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Sedimentological Sampling and Results from the Diver Lock-Out Facility of the Submersible Shelf Diver, Bay of Fundy, Nova Scotia*

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The present study was one of a series of four separate exercises carried out by marine geologists of the Atlantic Oceanographic Laboratory, involving the use of the research submersible Shelf Diver to carry out specific geologic projects. Dives were made to the 800-foot depth limit of the submersible in order to make observations on suspected areas of bedrock occurrences, to observe certain dynamic processes and features of marine sedimentation, and to sample and photograph a variety of sedimentary and benthic environments on a closely controlled survey plan.

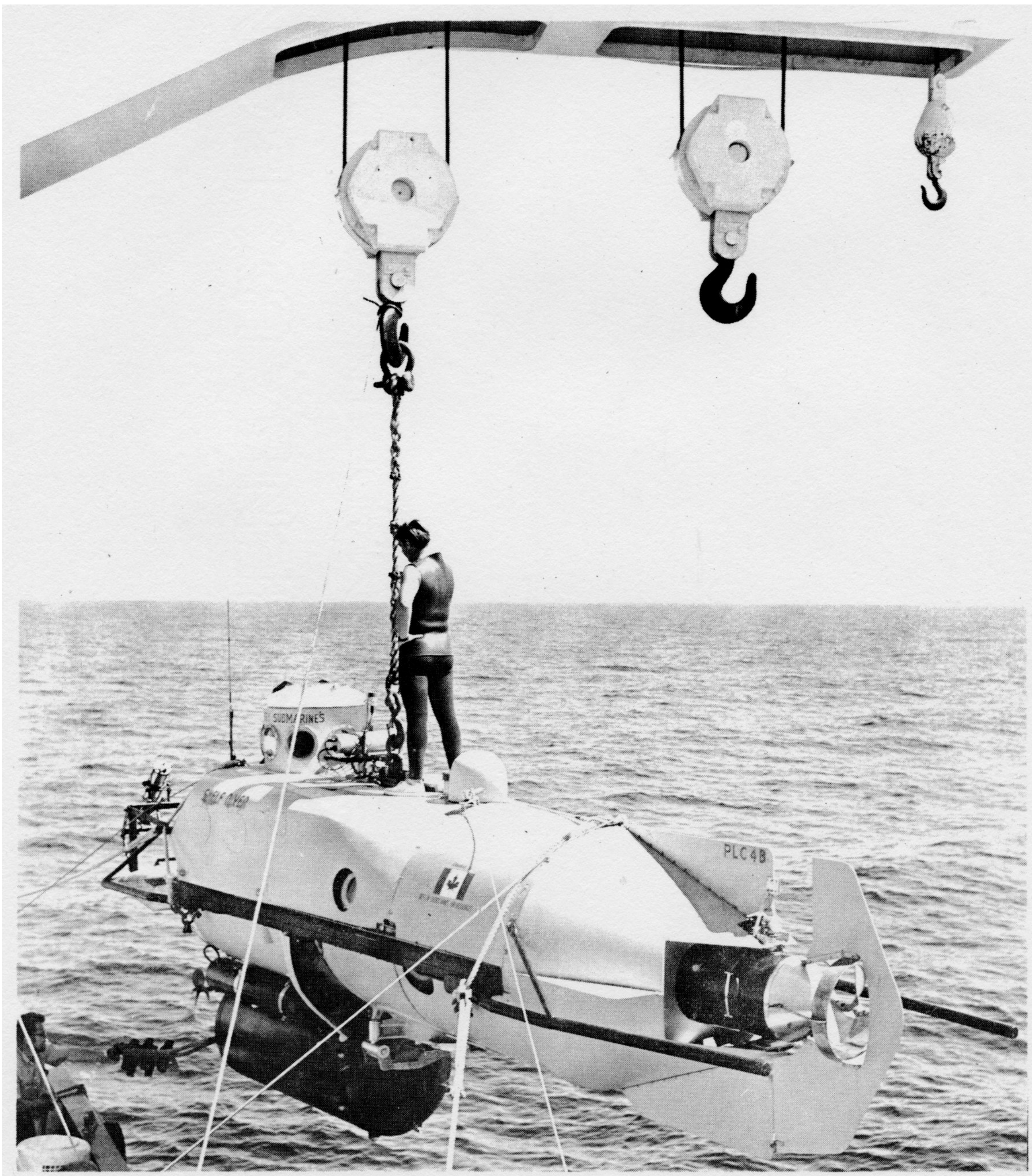

Figure 1: Shelf Diver going over the side from C.D. Howe, Bay of Fundy. Negative 1375-56 AOL, Bedford Institute.

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Some of this work has been discussed previously. King and MacLean (1970) described samples of Cretaceous rocks from the Scotian Shelf near Sable Island that were obtained with special tools mounted externally on Shelf Diver. Schafer (1969, 1970) reported his results of lock-out sampling of foraminiferal populations in the Gulf of St. Lawrence, and Drapeau (1971) observed the movement of sand on the southwestern portion of the Scotian Shelf, and described the configuration and origin of large sand waves in that area with the aid of underwater photography, television and video-tape replay. The final project of the geological program was carried out by the writer who directed an exercise on sediment sampling and bottom photography in the Bay of Fundy. This work was accomplished with the aid of SCUBA divers of the Royal Canadian Navy, who carried out the lock-out sampling of the seabed, and by the photographic unit of the Atlantic Oceanographic Laboratory which undertook the task of fitting cameras and associated accoutrements to the submarine. In most cases the visibility in the water was clear only to eight feet, although it was somewhat better in the shallow water. However photography was carried out at all stations including the traverses made on dives when sampling was not undertaken.

Shelf Diver (Fig. 1) was obtained on charter from the Perry Oceanographic Company of Miami, Florida, and was shared with biologists of the Fisheries Research Board of Canada at St. Andrews, New Brunswick. The Department of Energy, Mines and Resources (Government of Canada) held the charter for the Atlantic Oceanographic Laboratory, Dartmouth, Nova Scotia. The Canadian Coast Guard Ship C.D. HOWE, operated by the Department of Transport, served as the tender for the submarine. With four major agencies of government participating directly in the program, these studies were realized as a practical and fruitful co-operative venture on an interdepartmental basis.

Description of Shelf Diver

The Shelf Diver is constructed basically of two pressure spheres which are mated in order to permit transfer of personnel between compartments while the vessel is submerged (Fig. 2). The submersible is 23 feet in length, 5.6 feet in diameter, and weighs 8.5 tons. It is battery-powered and propelled by means of a single-pod, stern-mounted motor with about 37 kw of power at 120 volts D.C. An auxiliary motor is installed forward, and is used to make vertical adjustments in course although in practise this is generally carried out in transit by adjusting the bow plane that is mounted externally just ahead of the forward viewing windows. The vessel cruises at 3.5 knots with an 8-hour endurance on full power, and has a 48-hour endurance life-support system. Shelf Diver can be made into two separate compartments merely by closing a hatch that separates the diving chamber aft, from the observation and control area forward (Fig. 2). This permits the observer or his diving officer to direct the diving operations from the forward part of the submersible which is maintained at one atmosphere of pressure. This arrangement also affords the pilot an opportunity to study all phases of the operations, both internally and externally, and carry out the necessary maneuvers to assist the investigation.

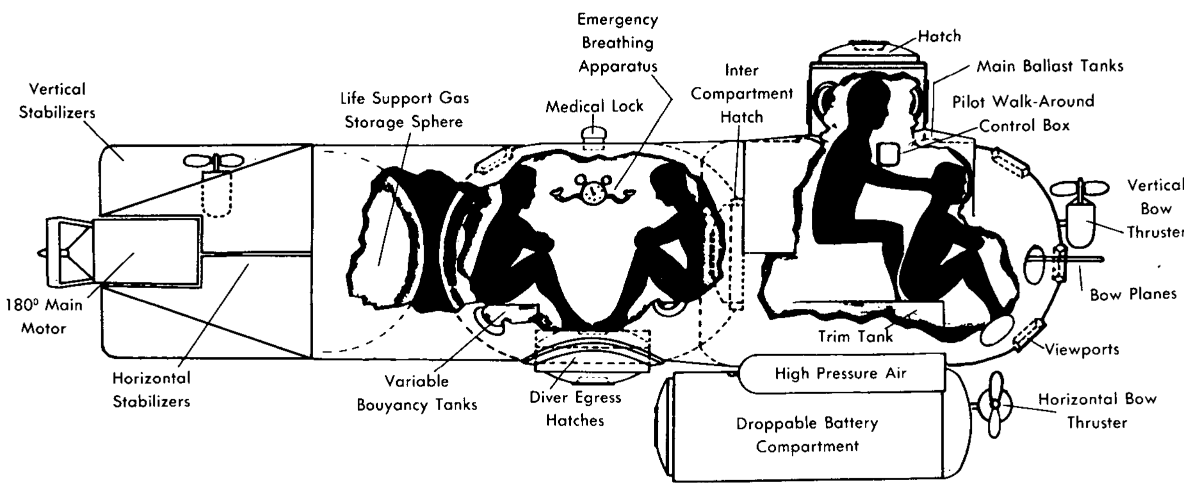

Figure 2: Schematic drawing of Shelf Diver.

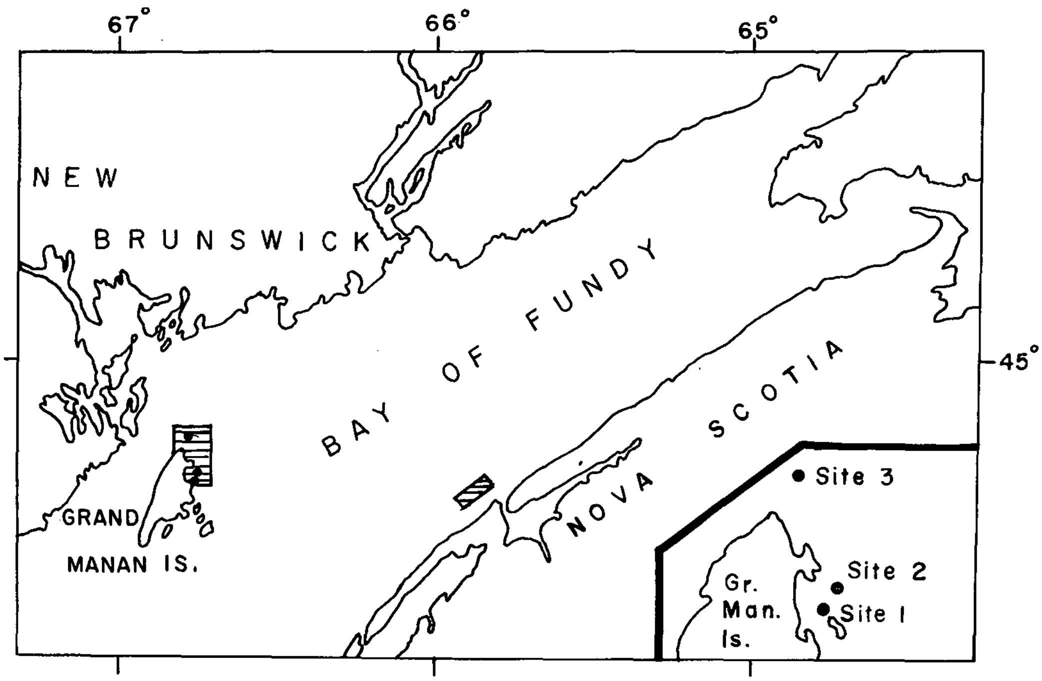

Figure 3: Sampling locations in vicinity of Grand Manan Island, Bay of Fundy. Ruled areas indicate photographic coverage dots indicate sediment sampling sites (see insert sketch).

Location of Sampling Sites

Although six dives were made during this program, only three were used for diver lock-out sampling. Lock-out dives were made in the vicinity of Grand Manan Island (Fig. 3) near the mouth of the bay, in water depths of 15.2, 29.3 and 38.4 metres respectively. Currents were present but their velocities were less than 0.5 knots, and offered no significant hindrance to the sampling operations.

Positioning of the sampling sites was undertaken by C.D. HOWE which fixed the position of an orange float towed by the submarine. As the float was directly above the submarine, horizontal control of its position was established by the bridge officers. The sampling map, prepared for the sea-floor operation, could then be oriented relative to the submarine's position, thereby assuring horizontal control of the sampling stations.

Sampling Procedure

Before making their descent to the bottom aboard Shelf Diver, the SCUBA divers were given the sampling map or pattern that was prepared in advance of the dive. Briefly this pattern consisted of two perpendicular lines forming a cross, with the submarine at the centre. For convenience the major and minor horizontal axes of the submarine were aligned parallel to the arms of the cross, thus giving the directional control necessary for the sampling. Along each arm of the sample grid four stations were selected at 4.5 metre intervals, beginning 4.5 metres from the centre of the cross. This arrangement gave 16 samples for each site and 48 for the entire program.

With the sampling jars numbered aboard ship, the diver merely had to use the sampling bottle designated for the given station indicated on his sampling map. A hand-held iron rack, devised by the divers, proved most suitable for holding the sample jars during this operation. Generally the divers would collect the samples along one line of stations and then return to the submarine to store the samples. The samples were collected by scooping the sediment with the jar which was 7 cm in diameter at the mouth. About 15 to 20 minutes were required to complete the work at a given site. Meanwhile, the investigator being situated in the foreward compartment, could observe the sampling procedure, take photographs, describe the location, and be in immediate contact with the conduct of the operation, as well as with the diver by means of an acoustic telephone link.

An umbilical life-line was used by the divers, which they unrolled from the side of the submarine as the line was connected to air tanks mounted on the hull. The submarine pilot or the diving officer maintained the diving schedule and the controls of the pressure chamber. When the sampling was completed, the divers were returned to the aft pressure sphere and the lower hatch was closed. The submarine was then brought to the surface and hoisted aboard the tender vessel while the divers remained inside undergoing decompression.

Sedimentological Results

Several textural parameters were selected for the purpose of making a qualitative comparison and evaluation of the sampling technique employed by the divers compared with sampling from the ship using conventional bottom grabs. Despite the fact that four divers were used to carry out the sampling, the same mechanical devices were used each time and in the same manner so that operator bias is minimal. The main source of difference then must lie in the methodology of the sampling operation from the sea surface as compared with that from the sea floor. In the former case the investigator is never certain of the sedimentary facies sampled with respect to the true representation, even though he may have both acoustical and optical aids. In the latter case, he sees exactly what is sampled and can determine immediately if the sample is representative of the facies.

Using the classification of Folk (1964), D.J. Swift et al (in press) determined the probabilities of a given sample obtained by surface methods being representative of a given facies for different areas of the Bay of Fundy. For the combination of the muddy sandy gravel-sandy gravel facies, similar to sediments at Site 1, the probability ranges between 33 to 100 percent (aver. 72 percent); for the muddy gravel-gravel facies, similar to sediments at Site 2, the probability ranges from 43 to 100 percent (aver. 63 percent); and for the sandy to gravelly mud facies, similar to sediments at Site 3, the probability ranges from 25 to 80 percent (aver. 55 percent). Using the same basis of comparison the probability for consistent sampling from the sea floor for this present experiment was 94 percent for Site 1, 100 percent for Site 2 and 88 percent for Site 3. The high level of consistency of diver lock-out sampling is immediately apparent.

In the present experiment three different shallow-water sites were selected, and a statistically small representation (16 samples) was obtained from each. The sediments were analyzed mechanically to determine their granulometric characteristics, and the results were treated statistically by means of moment measures. However an examination was first made on the gross characteristics of the sediments by means of a comparison of the lithologic ratios on the basis of gravel, sand, and mud percentages. These results are plotted in a ternary diagram (Fig. 4), which shows that a good consistency exists in the sampling representation. Deviations from the average position in the lithologic field arise mainly in the coarser samples due to the presence of the gravels, especially at Site 1, and due as well to the geographic location near shore; it is also to be expected with the use of small sampling devices (approximately 0.5 litres in volume).

In view of the larger percentage by weight of the gravel component in these small samples, a refinement of the lithologic ratio was introduced in order to examine more closely the ratio between the suspension load and the traction load. In this procedure the gravel component was eliminated and the percentages were recalculated on the basis of 100 percent for the components of sand, silt and clay. These results are also plotted on a ternary diagram (Fig. 5), which shows the relationships of these loads to hydrodynamic vigour. Generally sediments related directly to an environment of high hydrodynamic vigour will be coarse-textured, and this texture will decrease progressively with a progressive decrease in hydrodynamic vigour. In such a sedimentary system,

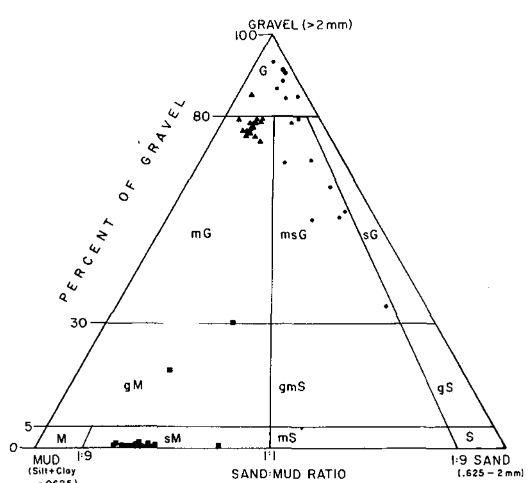

Figure 4: Ternary plot based on lithologic ratios (after Folk, 1964). Circles represent samples from Site 1, triangles from Site 2 and squares from Site 3.

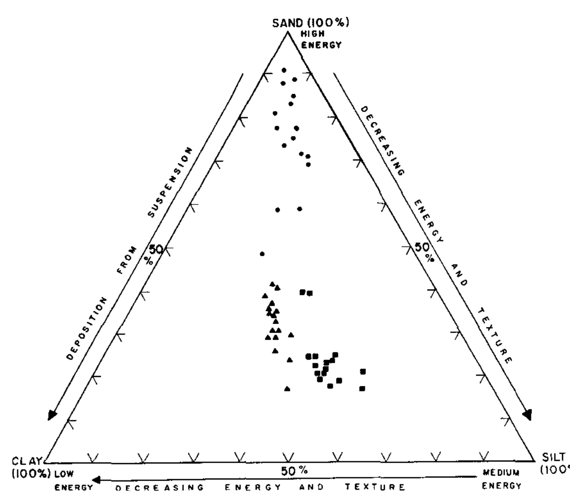

Figure 5: Recalculated textural plot from Fig. 4 *showing relationship of sample texture to* available mechanical energy in a hydrodynamic environment (see Fig. 4 for legend).

equilibrium is demonstrated by a plot of the lithologic ratios for each sample. All ratios would plot on the boundary which extends from the apex, representing the coarse sediment, to the apices of the medium and fine sediments successively. Sediments deposited from suspension are shown by the plot of the lithologic ratios along the boundary between the coarse and fine apices of the triangle (Fig. 5). This boundary shows an absence of hydrodynamic vigour. Therefore sediments plotted close to this boundary are correspondingly remote from a position of sedimentary-hydrodynamic equilibrium. This plot was used for a similar study of sediments in Hudson Bay (Pelletier, 1968, see Figs. 19-21 op. cit.) in which the removal of the gravel element was undertaken to eliminate the sediment contributions by means of ice-rafting. In that study, the recalculated plot showed the positions of the lithologic ratios (sand:silt:clay) closer to the boundary representing sediment-hydrodynamic equilibrium, and correspondingly more remote from the boundary representing deposition from suspension. This is to be expected in Hudson Bay where ice-rafting is a common agent of sedimentary distribution. However the plot of sediments from the Bay of Fundy shows no such phenomenon, and on the basis of this comparison it is concluded that ice-rafting is not a significant means of sediment dispersal in Fundy.

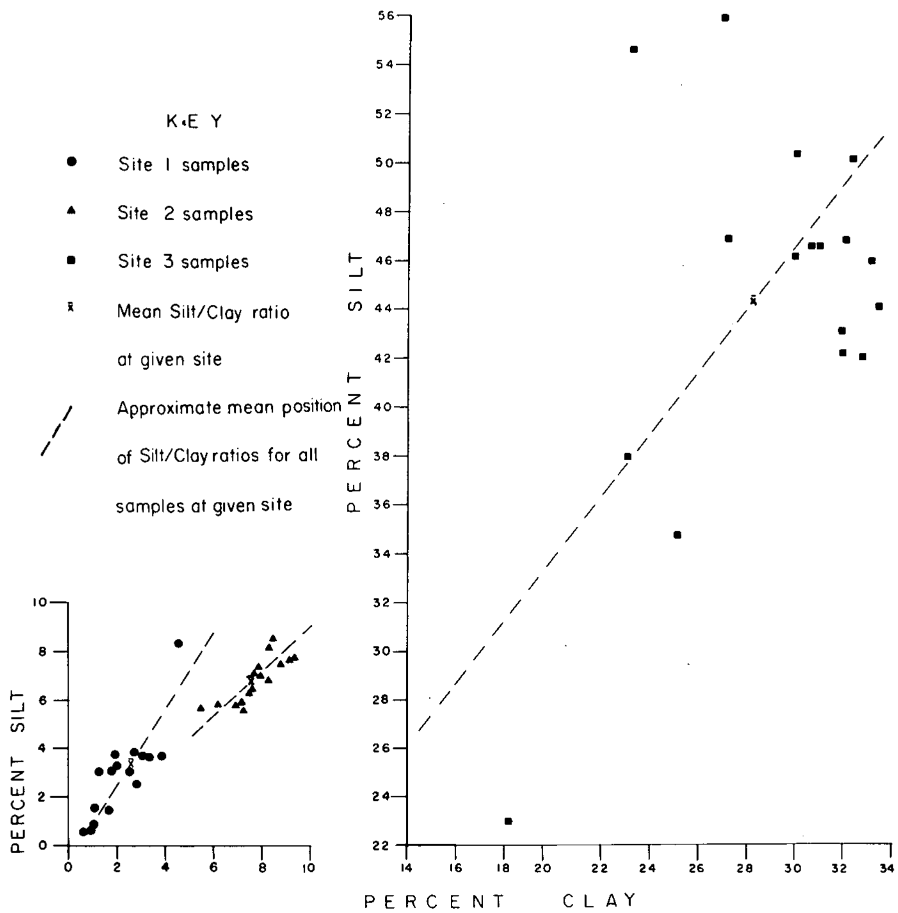

Figure 6: Silt: clay ratios for each sample at each sampling site.

A further refinement of the gross characteristics was made by means of a two-dimensional plot of the percentage of silt versus the percentage of clay (Fig. 6). This plot is a modification of the rectangular diagrams of Doeglas (1955, 1960 and 1962), and the presentation of Brambati (1967, Fig. 2, p. 108). Based on an approximation of the best-fitting curve, most values of this ratio lie within 5 percent of the curve itself except for Site 3 which is due to the presence of less hydrodynamic vigour than that occurring in the inshore tidal area. These plots (Fig. 6) show a reasonably good correlation from sample to sample with reference to those samples obtained at a given site. This ratio is consistent with the general views of Doeglas (1946), Favejee (1951), Van Straaten (1963), Nota and Loring (1964), Brambati and Venzo (1967), and Brambati (1968) in that suspended matter from various sources remains in suspension in the sea sufficiently long to be thoroughly mixed before being deposited. Mineralogy, electrolytic action of the salts in the sea, and the influence of organic substances also have an effect on such deposition and consequently, the resulting silt:clay ratio that ensues.

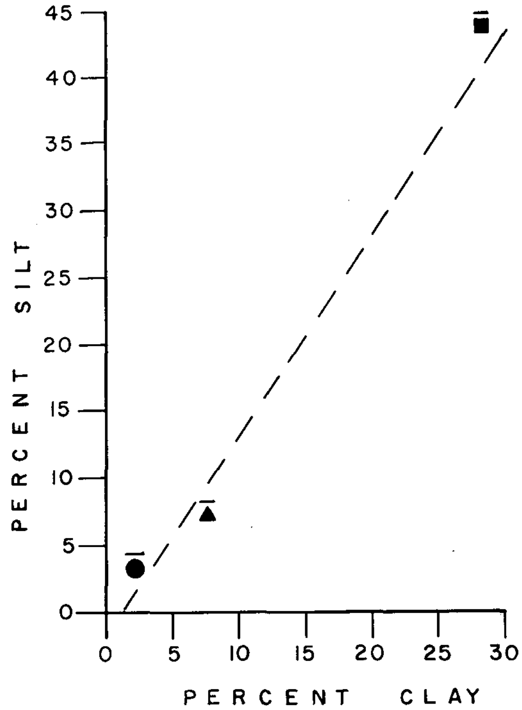

Figure 7: Grand mean of silt: clay ratios based on the means of each sampling site (see Figs. 4, 5 and 6 for legend).

Silt:clay ratios in this study are based on the textural analyses of samples obtained from different depths of water and from varying distances from shore. No significance is attached to the slope of the ratio line as a whole, because the sampling represents such a small area. However, the cluster of values for each site, occurring as they do at distinct intervals of the curve, indicates a significant difference in environmental conditions (Fig. 7). Excluding the nature of the source material and other factors mentioned earlier, this phenomenon may be due to differences in depth or geographic location, or a combination of both. The conclusion is reached that the silt:clay lithologic ratios representative of sediments occurring close to shore and in shallower water plot closer to the origin than do those remote from shore and in deeper water. This is consistent with the general observation that coarser sediments are found in the inshore areas and the finer ones, further offshore. Because of the consistency of sea-floor sampling, the present conclusion can be stated with reasonable confidence.

Moment measures based on phi values were calculated, but were not used for the purpose of hierarchal testing of the sampling error. An inspection of the ternary diagrams and lithologic ratios revealed the practical consistency of the sampling. This was further substantiated by means of a Chi Square test using a two-by-two contingency table and the null hypothesis: "That samples were not representative of a given facies". The hypothesis was rejected at the 5 percent confidence level. Therefore, the textural statistics were examined in relation to each other and with reference to a given sample.

From this study the following relationships were observed. As expected, kurtosis varied inversely with standard deviation, and the larger values of kurtosis varied directly with the coarseness of the sedimentary texture (Fig. 8). Proceeding around the ternary diagram from coarse, to medium, to fine sediments this becomes apparent. Kurtosis values become smaller even though standard deviation remains small. This relationship is shown graphically in Figure 8. The explanation appears somewhat obscure, and factors such as the availability of mechanical energy, amount and size of available material in the source area, geographic and physiographic location of the depositional site, and possibly characteristics of the grade scale itself must be examined and evaluated. It is too early to suggest an external mechanism for this relationship although it appears to be established by a mathematical relationship in the definition of the moments themselves.

Values of skewness when plotted against those of kurtosis on a variation diagram (Fig. 8), show a direct relationship; as the values of kurtosis rise, so do those of skewness although in a less pronounced fashion. However, conformity of the two moments does exist regardless of the nature of the sedimentary texture. It is interesting to note that the overall signature of the variation diagram for kurtosis becomes more subdued (lesser amplitude) with decreasing mean diameters, although the signature for skewness remains subdued. This further suggests that high kurtosis values are associated directly with the mean grain size of the sedimentary population, rather than with the shape of the frequency distribution curve itself. However, no satisfactory explanation exists for the relative subdued nature of the signature for skewness (Fig. 8) in all textures. This characteristic of skewness is a puzzling phenomenon, considering that this statistic lies between the second and fourth moments both of which appear to be related, and to have a dynamic implication on sedimentary dispersion.

Conclusions

Many of the conclusions based on the textural examination of the sediments and the associated analytical data are given considerable credibility because of the confidence placed in the sampling techniques used in this study. This was made possible by the diver lock-out system of the submersible, which afforded exceptionally good control over the sampling plan, more so than would be obtained with conventional sampling techniques from the sea surface. Textural studies confirm the possibility that ternary diagrams and bivariant analyses of the silt:clay ratio can be used to good advantage for both descriptive and interpretative purposes. New relationships of moment measures can be established with each other, in a given sample, and with the lithologic ratios in a ternary plot. The overall concept that these relationships may also be associated with external energies, environmental conditions, geographic factors, and the nature of the parental material seems to have a significant working basis in fact.

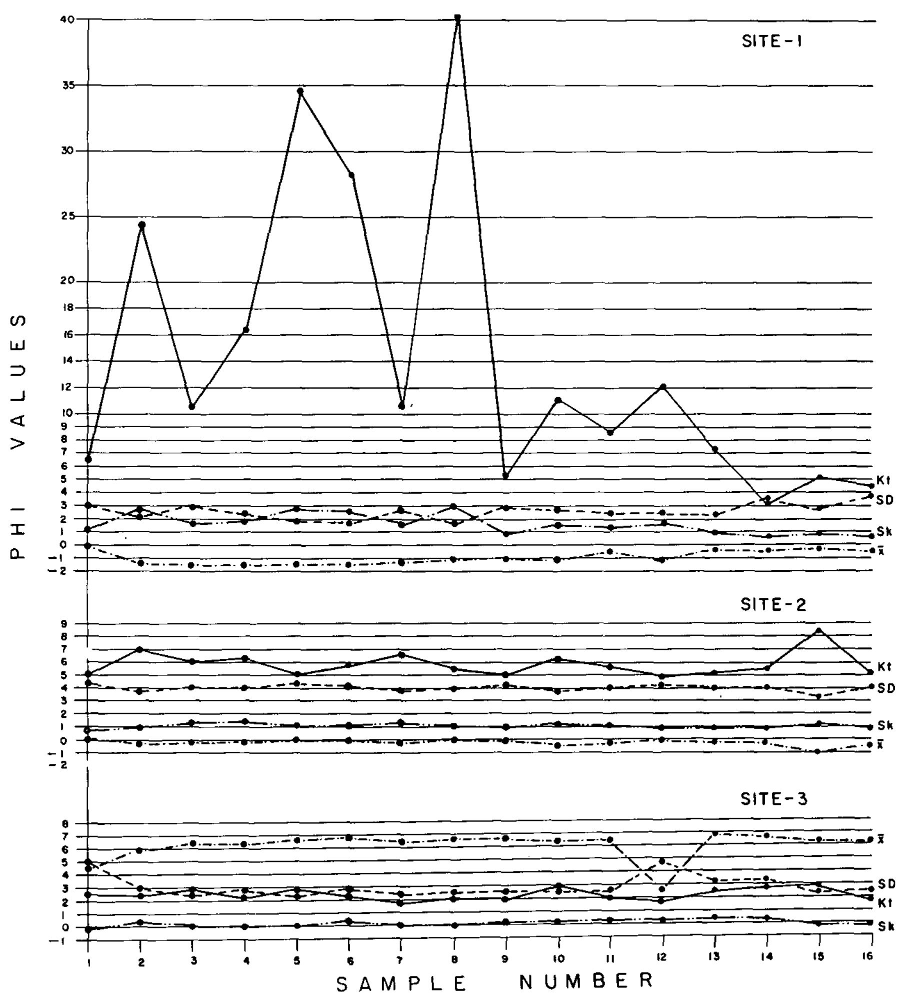

Figure 8: Variation diagram of textural statistics in terms of phi values for each sample. Various lines represent the following moments: mean (X), standard deviation (SD), skewness (Sk) and kurtosis (Kt) are shown on right hand side of diagram for each site. Circles represent graphical position of these moments for each sample at each site.

Acknowledgements

Although this portion of the project was not extensive in terms of the overall AOL program with Shelf Diver, many groups contributed to its success as they did to that of the preceding geological projects. My thanks go to Mr. James Dudley, pilot of Shelf Diver, and to his technical crew that supplied the necessary services to have the submersible available at all times, and to Captain J.A. Oulette, Master of CCGS C.D. HOWE, who, with his officers, handled the submarine 102 times over the entire operation without mishap. A special debt is owed to the divers of the Royal Canadian Navy, and on this portion of the cruise to Lieutenant Barry Ridgewell, who directed his divers on this successful sampling operation. Finally, thanks must be rendered to our AOL photographers, Mr. N.E. Fenerty and Mr. R.J. Belanger, who installed the camera equipment, advised on film, and took considerable footage. The writer also thanks C.T. Schafer, G. Drapeau and G. Vilks for their critical review of the manuscript and the advice given.

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