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Bernard R. Pelletier

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REPORTS

Sedimentation in Arctic Waters of the Western Queen Elizabeth Islands; District of Franklin, Canada*

B. R. PELLETIER
Bedford Institute of Oceanography, Dartmouth, N. S.

Introduction

This report is a preliminary statement of continuing studies of sedimentation carried out since 1960 in Canadian Arctic waters under the direction of the Polar Continental Shelf Project (Department of Energy, Mines and Resources). The program includes investigations in the following sedimentary environments: lacustrine, fluvial, inshore deltaic, inshore non-deltaic, channel, and offshore marine (i. e. Arctic continental shelf). The major area of study is in the western portion of the Queen Elizabeth Islands (Figure 1).

Previous work

The general work in oceanography undertaken in the western Arctic was reported by Collin (1962, 1966) while the geological work was reported by Pelletier (1962, 1966). Studies in Peary Channel were carried out by Horn (1963, 1967) and in the Prince Gustaf Adolf Sea by Marlowe and Vilks (1963) and Marlowe (1966, a). Development of submarine physiography in the Arctic Archipelago, based on the concept of a submerged Tertiary drainage system suggested by Fortier and Morley (1956), was discussed by Pelletier (1966). Faunal studies from samples collected over the Arctic continental shelf were made by Wagner (1962, 1964) and those over the inshore areas of the western Queen Elizabeth Islands by Vilks (1964, 1967). In recent years, work in the eastern Archipelago was undertaken in Lancaster Sound by Buckley (1963), in Exeter Bay on the eastern coast of Baffin Island by Kranck (1965), in northern Baffin Bay by Grant (1965), and central Baffin Bay by Marlowe (1966 b).

Present studies

Arctic investigations in marine geology presently under preparation at the Bedford Institute include studies in the following areas: Hecla and Griper Bay by R. M. McMullen and G. Vilks, Fitzwilliam Channel by G. Vilks, Marie Bay adjacent to the east side of Fitz william Channel by J. D. Macdougall, Barrow Strait by Mrs. John Henderson (née Penelope Wise), Baffin Bay by J. I. Marlowe, and finally Nares Strait, Jones Sound and the Arctic Continental Shelf by F. J. E. Wagner and B. R. Pelletier. The present report deals mainly with the writer's research in Arctic marine geology in the western Queen Elizabeth Islands (Figure 1).

Mechanical sedimentation

Samples were collected from all aqueous environments and several characteristics of the samples compared. In the fluviatile environment it was possible to sample all physiographic reaches of the stream due to the fact that most rivers are less than 20 miles in length, and all portions are accessible. Although several rivers were sampled, the data from only one trunk system is presented in Figure 2.

Textural analyses of these river samples were made and the data were plotted as size frequency histograms (Figure 2). The most striking features of these are the bimodal distributions, which are characteristic of highland sediments, and the unimodal distributions characteristic of the lowland sediments. A decrease in grain size with distance of sedimentary transport is apparent, but on a semi-logarithmic plot of average size (log. mm) versus distance of transport (linear distance), the points do not lie on a straight line (Figure 3). However by substracting the coarse gravel mode and plotting the mean of the sand mode, all points lie on a straight line and Sternberg's law of exponential size decrease with distance of sedimentary travel holds.

Sorting values decrease from highland to lowland reaches, and a comparative decrease in the content of heavy minerals also takes place. The gravel and sand content decreases regularly and progressively downstream, the former ceasing to be an important constituent within a very short distance of the highland area.

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Map of Arctic Islands. Traverses of 1960-61 shown in solid lines; traverses of 1962 shown in dashed lines. Shaded areas indicate inshore traverses

Figure 1. Index map showing location of the Queen Elizabeth Islands, their inter-island channels and adjacent Arctic Ocean.

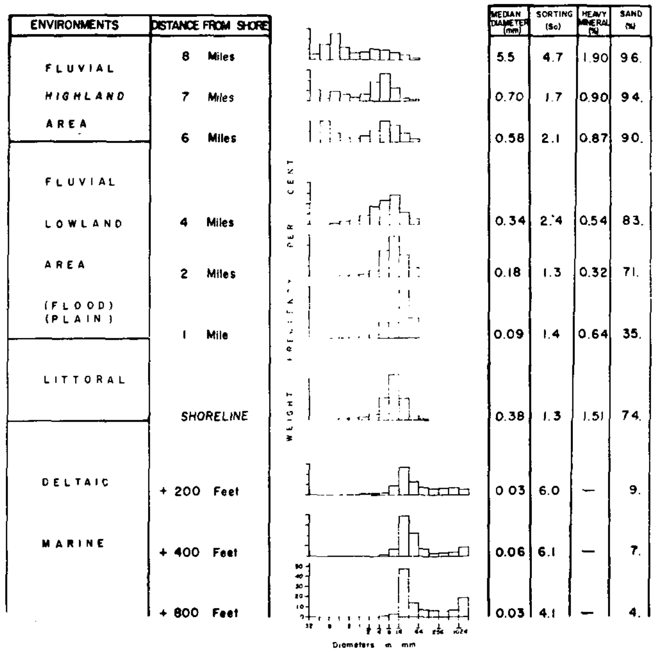


Figure 2. Sedimentary transport in the arctic fluvial environment. Mechanical properties are shown to decrease in magnitude with progressively larger distance from the highland source area. Re-concentrating of heavier and coarser fractions occurs at the shoreline due to the winnowing influence of wave action during periods of open water.

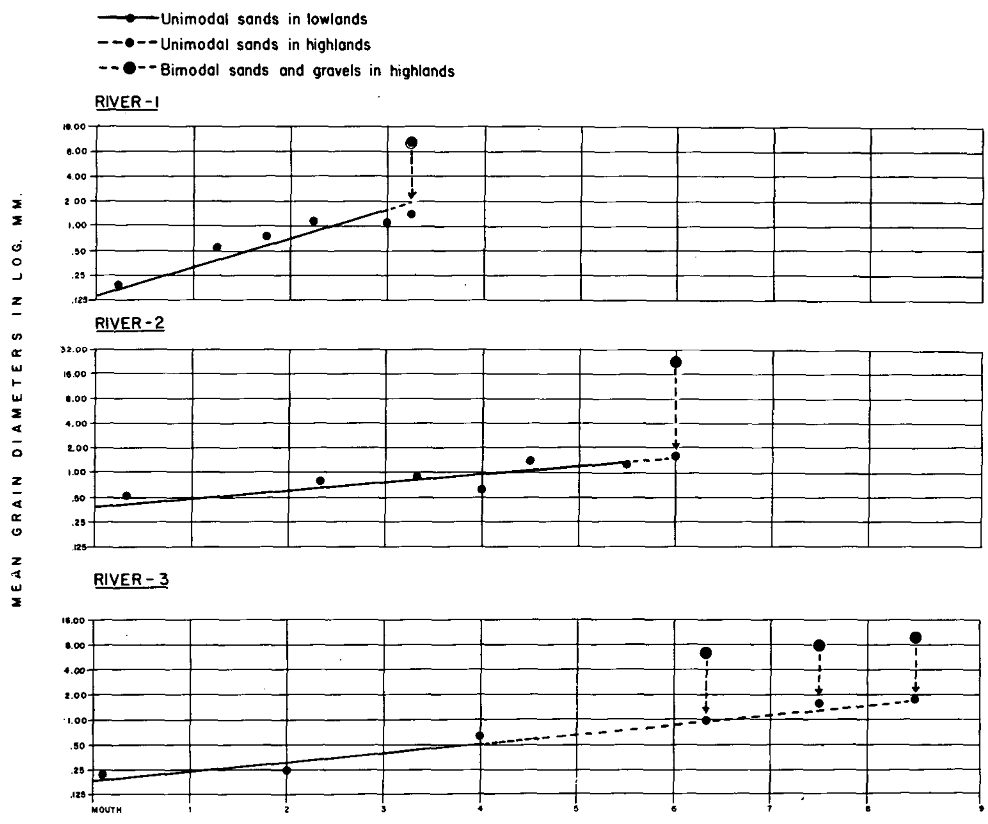


Figure 3. Exponential size decrease of sediments during transport in three arctic rivers. When the arenaceous content is subtracted from the coarser biomodal clastics of the highlands and is re-plotted, the mean sand diameter falls on the extrapolated curve of the unimodal lowland sands. Note: large dot represents bimodal sands and gravels *in highlands; small dot* on broken line represents unimodel sands in highland; and small dot on solid line represents unimodal sand in lowlands.

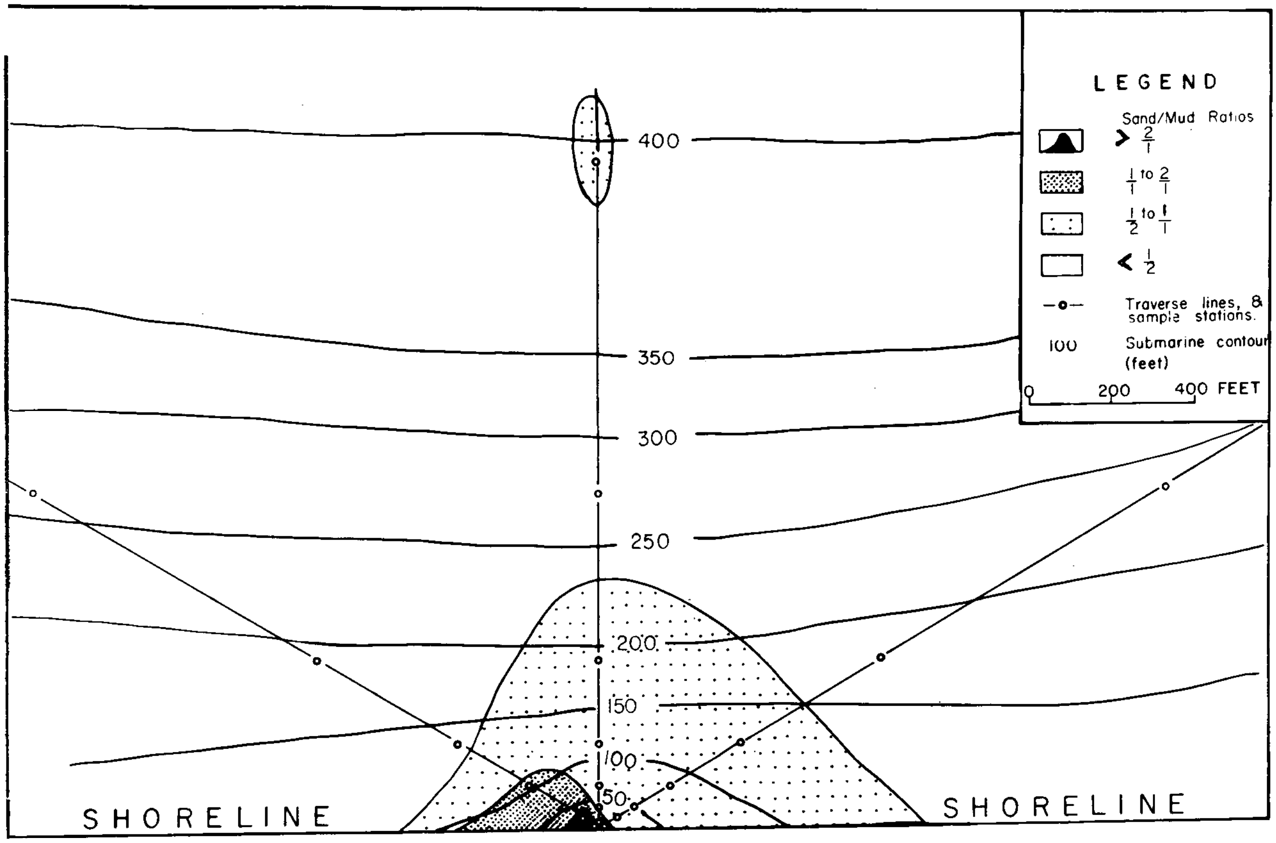
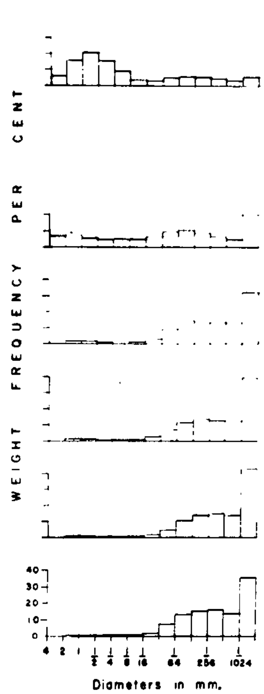


Figure 4. Lithofacies of an arctic marine delta. Coarsest sediments are near the shoreline. Asymmetric arcuate pattern is developed over regular bathymetric controus indicating a prograding pattern which may be due to recent uplift in the area. Asymmetry of arc is due to continuing longshore drift from left to right so that fine sediments trail current-ward.



INSHORE LACUSTRINE					INSHORE MARINE			
MEDIAN DIAMETER (mm)	HEAVY MINERALS (%)	SORTING (So)	SAND (%)		MEDIAN DIAMETER (mm)	HEAVY MINERALS (%)	SORTING (So)	SAND (%)
.340	5.01	7.3	68.0	SHORE	.440	8.76	1.6	97.0
				+50'	.014	5.86	4.5	35.50
.014	14.36	10.0	33.0	+100'	.005	—	7.9	19.84
.003	4.91	3.8	4.88	+200'	.018	5.68	4.2	11.14
.002	5.94	3.6	4.23	+400'	.002	6.56	2.3	5.57
.0016	6.99	3.6	2.02	+800'	.0016	6.09	4.3	1.87
.002	2.23	3.1	1.00	+1600'	.0014	—	3.0	1.5
				+3200'	.0012	2.77	3.5	0.18

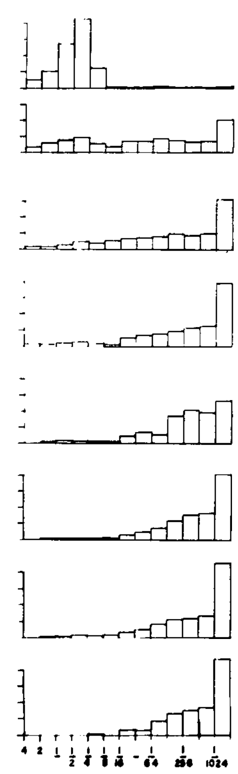


Figure 5. Sedimentary transport in non-deltaic arctic inshore waters. A parallel decrease in magnitude of mechanical properties of sediments with distance from shore is shown for both lacustrine and marine bodies.

Samples collected in marine waters were obtained from the shoreline and at logarithmic intervals away from the shore (e. g. 50, 100, 200, 400, 800 feet and so on). These intervals were selected on the empirical observations that textural properties of clastic sediments vary exponentially with distance of sedimentary transport. Therefore, the number of samples was proportionately larger in the inshore area. Across one delta, three traverses were made beginning at a common origin on shore: one along the axis of the delta, and two others at 60° on either side of this axis (Figure 4). A lithofacies analysis of these samples (Figure 4) revealed a pattern of concentric arcuate belts of varying textures with the coarsest sediments near shore, and the finer ones further seaward. A prograding pattern is evident and is expected, as this area is undergoing relative uplift.

Marine and lacustrine sediment samples were collected in areas adjacent to non-deltaic coastlines. Upon mechanical analysis the results of each set of samples were found to be strikingly similar and thus they are presented together (Figure 5). The size-distributions represented by the histograms, are similar for samples obtained at equal distances from the shoreline as shown by the parallel shift in the principal textural modes. The content of heavy minerals decreases gradually at similar distances from shore for both sets of samples. Sand content as well decreases markedly from the same 200-foot mark in each set of samples. Sorting values are generally the same in each set of samples and improve seaward from the 200-foot sampling interval.

In the open marine environment of the continental shelf and adjacent western approaches of the Arctic channels, sedimentary textures appear to reflect the winnowing action of currents rather than the distance of sedimentary transport from nearby island sources. This may be due to the existence of stronger currents flowing over the medial ridges on the floor of the inter-island channels, as well as over the shallow areas located off the island headlands. This is shown in Figures 6 and 7. Generally the coarser sediments, exclusive of ice-rafted pebbles and cobbles, are abundant on the topographic highs and the finer sediments are found in greater amounts in the topographic lows.

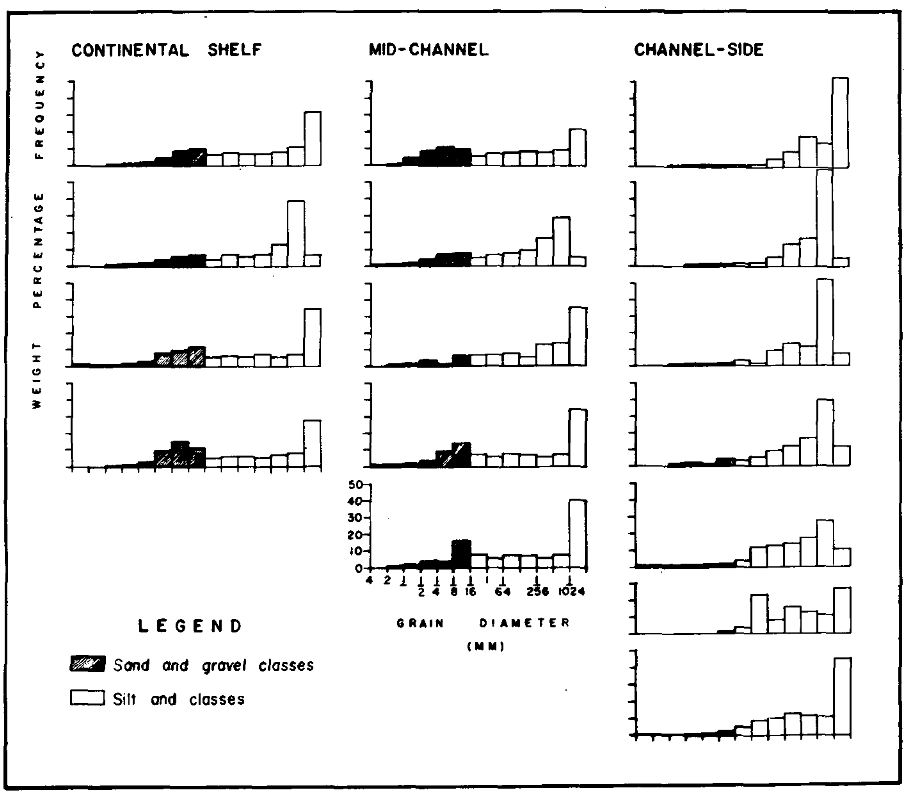


Figure 6. Histograms of arctic marine sediments. Samples of shelf sediments taken northwest of Ellef Ringes Island (Fig. 7); mid-channel and channel-side samples taken from Peary Channel and Prince Gustaf Adolf Sea (Fig. 7) as well as Ballantyne and Wilkins Straits immediately southwest of Bordon Island (not shown). Note: for "silt and classes" read "silt and clay classes".

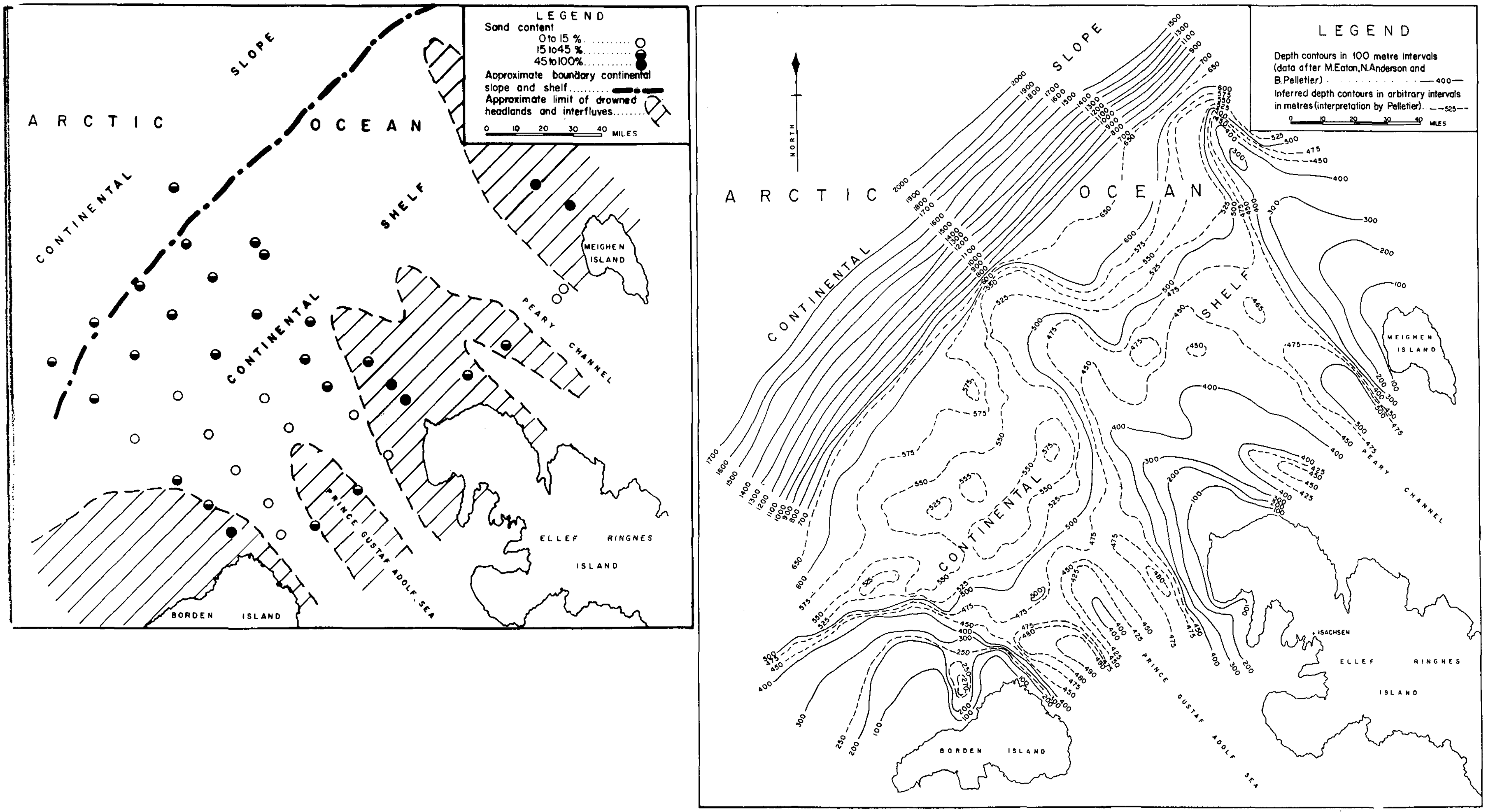


Figure 7. Textures of arctic marine sediments. The right-hand panel shows the bathymetry of the area studied, particularly, the median ridges in the channels between the islands. The left-hand panel shows the sample locations with respect to the drowned areas. The limit of the drowned areas is 425 metres. The coarser sediments are associated with higher relief (e.g. median ridges), whereas the finer sediments are associated with low relief and troughs.

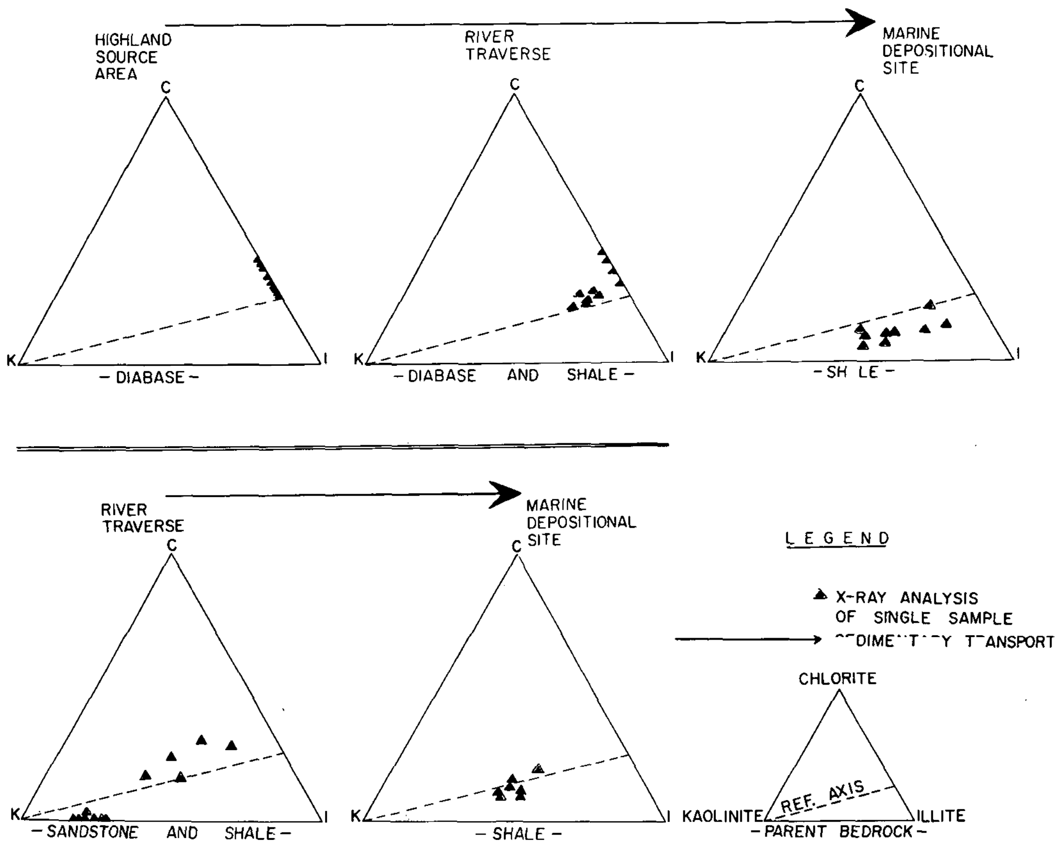


Figure 8. Clay mineral dispersion and bedrock. Note shift along reference axes (broken line) of composition of clay groups with distance from bedrock, and the direct influence of the composition of the underlying bedrock. Diabase contains chlorites and illites predominately, the sandstone contains kaolinite predominate; and the shale contain minor or intermediate amounts of all three clay groups as it is composed itself of products of long weathering.

Dispersal of clay minerals

A relationship exists between the dispersal of clay minerals and the associated parental bedrock. This is illustrated in the ternary compositional diagram (Figure 8) in which kaolinite (K), chlorite (C), and illite (I) form the apices of the triangle. Fluvial sediments obtained in areas underlain by diabase contain chlorite and illite. Further downstream where the area is underlain by shale, as well as by diabase in places, half the samples contain chlorite and illite only; the other half contains chlorite, illite and minor amounts of kaolinite. Further downcurrent still in the marine environment, which is underlain only by shale, all samples show major amounts of kaolinite and lesser quantities of chlorite and illite.

Another dispersal pattern is also shown in the lower panel of Figure 8. Here the analyses of clay minerals are plotted for samples obtained in the headwaters of an area underlain by both sandstone and shale, and for samples obtained in the adjacent marine depositional area underlain only by shale. In the former case, half the samples show major amounts of kaolinite as well as lesser amounts of illite and chlorite, and the other half show predominant amounts of kaolinite and illite but no chlorite. In the marine area underlain by shale, all samples show considerable amounts of kaolinite and illite, and minor amounts of chlorite. This is similar to the analyses from samples collected from other areas underlain by shale.

This suggests that clay minerals in these arctic environments are related to the adjacent geological formations and are detrital in origin. They appear to be unaltered by diagenetic processes.

Elemental Analyses

To date approximately 150 samples have been analyzed by means of spectrochemical methods in order to determine certain factors diagnostic of arctic environments. Preliminary results indicate that certain elements occur in an abundance which appears to be related directly to the geological formations underlying the drainage basins. These results also indicate the virtual absence of chemical activity at the site of deposition.

Distribution of the major oxides

Spectrochemical analyses were carried out on samples obtained from a river system and its adjacent delta. The data were resolved in terms of oxides, and the percentage composition of the oxides for both sets of samples were calculated and listed in Table I.

TABLE I

VARIATIONS OF MAJOR OXIDES - COMPARATIVE RESULTS

Oxides	River Sediments (Sand/Clay = 53/47 Av.)	Deltaic Sediments (Sand/Clay = 13/87 Av.)	Average Shale
SiO_2	60.75 %	59.33 %	58.10 %
Al_2O_3	17.68	16.93	15.40
Fe_2O_3	7.23	6.98	6.67
K_2O	2.43	2.57	3.24
MgO	0.33	0.24	2.44
Na_2O	0.30	0.85	1.30
Ti_2O	0.933	0.938	0.650
CaO	0.333	0.238	3.110
MnO	0.044	0.038	-----

These are averaged values, and the slight variation in percentage composition of the sediments from both environments is apparent. Silica for example, remains constant in both river and delta sediments irrespective of sedimentary texture. Ferric iron is generally uniform except at the shore line where heavy minerals, in the form of iron ores, are concentrated by wave action and slight tidal energy. Sodium oxide (Na_2O) is variable but tends to increase in the marine areas, perhaps due to the influence of saline waters. Calcium oxide (CaO) occurs in lesser amounts offshore except in the areas where calcareous-shelled organisms thrive. The accumulation of the tests and shells of these organisms in this zone probably influences the increased amounts of CaO shown in the analyses. Manganese oxide (MnO) is slightly less in sea water and this may be due to a transfer of manganese ions in sea water. Generally, diagenesis does not appear to have played a major part in the variation of the oxides in fluvial and deltaic sediments.

In Table I, a comparison is also given with the average shale, (Pettijohn, 1957, p. 100) and the data shows that the sedimentary body now forming in the delta will, upon induration, yield a geological formation that is fairly similar to a shale in composition.

Comparative environmental studies of pH, carbonate and organic carbon

Sediments from several depositional environments were analyzed for their pH value and for their content of carbonate and organic carbon. These results are given in Table II, and constitute the averages of several analyses. Significantly, the pH is lowest in fluvial sediments, probably because of the presence of humic soil acids. In the lake, fresh water neutralizes the acidity and in the deltas where rivers empty, the alkalinity is diluted by a discharge of fresh water. Further from the delta, alkalinity increases, and in the open ocean, it is the highest of all the environments.

Carbonate content increases in the marine environment due to the increased amounts of calcareous tests and shells. Over the continental shelf, this is most pronounced. Because the

TABLE II

COMPARATIVE STUDIES ON pH, CO_3, AND ORGANIC CARBON

Depositional Environment	AVERAGE VALUES		
	pH	Carbonate %	Organic Carbon %
Lacustrine	6.66	2.54	1.14
Fluvial	4.27	3.32	1.70
Deltaic (Protected Bay)	6.54	4.45	2.10
Non-Deltaic (Protected Bay)	7.00	3.61	2.42
Ocean (Cont. Shelf)	7.54	6.57	0.81

ice in the protected bays persists most of the year, photosynthesis is reduced in these waters and a corresponding reduction in the growth of phytoplankton and the food-dependent shelly organisms takes place. This in turn yields lower amounts of carbonate in the bottom sediments. Over the ocean, leads generally open in the ice, giving rise to increased photosynthetic activity. Nutrients are more available in the open ocean as prevailing currents transport continuous supplies and, consequently, life is more abundant. With the rain of planktonic tests on the bottom, together with the accumulation of benthic shells, the sediments are expected to contain more carbonate.

Organic carbon is low in lacustrine and fluvial areas due to its lack of preservation in the oxidizing environment of the atmosphere, and to the rigours of mechanical sedimentation. An almost similar case may be made for the sediments of the continental shelf. Here deposition is slow and preservation of the organic matter is not greatly effective. In the inshore marine areas of the protected bays, currents are weak and sedimentation proceeds at a faster rate than elsewhere in arctic waters. Thus preservation of organic carbon is enhanced. Although these values of organic carbon are high for arctic sediments, they are relatively low when compared with similar environments in warmer, ice-free waters where life is more abundant.

Summary

Generally the mechanical properties of sediments vary with distance of sedimentary transport which is demonstrated from analyses of river and deltaic sediments. Offshore the variation is related to topographic features and the existence of ocean currents. Diagenesis has very little effect on sediments as shown by the dispersal pattern of the clay minerals, and a comparison of the variation of the major metallic oxides from river and deltaic sediments.

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