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BOTTOM SAMPLES AS TAKEN BY THE HYDROGRAPHER AND THE GEOLOGIST

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INTRODUCTION

Over the past two decades, the hydrographer and the geologist have worked closely together on mutual operations on the Polar Continental Shelf Project in the Arctic ocean and adjacent channels to the east; hydrographers have provided bathymetric data, and the geologist the description of the sea bed. At the Bedford Institute of Oceanography in Dartmouth, Nova Scotia, geologists received bottom samples collected by the hydrographer from many marine areas in Canada, and from this sampling, laboratory work was undertaken and geological reports written. Soon hydrographers and geologists worked together on the interpretation of the sea bottom from an examination of the sounding records and a laboratory analysis of the samples. The results are superior charts of the sea bed.

In the matter of application, both groups of workers have made invaluable contributions to many projects. They have carried out site surveys to assist the following operations : (1) laying pipes and cables; (2) investigation of shipping routes and harbour sites; (3) environmental monitoring such as dredging and filling; (4) engineering works such as dams, coastal processes and installations; (5) offshore drilling; and (6) offshore fisheries. Other combined operations deal with resources programs in the offshore areas. These include the multiparameter surveys involving magnetic, gravimetric, bathymetric and geologic observations. In the research field, both disciplines have an intense interest in sonic (echo-sounding and side-scan sonar) and seismic (high-resolution) surveying.

Although hydrographers and geologists commonly combine their efforts on bottom-sampling operations, neither may see the sediment deposit in the same light, nor collect it in the same manner. They may not even obtain the same representation of the sea floor. Just as inconsistent is the practice of using descriptive qualifiers to represent the sample. For these reasons a set of recommendations is here given to serve as a guideline to eliminate the discrepancies in results due to the differing technologies of sampling.

Shallow, reflection-seismic profiling carried out by the geologist satisfactorily complements the work of the hydrographer. A mutual understanding is easily reached because the language of the work is basically that of physics, and its units have universal application. The multiparameter survey of the geologist and the geophysicist demands awareness of the hydrographer's appreciation of navigation, positioning devices and systems, and bathymetry and sounding technology. To a great extent there is mutual understanding of each group's work; it is mainly in the application of the acquired data that the hydrographer and the geologist may pursue their separate goals.

Bottom-sampling, however, is the subject of this paper. It is prepared for the hydrographer unfamiliar with sedimentological principles. Some background on sedimentary sizes, principles of sedimentation, terminology and laboratory practices is given. Illustrative material has been selected to demonstrate and illuminate these concepts, and arguments and case histories are presented throughout the text as additional support for the recommendations.

SAMPLING

Sampling operations can be considered under four major headings as follows : (1) sampling interval; (2) equipment; (3) description; and (4) cataloguing.

Sampling intervals are generally inconsistent with respect to line-spacing and numbers of samples per line, not only from area to area but commonly within the general survey area. For surveys over unknown sea bottom, a grid pattern is usually selected that can be sampled at regular intervals according to the time alloted to the survey. Hydrographers will sample additionally when it is necessary to have some indications of the nature of the sea floor, particularly in the search for anchorage. They may also sample shoals and banks to determine if rocky sea bottoms occur in those areas.

Geologists may sample for the same reason as hydrographers but, additionally, will seek to discover everything of geologic interest in the ship-time alloted. A grid pattern of sampling over uniform subsea terrain may yield to one based on changing topographic features of the sea bottom. Hydrographers follow this practice as well in the case of shoals in coastal areas, or with pingos such as in the Beaufort Sea, and commonly carry out a shoal examination. Where the sea-bed material changes quickly from area to area, the geologist must accelerate the sampling rate or lose comprehension of the nature of the sea bed. An area of intense economic or scientific interest will also dictate further sampling. The same is true for unknown areas as they offer scientific curiosity as an impetus for increased sampling.

No rigid precepts exist for the purpose of designing either grid or line spacing on a sampling pattern. In the deep-water areas of the oceans, or in the central portions of inland seas (Hudson Bay, for example) where hydrodynamic vigour is not extreme, sampling at 15 to 20 km intervals, or somewhat greater, is reasonable. Across the relatively hydrodynamically quiet Beaufort Sea shelf, an interval of 5 km seemed sufficient. Over the Scotian shelf, where considerably more energy is present to move sediments, about a 2 to 3 km spacing was adequate. In coastal, estuarine and beach zones the sampling interval generally varies from a few metres to several hundred metres. Commonly the interval is related to the scale of the charting. For example, a chart with a scale of 1:500 000 would require half the number of samples of a chart at a scale of 1:250 000.

In sampling operations the hydrographer generally uses the tallow-armed sounding lead because it gives an indication of the type of bottom in the survey area. Because of its size and construction, it is ideal for obtaining a small representative sample of the sea floor, where the latter is covered with fine-grained sediments. It is incapable of returning large particles or samples of bedrock. Under-way samplers were used a few years ago (and still are in some areas), but again these were unsuitable for sampling in areas covered with coarse material, or characterized by exposed bedrock. But these devices were ideal for confirming, over wide areas, the nature of the sediment surveyed by sonic methods such as the echo-sounder, side-scan sonar and seismic reflection profiler.

For more complete sampling the geologists use a variety of equipment : the bottom grab; a variety of trawl dredges, particularly in areas of bedrock; coring devices such as the gravity, piston and vibro corers, for obtaining samples of unconsolidated sediments through thicknesses of 20 m or so; various diamond drills, operated from submersible, ship or free-standing platform, for sampling bedrock either exposed or covered by less than 6 or 7m of unconsolidated sediment; and the heavy duty rotary drill used by oil companies (and *Glomar Challenger*), from seaborne drilling rigs and ships, to obtain well flushings (rock chips) and bedrock cores from hundreds of metres below the sea bed.

This variety of equipment would be difficult for any hydrographic vessel to handle, particularly the large drills and corers, but the smaller apparatus could be put on board and used by the hydrographer. A geologist should accompany the hydrographer but, if this arrangement is not possible, the hydrographer could be trained to handle the equipment and catalogue the sample. On some vessels, the crew could probably carry out the sampling under the direction of the hydrographer-in-charge.

Description of the sample should follow a basic format prepared and submitted in advance of the cruise. Such common items as type of sample, amount of sample, colour, sediment type, presence of pebbles or boulders, bedrock type, shape of fragments, sizes, etc., could be listed and serve as a check. Cruise information should also be given and should include : ship's name, survey area, date, time, position, depth, etc. This is generally information recorded in the ship's log, and the notes should be checked with that source.

Cataloguing of the sample is not heavy work but it is most important and should be done immediately upon completion of the sampling operation. The sample number is entered both in the sample log and on the sample container itself. It is sometimes entered in the ship's log. The information must include the number of the sample (sometimes the ship's station), the cruise number and name of the vessel, and the year. Depth is often included as it serves as a quick reference in the case of a misplaced sample. All samples should be packed and crated for shipment to the required address.

Some samples need special care such as storing in non-metallic containers, or maintaining them at a constant cool or freezing temperature, or perhaps preserving them with special chemical reagents. Instructions must obviously be given in these instances.

GRADE SCALES, UNITS AND TERMINOLOGY

A grade scale is merely an arbitrary division of continuous sizes designed to classify the sediment particles according to standard groups, or classes, of sizes for the purposes of description and analysis. One of the first scales was introduced by J. UDDEN in 1898 (see KRUMBEIN and PETTIJOHN, 1938), and was based on a geometric progression of sizes as follows (in mm.) : ...64, 32, 16, 8, 4, 2, 1, ½, ¼, 1/8, 1/16, 1/32, 1/64..., etc.

Other grade scales adopted for use with mechanically analysed sediments, such as those analysed by sieves and direct measurement, involve some geometric progression in the sizes selected as class intervals. Some grade scales were based on fall velocities of the particles in water, and these eventually were determined to have geometric progressions. Because the settling velocity varies as the size of the diameter, a direct comparison to size could be made.

Regardless of which grade scale is used, the importance of unequal intervals based on a geometric progression must be realized. If the interval of 0.001 mm is used in arithmetic progression to classify the fine-grained sediments such as clay, only a few classes would be required to describe the size distribution. However, if this same interval and progression is used to describe sands, pebbles and eventually boulders, more than one million class intervals would be involved. The same range of sizes may be covered by 20 to 25 classes in a grade scale using a given geometric progression such as UDDEN's. Grade scales are important additionally because they give an objective measure of comparison so that, with agreement, all workers may discuss the sediment in the same reference framework.

Table 1 (also fig. 1) illustrates an abbreviated example of the modern grade scale used by many geologists in Europe and North America, in fact, internationally. It is based on the $-\log_2$ progression of UDDEN, and gives the descriptive names generally agreed upon for most classes of sediments. Because the class intervals involve fractions (or decimals) the phi scale (Φ) was introduced by W.C. KRUMBEIN (see table 1, and fig. 1) for the sake of simplicity in representing and calculating the data. A simple log transformation or a nomograph will quickly convert the phi values to equivalent millimetres. The phi scale also offers a universal and objective system for the description and comparison of sediment particles.

TABLE 1
Grade scales and terminology

Modified after Udden and Wentworth			$\phi = -\log_2$ mm	mm	microns (μ)	Practical class limits (mm)
GRAVEL	BOULDERS		– 8	256	256 000	256
GRAVEL			– 7	128	128 000	128
GRAVEL	COBBLES		– 6	64	64 000	64
GRAVEL			– 5	32	32 000	32
GRAVEL			– 4	16	16 000	16
GRAVEL			– 3	8	8 000	8
GRAVEL	PEBBLES		– 2	4	4 000	4
GRAVEL	GRANULES		– 1	2	2 000	2
SAND	Very coarse		0	1	1 000	1
SAND	Coarse		1	1/2	500	0.5
SAND	Medium		2	1/4	250	0.25
SAND	Fine		3	1/8	125	0.125
SAND	Very fine		4	1/16	62.5	0.062
MUD	SILT	Coarse	5	1/32	31.3	0.031
MUD	SILT	Medium	6	1/64	15.6	0.016
MUD	SILT	Fine	7	1/128	7.8	0.008
MUD	SILT	Very fine	8	1/256	3.9	0.004
MUD	CLAY	Coarse	9	1/512	1.95	0.002
MUD	CLAY	Medium	10	1/1024	0.98	0.001
MUD	CLAY	Fine	11	1/2048	0.49	0.0005
MUD	CLAY	Very fine	12	1/4096	0.24	0.0002
MUD	COLLOID					

By using such grade scales — based on common metric units — and their accompanying terminology it is possible to eliminate the subjective comparisons shown in Table 2. In this list, the striking anomaly in the presentation lies in the fact that such diverse items as hens' eggs, walnuts, hazel nuts, peas, etc., supposedly representing sediment sizes, have their erosional velocities recorded to the third decimal place. The use of descriptive grade scales of this nature should be avoided.

The terminology applied to aggregates, or types of sediment, is shown in Table 1. It is the simplest and most widely used by sedimentologists, although differences may arise in the designation of the subdivisions. For example, some workers place the lower limit of silt at 0.004 mm, and others at 0.002 mm. Some geologists define everything finer than sand (0.062 mm) as mud, and make no further distinction of the grades in this major class of sediments. Agreement among workers is the important point, but commonly this is more difficult to achieve than an understanding of the system itself.

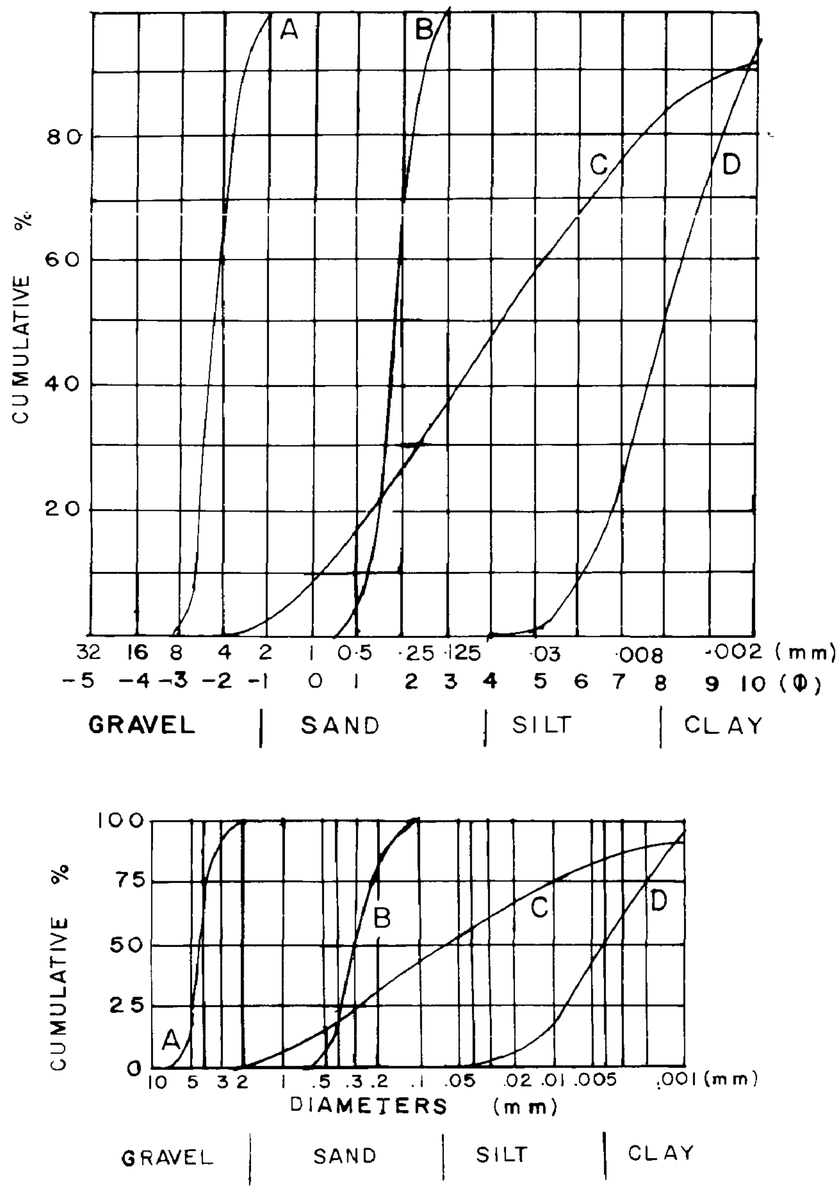

FIG. 1. — Comparison graphs of grade scales and cumulative frequency curves. The upper panel shows the millimetre (mm) and phi (Φ) scales subdivided into equal, arithmetic units; the lower panel shows the scales in logarithmic intervals. Generally the lower panel (the semi-logarithmic graph) is used. Curves A to D represent the *distribution of grain sizes in the following sediments :*
A — beach gravel; B — beach sand; C — glacial till; and D — marine clay.

TABLE 2

Current velocities required to start particle movement
(Table modified from TWENHOFEL, 1950, p. 209)

A. *Stream bed covered with fine sediment*	m/sec
Under current action only, no movement with bottom velocity	0.694
After stirring:	
Bran-size particles moved at bottom velocity	0.897
Hazel nut-size particles moved at bottom velocity	0.923
Walnut-size particles moved at bottom velocity	1.062
Pigeon egg-size particles moved at	0.923
B. *No sediment on stream bed*	
Smallest particles moved at bottom velocity	1.180
Pea and Hazel nut-size particles moved at bottom velocity ..	1.247
Walnut-size particles moved at bottom velocity	1.476
1 000-gram particles moved at bottom velocity	1.589
C. *General movement of pebbles*	
To size of pigeon egg at	1.800
To size of chicken egg at	1.717
Particles of less than 2 500 grams at	1.800
All particles move at	2.063

Another important aspect of aggregate terminology is that of quantity. For example, how much of a given sediment type (such as sand) should constitute the sample? Should it be 100%, 90%, 75%, 50% or at least one-third? There is no general rule, and therefore a variety of classifications is in use. The same problem exists in the classification of gravels, silts, clays and muds.

If a three-fold terminology is used, such as gravel-sand-mud or sand-silt-clay, then ternary (triangular) diagrams may be constructed and the mechanical composition of the sediments plotted in them (figs. 2 and 3). These are essentially equilateral triangles subdivided into equal percentage intervals. In the ternary diagram (fig. 2A) describing gravel-sand-mud, the apices represent 100% gravel, sand and mud respectively. If the sediment contains two types, sand and gravel for example, then the composition of the sediment will plot along the sand-gravel border. If mud is also present, then the position of the sediment will be in the interior of the diagram. Percentages are plotted along an orthogonal bisectrix from the apex to the opposite side, with the apex at 100 % and the side at 0 %. This procedure is followed for each sediment type, and the point of intersection of the three represents the position of the sample in that diagram. This will place the sample in a given compositional field relative to other samples. The result is most useful in deducing the depositional environment of the sediment, and its transportational history.

Other ternary diagrams (figs. 4 and 5) have been devised so that their subdivision may also represent a mixture of sediment types. In these cases, the sediment may be called "sandy gravel", or a "muddy sand", or a "silty clay", depending upon the subdivisions of the ternary diagram. Fixed percentage limits are given which are basėd on the data from the mechanical analyses carried out in the laboratory, or by estimates made in the field by means of simple measuring devices or grain-size comparitors.

Sediments may be classified according to a two end-member series such as gravel and sand. This type of series could include the following: gravel, sandy gravel, gravelly sand, and sand. In this case, gravel and sand are the end members designated at 100%, and the subdivisions are set at some arbitrary percentage limit. These deposits would generally be found in shallow water such as beach zones, shoals and banks.

Other sediment frequency distributions could be shown on graphs such as the histograms of figs. 6 and 7, or the cumulative frequency curves of fig. 1. These devices are used as aids in presentation of data and interpretation of the sediment deposit. They are not intended for field use because they generally depend upon laboratory results and methods for their construction.

REVIEW OF SIZE CONCEPTS

The terminology on bottom sediments is based on texture or, specifically, size. Virtually several volumes have been published on the subject of sediment size, and the account is still incomplete. Some of the concepts regarding the size of particles involve an understanding of many factors, including fall velocity of sediments through water, weight, volume, cross-sectional area and diameters of particles.

Fall velocities of sediments are measured as the speed at which a particle of a given size falls through a column of water. This velocity may be shown mathematically from an examination of Stokes' Law. This rule is based on the principle that the largest and heaviest particles fall fastest,

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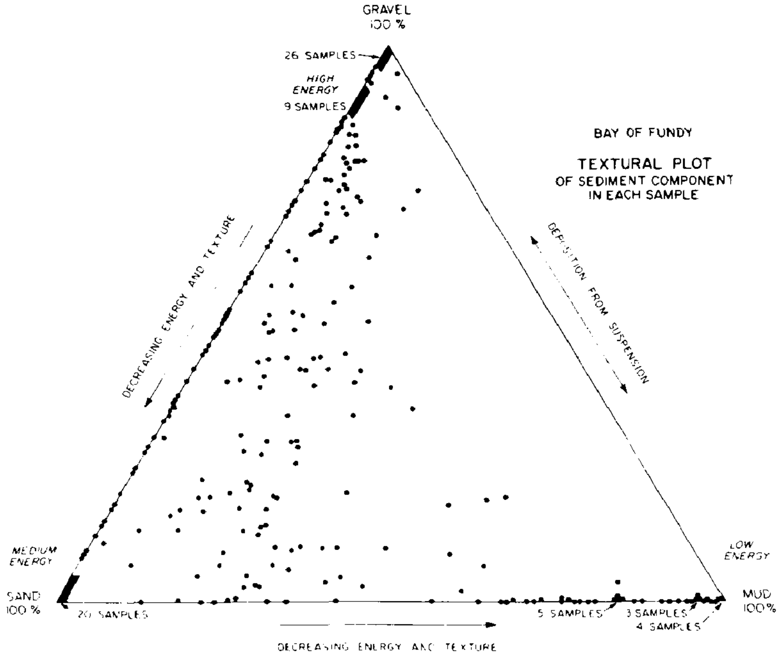
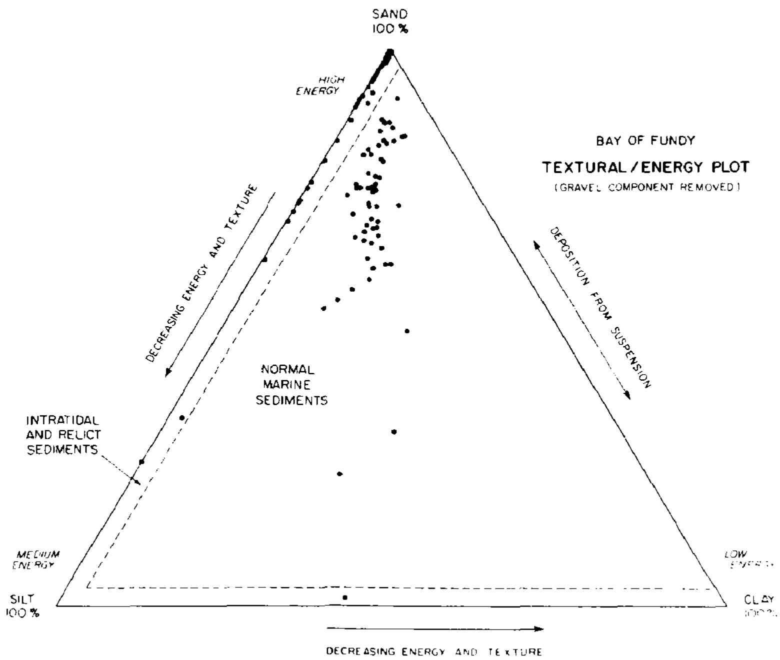
FIG. 2. — Ternary textural diagrams of sediments from the Bay of Fundy.

A. Textural plot showing gravel, sand and mud as the major sediment components. Because less energy is required to transport the finer sizes, then the coarser particles deposit first, as shown by the direction of the arrow representing decreasing energy and texture. This diagram helps to illustrate the fact that two major sedimentary systems are present : one which is associated with strong wave and current action; and one which is part of a normal marine system.

B. Plot showing sand, silt and clay as the major components. The presence of gravel, which may belong to an earlier period of deposition, commonly obscures the mechanism of the modern sedimentary processes. By removing gravel from the analysis (i.e. analogous to removing "noise" from radio systems) the interpretation is reached more satisfactorily (i.e. better "signal" is received). The plot clearly demonstrates the two depositional modes discussed in Figure 2 A.


GRAVEL
100 %
26 SAMPLES
HIGH
ENERGY
9 SAMPLES
BAY OF FUNDY
TEXTURAL PLOT
OF SEDIMENT COMPONENT
IN EACH SAMPLE
DECREASING ENERGY AND TEXTURE
DEPOSITION FROM SUSPENSION
MEDIUM
ENERGY
LOW
ENERGY
SAND
100 %
20 SAMPLES
5 SAMPLES
3 SAMPLES
4 SAMPLES
MUD
100%
DECREASING ENERGY AND TEXTURE


SAND
100 %
HIGH
ENERGY
BAY OF FUNDY
TEXTURAL / ENERGY PLOT
(GRAVEL COMPONENT REMOVED)
DECREASING ENERGY AND TEXTURE
DEPOSITION FROM SUSPENSION
NORMAL
MARINE
SEDIMENTS
INTRATIDAL
AND RELICT
SEDIMENTS
MEDIUM
ENERGY
LOW
SILT
100 %
CLAY
DECREASING ENERGY AND TEXTURE

assuming the particles to be spheres. This statement is expressed in the following equation:

$$v = \frac{2}{9} \frac{(d_1 - d_2)\, gr^2}{n}$$

where v = fall velocity (cm . sec^{-1})
d_1 = density of the sphere (particle)
d_2 = density of the fluid
g = acceleration due to gravity (cm . sec^{-2})
n = viscosity of fluid

This measurement is applied directly to the determination of sizes of sediments in the finer ranges (< 0.062 mm). The so-called pipette method is used, in which a portion of the sediment is withdrawn at a given time from a given depth in a tube in which the sediment has been mixed with water and allowed to settle.

Volume of particles may be measured by means of displacement in water. With irregularly shaped pebbles this may be the only satisfactory method. From this determination, a sphere of that volume may be assumed and a nominal diameter calculated. The converse is also applicable in that a given diameter of a pebble can be measured directly, and the volume calculated subsequently.

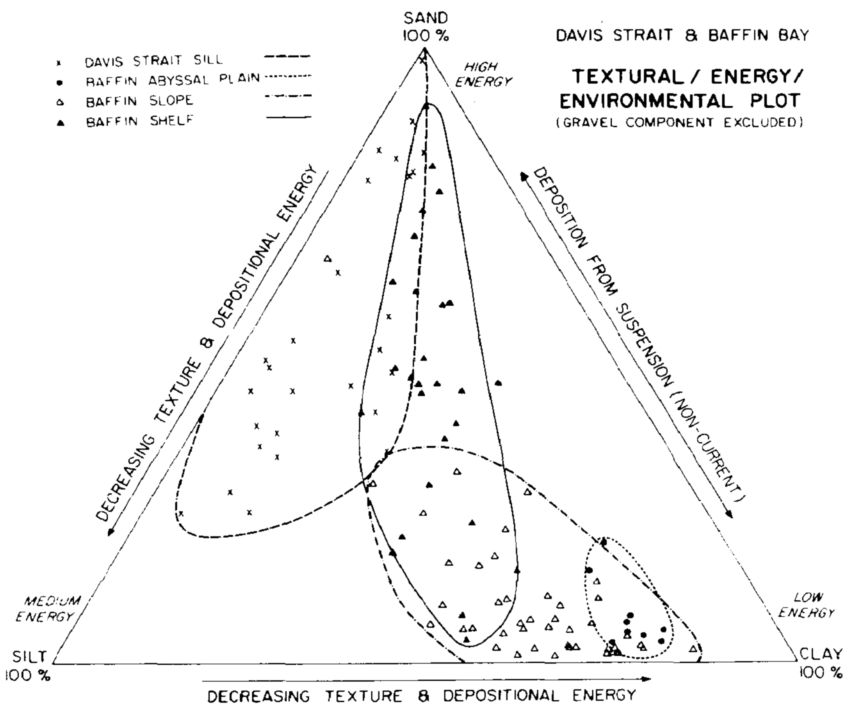
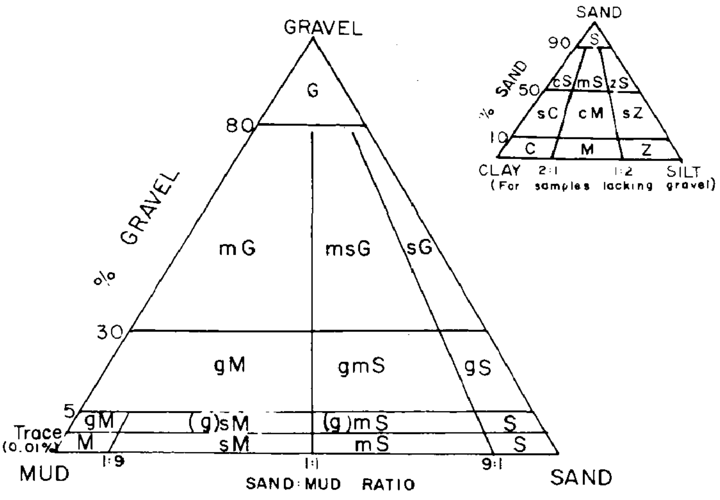


FIG. 3. Ternary textural plot of sediments from Davis Strait and Baffin Bay. The different depositional environments are clearly indicated in the outlined areas within the diagram. This technique is used as an aid in interpreting the origin of sedimentary deposits.



G – Gravel, g – gravelly
S – Sand, s – sandy
M – Mud, m – muddy
Z – Silt, s – silty
C – Clay c – clayey

FIG. 4. — Classification of sediments according to R.L. FOLK (1964). This diagram can be used in conjunction with those of figure 2.

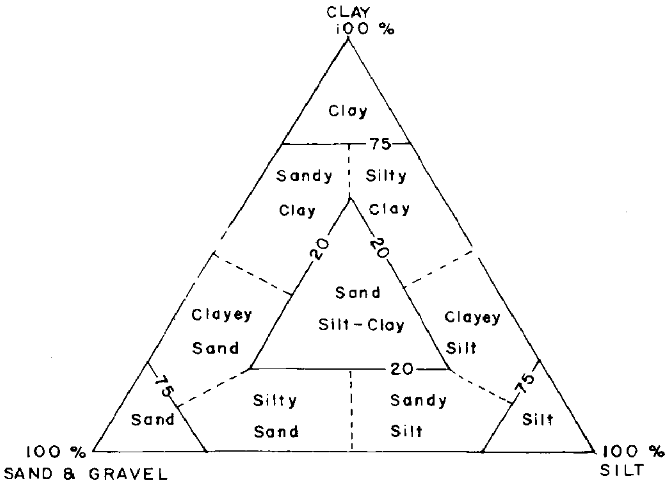


FIG. 5. — Classification of sediments according to F.L. SHEPARD (see PETTIJOHN, 1957). *In this diagram sand and gravel are considered to be a single class, whereas many* other workers utilize silt and clay as a single class (mud) when gravel is included as one of the major components.

Weight is also a common observation, particularly with large blocks or boulders. Based on an estimate of the density (or specific gravity) of these materials, and from a measurement or estimate of their diameters, weight can be calculated. In the case of smaller fragments and pebbles,

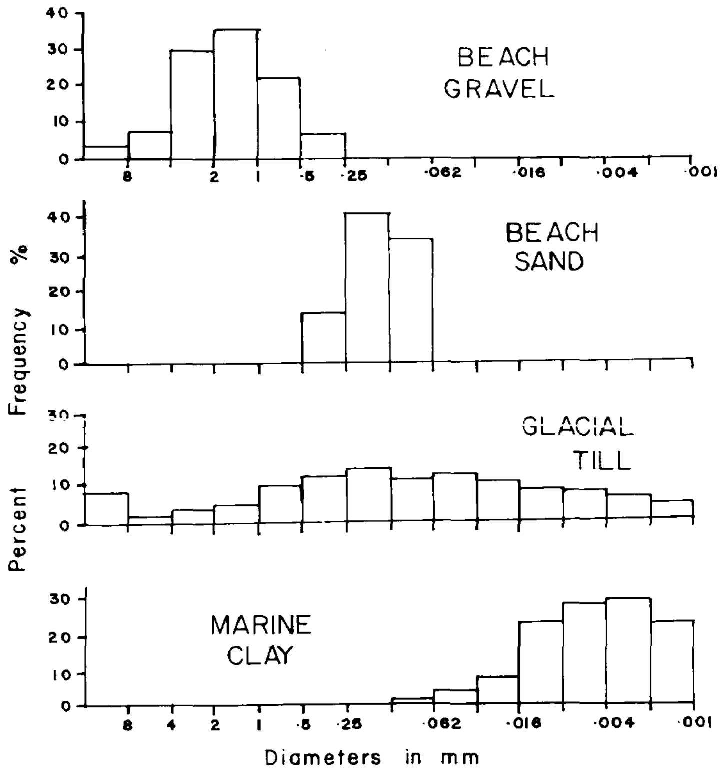


FIG. 6. Histograms of the frequency distribution of sediments from various environments. The shift in the major classes of sediments is clearly seen from one environment to the next. These diagrams correspond to the cumulative frequency curves in figure 1.

the material can be weighed directly on suitable balances. The weights of different size fractions, such as those obtained by means of sieving or pipetting, are also determined. The weight percentage frequency of these fractions provides the data for the construction of curves and graphs depicting size distributions based on frequency percent.

Diameters are the most significant parameters because they represent the most common description of sedimentary sizes. However it is necessary to consider several diameters in use before deciding upon that selected for mapping purposes. With pebbles and larger particles, the arithmetic mean diameter may be calculated from the measurements of the minimum, maximum and intermediate diameters, i.e.

$$\frac{a + b + c}{3}$$

where a, b and c are the diameters measured orthogonally to each other, and parallel with their respective axes. In cases of marked elongation of flattening, with respect to shape, the harmonic mean

$$\frac{ab + bc + ac}{3\,abc}$$

is calculated. Certain size distribution such as admixtures of sand, silt and clay are abnormal, so to bring the value of the mean diameter closer to the central portion of the distribution, the geometric mean $\sqrt[3]{abc}$ is used.

Another mean diameter in wide use is employed specifically in size distributions with a designated geometric interval forming the size grades. It is the so-called phi mean ($\bar{x}_\phi$) (fig. 8), and is calculated from the negative logarithm to the base 2 of the mid-points of these grades. One other diameter is in common use and it too is based on designated class intervals for the size frequency distribution of sediments. This is called the modal diameter (fig. 9), or modal class, and represents the chief class in the size frequency distribution of the sediment. The phi mean (fig. 8) and the modal class (fig. 9) show different interpretations of the sediment distribution.

Cross-sectional areas of particles may be determined in several ways, the most important of which is by sieving through screens with standard-size openings or mesh. Because these sizes represent the minimal cross-sectional area of the grain that it passes, a shape bias exists. For example, a rod-shaped particle has two extremely different cross-sectional areas. However, the sediment is generally shaken and rotated in the sieves in order to permit the passage of the particle through the graduated series of sieve openings, so that the minimal cross-sectional area is recorded. Those fractions that are retained on each sieve are weighed in order to determine the size frequency distribution of the sediment by weight.

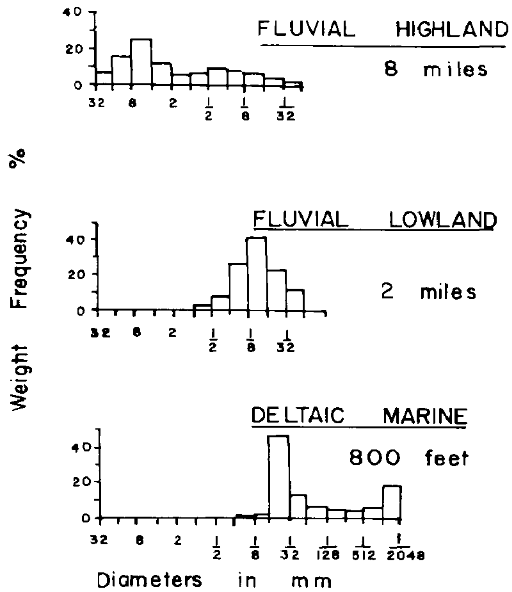


FIG. 7. — Histograms showing the shift in sediment sizes proceeding from the watershed to the delta in a small river system in the Arctic (Ellef Ringnes Island, District of Franklin, Canada). This demonstrates the principle of sedimentation outlined in figures 2 and 3, that transport of the heaviest and largest particles is associated with the greatest energy conditions (such as the swift river currents in the highlands), and the deposition of the finest particles taking place in quieter inshore marine areas.

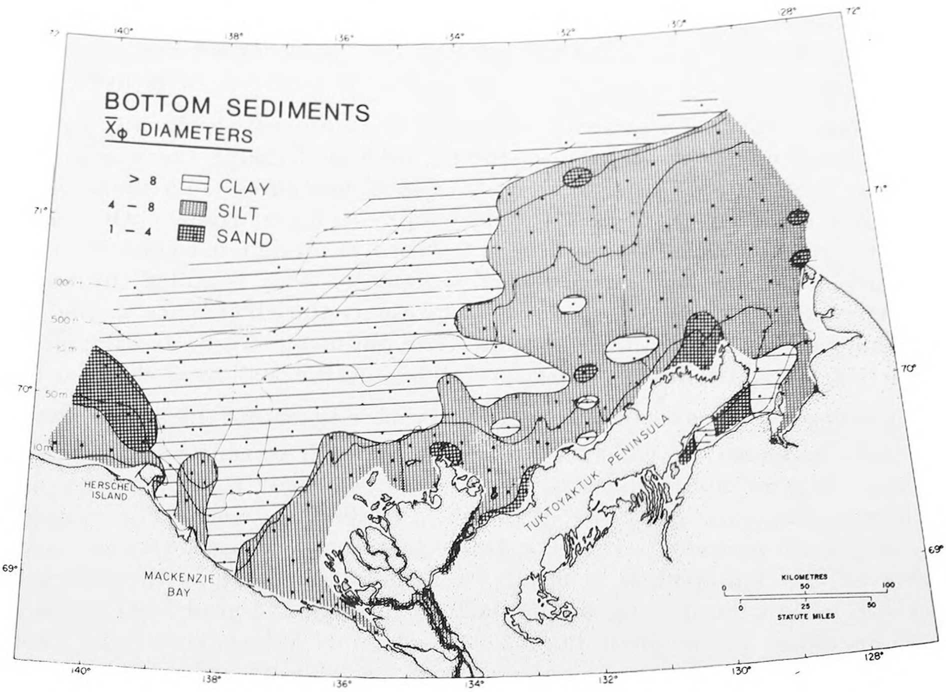


FIG. 8. — Map of types of bottom sediments of the Beaufort Sea based on phi mean diameters. Although gravel is present as a major class, it is not indicated in this diagram because the sum of the other classes (according to percentage frequency) is greater. Hence the average sediment size is much smaller than gravel.

Other methods of obtaining cross-sectional area involve the following: (1) direct measurement of diameter and calculating the respective area; (2) calculating the area from the nominal volume; and (3) measuring the area by indirect means such as the Coulter Counter which gives the resistivity of a particle falling through a standard orifice in water through which an electric current is passed. Resistivity is proportional to the cross-sectional area, and hence the diameter of the particle. Numerous other methods exist which involve special techniques with the microscope; others with settling tubes, and elutriation methods both in water and air.

SHAPE AND ROUNDNESS OF PARTICLES

A description of particle shape is most important for interpretative purposes, particularly with pebbles and coarser particles. It is also a useful parameter for making objective comparisons. *Shape* refers to the three-dimensional aspect of the particle, and employs such qualifiers as spherical, discoid, blocky, tabular, platy, elongate. *Roundness* refers to the degree to which edges and corners have been worn or rounded and hence it is a two-dimensional concept. A disc is circular in plan as is a sphere; yet rotate the disc to observe cross-section at right angles to its short axes and it

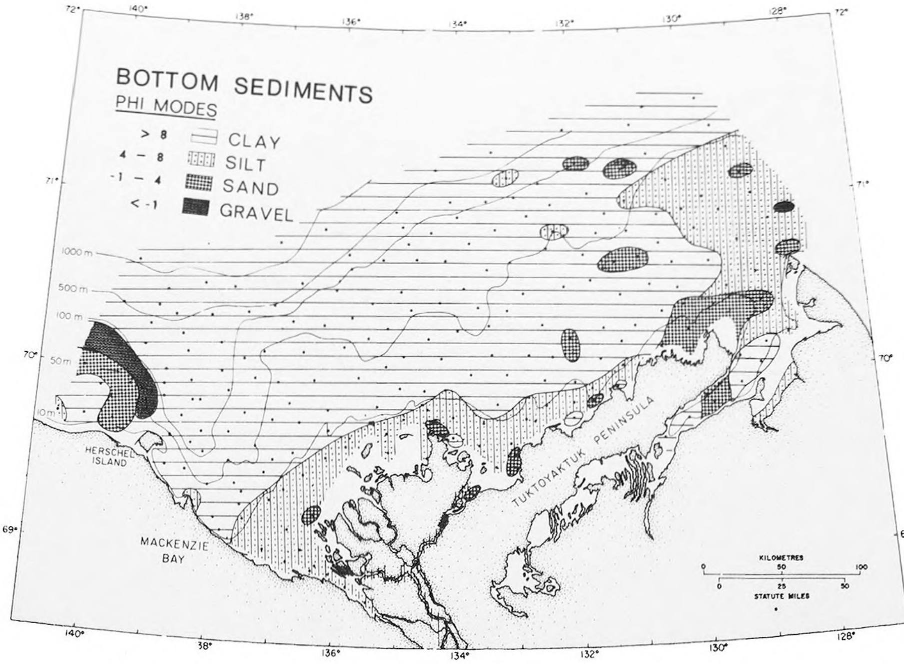


FIG. 9. — Map of types of bottom sediments of the Beaufort Sea based on phi modes. Note the appearance of gravel in this presentation. This is due to the predominance of gravel over the sand, or the silt or the clay classes respectively. The basic textural data is the same as that for figure 8.

appears to represent a plate. In another example, a rod appears to be circular in the plane of the short axes, but is elongate along the long axis. Similar cases can be made for plates and blocks.

Commonly, a large fragment is retrieved by the sampling device (a clam-shell sampler, or trawl dredge) and is called rock. On this basis, the sea floor is mapped as though characterized by a rocky bottom. If the fragment is angular with no rounded edges, it is quite probably a piece of bedrock torn from the bottom by the sampler. In this case, the bottom notation is correct. However, if the fragment is mixed with finer sediments it is possible that the fragment was brought to the depositional site by other means (perhaps by drift ice), and thus is not representative of the sea bottom at the sampling site. It is also possible that fine sediments settled over the fragment or even the bedrock. The correct notation would then be blocks, or blocks and mud.

Another example of erroneous interpretation of the bottom is shown in Canadian Hydrographic Service Chart 7602 (fig 10). The bottom notation indicates the presence of rock, as shown by the symbol R. However on examination of the sea bottom in this area, no bedrock was exposed, but blocks of hard clay were present. The clay on the sea floor had been compressed by over-riding keels of ice that were under pressure, and subsequently the clay was squeezed out of place and torn by the ice keels into blocks. The entire bottom was hard, with only a few centimetres of

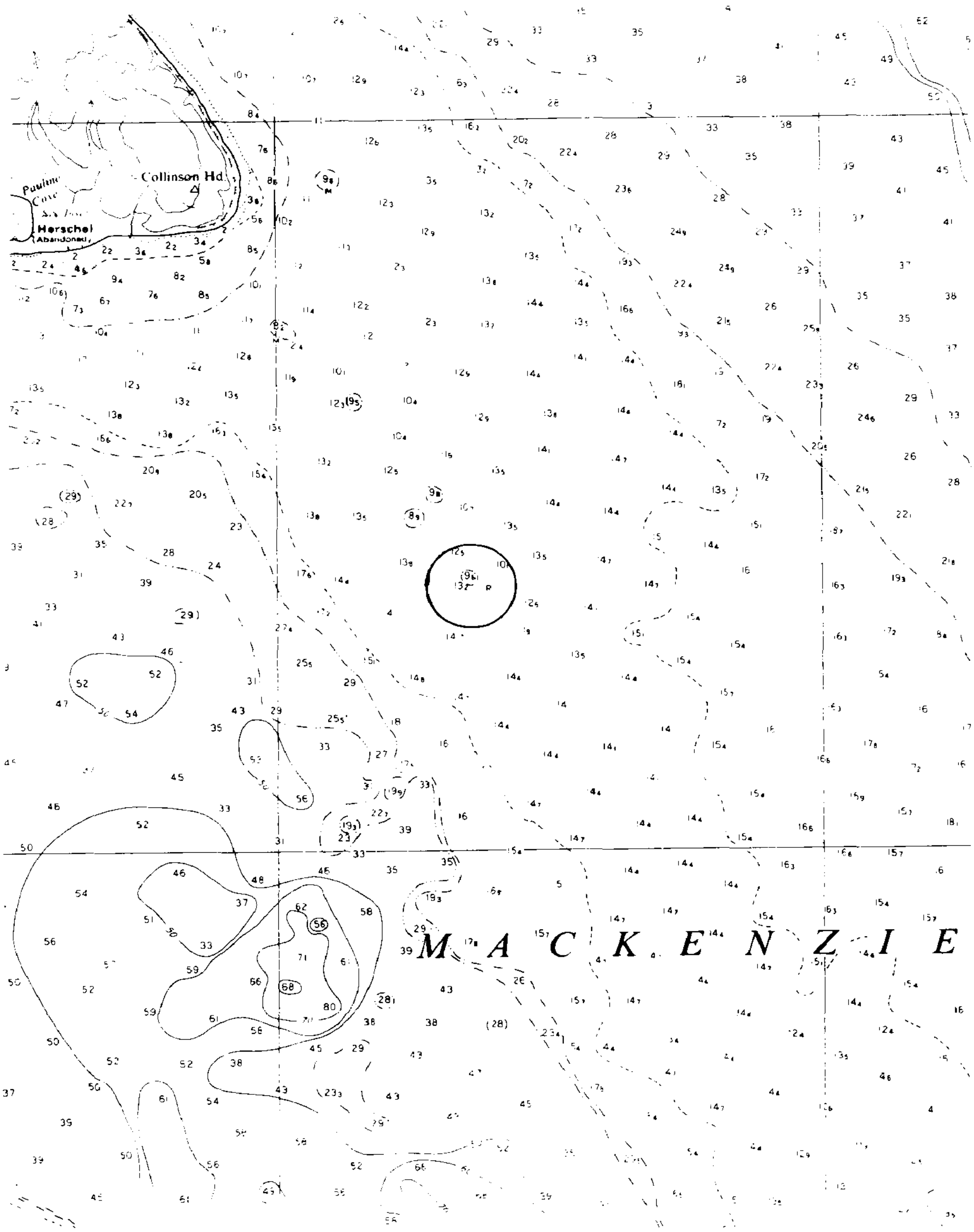


FIG. 10. — Bottom notation in Mackenzie Bay near Herschel Island, Yukon Territory, Canada. Circle around symbol R indicates location of rock bottom. Area is actually underlain by hard, compressed clay with a thin cover of soft sediment and a sparse distribution of coarser sediments that were deposited by means of ice rafting (see figs. 8 and 9).

soft sediment on the sea floor. In this case the bottom notation should be: "clay, hard". However a critical examination of the sample is needed to confirm this notation.

In some cases the coarse particles may be rounded, which implies transportation by water, and thus they may not have any relationship to the underlying bedrock. If the fragment has a triangular appearance (such as a flat iron) with rounded edges, it could possibly be an ice-eroded and transported fragment, and possibly derived from a source several hundred kilometres distant. This is particularly true in the case of transport within the body of drift ice.

Various categories of shape and roundness of sedimentary particles are shown on specially prepared reference charts. *Shapes* are categorized for spheres, blocks, plates, rods, etc.; and *roundness* (fig. 11) is depicted by cross-sectional views which show the edges as rounded, subrounded, subangular and angular. Both sphericity and roundness can be calculated from the measurements of various radii and axes of the particle and comparing them with similar measurements on spheres, or with ratios of the axes, or with ratios of small to large radii on the particles. This is a time-consuming procedure, so the comparison chart is recommended as it is quick, simple to use, and within 20 % of accuracy as compared with calculations.

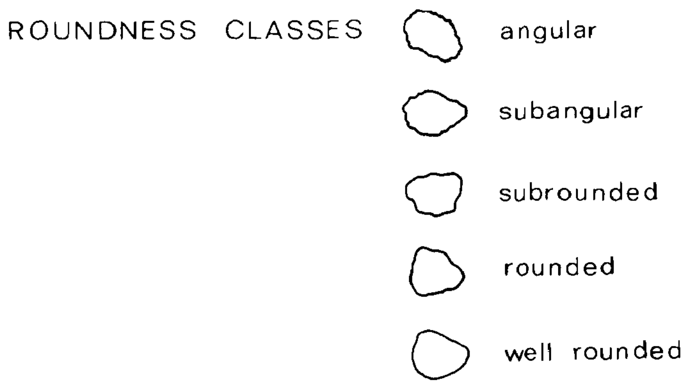


FIG. 11. — A typical chart illustrating the various degrees of roundness or angularity of sediment particles.

COMPOSITION OF FRAGMENT

To the hydrographer not trained in geology, this aspect of the description of bottom material can be a difficult problem. The field geologist must also cope with the same task and, many times, must return the material to the laboratory for further examination and subsequent identification. However with a modicum of instruction together with suitable literature and type samples of common rocks, the hydrographer can attempt a preliminary description. It is still good science to say "you don't know when you don't know" and therefore, when in difficulty, the best practice is to leave the sample or rock unnamed.

Certain common rock types can be learned easily, and these include the following: shale, sandstone, conglomerate, limestone, granite and some metamorphic and volcanic rocks. The latter two are somewhat more difficult than the others but again, a reference rock set can be used. Because minerals need to be identified in some cases, reference mineral sets can also be provided. (Such sets are obtained from the Geological Survey of Canada, Ottawa, at nominal cost). With the gross, or overall, description and naming complete, it is not necessary to subdivide further. Such a preliminary description will give many valuable indications on the origin of the fragment, as well as the material on the sea floor — whether it is bedrock or not.

Recently attempts have been made to distinguish the nature of bottom material by means of sonic and seismic investigations, and to digitize the findings on recorders or magnetic and punch-paper tapes. It is possible that, in the case of unconsolidated sediments (gravels, sand, silt and clay), this method could be highly successful. In the case of high-frequency sound sources, which offer good quality in the resolution of the sound returns, considerable promise is held for this technology. However, it will not distinguish rock types or the mineralogical composition of the sediment, so that strategic sampling must be an integral part of the operation, and personal examination of the sample should be carried out. Deep seismic reflection and refraction profiling are useful for determining rock structures, and, from velocity measurements, the nature of the rock may be deduced. Other geophysical data such as magnetic and gravimetric measurements may assist in this description but they are beyond the experience and duties of the hydrographer, although the latter may assist in such types of multiparameter surveys.

NOTATION

Once positioning has been established, the most important procedure following the sampling operation is to portray the quality of the bottom by the use of correct notation on the hydrographic chart. In Table 3, the notations shown are taken from the routine instructions given to the hydrographers of the Canadian Hydrographic Service. Although some debate exists on the usage of abbreviations, the issue here refers to the terminology itself. Names such as sand, mud, clay and gravel are well defined terms according to Table 1 and fig. 1, although they are not in logical order of size. Clay is the finer portion of mud, and silt is the coarser portion. However silt is not given. It would also be easier to understand and be more orderly in presentation to have lists given so that the sizes follow from coarsest to finest.

The term gravel refers to a major sediment type that includes pebbles and cobbles and even boulders. Therefore, some ambiguity exists in the present list (Table 3). Shingle refers strictly to pebbles, cobbles and boulders that are imbricated one upon the other on a beach, so that their

TABLE 3

Quality of the bottom

(modified after Chart No. 1, Canadian Hydrographic Service, Ottawa, 1976)

Gd	Ground	Wd	Weed
S	Sand	f	fine
M	Mud	c	coarse
Oz	Ooze	so	soft
Cy	Clay	h	hard
G	Gravel	l	large
Sn	Shingle	bl	black
P	Pebbles	b	blue
St	Stones	gn	green
R	Rock	y	yellow
Bo	Boulders	br	brown
Co	Coral	gy	gray
Sh	Shells	d	dark
Oy	Oysters		Fresh water springs in sea-bed
Ms	Mussels		

long axes are inclined towards the sea or lake. Stone is really a layman's term to include pebbles, cobbles, boulders, blocks or even crushed rock. It should be deleted. Rock refers to bedrock, and a piece of bedrock may be an irregular-shaped rock fragment or a block. This term should be defined clearly. Coral is an animal growth with a hard exoskeleton consisting of calcium carbonate generally. This hard portion of the coral forms a limestone reef when the coral grows in colonies; otherwise it is a solitary entity. The two types should be distinguished and noted. Plants and animals may thrive on the sea floor, but they are not the sea floor in themselves. Their presence should be noted by the use of an additional qualifier on the bottom-notation chart.

It may be necessary to expand the use of the textural qualifying terms, as coarse and fine may not be sufficient. The adjectives — hard and soft — with reference to bottom quality, are useful and should be retained. Notations on bottom roughness as an aid to fishermen would also be useful, and some charts do incorporate them. A colour description is essential and should be retained and expanded, but a standard reference code for colours should be used.

New marine geological maps produced by the Geological Survey of Canada and the Marine Sciences Directorate, Ottawa, carry a legend of the rock types and their respective ages in much the same fashion as their land counterparts. It may be worth considering the inclusion of diagrams to illustrate the mechanical composition of the bottom sediment; as an alternative, notation could be devised to indicate both the single and mixed type.

RECOMMENDATIONS

In order to maintain consistency in the mapping of the sea floor by the hydrographer and the geologist, and to attain widespread application of these maps, several recommendations are made. Some of these may not apply to surveys of short duration, but for long cruises it would be advisable to reserve space on board for the purpose of organizing a small laboratory to handle the bottom samples. The recommendations are as follows:

1. Bottom samplers and sampling technology should be standardized. Shipek, Dietz-LaFond or Van Veen samplers should be used.
2. Sampling intervals on routine surveys should be standardized according to the scale of the charting, the configuration of the bottom, and distance from shore.
3. Description of samples should be based on a routine procedure, and should be incorporated in the hydrographer's instructions.
4. Colour charts such as the Munsell colour-coded system should be supplied to all hydrographic vessels.
5. A standard grade scale based on a geometric progression such as the $-\log_2$ should be used.
6. Grain size comparators should be supplied to the hydrographers.
7. Certain sieves should be supplied that would assist in giving some estimate of size of the coarser particles such as pebbles.
8. Balances could be provided to obtain preliminary estimates of percentage by weight of the major sediment types. This is not essential on cruise.
9. Representative samples of the various sediment types and their admixtures should be kept on board permanently for reference.
10. Charts showing comparative roundness and shape of particles should be posted on board.
11. Bottom samples should be identified according to composition. Sets of common mineral and rock types, as well as sediment samples, can be placed on board for reference purposes.
12. Hand lenses should be issued so that sediments can be examined directly. Low-powered microscopes may also be used.
13. Geological handbooks or manuals should be kept on board for study and reference.
14. Procedures for cataloguing and delivery of samples should be part of the hydrographer's instructions.
15. A course of study on the principles of marine geology and pertinent laboratory practices should be offered to the hydrographer, and given by a marine geologist. The course should extend for a period of three or four weeks, with at least one half of each day given to practical classroom work supplemented with homework.
16. A revised system of bottom notations should be incorporated in the hydrographer's instructions. These notations should include descriptive qualifiers and suitable abbreviations.

17. Because the Canadian Hydrographic Service is part of the International Hydrographic Organization, it should modify its notation in keeping with that of the international body in order to ensure the production of a truly international chart-notation system.

CONCLUSIONS

Because of the use of mutual facilities and the general goal of mutual interests, the hydrographer and the geologist should extend their past working relationship to the design and furtherance of a national sea bed sampling program. This program, for the most part, should be compatible with an international hydrographic program in terms of professional objectives.

It is opportune to evaluate our sampling programs now, particularly with the advent of the new international charts of the oceans. It is necessary to commence with bottom-sampling operations, and to standardize our equipment, procedures, terminology, textural comparators, and bottom notations. Recommendations on the adoption of this program should be considered now, particularly as the timing of these deliberations is somewhat behind that of the international hydrographic body. These preparations will aid considerably the creation of more effective, economic, and scientifically useful operations. With this assistance from the hydrographer, both the technological and scientific aims of our respective services will be utilized more fully, and our objectives, as well as those of the international hydrographic community, will have a better opportunity of being reached.

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