SEDIMENTS OF THE NORRIS GLACIER OUTWASH AREA,
UPPER TAKU INLET, SOUTHEASTERN ALASKA

A

THESIS

Presented to the Faculty
of the University of Alaska
in Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE
IN GEOLOGY

by

[redacted]

Roger Malcolm Slatt, B.A.
College, Alaska
May, 1967

[redacted]

ABSTRACT

An 8-square mile outwash fan, composed of gravelly sediment, extends from the terminus of Norris Glacier to the waters of upper Taku Inlet, Southeastern Alaska. Thirty-seven surface sediment samples from the tidal portion of the fan form the bulk of this study. The tidal flat is largely composed of very poorly sorted muddy sediment and relatively well sorted sand which, for the most part, overlie outwash gravel. Mixing of various modal size classes has produced a complex sediment distribution pattern as well as a complicated size-sorting relationship. The sand-size fraction of the sediments consists of feldspar, quartz, rock fragments, amphiboles, pyroxenes, micas and opaques; the clay-size fraction consists of micas, chlorite, montmorillonite, feldspar and amphibole.

The sediments are the product of glacial abrasion in the Juneau Ice Field area. The sand and mud are derived largely from Norris and Taku Glacier detritus; their nature indicates valley glacier detritus may be fairly rapidly sorted when subjected to hydraulic action. Absence of quartz and presence of feldspar in the clay-size fraction may indicate the physical properties of these minerals control the size to which they can be reduced by valley-glacier abrasion.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

Purpose

This investigation concerns the textural and mineralogical characteristics of sediment recently deposited and presently accumulating in the Norris Glacier outwash area, upper Taku Inlet, Southeastern Alaska. In this region, the receding Norris Glacier, advancing Taku Glacier and Taku River, as well as tidal currents and subglacial streams probably all act to distribute and deposit sediment. Abrasional, transportational and depositional processes in this regimé operate with great intensity and their products accumulate in what may be the most dynamic environment known for terrigenous sediment. This study is a step toward describing this environment and evaluating the effect of each of the agents on valley glacier detritus. The present work is also significant in that, to the writer's knowledge, it represents one of the few attempts at defining the textural and mineralogical nature of valley glacier detritus.

Acknowledgements

The writer is indebted to Dr. C.M. Hoskin for invaluable advice and assistance during all phases of the study, Drs. T.D. Hamilton, G.D. Sharma and L.C. Hoskins for critically reviewing the manuscript, and Dr. H.D. Pilkington for assistance in the X-ray analysis of the clay minerals. The writer also thanks

REGIONAL SETTING

Description of the Area

Taku Inlet is situated 12 miles east of Juneau, Alaska, and just south of the Juneau Ice Field, a 700 square mile highland ice complex (Fig. 1). The inlet extends from the mouth of the Taku River southward for a distance of 14 miles where it terminates in Gastineau Channel.

The terminus of Taku Glacier, the main trunk glacier of the Juneau Ice Field, stands near the head of the inlet and is separated from the tidal waters by a series of end moraines which are exposed well above the high tide level. The smaller Norris Glacier is separated from Taku Glacier by an elongate bedrock ridge. An eight square mile outwash fan extends from the terminus of Norris Glacier to the tidal waters of the inlet (Fig. 2).

A spruce forest has developed on the remnants of a terminal moraine in the central area (Wentworth and Ray, 1936), and to the northwest, a lesser forest has developed on outwash sediment. The remainder of the fan is barren or only sparsely vegetated. East of the wooded area is a large tidal flat, the upper reaches of which are covered with a thick mat of marsh grass.

A small meltwater lake flanks most of the Norris ice terminus. The presence of elevated shoreline terraces and thick silt deposits in front of the present shoreline indicates this lake once extended further east. A large braided stream heads at the north end of the lake and flows eastward into the inlet waters.

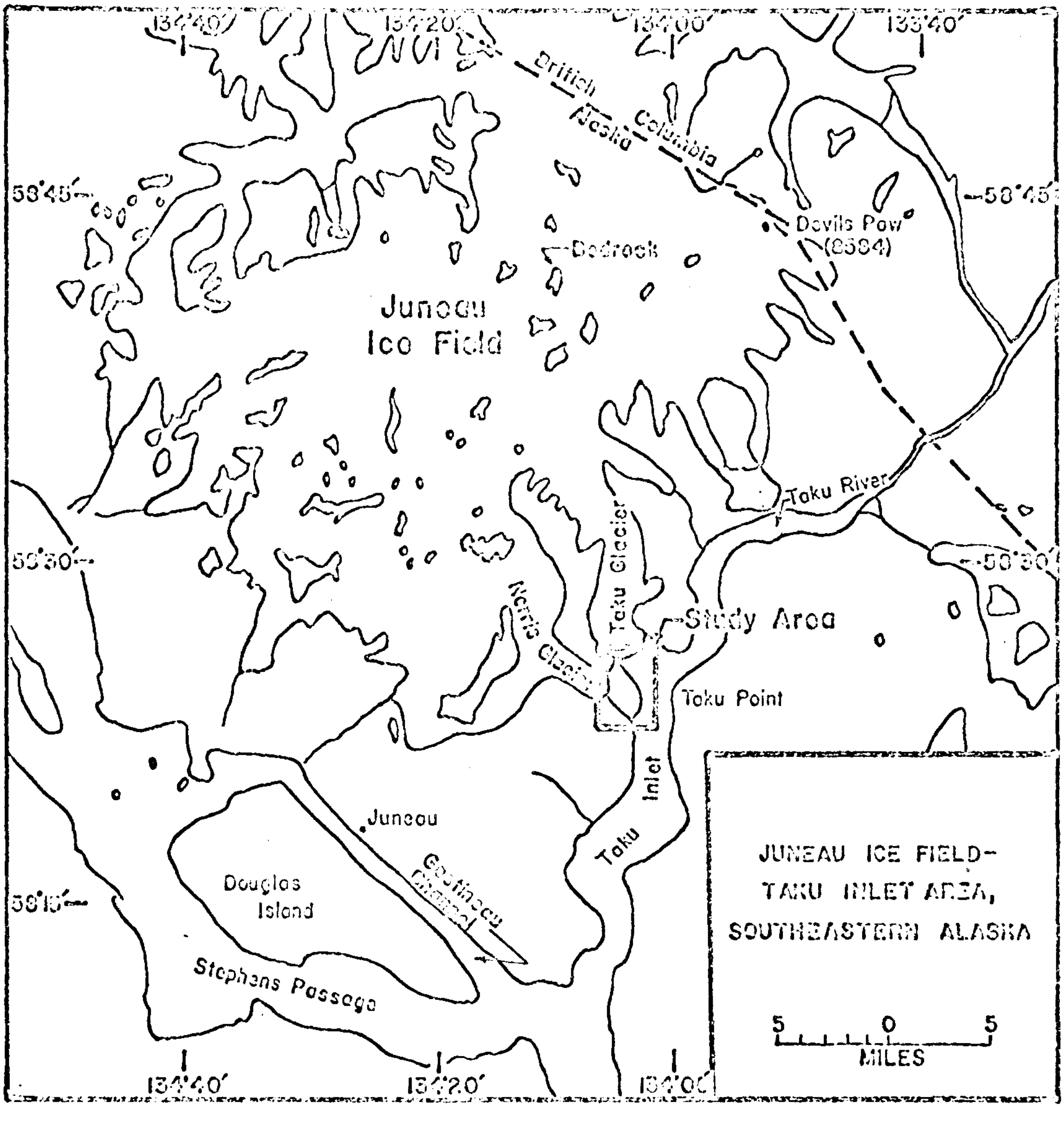


Fig. 1 - Index map showing the location of Taku Inlet, Southeastern Alaska. Simplified from Lawrence (1950).

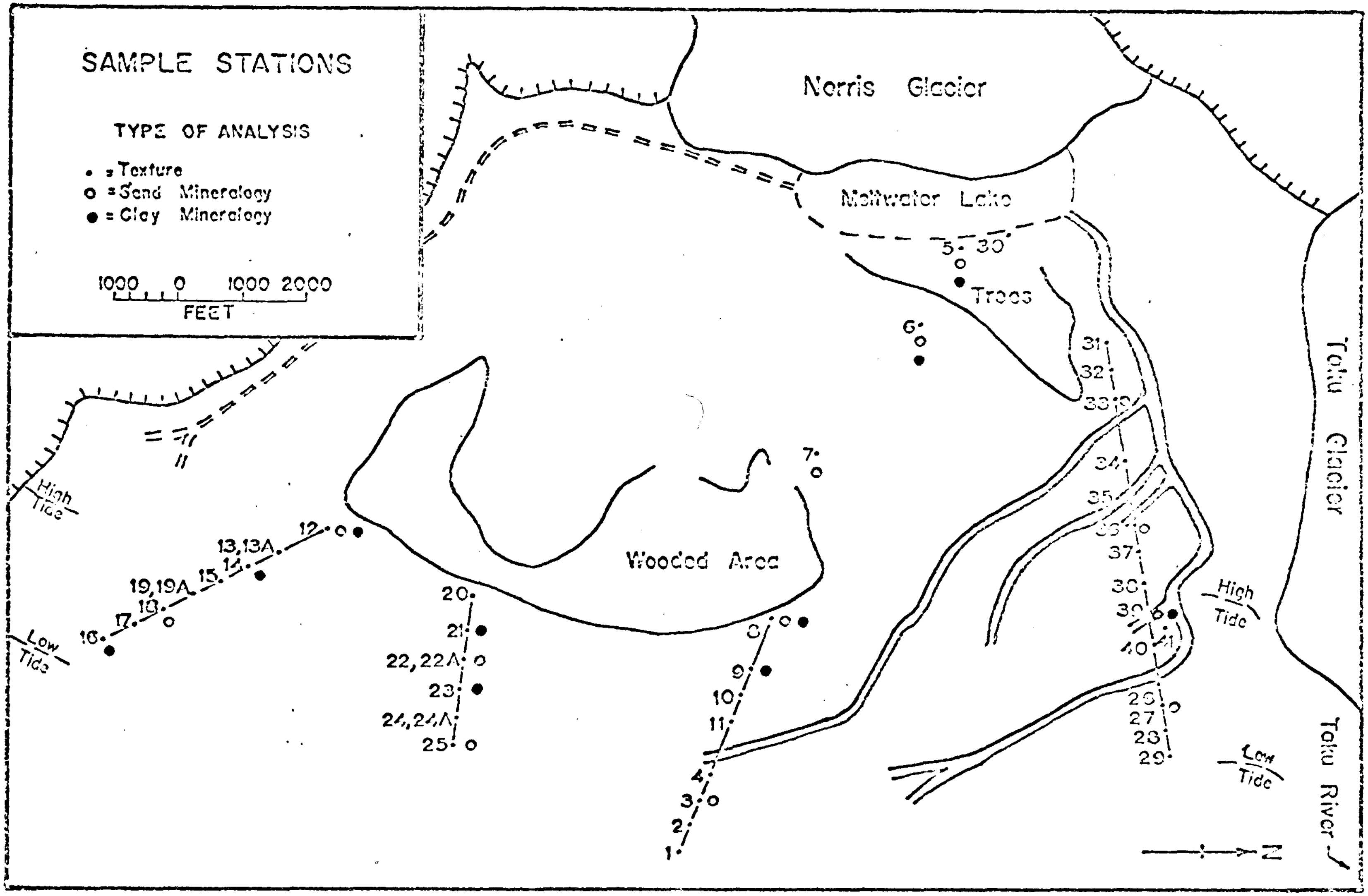


Fig. 2 - Location of sample stations and type of analysis. Modified from U.S.G.S., Juneau (B-1), Alaska Quadrangle 1:63,360 Series (Topographic), aerial photography of 1948.

In the vicinity of the outwash fan, the diurnal tidal range is 16.7 feet (Department of Commerce, 1966) and tidal currents are strong. Surface waters in the upper inlet are relatively non-saline due to the influx of large quantities of fresh water from subglacial streams (Hood, et al., 1966).

The climate is generally mild and humid. Annual precipitation at nearby Juneau averages 83 inches. January average temperatures range from 23 to 29° F; the July average range is 53 to 58° F (Heusser, 1954). Storms are common throughout the year, reaching their greatest intensity during the winter months when the "Taku Winds" sometimes exceed 100 mph.

Recent Glacial History

Except for minor fluctuations, Norris Glacier has retreated from the eastern edge of Taku Inlet to its present position more than 3 miles to the west since the middle 1700's (Lawrence, 1950). The Norris outwash fan has therefore developed within the last 200 years.

Taku Glacier, on the other hand, has been advancing steadily since the late 1890's (Miller, 1963). During the early 1930's the terminus was still tidal, but by the late 1930's a push moraine appeared above the tide level and shortly after, became a permanent emergent feature (Field, 1954).

Just prior to the 1890's, water in the upper inlet was 250-300 feet deep, but by the late 1930's, this depth had been considerably reduced due to the influx of large volumes of sediment to the upper inlet. Isostatic rebound has occurred in the area (Heusser, 1952) and may also have contributed somewhat to this rapid shoaling. At present, the water depth is approximately 5 feet at high tide. According to Jordan (1962) over 370 million cubic meters of sediment were deposited in the upper inlet during the period 1890-1960.

SEDIMENT TEXTURE

Methods of Sampling and Analysis

Thirty-seven surface samples were obtained at 500 foot intervals, when possible, along four traverses east of the forests (Fig. 2). As sediment west of the wooded area is gravelly, only two samples were collected in this region due to the practical difficulties involved in obtaining representative samples of gravel. Four sub-surface samples were also collected from the intertidal region and two samples were collected from near the meltwater lake.

Textural analysis of the sediment was done according to the methods of Folk (1965). Sands were sieved with a set of one-quarter phi interval U.S. Standard Series screens, and pipette analyses were run on the muds. Samples consisting of mud and sand were fractionated by wet-sieving while those containing mixtures of sand and gravel were fractionated with a -1 phi screen.

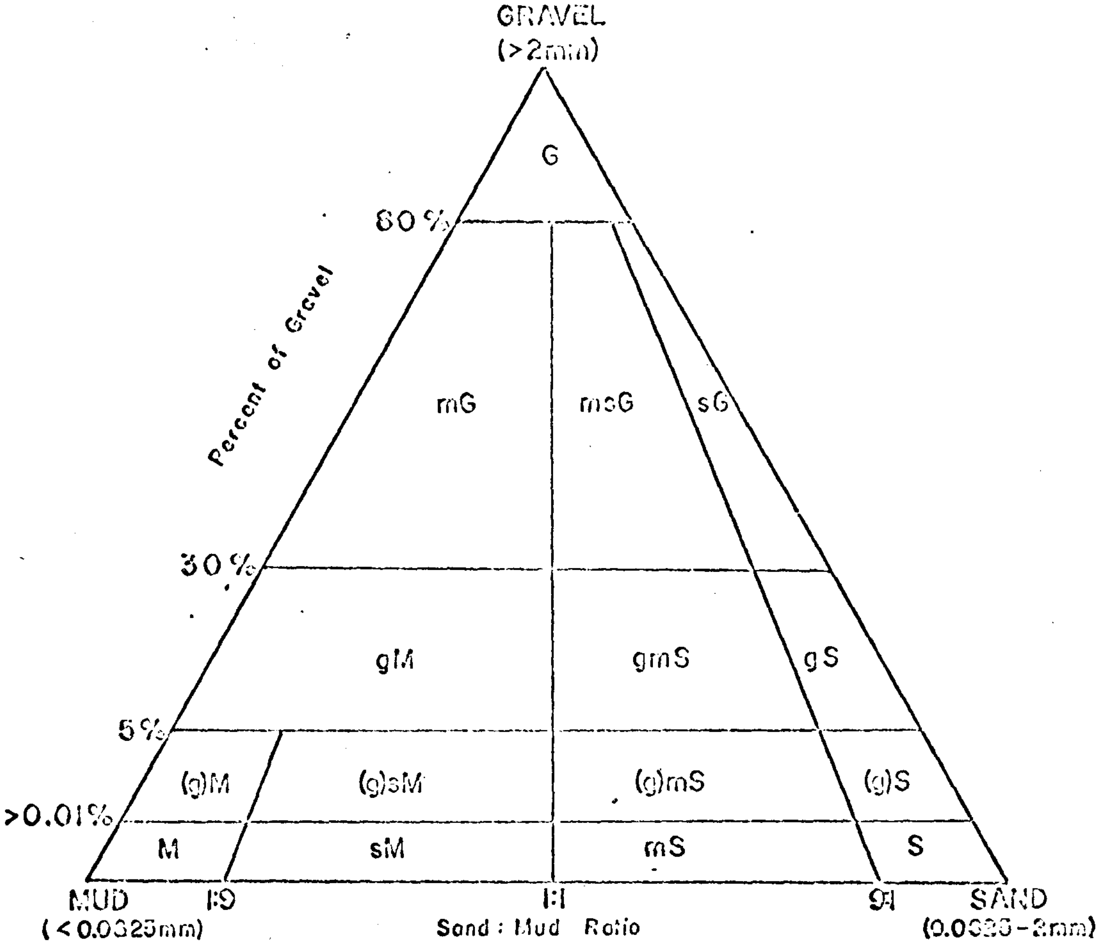
With the resulting data, cumulative curves were constructed on arithmetic coordinate paper, and mean size, standard deviation (sorting), skewness and kurtosis were calculated for each sample using the formulas of Folk and Ward (1957) (Appendix A). Folk and Ward strongly recommend the use of arithmetic probability paper for graphical analysis of sediments, however, it was found that cumulative curves for muddy samples, when plotted on these coordinates, invariably showed a sharp change in slope at the 10 phi intercept, apparently due to extrapolating to 100% at 14 phi. This change in slope produced skewness and kurtosis values which probably are not valid. As cumulative curves on arithmetic coordinates approach 100% at 14 phi asymptotically, this change in slope is not apparent and does not noticeably affect the calculated skewness and kurtosis. For this reason, arithmetic coordinates were used and it is suggested that the common method of extrapolating to 100% at 14 phi may not be valid for all sediments.

The sediments were classified according to Folk (1954) (Fig. 3). The areal distribution of the resulting twelve textural groups is shown in Fig. 4, while Figs. 5 and 6 show the mean size and sorting of sediments making up these groups.

Description

On the basis of two samples analyzed, sediment west of the wooded area is very poorly sorted, muddy sandy to sandy gravel which is strongly fine-skewed and platykurtic to very platykurtic. Sediment in this region exhibits extreme textural variations, but the dominant component appears to be gravel and thus the characteristics of these two samples are probably representative of the entire sediment body.

East of the wooded area, silt and clay are presently accumulating in a shallow north-south trending depression that is bordered on the east and west by surface exposures of outwash sediment. In much of this depression a one-foot thick layer of mud to slightly gravelly mud directly overlies outwash gravel. To the east, a thinner band of slightly gravelly sandy mud overlies a nine-inch thick layer of coarse sand above outwash gravel. Further east, muddy sandy gravel is exposed at the surface as a series of north-south trending banks. This sediment



Terminology

G = Gravel
mG = muddy Gravel
msG = muddy sandy Gravel
sG = sandy Gravel
S = Sand
(g)S = slightly gravelly Sand
gS = gravelly Sand
gmS = gravelly muddy Sand
(g)mS = slightly gravelly muddy Sand
mS = muddy Sand
(g)sM = slightly gravelly sandy Mud
sM = sandy Mud
gM = gravelly Mud
(g)M = slightly gravelly Mud
M = Mud .

.Fig. 3 - Textural classification diagram. After Folk (1954).

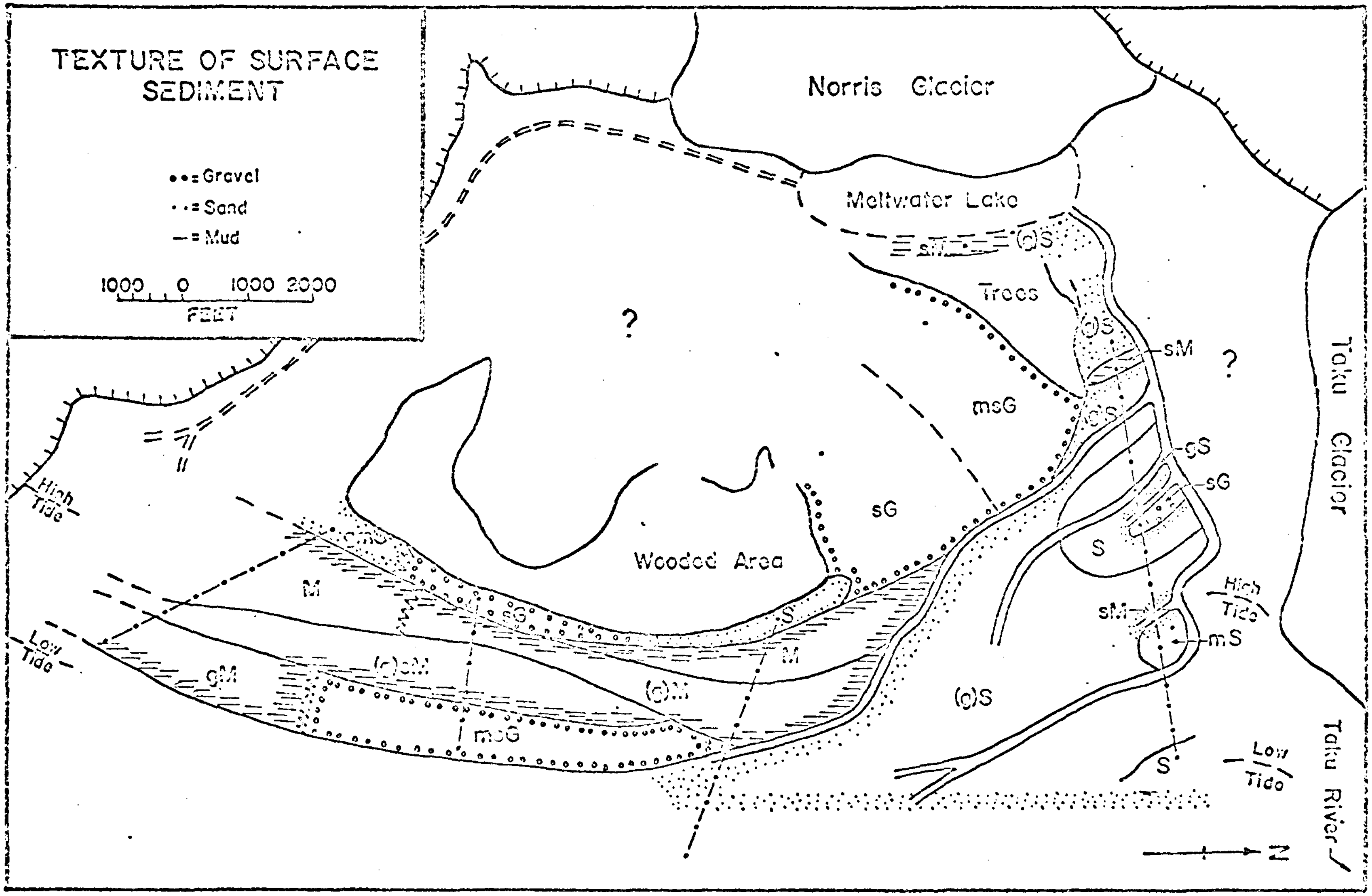


Fig. 4 - Texture of surface sediment. Terminology after Folk (1954).

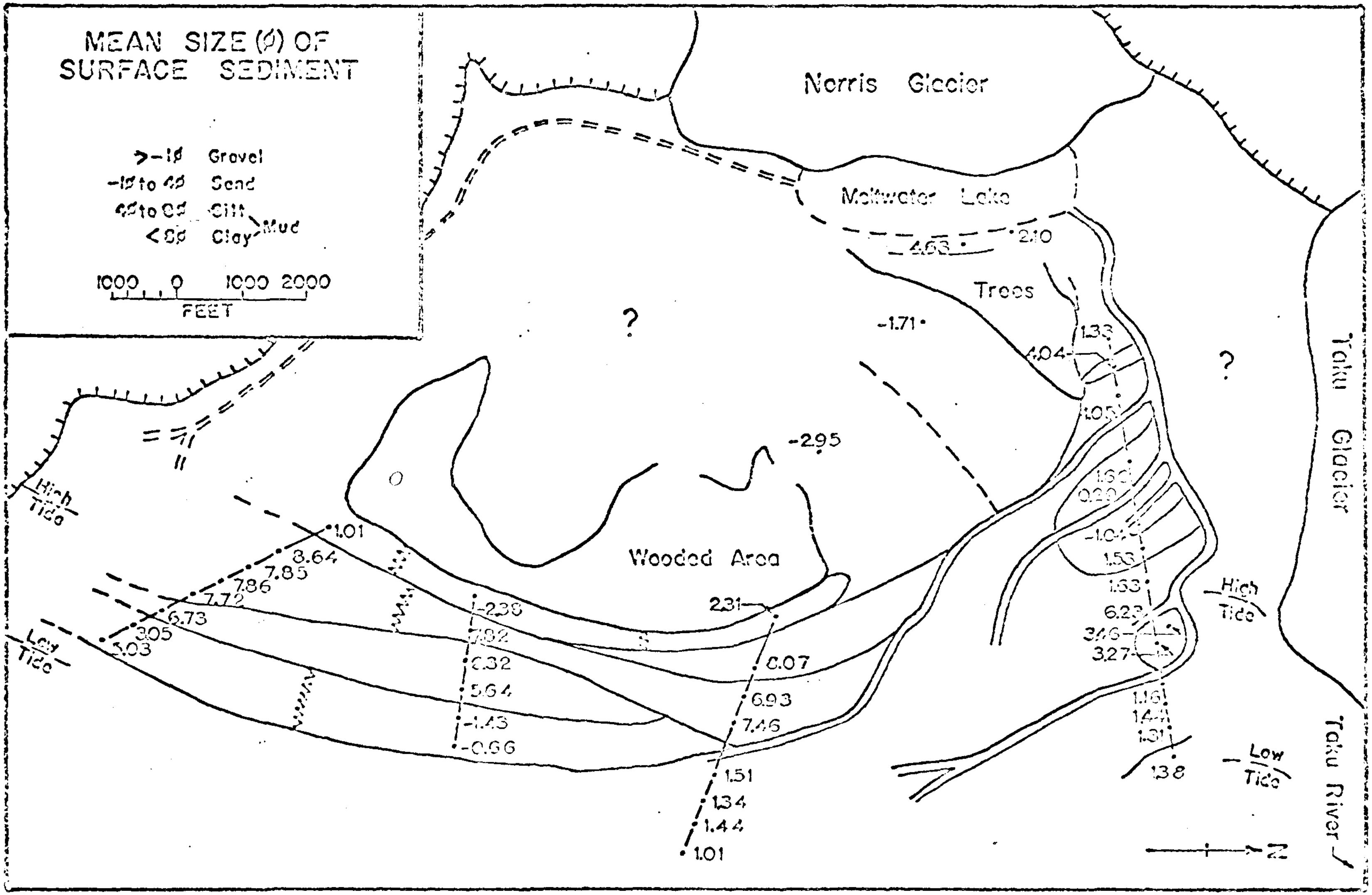


Fig. 5 - Mean size of surface sediment. Classification scale after Folk and Ward (1957).

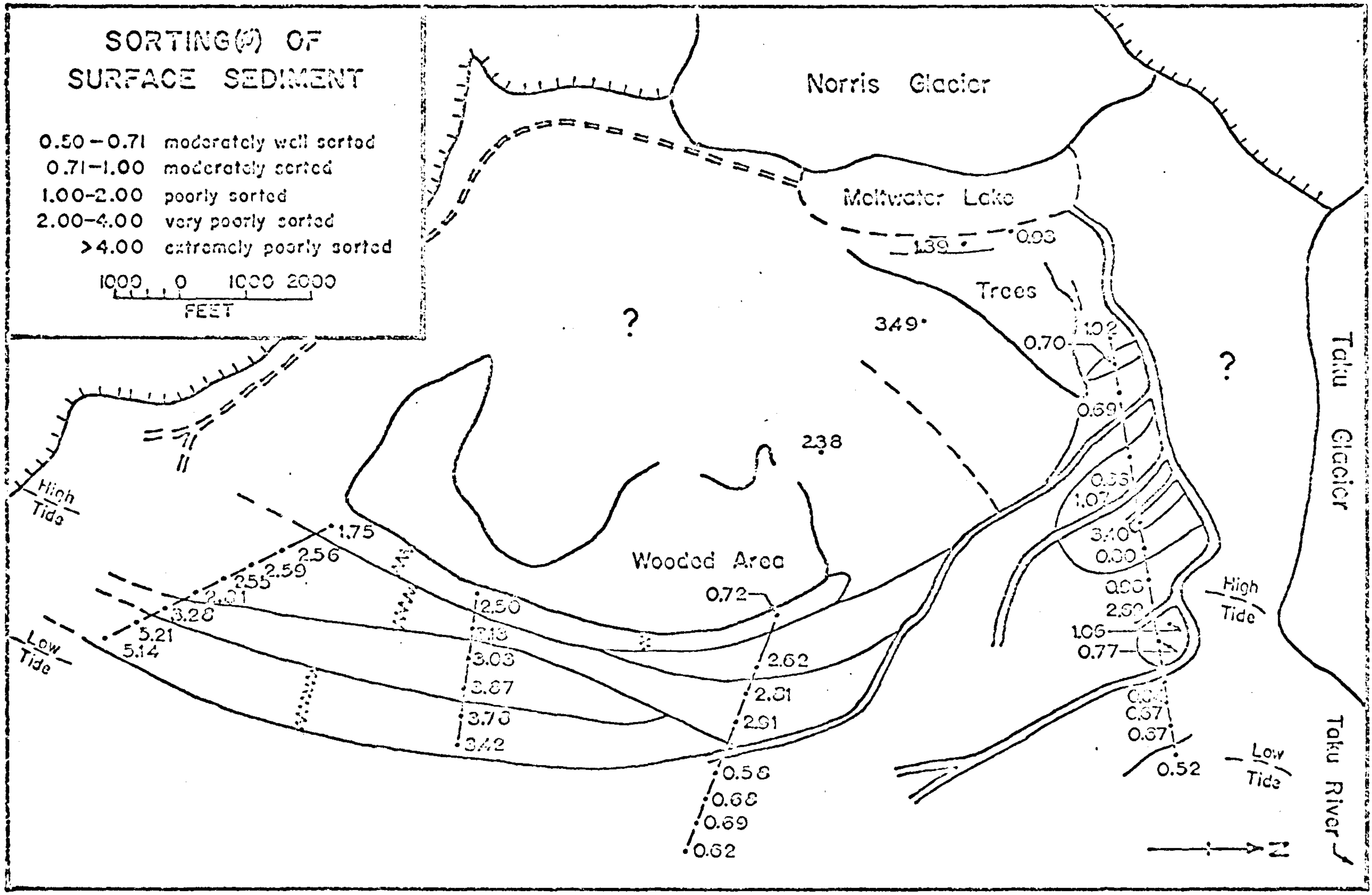


Fig. 6 - Sorting of surface sediment. Classification scale after Folk and Ward (1957).

grades southward into gravelly mud.

The inlet waters in this region carry fine material in suspension and the depression acts as an ideal depositional site for the mud. The relatively deeper water, the elongate banks and the thick mat of marsh grass probably cause a slight reduction in turbulence and the vegetation should also act as a sediment trap. These factors would enhance conditions for deposition of some of the suspended sediment. The greater thickness of mud in the central part of the basin implies deposition is most rapid here.

To the north, the sediment is sand to slightly gravelly sand which is moderately to moderately well sorted, and which has a nearly symmetrical to coarse-skewed, leptokurtic frequency distribution. The northern limit of the sediment body is unknown as no samples were collected north of the meltwater stream. Just south of this stream the sand overlies Norris outwash sediments which are exposed in several small gravel-bottomed channels. The sand body extends southeastward where it lies in contact with the muddy sandy gravel, slightly gravelly mud and mud of the tidal flat. The occurrence of a small sand patch at the northern end of the wooded area is probably the remnants of a former extension of this sand body which has since been removed by meltwater stream erosion.

In the intertidal zone, the sand body contains two sets of dominantly northwest trending current ripples, both sets having lee slopes facing south. These two sets are differentiated by ripple length; the larger set has ripples upwards of thirty feet in length while the smaller, but more abundant set has ripples approximately one foot in length. These ripples were only observed at low tide and the smaller set probably shifts with the tides, however, they overlie the long ripples thus suggesting the latter may be semi-permanent.

On the basis of one analysis (Sample 5), the lake deposit near the elevated shoreline terraces is sandy mud. Similar sediment (Samples 32 and 39) is found in two of the many distributaries of the meltwater stream. One of these distributaries (at the location of Sample 32) is presently inactive. The other is located in the intertidal zone and immediately adjacent to it is a small patch of muddy sand (Samples 40 and 41). One other sample (Sample 30) collected close to the present shoreline of the lake is moderately sorted, slightly gravelly sand.

Modal Size Classes

The sediment distribution pattern is obviously complex. The modal size classes in each of the samples collected were determined (Appendix B), and the frequency of occurrence of these classes is shown in Fig. 7. There is no one dominant gravel mode, however, this is probably due to the lack of such samples. The -5 to -6 phi and -3 to -4 phi material, in most cases, consists of one or two large gravel fragments and, as such, probably do not represent true modal classes. There are two sand modes, at 1 to 2 phi and 3 to 4 phi, and two mud modes, at 4 to 5 phi and 6 to 7 phi. The 11 to 12 phi class was arbitrarily chosen to represent clay-size material that is present in muddy samples, however, there is no actual data for material finer than 10 phi.

The distribution of the modal classes in various surface sediment types is shown in Fig. 8. Sediment west of the wooded area consists of a polymodal mixture

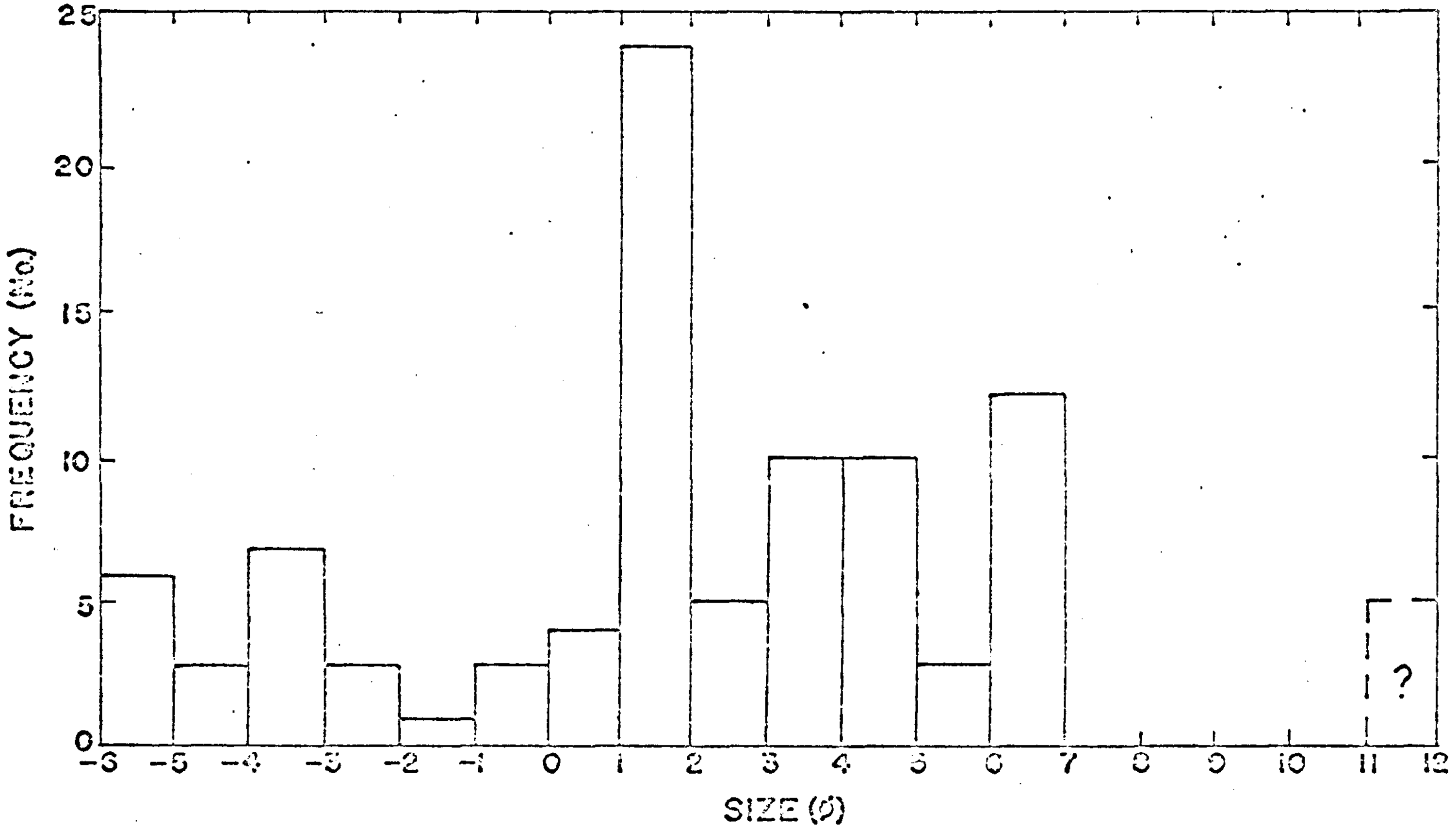


Fig. 7 - Histogram showing frequency of occurrence of modal size classes.

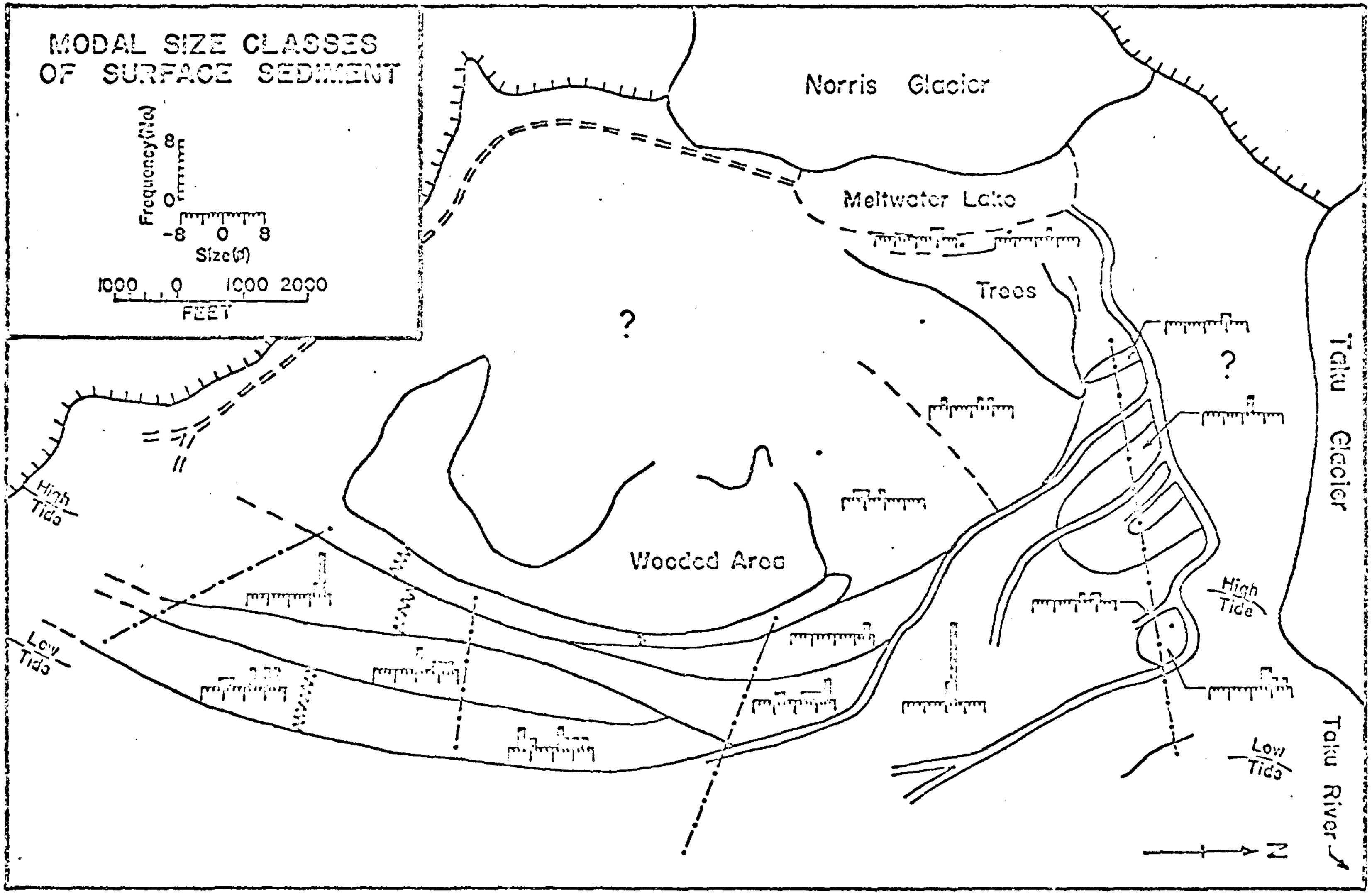


Fig. 8 - Distribution of modal size classes of surface sediment.

of sand and gravel, whereas the sand to the northeast is unimodal. The distribution of modal classes in the area of mud accumulation is somewhat more complex. The amount of sand and/or gravel in these sediments is reflected in the number and size of modal classes present. Of particular interest is the distribution of coarse silt (4 to 5 phi) and fine silt (6 to 7 phi). The gravelly mud, slightly gravelly sandy mud and muddy sandy gravel are found in areas where lesser quantities of fine material are accumulating. In these sediments, both silt modes occur in equal abundance. The slightly gravelly mud and mud, on the other hand, are the products of deposition of relatively larger amounts of suspended sediment, and in these the fine silt mode is dominant. This suggests the bulk of the mud presently being deposited is finer than 6 phi.

The sandy mud near the meltwater lake is a mixture of very fine sand (3 to 4 phi) and coarse silt (4 to 5 phi), while sediment closer to the present shoreline is largely 2 to 3 phi sand. Sandy mud in the two stream distributaries previously described also consists of 3 to 5 phi material whereas the patch of muddy sand adjacent to the easternmost distributary is largely a mixture of 2 to 5 phi particles. This association indicates sediment is being transported and redeposited downstream. The muddy nature of this stream suggests that finer particles are being transported and dispersed into the inlet waters.

MEAN SIZE-SORTING RELATIONSHIP

These polymodal sediments afford an opportunity to examine the mean size-sorting relationship proposed by Folk and Ward (1957). For a bimodal sediment system consisting of river sands and gravels, Folk and Ward found a distinct sinusoidal relationship in which minima (best sorting) corresponded to pure modal classes and maxima (poorest sorting) corresponded to equal mixtures of sand and gravel having an intermediate mean size. Nienaber (1963) found a similar relationship for deltaic and nearshore sediment composed of sand and mud in the Gulf of Mexico.

A plot of mean size versus sorting is shown in Fig. 9; textural class names and modal classes are also shown. It is apparent from the data in Fig. 9 that the size-sorting relationship for these polymodal sediments is considerably more complex than it is for simpler bimodal mixtures. Although more data points are highly desirable, it is believed that several separate sinusoidal trends can be seen in Fig. 9. No single curve may be drawn through all the points. The only way in which a single curve could be drawn would be to split each sample into fractions so that each fraction represented one modal class and then determine the mean size and sorting of each fraction. Following the ideas of Folk and Ward (1957) these fractions could then be related. A theoretical curve predicting the results of such a process is shown in Fig. 10.

In this predicted size-sorting curve, the first sorting maximum represents

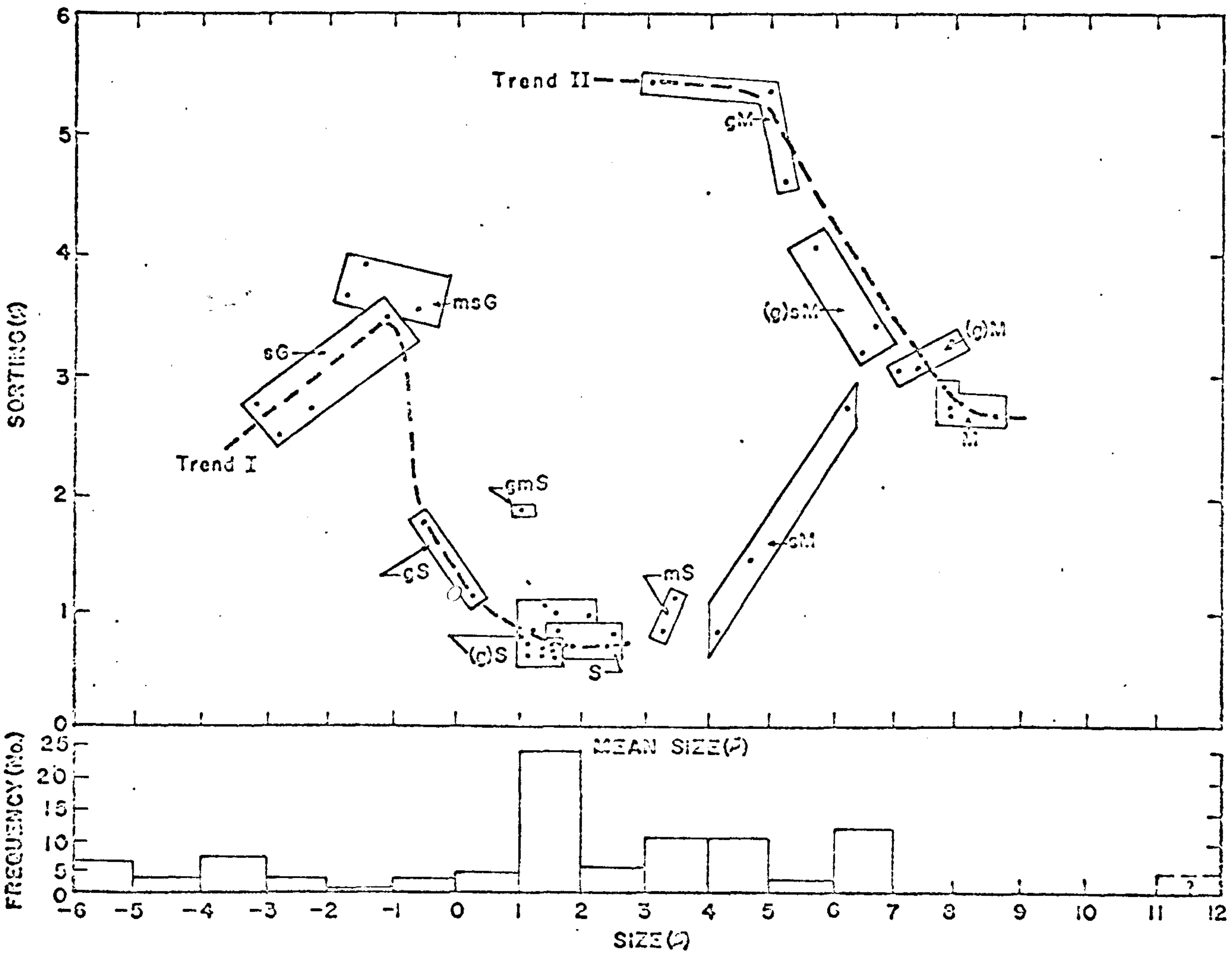


Fig. 9 - Size-sorting relationship of individual samples and textural groups. Frequency of occurrence of modal size classes is also shown.

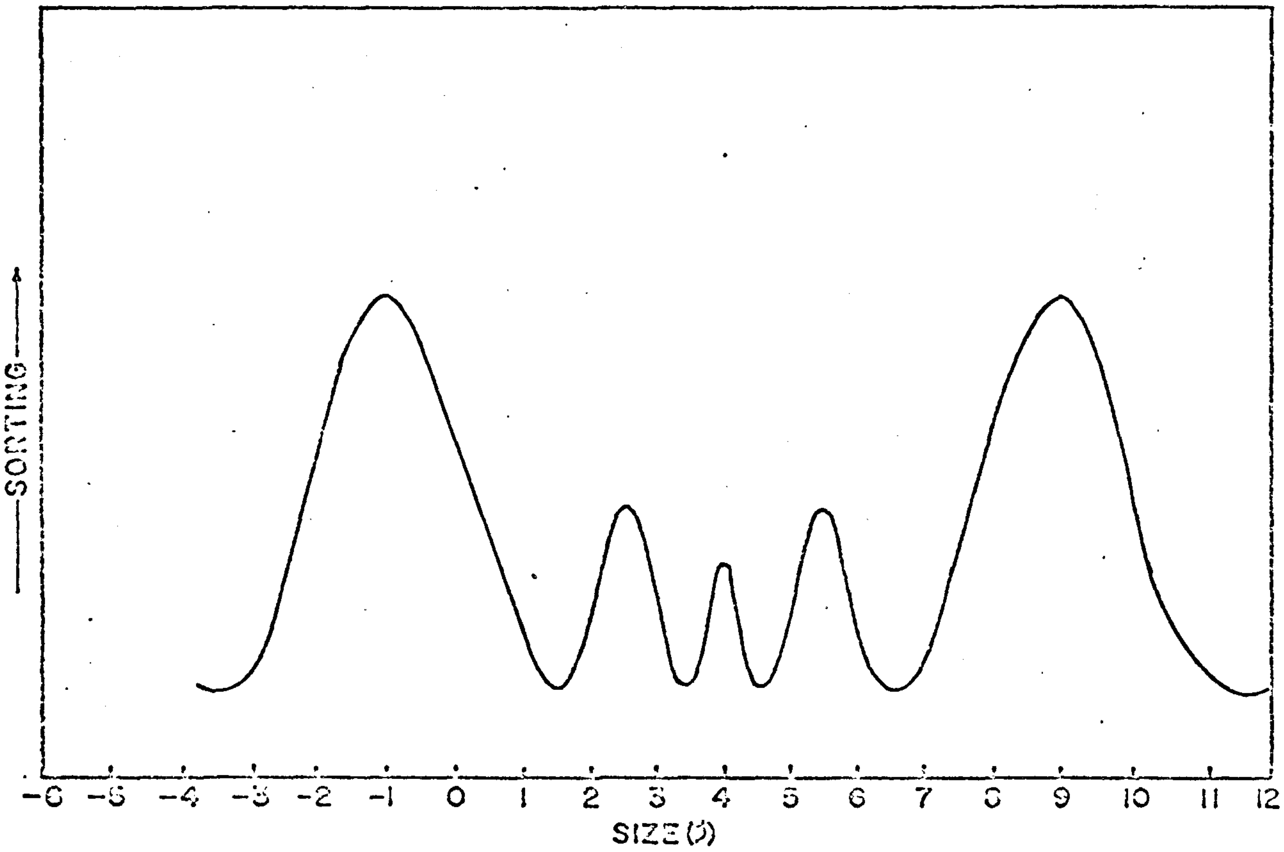


Fig. 10 - Theoretical size-sorting curve for the polymodal sediments.

mixtures of -4 to -3 phi gravel and 1 to 2 phi sand. Since the size range involved is relatively large (4 phi + 2 phi = 6 phi), the sorting of this mixture is poor. The second sorting maximum represents mixtures of 1 to 2 phi and 3 to 4 phi sand. The size range covered by this mixture is 4 phi - 1 phi = 3 phi. The third sorting maximum represents mixtures of 3 to 4 phi sand and 4 to 5 phi silt. Since the size range covered by this mixture is small (5 phi - 3 phi = 2 phi) the sorting maximum will occur at a lower position relative to mixtures covering a wider size range. The fourth sorting maximum represents a mixture of 4 to 5 phi and 6 to 7 phi silt. As the size range for this mixture (7 phi - 4 phi = 3 phi) is the same as that of the sand mixture (4 phi - 1 phi = 3 phi), the sorting maxima are of equivalent magnitude. The last sorting maximum represents a mixture of 6 to 7 phi silt and 11 to 12 (?) phi clay, and because the size range involved here is the same as that for the gravel-sand mixture, the sorting maxima are of equivalent magnitude.

Following this line of reasoning permits an analysis of the data in Fig. 9, in which two trends have been drawn. Trend I clearly shows a sinusoidal relationship between 1 to 2 phi sand and much coarser gravel. The gravel is probably polymodal but since no single mode is known to be dominant, gravel can be considered as representing a single mode. Unimodal sand and slightly gravelly sand exhibit the best sorting and as increasing amounts of gravel are added to this sand, the mean size increases and sorting becomes poorer. At -1 phi a sorting maximum is reached and with further additions of gravel the sorting improves. More gravel samples are needed to accurately define this part of the size-sorting diagram.

Trend II relates mixtures of gravel and mud. For Trend II, sorting becomes progressively better and mean size becomes progressively finer as the gravel content decreases. Gravelly muds contain equal proportions of coarse silt (4 to 5 phi) and fine silt (6 to 7 phi), but in slightly gravelly muds and mud the latter silt mode is dominant. Large amounts of gravel will have a greater effect on sorting than will large amounts of one or the other silt modes in these sediments, thus substantiating the sinusoidal relationship expressed as Trend II. However, muds are considerably displaced from the 6 to 7 phi region, and in fact, the mean size of some of these muds is in the clay-size range (less than 8 phi). This is apparently due to the presence of a third mode (11 to 12 ? phi) in the mud. This group of points (muds) must then represent a maximum of sorting for mixtures of fine silt and clay-size material. The gravel-mud system contains four modal classes (assuming gravel to be unimodal) and thus the size-sorting relationship of this system is actually more complex than that depicted by Trend II. The presence of gravel and clay in these silty sediments has resulted in displacement of points in such a manner as to obscure the relationship between the 4 to 5 phi and 6 to 7 phi silt modal classes. Removal of clay from the muds would increase the sorting and coarsen the mean size, thus shifting the points toward the 6 to 7 phi region while removal of gravel from the gravelly muds would decrease the mean size and increase the sorting so that this group of points would fall somewhere in the 4 to 7 phi region. Only when these lesser modes are absent would a sinusoidal relationship be observed with sorting minima at the 4 to 5 phi and 6 to 7 phi positions and a sorting maximum in an intermediate position.

Any attempt at describing the size-sorting relationship(s) of these polymodal sediments involves fractionation of the samples. This, of course, ruins any attempt at using this relationship as an environmental indicator. From the results found here, it is suggested that great caution be exercised when interpreting the size-sorting relationship(s) of such sediments as the relatively simple trend seen for bimodal sediment is not as pronounced for more complex mixtures.

MINERALOGY

Sand Fraction

Methods. Thirteen samples were chosen for mineralogical analysis of the sand-size fraction (-1 to 4 phi). Of these, five are representative of sand-rich sediments and four each are representative of gravel- and mud-rich sediments. The location of the samples is shown in Fig. 2.

Both light and heavy mineral fractions were studied petrographically. The fractions were separated with Tetrabromomethane (sp. gr. = 2.92). Representative portions of the heavy minerals were mounted on glass slides with Lakeside-70. The light minerals were mixed with Boat-Armor Super Iso-resin which acted as a rigid binder so that thin sections could be prepared. Counts of 300 grains were made on each slide. Point counts were made to give volume percent for the light minerals and number percent for the heavy minerals.

Light Minerals. The light minerals are quartz, feldspar and rock fragments (Appendix C). The feldspars are 4:1 mixture of plagioclase and K-spar. Most of the plagioclase is twinned andesine and oligoclase, but some untwinned plagioclase was also found. The K-spar is almost entirely orthoclase with only trace quantities of microcline. Trace amounts of micropegmatite and perthite were also found. The rock fragments are mainly metamorphic rock fragments and "coarse-grained" fragments. The latter type is consistently more abundant and is composed of feldspar, quartz, micas and/or amphiboles. Gneiss and schist make up most of the metamorphic fragments, but minor amounts of greenschist and /or amphibolite (?) were found. Except for the lack of directional properties, the overall appearance of the "coarse-grained" fragments is so similar to that of the gneissic fragments that probably most, if not all, of of these are of similar nature. Trace amounts of volcanic rock fragments were also found in a few samples.

Individual grains are angular to subangular with the exception of some of the larger rock fragments which are subrounded. The lack of chemical weathering is reflected in the fresh nature of the grains. Approximately one-fourth of the feldspar grains exhibit varying degrees of sericitization, but this feature is undoubtedly inherent to the source rock.

The light-mineral composition is plotted in Fig. 11. The mineralogy of all samples is reasonably consistent with the exception of gravelly sediments which contain a somewhat higher proportion of rock fragments. According to Folk's (1965) classification, these sediments are considered to be Arkoses to Impure Arkoses.

Heavy Minerals. The weight percent of heavy minerals in each of the 13 samples was calculated (Appendix D), and from these figures, average percentages were computed for each of the sediment groups. These values are: sands = 4.5%, gravels = 8.2% and muds = 10.8%.

For descriptive purposes the majority of heavy minerals were placed into three groups: (1) amphiboles and pyroxenes, (2) micas and (3) opaques. The amphiboles and pyroxenes may be treated together as they react in a hydraulically

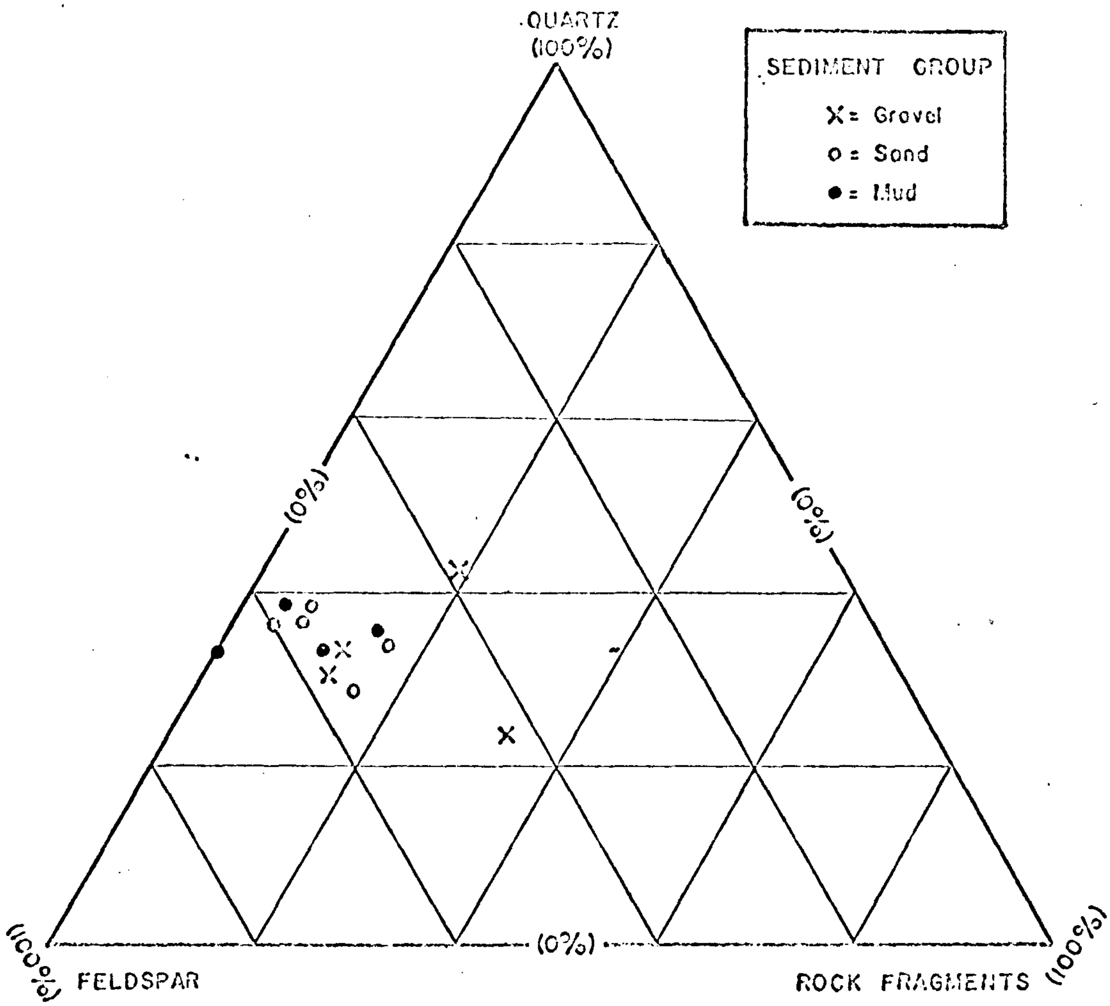


Fig. 11 - Light mineral composition of the sand-size fraction of the sediments.

similar manner compared to the micas and opaque minerals (Rittenhouse, 1943). Of this group, the amphiboles and pyroxenes occur in a 10:1 ratio with green hornblende being the most abundant mineral with considerably smaller amounts of diopside, actinolitic-hornblende and actinolite, and trace quantities of tremolite and hypersthene. The mica group is largely biotite with minor amounts of chlorite and biotite-chlorite. Opaque minerals are largely euhedral to subhedral magnetite grains. Aside from these major components, trace constituents found in the heavy mineral fraction include sphene, garnet, apatite, euhedral zircon, sillimanite, tourmaline (?), epidote and staurolite. The heavy minerals are angular to subangular and show no signs of chemical weathering.

The heavy-mineral composition is plotted in Fig. 12. For this purpose, the trace constituents were omitted and the proportions of amphiboles and pyroxenes, micas and opaques re-calculated on a 100% basis. It is evident that the sandy and gravelly sediments are mineralogically similar. The muddy sediments are mica rich. Two of the four muddy samples analyzed are the bimodal (3 to 4 and 4 to 5 phi) sandy muds previously described, thus suggesting these modes represent concentrations of this mineral group in this size range.

Clay-size Fraction

Methods. Ten samples were chosen for mineralogical analysis of the clay-size fraction (less than 2 micron). Of these, six are representative of muddy sediments in the intertidal zone, two are representative of sandy material bordering the wooded area, and one each is representative of the sandy mud near the melt-

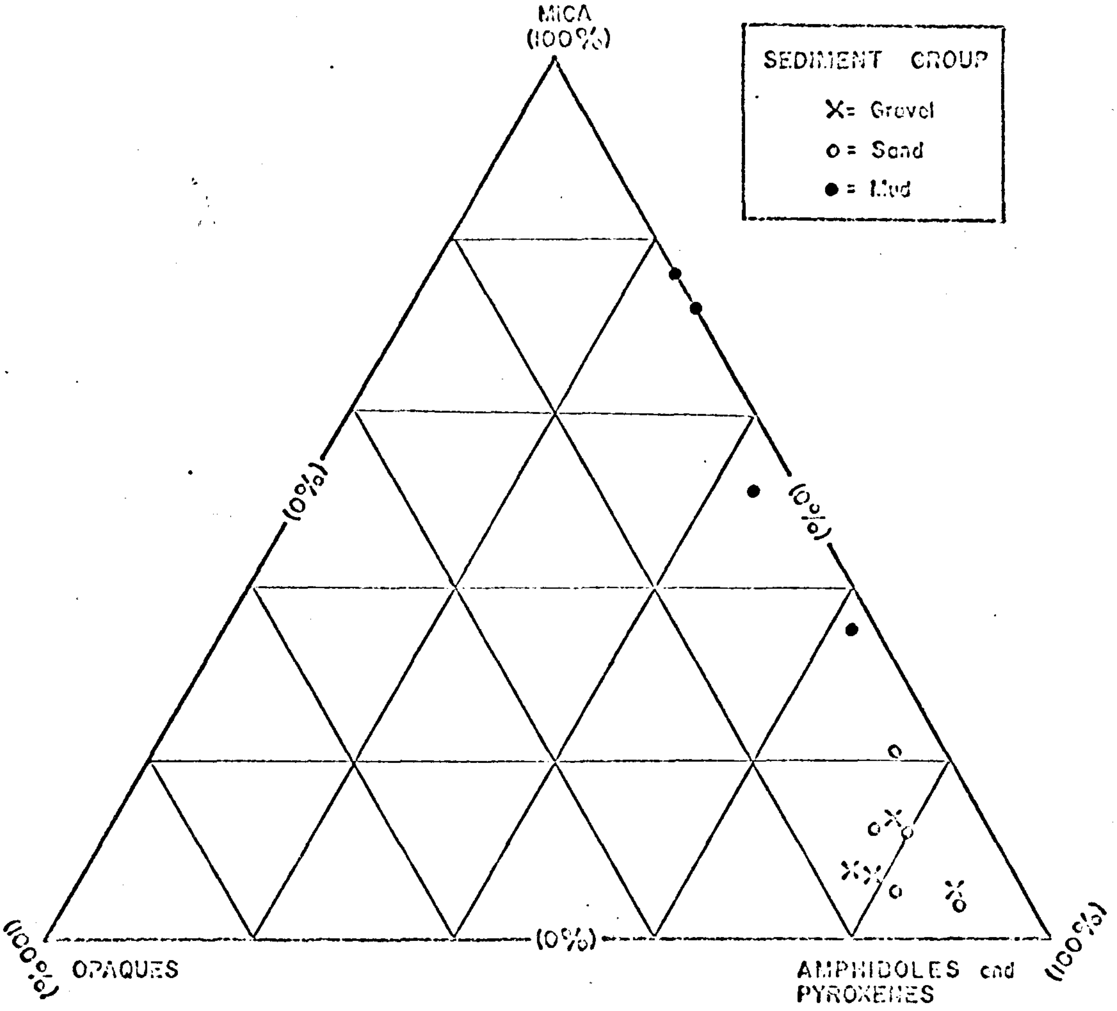


Fig. 12 - Heavy mineral composition of the sand-size fraction of the sediments.

water lake and the gravelly outwash. The location of the samples is shown in Fig. 2.

Each sample was treated with a 20% solution of hydrogen peroxide to remove organic matter, flocculated with IN-magnesium chloride, washed, then dispersed in a 0.25% solution of sodium hexametaphosphate (Calgon) from which 0.2-2.0 and less than 0.2 micron size fractions were extracted by centrifuging. These fractions were then pipetted onto glass slides and air-dried to give oriented aggregates. Mineralogical analysis was accomplished with a Type 12045 Norelco Diffractometer employing Ni-filtered Cu K-alpha radiation. The following four diffraction patterns were run on the two size fractions of every sample: (1) untreated, (2) treated for 12 hours at 60° C in a metal can containing ethylene glycol, (3) heated to 400° C for one hour and (4) heated to 550° C for one hour.

<u>Qualitative Analysis.</u> Mica-clay minerals were identified by a strong 10Å peak that was unaffected by glycolation or heat treatment (Molloy and Kerr, 1961). A weak 5Å peak further distinguishes these as being trioctahedral micas (biotite) (Weaver, 1958). Iron-rich chlorite was identified by strong second and fourth order reflections and weak first and third order reflections on the untreated pattern (Weaver, 1958). The 14Å reflection was unaffected by glycolation. At 400° C the 7Å reflection decreased somewhat in intensity (Hayaski and Oinuma, 1963), and at 550° C this peak was destroyed with a subsequent increase in intensity of the 14Å peak (Martin, 1954, Dixon and Jackson, 1960). Montmorillonite was identified by a first order reflection at 12-15Å which expanded to the 17Å region upon glycolation and collapsed to approximately 10Å upon heating to 400° C (Weaver,

1958). A strong reflection in the 3.2Å region of the untreated pattern was identified as feldspar (Smith, et al., 1959) while a reflection in the 8.4Å region which was unaffected by all treatments was identified as amphibole (Hood, et al., 1966).

Quantitative Analysis. The relative proportions of micas, chlorite and montmorillonite were calculated by a method of peak area ratios modified from Hathaway and Carroll (1954) (Appendix E). Basal peak areas on the glycolated patterns were computed by multiplying the height of the peak above background by the width of the peak at one-half the peak height. Talvenheimo and White (1952) found that equal mixtures of montmorillonite, hydrous mica and kaolinite have a peak area ratio of 5:1:1 and Weaver (1958) implies a 1:1 ratio for mixtures of illite and chlorite. Thus a rough estimate of the relative proportions of montmorillonite, chlorite and micas can be made by using a 5:1:1 peak area ratio. In all cases, the basal peak area of montmorillonite was less than 10% of the total area for the three minerals, so it was divided by five rather than using the Nomograph suggested by Hathaway and Carroll (1954). Individual areas were then added and relative percentages of the three minerals were calculated.

The results of the analysis indicate mica-clays and chlorite occur in a ratio of 5:1, with only trace amounts of montmorillonite being present. Feldspar and amphibole seem to occur only in trace quantities and these are largely confined to the 0.2-2.0 micron size fraction. No quartz was detected in the clay-size material.

DISCUSSION

In the Juneau Ice Field, where Norris and Taku Glaciers originate, bedrock is dominantly crystalline schist with lesser amounts of intrusives and some volcanics (Forbes, 1959). The bulk mineralogy of the bedrock is well represented by the mineral assemblage of sediments in the study area. Bedrock in the upper Taku River Valley in the vicinity of the International Boundary consists largely of volcanics and metasediments (Kerr, 1948). Since such types are not well represented in the sediments it is apparent that significant quantities of sand-size material are not presently being contributed from this area. In the lower Taku River Valley, on the Alaskan side of the Boundary, bedrock is similar to that in the eastern part of the Juneau Ice Field, so it is not possible to determine how much, if any, sediment is being transported from this area. It appears that the majority of the sand-size material is a product of glacial erosion and transportation.

The derivation of the sand is of considerable interest. The dominant modal class of this sand (1 to 2 phi) is also present in Norris Glacier outwash, and the close correlation in sand-size mineralogy between outwash gravel and the sand indicates at least some of this sediment is the product of transportation of outwash by the meltwater stream complex. In a similar manner, some of this sand is probably being contributed from erosion of the moraines flanking the Taku Glacier terminus. The presence of the longer ripples in the sand body and the relatively non-saline nature of the inlet waters suggests the ebb tide may be stronger than the incoming tide, thus sediment from near the Taku Glacier terminus could be transported in a southerly direction. No evaluation may be made as to which of the two sources, Norris Glacier outwash or Taku Glacier morainal material, is the dominant contributor of this sand as no samples were collected from the Taku Glacier terminus. The most significant fact concerning this sand is its relatively well sorted nature, which indicates glacial detritus can be fairly rapidly sorted when subjected to the proper environmental conditions, in this case tidal and/or stream action.

The derivation of the suspended mud in the upper inlet waters presents a similar problem. The turbid nature of the meltwater stream draining Norris Glacier was noted by the writer and Miller (1963) claims that both the Taku River and subglacial streams draining Taku Glacier are mud-laden. Three possible sources for this mud are therefore present. The mud fractions analyzed are largely composed of coarse silt (4 to 5 phi) and fine silt (6 to 7 phi) modal classes with some clay-sized material (11 to 12? phi). In Queen Inlet, Glacier Bay National Monument, these two silt modes are present in glacially derived muds (C.M. Hoskin, personal communication), thus suggesting a glacial origin for much of the mud in upper Taku Inlet. Most of the suspended mud seems to be less than 6 phi in size, as it is this material that is most rapidly being deposited in the depression east of the wooded area. This may imply a slight selective sorting process whereby more of the finer silt and clay is removed by hydraulic action thus leaving a concentration of coarse silt in the glacial detritus. Removal of mud-sized material also represents fairly rapid size sorting of glacial detritus.

With the exception of montmorillonite and quartz, the minerals composing the clay-size fraction of the sediments are common in the sand-size fraction, indicating these minerals are detrital in nature and represent the products of physical abrasion by glacial action. This conclusion has also been reached by Kunze et al. (1966), who describe a similar mineral assemblage of the clay-size fraction of suspended and bottom sediments in Taku Inlet and deposits on the surface of Taku Glacier and in mud flats adjacent to the glacier. Kunze et al. (1966) attribute the montmorillonite to trioctahedral micas that have been stripped of their interlayer potassium.

The apparent lack of quartz in the clay-size fraction represents an anomalous situation. Murray and Leininger (1956), Horberg and Potter (1955) and others have found quartz to be common in the clay-size fraction of tills derived from Pleistocene continental glaciation. Rae and Knowles (1965) found no apparent evidence of quartz in the clay-size fraction of bottom sediments from Glacier Bay National Monument, Alaska. Kunze et al. (1966) found only trace quantities of quartz in the 0.2-2.0 micron fraction of the Taku Inlet sediments described by them, although the sand and silt-size fractions of these sediments were rich in quartz. The most plausible explanation for the lack of significant quantities of quartz, as suggested by Kunze et al. (1966) is that these glaciers simply do not reduce much quartz and feldspar to clay size. The writer feels the differences in physical properties of quartz and feldspar could account for the presence of relatively larger quantities of feldspar in the clay-size fraction. Quartz, which lacks cleavage and has a hardness of 7, should be slightly more resistant to physical abrasion than feldspar, which has good cleavage and a hardness of 6.

CONCLUSIONS

1. Transportational and depositional agents include Norris and Taku Glaciers, subglacial streams, tidal currents and Taku River. The interaction between the availability of different grain size populations and these agents has resulted in a complex distribution of sediments in the Norris Glacier outwash area.

2. The various modal size classes present in these sediments are: (1) gravel, (2) 1 to 2 phi sand, (3) 3 to 4 phi sand, (4) 4 to 5 phi silt, (5) 6 to 7 phi silt and (6) 11 to 12? phi clay. The size-sorting relationship of these sediments is complex due to mixing of these numerous modal classes.

3. Even though the dominant contributor cannot be identified, both Norris Glacier outwash and Taku Glacier morainal material are apparently contributing sediment to the large sand body.

4. Valley glacier detritus can be fairly rapidly sorted when subjected to tidal and/or stream action as evidenced by the nature of the sand and mud.

5. The light mineral assemblage of the sand-size fraction is, in decreasing order of abundance, feldspar, quartz and rock fragments. The heavy mineral assemblage is largely amphiboles and pyroxenes (dominantly green hornblende), with lesser amounts of micas (dominantly biotite) and opaques. These minerals are the product of glacial abrasion of bedrock in the Juneau Ice Field.

6. Clay-size minerals in these sediments are largely micas (biotite) with lesser amounts of chlorite and trace quantities of montmorillonite, feldspar and

amphibole. These minerals are the product of glacial abrasion.

7. These valley glaciers are apparently not reducing significant amounts of quartz or feldspar to clay-size particles. The apparent absence of quartz and presence of feldspar in this size range may be due to the slightly greater resistance of quartz to physical abrasion.

8. Although the present study involves valley glacier detritus from only one area, some of the characteristics found here may possibly be diagnostic of Recent valley glacier sediment. These characteristics include: (1) extreme polymodality, (2) angular, unweathered sand-size grains, (3) detrital clay-size particles and (4) insignificant quantities of quartz and feldspar in the clay-size fraction.

REFERENCES

Department of Commerce, 1966, Tide Tables, West Coast North and South America: U.S. Government Printing Office, Washington, D.C., 224 p.

Dixon, J.B., and Jackson, M.L., 1960, Mineralogical analysis of soil clays involving vermiculite-chlorite-kaolinite differentiation: Clays and Clay Minerals, v. 8, p. 274-285.

Field, W.O., 1954, Notes on the advance of Taku Glacier: In: Heusser, C.J., et al., 1954, Geobotanical studies of the Taku Glacier anomaly: Geog. Rev., v. 44, p. 224-239.

Folk, R.L., 1954, The distinction between grain size and mineral composition in sedimentary rock nomenclature: Jour. Geology, v. 62, p. 344-359.

__________, 1965, Petrology of Sedimentary Rocks: Hemphills, Austin, Texas, 159 p.

Folk, R.L., and Ward, W.C., 1957, Brazos River bar: A study in the significance of grain size parameters: Jour. Sedimentary Petrology, v. 27, p. 3-26.

Forbes, R.B., 1959, The geology and petrology of the Juneau Ice Field area, Southeastern Alaska: Unpublished PhD. dissertation, Univ. Washington, 259 p.

Hathaway, J.C., and Carroll, D., 1954, Distribution of clay minerals and ion-exchange capacity in some sedimentary materials: Clays and Clay Minerals, NAS-NRC publ. 327, p. 264-276.

Hayashi, H., and Oinuma, K., 1963, X-ray and infrared studies on the behaviours of clay minerals on heating: Clay Science, v. 1, No. 6, p. 8-28.

Heusser, C.J., 1952, Pollen profiles from Southeastern Alaska: Ecol. Mono., v. 22, p. 221-352.

__________, 1954, Additional pollen profiles from Southeastern Alaska: Amer. Jour. Sci., v. 252, p. 106-119.

Hood, D.W., Knowles, L.I., and Burrell, D., 1966, Ecological implications of clay-metal associations in aquatic environments: AEC Contract AT(04-3) -310, June 1965-Jan. 1966 Progress Report, Univ. of Alaska Institute of Marine Science, 35 p.

Horberg, L., and Potter, P. E., 1955, Stratigraphic and sedimentologic aspects of the Lemont Drift of Northeastern Illinois: Illinois Geol. Survey, Rept. Inv. 185, 23 p.

Jordan, G. F., 1962, Redistribution of sediments in Alaskan bays and inlets: Geog. Rev., v. 52, p. 548-558.

Kerr, F.A., 1948, Taku River Map-Area, British Columbia: Canadian Department of Mines and Resources, Geol. Survey Memoir 248, 84 p.

Kunze, G.W., Knowles, L.I., and Kitano, Y., 1966, The distribution and mineralogy of clay minerals in the Taku Estuary of Southeast Alaska: mimeographed pre-print distributed at the 11th Pacific Science Congress, Tokyo, Japan, Sept. 1966, 8 p.

Lawrence, D.B., 1950, Glacier fluctuation for six centuries in Southeastern Alaska and its relation to solar activity: Geog. Rev., v. 40, p. 191-223.

Martin, R.T., 1955, Reference chlorite characterization for chlorite identification in soil clays: Clays and Clay Minerals, NAS-NRC publ. 395, p. 117-145.

Miller, M.M., 1963, Taku Glacier evaluation study: State of Alaska Department of Highways, 200 p.

Molloy, M.W., and Kerr, P.F., 1961, Diffractometer patterns of A.P.I., reference clay minerals: Amer. Mineralogist, v. 46, p. 583-605.

Murray, H.H., and Leininger, R.K., 1956, Effect of weathering on clay minerals: Clays and Clay Minerals, NAS-NRC publ. 456, p. 340-347.

Nienaber, J.H., 1963, Shallow marine sediments offshore from the Brazos River, Texas: In: Publications of the Institute of Marine Science, Univ. of Texas, v. 9, p. 311-372.

Rae, K.M., and Knowles, L.I., 1965, Ecological implications of clay-metal associations in aquatic environments: AEC Contract AT(04-3)-310, March 1964-April 1965 Progress Report, Univ. of Alaska Institute of Marine Science, 32 p.

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

Smith, J.V., et al., 1959, X-ray powder data file, ninth set: Amer. Soc. Testing Materials Publ. No. 48-H, Philadelphia, Pa.

Talvenheimo, G., and White, J.L., 1952, Quantitative analysis of clay minerals with the x-ray spectrometer: Analytical Chem., v. 24, p. 1784-1789.

Weaver, 1958, Geologic interpretation of argillaceous sediments, Part I, Origin and significance of clay minerals in sedimentary rocks: Bull. Amer. Assoc. Petrol. Geol., v. 42, p. 254-271.

Wentworth, C.K., and Ray, L.L., 1936, Studies of certain Alaskan glaciers in 1931: Geol. Soc. America Bull., v. 47, p. 879-934.

APPENDIX A

PHYSICAL DATA OF THE SEDIMENTS

Sample			Weight %						Normalized	Text.
No.	Gravel	Sand	Mud	Silt	Clay	Mean Size	Sorting	Skewness	Kurtosis	Class
1	0.3	99.4	0.3			1.01	0.62	+0.06	0.52	(g)S
2	0.1	98.3	1.6			1.44	0.69	-0.08	0.56	(g)S
3	0.3	99.6	0.1			1.34	0.68	-0.11	0.51	(g)S
4	0.4	98.2	1.4			1.51	0.58	-0.11	0.54	(g)S
5	0	31.5		64.9	3.6	4.63	1.39	+0.33	0.54	sM
6	60.0	33.1		6.5	0.4	-1.71	3.49	+0.71	0.35	msG
7	74.8	24.8	0.4			-2.95	2.38	+0.43	0.43	sG
8	0	95.5	4.5			2.31	0.72	+0.19	0.55	S
9	0	3.0		59.1	37.9	8.07	2.62	+0.37	0.51	M
10	3.1	4.6		65.6	26.7	6.93	2.81	+0.22	0.59	(g)M
11	0.2	5.5		59.9	34.4	7.46	2.91	+0.29	0.51	(g)M
12	9.2	81.5		5.9	3.5	1.01	1.75	+0.13	0.80	gmS
13	0	1.1		47.8	51.1	8.64	2.56	+0.31	0.47	M
13A*	64.5	32.2	3.4			-2.45	2.59	+0.35	0.36	sG
14	0	1.2		61.3	37.5	7.85	2.59	+0.33	0.51	M
15	0	1.0		61.8	37.2	7.86	2.55	+0.38	0.51	M
16	15.6	20.3		35.9	28.2	5.03	5.14	-0.23	0.48	gM
17	22.1	30.5		29.0	18.4	3.05	5.21	+0.05	0.48	gM
18	0.4	17.5		54.0	28.1	6.73	3.28	+0.19	0.39	(g)sM
19	0	4.4		58.0	37.7	7.72	2.81	+0.30	0.49	M
19A*	5.9	29.8		38.8	25.5	5.14	4.41	+0.11	0.47	gM
20	66.6	31.7	1.7			-2.38	2.50	+0.20	0.43	sG
21	3.2	5.4		53.1	38.4	7.82	3.13	+0.17	0.61	(g)M
22	2.0	14.0		62.5	21.6	6.32	3.03	+0.18	0.61	(g)sM

APPENDIX A (cont'd.)

PHYSICAL DATA OF THE SEDIMENTS

Sample	Weight %								Normalized	Text.
No.	Gravel	Sand	Mud	Silt	Clay	Mean Size	Sorting	Skewness	Kurtosis	Class
22A*	26.5	69.6		3.1	0.8	-0.53	1.71	-0.37	0.56	gS
23	2.9	30.3		42.0	24.9	5.64	3.87	-0.03	0.48	(g)sM
24	53.4	35.5		6.7	4.4	-1.43	3.78	+0.29	0.46	smG
24A*	74.0	24.5	1.6			-3.32	2.64	+0.73	0.38	sG
25	47.1	45.8		5.9	1.3	-0.66	3.42	-0.11	0.39	msG
26	0.3	95.1	4.5			1.16	0.84	-0.02	0.58	(g)S
27	0.3	98.5	1.2			1.44	0.67	-0.09	0.51	(g)S
28	0.5	98.9	0.7			1.31	0.67	-0.15	0.51	(g)S
29	0	99.1	0.9			1.38	0.52	-0.08	0.53	S
30	2.0	95.2	2.9			2.10	0.93	-0.08	0.55	(g)S
31	3.6	95.8	0.6			1.33	1.02	-0.17	0.53	(g)S
32	0	45.3		53.8	0.9	4.04	0.70	-0.02	0.55	sM
33	0.7	98.9	0.5			1.05	0.69	+0.05	0.55	(g)S
34	0	97.2	2.8			1.66	0.66	+0.17	0.59	S
35	10.1	88.6	1.3			0.29	1.07	-0.16	0.62	gS
36	45.5	49.9		4.0	0.6	-1.04	3.40	-0.19	0.35	sG
37	0	97.9	2.1			1.53	0.80	+0.12	0.53	S
38	2.0	96.4	1.7			1.63	0.98	-0.12	0.54	(g)S
39	0	11.6		59.4	29.0	6.23	2.62	+0.42	0.55	sM
40	0	81.9		17.4	0.7	3.27	0.77	-0.02	0.46	mS
41	0	74.8		22.2	3.0	3.46	1.06	+0.55	0.60	mS

* sub-surface

APPENDIX B

DISTRIBUTION OF MODAL SIZE CLASSES

Sample	Modal Classes												
No.	-6 to -5	-5 to -4	-4 to -3	-3 to -2	-2 to -1	-1 to 0	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7
1							x						
2								x					
3								x					
4								x					
5										x	x		
6	x							x		x			
7	x	x	x			x							
8								x					
9													x
10				x								x	
11										x			x
12				x							x		
13													x
13A	x		x				x						
14													x
15												x	
16			x					x			x		x
17		x		x				x			x		x
18								x			x		x
19								x					x
19A				x				x		x	x		
20	x		x				x						
21			x					x	x		x		x
22								x		x		x	

APPENDIX B (cont'd.)

DISTRIBUTION OF MODAL SIZE CLASSES

Sample	Modal Classes												
No.	-6 to -5	-5 to -4	-4 to -3	-3 to -2	-2 to -1	-1 to 0	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7
22A			x			x	x				x		
23								x			x		x
24	x		x					x			x		x
25	x							x	x				
26								x					
27								x					
28								x					
29								x					
30									x				
31								x					
32										x	x		
33							x						
34								x					
35			x		x		x						
36	x		x			x		x		x			
37								x					
38								x					
39								x		x	x		
40									x	x			
41									x	x	x		x

APPENDIX C

MINERALOGY OF SAND-SIZE FRACTION-LIGHT MINERALS
(Percentages based on 100% for light minerals)

Sample No.	% of Sand-size Fraction	Quartz	Orthoclase	Microcline	Plagioclase	Undifferentiated Feldspar	Perthite	Micropegmatite	Coarse Rock Fragments	Gneiss	Schist	Volcanics	Greenschist/ Amphibolite (?)
3	94.6	36.7	5.0	-	25.4	25.3	-	0.3	6.3	0.3	0.3	0.3	-
5	85.1	33.0	7.3	0.3	22.6	36.7	-	-	-	-	-	-	-
6	94.4	33.2	3.5	1.0	39.0	33.3	-	-	11.0	0.3	-	-	-
7	93.3	23.4	3.9	0.3	29.0	9.7	-	-	23.7	5.5	3.2	0.6	0.6
8	95.9	36.5	6.4	0.3	31.1	21.7	-	-	3.0	1.0	-	-	-
12	95.0	28.2	4.3	0.3	31.3	18.7	-	1.0	10.7	3.0	1.3	0.7	0.3
18	91.7	33.8	13.4	-	30.9	11.0	0.3	0.3	4.3	3.0	2.7	0.3	-
22	91.2	35.4	10.3	1.3	25.8	10.9	0.3	0.3	7.9	5.3	1.3	0.7	-
25	88.5	42.4	1.3	0.6	18.3	17.7	0.3	0.3	10.1	3.2	3.8	1.6	0.3
27	95.4	37.0	9.3	0.3	30.5	15.8	-	-	4.8	1.3	0.6	0.3	-
33	96.7	33.0	6.7	0.6	31.7	10.7	0.3	0.3	11.3	2.0	1.7	0.7	0.7
36	91.1	30.5	8.9	0.7	33.8	13.9	-	-	8.3	1.6	0.7	1.7	-
39	88.7	37.6	2.0	-	27.2	28.8	-	0.3	3.9	-	-	0.3	-

APPENDIX D

MINERALOGY OF SAND-SIZE FRACTION-HEAVY MINERALS

(Percentages based on 100% for heavy minerals)

Sample No.	% of Sand-size Fraction	Hornblende	Diopside	Actinolite	Actinolitic-Hornblende	Tremolite	Hypersthene	Biotite	Chlorite	Biotite-Chlorite
3	5.4	58.7	7.3	1.0	4.0	0.7	-	8.6	1.3	1.0
5	14.9	20.3	1.0	1.0	1.0	0.3	0.3	68.7	5.6	-
6	5.6	66.4	8.0	1.6	1.6	-	0.6	4.5	0.6	-
7	6.7	55.8	10.6	-	2.0	-	1.7	6.6	-	-
8	4.1	64.6	8.9	3.6	1.7	-	-	3.3	-	-
12	5.0	63.0	6.3	0.7	0.3	0.7	-	3.3	1.7	-
18	8.3	40.5	6.4	4.8	5.4	0.3	0.6	28.7	4.5	0.3
22	8.8	26.8	6.5	2.3	3.9	1.6	0.3	43.2	4.5	0.3
25	11.5	53.7	8.0	3.3	1.3	-	0.7	6.3	1.0	-
27	4.6	55.6	8.3	0.7	1.7	-	0.7	10.3	1.0	0.3
33	3.3	59.0	5.4	0.9	2.5	-	0.3	12.3	2.2	3.8
36	8.9	60.1	4.3	1.7	4.7	-	0.3	11.6	1.0	-
39	11.3	24.4	0.6	0.3	0.3	0.9	0.3	66.4	1.8	1.8

APPENDIX D (cont'd.)

MINERALOGY OF SAND-SIZE FRACTION-HEAVY MINERALS
(Percentages based on 100% for heavy minerals)

Sample No.	Opaques	Sphene	Garnet	Apatite	Zircon	Sillimanite	Tourmaline (?)	Epidote	Staurolite	Unidentified
3	8.3	2.0	1.0	8.7	0.3	-	-	0.3	0.3	4.3
5	-	0.3	-	-	-	0.3	-	-	-	1.0
6	6.1	2.9	0.6	1.0	1.3	0.3	-	0.6	-	3.8
7	12.9	1.7	1.7	-	0.3	-	-	-	-	5.3
8	7.3	3.0	0.3	1.3	0.7	1.3	-	-	-	3.9
12	11.7	2.0	3.7	1.0	0.3	0.3	-	0.3	-	4.6
18	2.2	1.6	-	1.3	-	-	-	-	-	3.2
22	4.2	1.0	0.3	0.3	-	0.3	-	-	-	4.5
25	14.3	3.3	1.0	0.7	0.3	-	0.6	-	0.3	5.0
27	11.0	3.0	1.3	0.7	-	-	-	0.3	-	5.0
33	6.0	1.6	0.6	0.6	-	-	-	-	-	4.7
36	8.3	1.7	0.7	0.7	0.7	0.7	1.6	-	-	2.0
39	0.3	-	-	1.8	-	-	-	-	-	0.9

APPENDIX E

PERCENTAGES OF MICAS, CHLORITE AND MONTMORILLONITE IN THE CLAY-SIZE FRACTION

Sample No.	Size Fraction (microns)	% of Total Peak Area		
		Mica	Chlorite	Montmorillonite
5	(0.2-2)	91	9	-
6	(0.2-2)	58	42	-
8	(0.2-2)	88	12	Tr
9	(0-0.2)	83	17	-
	(0.2-2)	83	15	2
12	(0-0.2)	81	19	Tr
	(0.2-2)	75	25	Tr
14	(0-0.2)	82	18	-
	(0.2-2)	89	10	Tr
16	(0-0.2)	84	16	Tr
	(0.2-2)	88	12	Tr
21	(0-0.2)	88	12	-
	(0.2-2)	86	14	-
23	(0-0.2)	69	31	-
	(0.2-2)	80	19	1
39	(0-0.2)	87	13	Tr
	(0.2-2)	86	12	2