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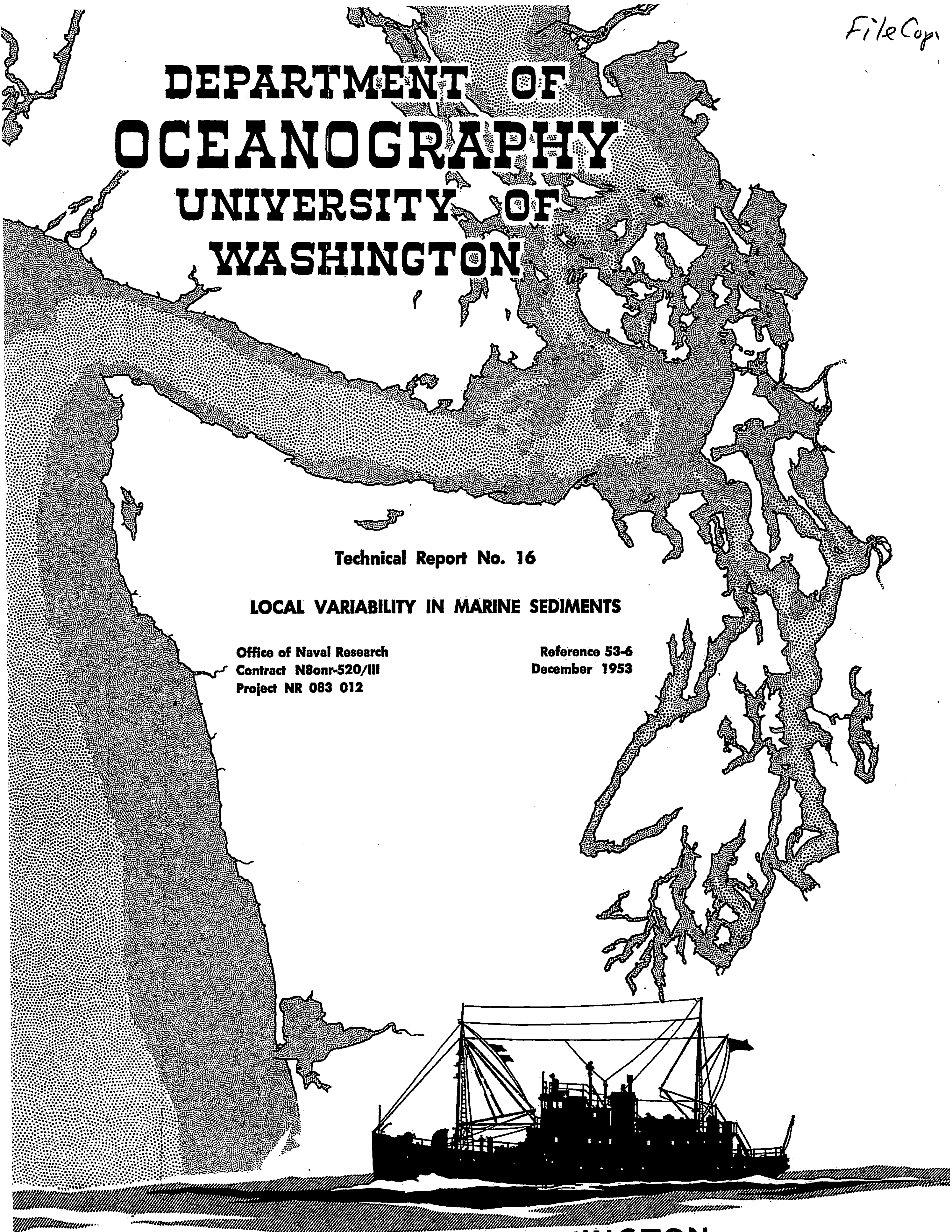

Technical Report No. 16

LOCAL VARIABILITY IN MARINE SEDIMENTS

Office of Naval Research
Contract N8onr-520/III
Project NR 083 012

Reference 53-6
December 1953

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by

Richard G. Bader

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Richard H. Fleming
Executive Officer

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ABSTRACT

This investigation was undertaken in order to determine the variability in particle size distribution over small horizontal distances in a section across central Puget Sound. Sampling was accomplished by means of a device which simultaneously obtained three cores, spaced in a triangular pattern, one foot apart.

The degree of variability found indicates that defining of sediments in this, or similar regions, by use of isolines based on statistical parameters from individual cores may be misleading. Apparently, the local variability decreases with increasing depth on the slopes and is at a minimum on the nearly flat bottom between the slopes. The greatest discrepancies between the closely spaced cores occur in samples with median diameters in the smaller sand sizes.

LOCAL VARIABILITY IN MARINE SEDIMENTS

INTRODUCTION

The sampling problem involved in obtaining any natural sample is often exceedingly complex and has received much consideration in the literature. In the process of obtaining any one sediment sample by means of a coring tube or other sampling device, only an exceedingly minute portion of the sea bottom is sampled. In a strict sense any single sample is merely representative of the exact spot sampled. Unless the process of sampling continues systematically in this and adjacent areas, radial extrapolation from the sample is subject to great error, with any single sample being representative of only itself. The introduction of this limitation on problems of sedimentation or sedimentary environmental studies, whether they be physical, chemical, or biological, presents a serious handicap. In order to proceed with any sedimentary research it is necessary to know the limitations of the samples obtained and to understand, at least to some degree, the existing local variations and the probabilities for such variations.

The purpose of this paper is to briefly present some of the initial results concerning a problem of sampling marine sediments in the region of Puget Sound, in the State of Washington. The information to date consists of the data from a particle size analysis of the bottom sediments obtained along an east-west traverse of Puget Sound, about 12 miles north of the city of Seattle.

REGIONAL DESCRIPTION

Puget Sound is a pre-existent valley system which has been partially drowned by the sea. It is one of the deepest salt water basins in the United States. The mid-channel bottom area exceeds 900 feet in depth in some localities. Depths of 600 or more feet below sea level are usually encountered in the channel portions of the Sound. Except for local areas, the shore slopes and underwater slopes are steep; inclines of 25 degrees are common.

The topography of the Puget Sound area is due primarily to glacial action by a lobe of the Cordillerian ice sheet. The shore line is bordered by deposits of clay, sand, gravel and till, reminiscent of the glacial control. These glacier-derived sediments often form shore line cliffs 200 or more feet high.

Glacial till is a prominent source of sediments in Puget Sound and may become a part of the marine sediment in various ways. (1) The slopes may be in part composed of glacial deposits in situ. (2) The erosion of cliffs and beaches will also be a supply of glacial sediments. (3) The streams are imposed on glacial till and will transport this material to the marine environment. (4) Slumping of the cliffs, which are composed of glacial deposits, will add to the marine sediments.

Chemically and mechanically weathered material from the basement rocks of the Cascade and Olympic Mountains contributes to the sediments as they are carried to the Sound by the numerous streams and rivers. Volcanics, from direct dust-falls and from inland erosion, probably account for some sediment supply in the Sound.

In the area of sampling (Figure I), between President Point on the west shore and Point Wells on the east, the bottom configuration is analogous to the steep shore bluffs. The eastern underwater slope is generally steep and continuous with a value of 1:3.5 from a single [illegible] small [illegible] base [illegible] the slope which [illegible] a few localities have slopes of 1:1. The western slope is not as continuous, being divided into areas with different slope angles. Some portions are exceedingly steep with values as great as 1:3, others have gradual slopes with an average value of 1:15. This suggests that bathymetrically the two slopes are different (See Figure III). In this region the slope areas account for about one-half of the total sound width of 3.7 miles. The mid-channel region, representing the remaining one-half, is relatively flat with a maximum relief of about 70 feet.

METHOD OF SAMPLING AND ANALYSIS

Initial examination of core samples from Puget Sound indicated that extreme variability in particle size existed. It was suspected that this variability occurred over exceedingly small horizontal distances. In order to study the variability both horizontally as well as vertically, over small horizontal distances, a device was designed to simultaneously obtain three cores spaced in a triangular pattern, 1 foot apart (Figure II). The cores obtained by this method were cut into sections 4 cm. in length from the surface down, thus three approximately equal surface samples and three samples for every subsequent 4 cm. in depth were obtained for analysis. Some 60 locations on a traverse across Puget Sound have been sampled, making available for comparison the data obtained from the analysis of 180 cores.

(Figure III gives the location of these samples.) The sampling of approximately 18 to 20 locations in the mid-channel and on the near shore slopes is planned for the near future.

The vertical sectioning of the cores in the manner just described yielded well over 500 individual samples. Each sample was analyzed for particle size by standard methods. The material coarser than 1/16 mm. in diameter was sieved mechanically, separating it into standard fractions. The material finer than 1/16 mm., previously separated from the sample by wet sieving through a 1/16 mm. sieve, was submitted to a pipette analysis for size determination. This latter method is based upon Stokes Law; that is upon the settling velocities of spheres of a given radius suspended in a fluid of known viscosity.

Since this study deals with the variation in the results obtained in the size analysis of adjacent core samples it is essential to know the analysis error. The standard method briefly described above satisfies this condition in allowing an impartial duplicate analysis of the same sample to be run under essentially standard laboratory conditions. When the reproducibility of the results are known, it is possible to differentiate between inconsistencies due to analysis and the actual variation between samples.

Duplicate analysis of 20 samples indicated that the analysis error was very small, with an average reproducibility for any one size determination of ± 0.2 percent. There was very little divergence from this average, with only about 20 percent exceeding the average by a factor of 2. The probabilities are thus in favor of actual sample variation accounting for percentage differences between adjacent samples which exceed ± 0.4 percent.

INITIAL RESULTS

In order to present a summation of the results obtained, the east-west traverse of the Sound has been divided into three general areas. The eastern and western slope area from sea level down to about 500 feet below sea level represents one division. The lower portion of both slopes, from about 500 feet below sea level to the base of the slopes and adjacent channel areas, represents the second division. The last division is the mid-channel region.

Table I presents some of the differences in grade size percentages between the samples from the three cores obtained simultaneously at one location. The percent differences shown are thus indicative of variations in particle size distribution from samples only 1 foot apart.

Very often the data from sediment size analysis are reported in terms of major fractions; such as sand-silt-clay ratios. Coarse, medium and fine classifications are often used where coarse material includes coarse sands and larger, medium material represents a composite of medium and fine sands and the fine matter is a summation of the amounts of silt and clay. Using such a coarse-medium-fine differentiation for the sediments in this study, the variations in frequency percent between categories of any two adjacent samples is markedly increased. The slope area presents a maximum variation of 33 percent for both the medium and fine fractions. The base of the slopes show a maximum variation between adjacent samples of 18 percent for the medium and fine fraction. The maximum variation for the mid-channel is 10 percent in the medium and fine ranges. The average variation between the same categories of adjacent samples, using this type of classification, is also significantly

TABLE I

Differences in Grade Size Percentages

Size (mm)	Slope Max. %	Slope Min. %	Slope Aver. %	Base of Slope Max. %	Base of Slope Min. %	Base of Slope Aver. %	Mid-channel Max. %	Mid-channel Min. %	Mid-channel Aver. %
4	1	1	1	-	-	-	3	1	1
4-2	2	1	1	1	1	1	1	1	1
2-1	1	1	1	1	1	1	1	1	1
1-1/2	1	1	1	3	1	1	1	1	1
1/2-1/4	18	1	4	1	1	1	1	1	1
1/4-1/8	13	1	4	5	1	2	1	1	1
1/8-1/16	20	1	5	10	1	4	6	1	3

These are approximations based on the analysis of cores from 36 of the 60 locations.

increased. The slope area has an average variation of 10 to 12 percent, the base of the slopes 6 percent, and the mid-channel region 4 percent. 1/

Sediments are often described and/or classified according to statistical characteristics such as mode, median and quartile deviation. In view of this a few examples of the similarities and differences in these factors between immediately adjacent samples shall be presented.

Figure IV, graphically presents the data from two sample locations. Sample 6L1 is located on the east slope at about 560 feet below sea level. Sample 1P2 is from the west slope, approximately 600 feet below sea level. The first sample presents an exceptionally good match between the three adjacent cores. The modes are the same, while the maximum differences between the median diameters is very small, only 0.046 mm. The coefficient of sorting, i.e. the log of the geometric quartile deviation ($\log \sqrt{Q3/Q_1}$), which is indicative of the sorting of the sample, differs by a factor of 1.23. They are all normally sorted sediments ranging from a sorting coefficient of 0.428 to 0.528.

Visual inspection of 1P2 (Figure IV), shows two fairly well matched bimodal curves. The cumulative curves also approximate one another. The median diameters differ by 0.29 mm.; both are poorly sorted with coefficients of 1.088 and 1.100.

Sample 7M1 (Figure V) is located on the west slope at a depth of about 500 feet. The frequency curves for the three adjacent cores are similar; however core A has a mode between 0.125 and 0.065mm., while cores B and C have their modes between 0.065 and 0.031 mm. The median diameters

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1/ The approximate variations given here are the averages of the numerical differences in the percent of each individual category. For example: Core A - 40 percent fine sand; Core B - 20 percent fine sand; the variation in the fine sand is thus 20 percent.

are essentially the same, with only a 0.03 mm. difference. The most striking feature is shown in the numerical value for the sorting; 0.139 for core A and 0.385 for core B. They differ by a factor of 2.87, yet they all represent good sorting. All three cores are generally comparable.

Sample 3P3 (Figure V) shows some divergence between the three adjacent cores. There is a 10 percent difference in the frequency of the major modes. Cores A and B have modes between 0.5 and 0.25 mm. while core C has a mode between 0.125 and 0.0625 mm. This represents a difference of two standard grade sizes. The median diameters have a maximum difference of 0.34 mm., or vary by a factor of 3.10. Sorting is essentially normal in all three cores with coefficients ranging from 0.431 to 0.597.

Sample 5L2 (Figure VI) from the east slope at a water depth of 700 feet shows a marked visual difference. Core A is bimodal while Core B is unimodal. The median diameters and the coefficients of sorting differ by factors of 1.8 and 1.32 respectively. Core A is poorly sorted and core C is normally sorted.

Sample 1P1 (Figure VI) taken from the east slope at a depth of approximately 500 feet shows a striking variation between adjacent cores. Core B is definitely unimodal, with the mode between 0.5 and 0.25 mm. Core C is slightly bimodal with the major mode between 16 and 8 mm. The median diameters differ by a factor of 1.8; the coefficients of sorting by a factor of 1.68. Both are poorly sorted.

The horizontal variation of the median diameters of the particles at particular depths in the cores is shown in Figure VII. Sample P6 shows a good relationship with depth between the median diameters of the three adjacent cores. The remaining samples present varying degrees of divergence in the median diameters.

SUMMARY AND CONCLUSIONS

Since the Puget Sound sediments are a composite of many sources, the sediment system is a complex one. Many of the sampling difficulties probably arise due to the glacial deposits, especially from those in situ and those added by the slumping of the shore bluffs.

From the analysis obtained thus far, it appears that the local variability increases up the slope and that maximum variations commonly occur on the upper slope regions, in areas of about 200 to 300 foot water depth. The degree of reliance for the data of any one core sample, in terms of horizontal extrapolation, decreases as the water depth decreases. It is also apparent from the data obtained that the greatest discrepancies between any two adjacent samples usually occur in the smaller diameter sand sizes.

Differences between adjacent samples mean very little in themselves, but by a continuation of systematic sampling and analysis, coupled with an analysis of variance as a statistical treatment of the data, variation may be placed on a quantitative basis. It is quite possible that definite horizontal and vertical trends in local variations may be defined. A continuation of this study may also assist in the determination of "in situ" glacial deposits, if sampling is carried out on the adjacent land in known glacial sediments.

Marked variations in the character of the sediments will affect the statistical values used to classify the sediments. The defining of the sediments in this or similar regions, by use of isolines or other conventional means based on these statistical values, may be erroneous or at least misleading.

This general method of sampling is not limited to the determination of local variability in physical characteristics of sediments. The sedimentary chemist may find such a study applicable as an introductory investigation of any area. The sedimentary bacteriologist and the neo-ecologist, paleo-ecologist or paleontologist studying the foraminifera and diatom distribution in sediments may consider this or some similar method useful as a preliminary investigation.

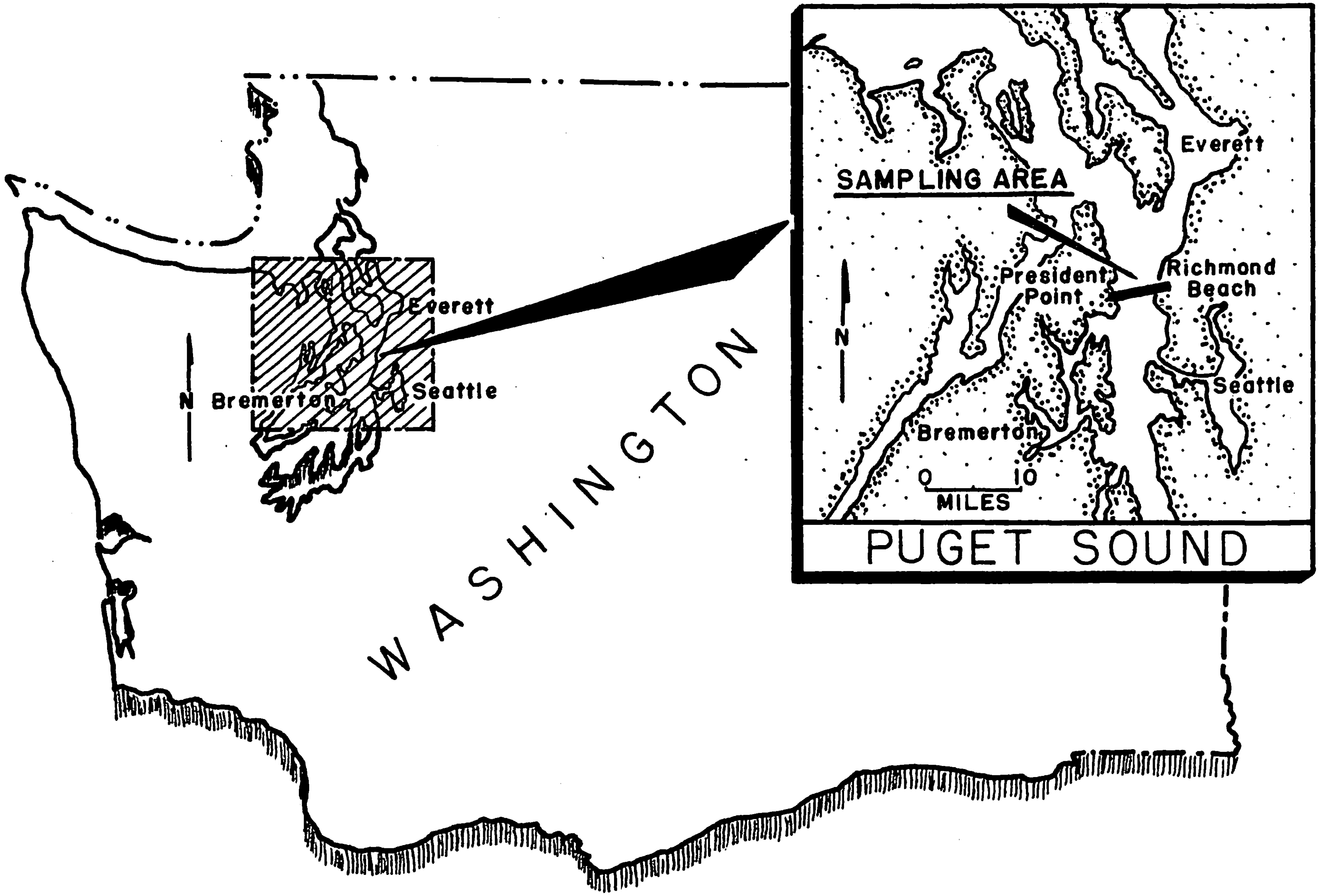

FIGURE 1. Outline map showing the sampling area.

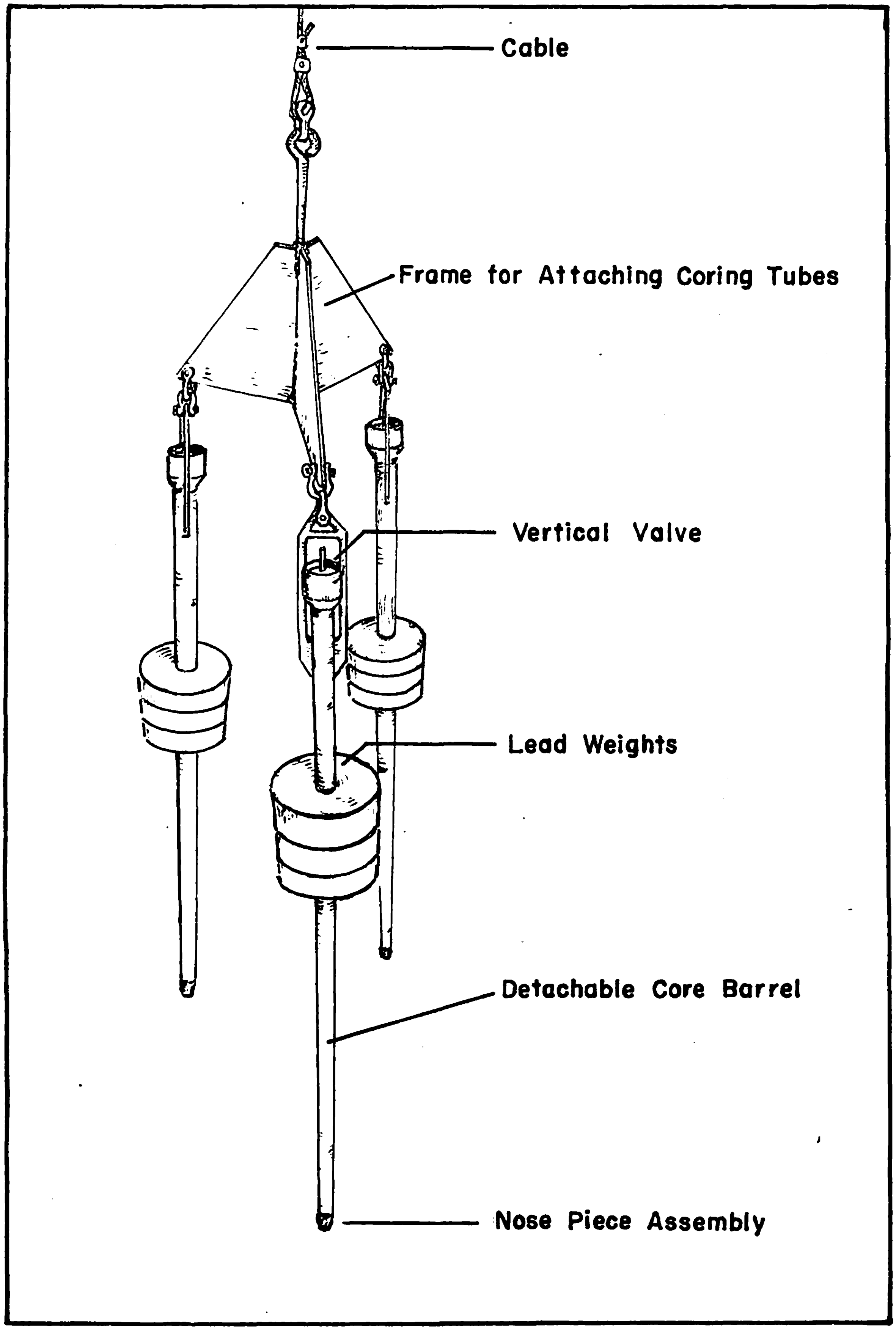

FIGURE 2. Device for obtaining three simultaneous cores.

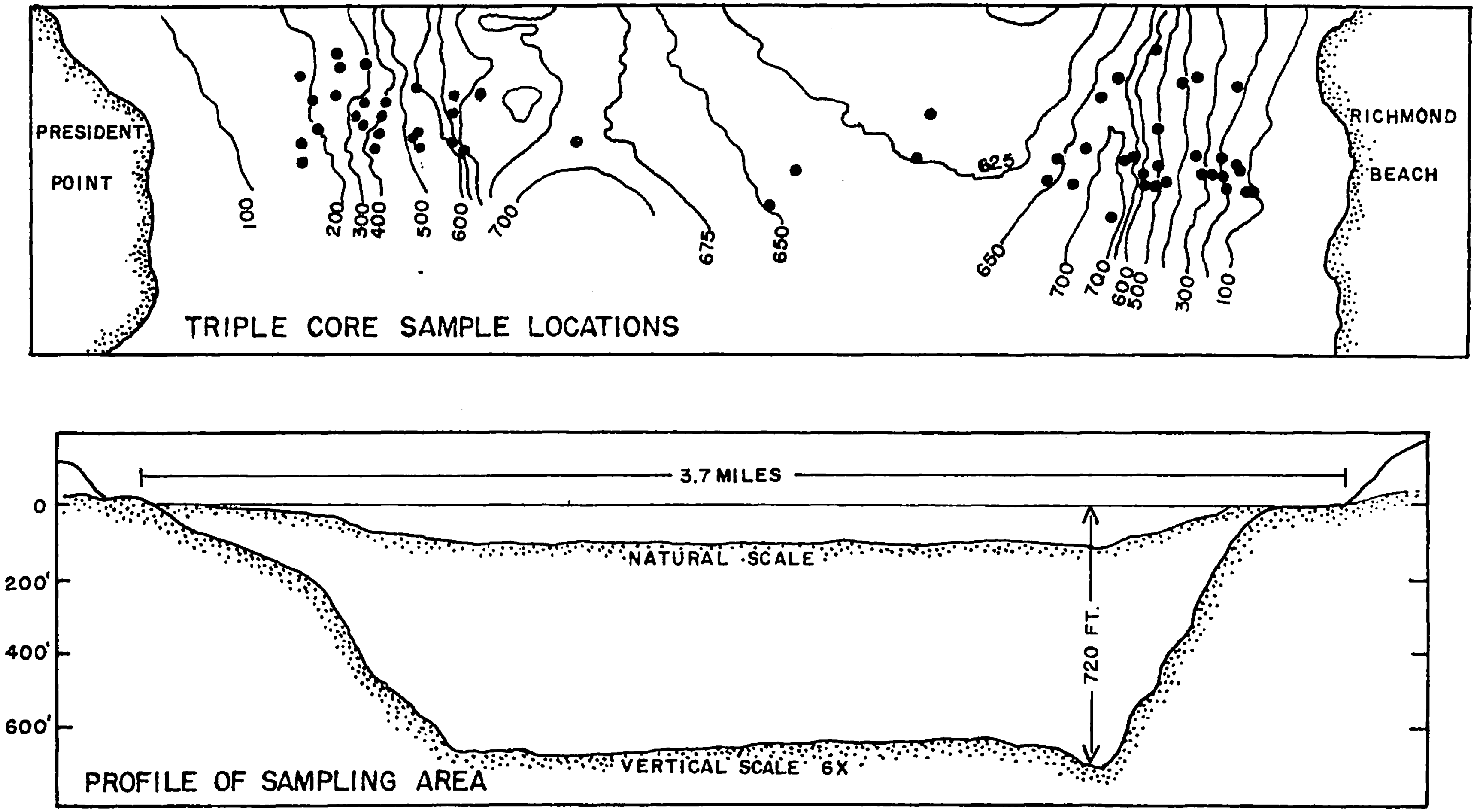

FIGURE 3. Upper half of figure shows sampling locations and bottom contours. Each location indicated was sampled by use of the triple coring device. Lower half of figure is a profile of the sampling area.

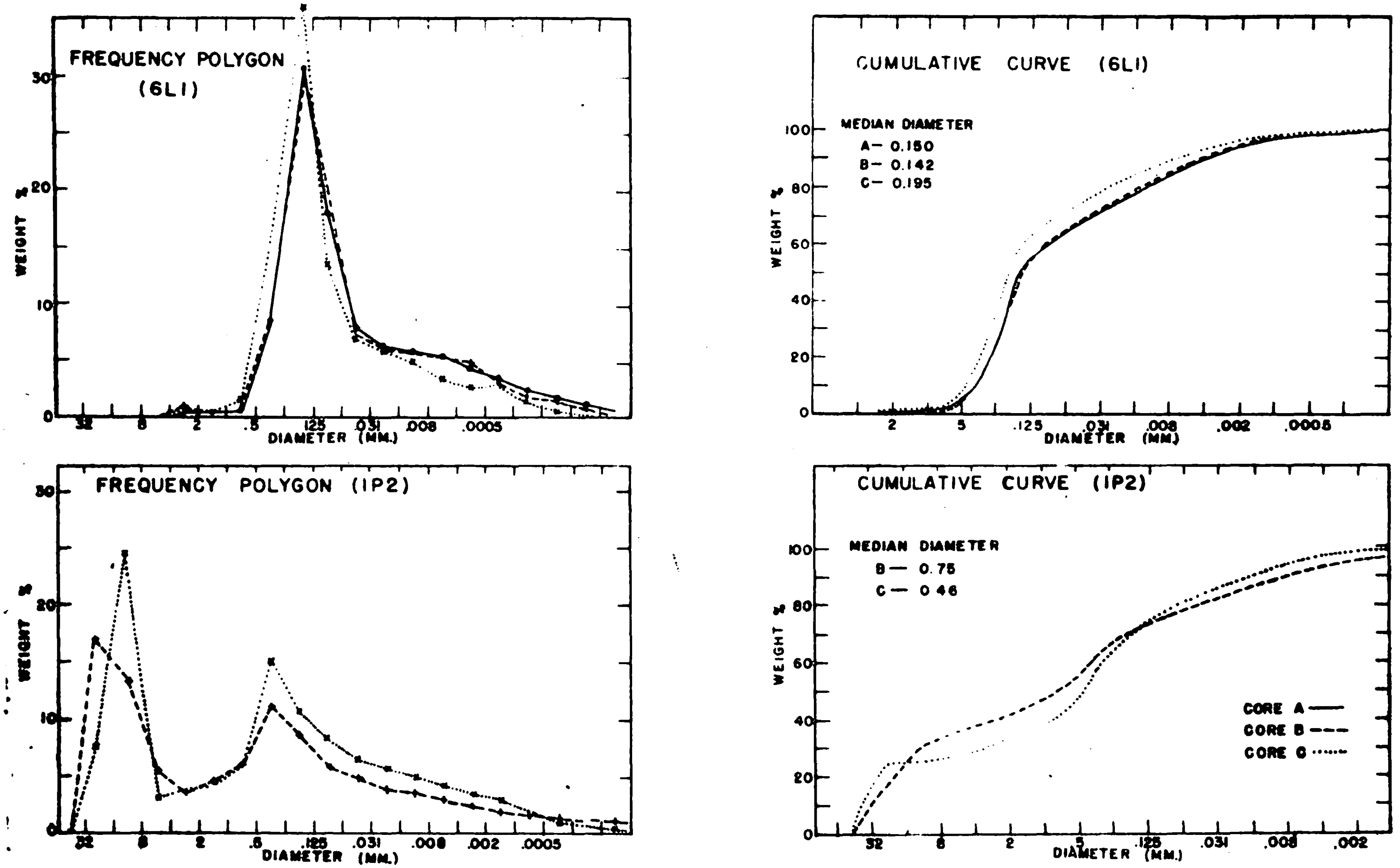

FIGURE 4. Size-frequency polygons and cumulative curves for locations 6L1 and 1P2. 6L1 is located on the east slope at 560 foot depth; 1P2 is located on the west slope at a depth of 600 feet. Both samples show good correspondence between adjacent cores.

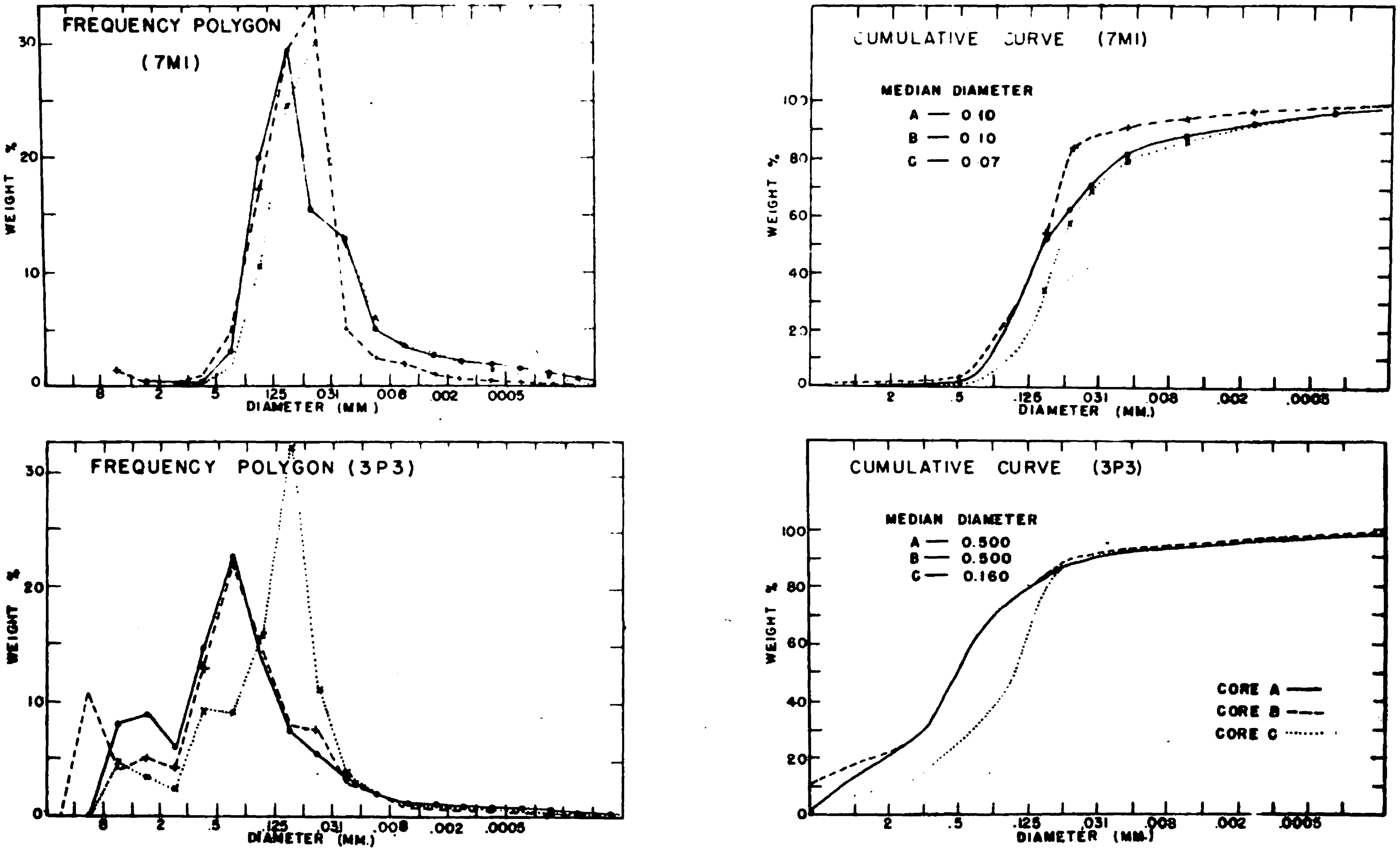

FIGURE 5. Size-frequency polygons and cumulative curves for locations 7M1 and 3P3. 7M1 is located on the west slope at 500 foot depth; 3P3 is located on the east slope at 450 feet. The beginning of divergence between adjacent samples can be observed.

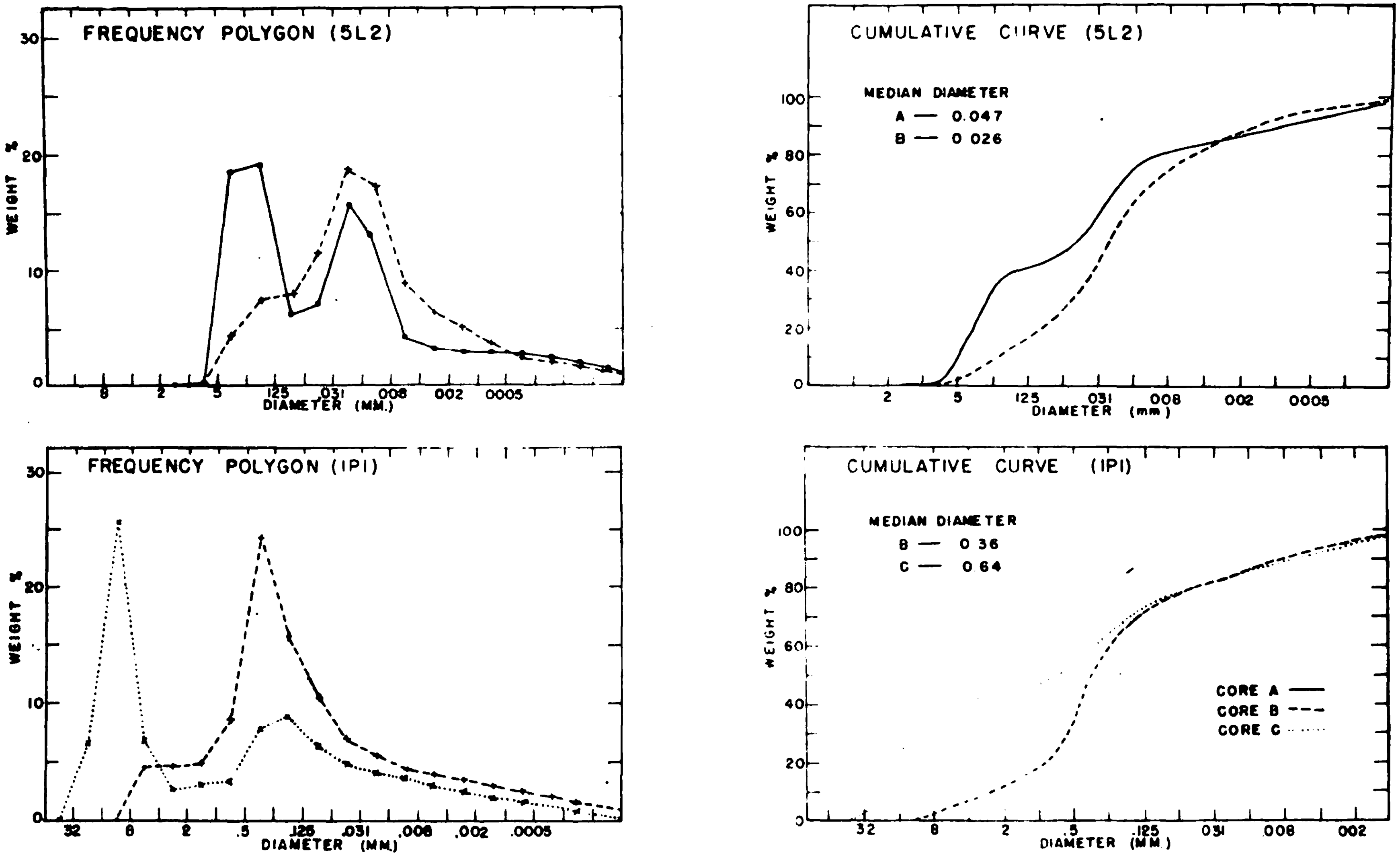

FIGURE 6. Size-frequency polygons and cumulative curves for locations 5L2 and 1P1. 5L2 is located on the east slope at a depth of 500 feet; 1P1 is located on the east slope at 500 foot depth. Marked variations between adjacent cores can be observed.

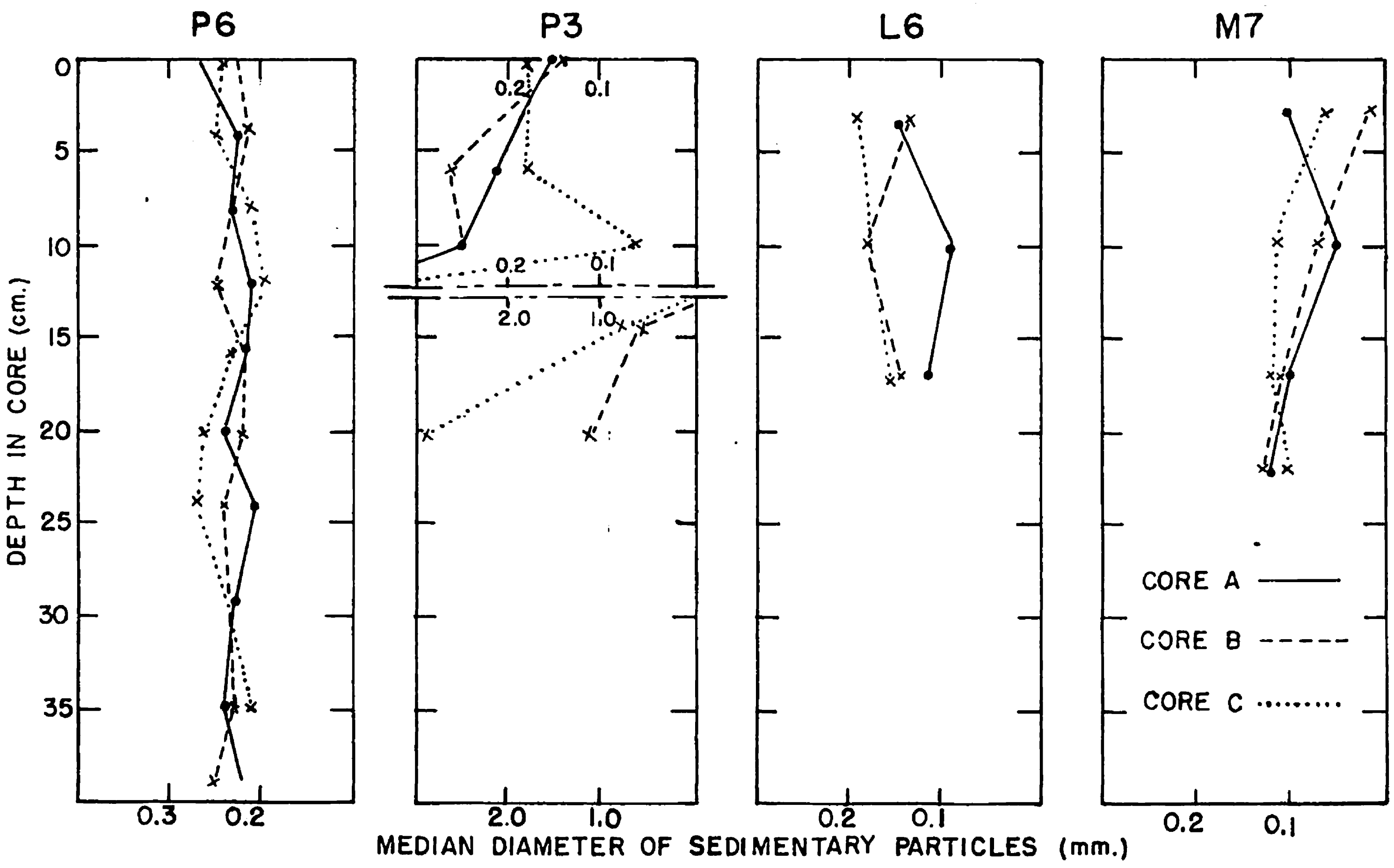

FIGURE 7. Comparison of particle size median diameter with depth in core for adjacent cores from four different locations. Sample P6 shows good correspondence between adjacent cores at all depths. Sample P3 (note change in scale between 10 and 15 cm.) shows good correspondence between adjacent cores on the surface with threefold differences between cores at 10 and 20 cm. depths. Samples L6 and M7 show intermediate divergences with depth.

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