Manual of sedimentary petrography: New York, Appleton-Century-Crofts Inc.

KUNTZ, V.E., McNAIR, A.T., and WADES, D.B., 1952, Stratigraphy of the Dundas Harbour area, Devon Island, Arctic Archipelago: Am. Jour. Sci., v. 250, no. 9, p. 636-655.

PELLETIER, B.R., 1963, Contributions of the Marine Geology Unit of the Geological Survey of Canada to the Polar Continental Shelf Project, District of Franklin, 1962: Geol. Survey, Canada, Topical Rept. 69.

PETTIJOHN, F.J., 1957, Sedimentary rocks: New York, Harper & Brothers.

POOLE, D.M., 1957, Size analysis of sand by a sedimentation technique: Jour. Sed. Petrology, v. 27, p. 460-468.

RITTENHOUSE, Gordon, 1943, Transportation and deposition of heavy minerals: Geol. Soc. America Bull., v. 54, p. 1725-1780.

RUBEY, W.W., 1933, Settling velocities of gravel, sand, and silt particles: Am. Jour. Sci., v. 25, no. 147, p. 325-338.

RUSSELL, R.D., 1938, Effects of transportation on sedimentary particles, *in* Trask, P.D., 1955, Recent marine sediments, a symposium, Tulsa, Oklahoma, Soc. Econ. Paleontologists and Mineralogists, p. 32-47.

SPENCER, D.W., 1963, The interpretation of grain size distribution curves of clastic sediments: Jour. Sed. Petrology, v. 33, no. 1, p. 180-190.

SWITHINBANK, Charles, 1960, Ice atlas of Arctic Canada: Ottawa, Queen's Printer.

THORSTEINSON, Raymond, and TOZER, E.T., 1961, Structural history of the Canadian Arctic Archipelago since Precambrian time, *in* Raasch, G.O., Geology of the Arctic, v. 1, p. 339-360, University of Toronto Press.

TURNER, F.J., and VERHOOGEN, John, 1960, Igneous and metamorphic petrology (second ed.): New York, McGraw - Hill.

WELLER, M.J., 1960, Stratigraphic principles and practice: New York, Harper and Brothers.

NOTE: The tables of data are given in the Appendices of the original thesis deposited with the Library, Department of Geology, University of Western Ontario, London, Ontario.