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**GRANULOMETRIC ANALYSIS OF RECENT SEDIMENTS
OF TILLAMOOK BAY, OREGON**

by
GENNARO WILLIAM AVOLIO

**A thesis submitted in partial fulfillment of the
requirements for the degree of**

**MASTER OF SCIENCE
in
EARTH SCIENCE**

**Portland State University
1973**

AN ABSTRACT OF THE THESIS OF Gennaro William Avolio for
the Master of Science in Earth Science presented May 24,
1973.

Title: Granulometric Analysis of Recent Sediments
of Tillamook Bay, Oregon

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

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The author has sampled the recent bottom sediments in Tillamook Bay, Oregon. Sediment distribution is assessed in relation to sediment source areas and related to sedimentary environments. Particular attention was directed to the precision with which granulometric data can be stated. It was found that variance is quite high for granulometric parameters of the bay sediments.

Sediment distribution using different measures are displayed on charts of the bay. Size distributions of sediments at any given location are examined for geologic

significance. Plotting of size distributions on graph paper using probability ordinate is shown to increase the ease of geologic interpretation.

Total heavy minerals were X-rayed and provenance determinations from this and other data show a marine sediment source for a small area of the bay near the mouth and terrestrial source for the remainder of the bay.

TO THE OFFICE OF GRADUATE STUDIES:

The members of the Committee approve the thesis of
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INTRODUCTION

I OBJECTIVES

The objectives of this study are:

1. To describe the sediments in Tillamook Bay in granulometric terms and to display their areal distributions in a pictorial manner,
2. To determine mathematically the precision with which the granulometric data can be stated,
3. To relate the sediment distribution to the sedimentary environment,
4. To assess the relationship of source areas to sediment distribution.

II PURPOSE

Tillamook Bay was chosen for this study as the bay provided several sedimentary environments and these environments would be reflected in the sediment distribution.

No previous sedimentation studies of Tillamook Bay are known. With the increased public interest and emphasis on estuaries, studies are needed to provide comparative data for the future.

III PLAN

Samples were taken in the shortest possible time to reduce the effects of change within the bay on results. Laboratory work was completed during the following academic year. Data is displayed primarily in a pictorial manner on maps or charts.

BACKGROUND INFORMATION

I TILLAMOOK BAY

Tillamook Bay is approximately 10 kilometers (6 miles) long and 5 kilometers (3 miles) wide, the greatest dimension being in a north south direction. The area of the bay is nearly 36 square kilometers (14 square miles) at high water and slightly over 19 square kilometers (7 and 1/2 square miles) at low water. The Corps of Engineers uses a figure of 58,000 acre feet for the tidal prism.

Five rivers flow into the bay, the Miami, Kilchis, Wilson, Trask and Tillamook, and together drain an area of about 1,450 square kilometers (570 square miles).

II PHYSIOGRAPHY

Tillamook Bay (Figure 1) and the five major drainage basins associated with it, are located on the western side of the Oregon Coast Range in the northwest part of Oregon. The coastline of northern Oregon has been described by Kulm and Byrne (1966) as "...a series of beaches interrupted by erosionally resistant headlands and numerous estuaries." On the headlands in the vicinity of Tillamook Bay and on higher ground further inland,

Figure 1. Sketch map of the northern coast of Oregon showing Tillamook Bay and associated drainage basin.

uplifted marine terraces are found. Palmer (1967) identifies an extensive well developed terrace at approximately 130 meters (400 feet) elevation and a terrace at the 250 meters to 300 meters (800 to 900 feet) elevation that is poorly preserved except on the headlands.

To the north of Tillamook Bay the coast consists of a relatively narrow, nearly straight beach with the foothills of the Coast Range rising abruptly within 3 kilometers (two miles) to 550 meters (1700 feet). The outer beach is a typical narrow dune complex which has obstructed the drainage from the foothills. As a result, several fresh water lakes and marshes are located between the beach and the rising topography of the Coast Range. The north jetty, which protects the navigation channel to Tillamook Bay, is the southern terminus of the dune complex. This jetty was constructed between 1913 and 1917 and presently extends 2 kilometers (1.2 miles) westward. Comparison of the present coastline with a chart published by the United States Coast and Geodetic Survey in 1908 indicates that the beach has prograded westward about 0.9 kilometers (0.6 miles) on the north side of the jetty. The exposed area of sand behind the jetty is now about 1.0 square kilometers (0.4 square miles).

In 1927 the north jetty was extended to improve navigation into the bay. The present project depth of eighteen feet for the channel to the town of Garibaldi

has been maintained fairly well with only infrequent dredging. In 1971 construction was started on a south jetty to further improve navigation into the bay.

The outer spit that forms the western boundary of Tillamook Bay is composed of Recent and older (Pleistocene?) dune sand. This spit was breached by storm waves in the winter of 1952. The break was repaired when a Corps of Engineers contract was let in 1956. To the south of the spit is Cape Meares, a bold headland composed primarily of Miocene volcanic rocks.

III CLIMATE

The climate of the northern Oregon coastal area is one of cool, relatively dry summers and cool, wet winters. A mean annual precipitation of about 190 centimeters (75 inches) with mean summer temperature of 14°C (59°F) and mean winter temperature of 6°C (42°F) characterize the climate. Seasonal wind patterns have been described by Cooper (1958). Onshore winds from the north-northwest are the most common in spring, summer and fall. Most of the time during the winter months the winds are offshore with fairly low velocity. Winter storms, however, bring high velocity winds from the south to southwest. The dimensions and orientation of Tillamook Bay are such that both the north-northwest and southwest winds can build a quite extensive wave system at the north or south end of

the bay.

IV REGIONAL GEOLOGY

The rivers that empty into the bay drain part of the western slope of the northern Coast Range. The rocks of the Coast Range consist of Tertiary volcanics, both submarine and subaerial, and marine sediments, gently folded into an anticlinorium, so that in the Tillamook area dips are predominantly to the west.

Geologic formations in the drainage area of the rivers flowing into Tillamook Bay include the Siletz River Volcanics, the Tillamook Volcanic series, the Nestucca Formation, Miocene intrusive and flow rocks, and the Astoria Formation.

The Siletz River Volcanic Series is early Eocene and, as noted below, is correlative with the lower Tillamook Volcanic Series.

The term Tillamook Volcanic Series was assigned by Warren and others (1945) to an accumulation of Eocene Volcanic rocks in northwestern Oregon. The younger parts of this series are now referred to the Goble Volcanics and the Nestucca Formation while the older parts are commonly referred to as parts of the Siletz River Volcanic Series, originally described by Snively and Baldwin (1948). It consists of some thousands of feet of marine basaltic flows, pillows, flow breccias and pyroclastics.

The mineralogy of the basalts consists of labradorite, augite and titaniferous magnetite as major constituents and calcite, stilbite, natrolite and mordenite as secondary minerals. Volcanic glass is found in varying amounts and chloritization is ubiquitous. The pillow lavas of the lower section are tholeiitic and high in the section alkalic derivatives can be found locally (Snively and others 1968).

The Nestucca Formation (Snively and Vokes 1949) is composed of interbedded tuffaceous siltstones and claystones. In the lower part of the section some cross bedded and carbonaceous feldspathic sandstone is found. In the northern portion of the area, basaltic flows with associated pillows, breccias and other pyroclastic rocks are found also. The Nestucca is late Eocene in age.

Miocene intrusive and flow rocks of the Coast Range commonly are granophyric gabbro, composed of labradorite and augite with interstitial quartz, orthoclase and accessory minerals.

The Astoria Formation is described by Howe (1926), Dodds (1963), and Snively and others (1969) among others. The lithology of rocks assigned to this formation is characteristically sandstone interbedded with what is called silty shale but in actuality are more properly called mud rocks as the fissillity is almost non-existent. The sandstone is yellow to gray, massive to

cross bedded, medium to fine grained and feldspathic. There are local areas of micaceous and tuffaceous beds.

Rocks usually referred to be Astoria Formation contain beds that have been assigned ages from Oligocene through late Miocene (Dodds 1956).

V BATHYMETRY

The bathymetry of Tillamook Bay, as can be seen in Figure 2, is fairly complex with numerous dendritic channels. However, it may be divided into two zones:

1. Tidal channels and estuaries characterized by being under water except at the lowest tides, and
2. Tidal and grass flats that are exposed at low tide.

The major portion (over 70 percent) of the bay is in the latter classification.

That area to the south and east where the outline of the bay is not shown on Figure 2 is covered with vegetation and was not sampled in this study.

VI HYDROLOGY

Tillamook Bay has been classified by Burt and McAllister (1959) using the system of Prichard (1955). This system is based on salinity of water on the surface and bottom at selected sample locations. Burt and McAllister use three definitions to classify Tillamook Bay.

Figure 2. Bathymetry and station locations in Tillamook Bay. The zero reference datum is mean lower low water.

When the difference in salinity between top and bottom water exceeds twenty parts per thousand the estuary is said to be two-layered. When the difference ranges between four and nineteen parts per thousand the area is classified as partly mixed, and when the difference is less than four parts per thousand, the area is well-mixed.

Data reported by Burt and McAllister shows Tillamook Bay to be two-layered 10 kilometers (6 miles) from the mouth of the bay in January. During April and October respectively, the bay is well-mixed 10 kilometers (6 miles) from the mouth and 13 kilometers (8 miles) from the mouth. Their study was too limited to reveal the dates of transitions or any other fluctuations which may occur.

The classification depends on the amount of tidal energy available and the amount of river discharge. The tidal energy remains more or less constant throughout the year while the runoff fluctuates seasonally. During times of low discharge tidal energy is capable of mixing the fresh water and sea water so that little or no change in salinity occurs from top to bottom. As fresh water discharge increases, a point is reached where there is not enough energy to mix the salt and fresh water. Then vertically homogenous conditions no longer prevail and either partly mixed or two-layered conditions exist.

As has been pointed out by Blanton (1969),

flushing time, or the time for a particle to be flushed out of the estuary, is affected by fresh water discharge. A short flushing time is associated with high discharge and long flushing time with low discharge. Pollutants may remain in an estuary for a long time during periods of low discharge.

VII CUT AND FILL

A study of navigation bathymetric charts published since 1908 reveals that both erosion and deposition have been taking place in the bay with deposition being the dominant process. Figure 3 shows areas of cut and fill since 1928. (The year 1928 was chosen because of the possibility of earlier charts using a different reference datum.) The areas shown as fill in Figure 3 are those areas that are shallower on the current United States Coast and Geodetic Survey chart than on the 1928 chart. Those areas shown as cut, conversely, are areas that are deeper now than in 1928. Charts between 1928 and the present were checked to see if there were areas of changing process. Generally those areas shown as fill have been filling since 1928. Areas of cut have not been so stable and within the bay those areas shown as cut or erosion have not been constantly eroding since 1928.

The United States Coast and Geodetic Survey charts are designed primarily for use by mariners and

Figure 3. Cut and fill areas in Tillamook Bay.

consequently do not show water depths less than zero. This means that filling can occur in these areas and no change will show on the charts. That portion of the bay to the south of the large fill area in the center of the bay is such an area and probably has filled also, even though not shown as fill in the figure. The general trend seems to be that the bay is filling from south to north.

VIII CLIMATIC INFLUENCE

Kulm and Byrne (1966) state that because of the constancy of tidal and basin characteristics, the primary factor which determines the change in estuarine system is river discharge. River discharge is in turn related to precipitation. They point out that on the southern Oregon coast a marked increase in precipitation in October is not reflected by an increase in runoff as shown by salinity until about a month later. This pattern is probably the same in Tillamook Bay also, but data is not available to assess at this time.

One other possible climatic control of the estuarine system is storm wave mixing. As noted before, the location and orientation of Tillamook Bay is such that prevailing winds sometimes create a wind driven chop and over large areas of the bay these waves "feel" the bottom and aid

the mixing as well as assist in moving sand and silt sized particles.

The author observed a typical summer day with a northwest wind of about 450 meters per minute (15 miles per hour). This weather, within a few hours, built up a chop with a wave height of nearly one meter. These were relatively short steep waves so the wave length was on the order of six meters. These waves could easily affect the bottom at three meters and probably deeper.

IX ESTUARINE CURRENTS

Currents, as pointed out by Burt and McAllister (1959), are to a large degree controlled by the type of estuarine system. Some estuaries in Oregon, when well-mixed, display a slow net drift of water in a seaward direction at all depths. When partly-mixed, they show a net upstream movement along the bottom and net seaward movement on the surface. No measurements were taken in Tillamook Bay to establish the currents to see if these patterns hold true to type. The United States Corps of Engineers did attempt to measure currents in the outer channel but the equipment carried away at twelve feet per second and the United States Coast Pilot shows a current velocity of up to three knots in the channel. Inside of the bay proper no extensive and continuous measurements of currents have been made.

X PREVIOUS WORK

No previous geologic studies have been made of the bay system. However, coastal land forms including dunes and terraces are discussed by Twenhofel (1943 and 1946), Dicken (1955), Cooper (1958), McKay (1962), Baldwin (1964), North and Byrne (1965) and Palmer (1967). Kulm, Schedegger and Spigai (1968) reported on the heavy mineral assemblages of Oregon and northern California coastal rivers. Brown, Clark and Pope (1958) describe the closure of the break of the Bayocean Peninsula and the recent erosional history of the spit.

Geology of the northern Coast Range has been done by numerous workers, among them Warren and others (1945) and Brown (1956). Schlicker and others (1972) describe the engineering geology and geologic hazards of Tillamook and Clatsop counties.

INVESTIGATIVE PROCEDURES

I FIELD SAMPLING PLAN

A rational sampling plan was made to take into account any previous information available. An initial prediction was made that sediment physical parameters are strongly dependent upon water depth, with the assumption that within the bay the deeper the water, the higher the energy or faster the current. This is assumed to be the primary controlling agent for determining particle size parameters. Sediment descriptions involving size characteristics are incomplete without an assessment of variability or variance. For a discussion of this subject as related to geology see Krumbein and Graybill (1965) and for a statistical approach see Cochran (1963). Accordingly, steps were taken to assess this factor.

An initial survey was conducted and three samples were taken from 0 meters, 1 meter (3 feet) and 2 meters (6 feet) depths. The datum plane is mean lower low water. Lower low water is the lowest of the two daily low tides. Three grabs were taken at each station by successive lowering of the sampler. The upper 0.5 centimeter of each grab was sampled three times for analysis. The sampling scheme is a three stage nested plan and allows

a three level nested analysis of variance program (Table I). Three level random nested models for the analysis of variance are described by Krumbein and Graybill (1965) and Cochran (1963).

Variance was analyzed using the terms shown in Table I. The analysis of variance (Table II) of the preliminary stations indicates a greater variance between stations than between samples. Ranking of variance estimates is done by comparing F ratios. The higher the F ratio the better one is able to discriminate between stations with that measure.

At the next level, the between-subsample variation of sorting and skewness is greater than the between-sample variation. Because of this, to increase precision of the values of percent sand, percent silt and median phi, one would increase the number of samples, not subsamples. Conversely, to increase precision on measures of sorting and skewness, one would increase the number of subsamples.

One other computation was done on the data before proceeding. Contour lines separated by $2.48\sqrt{\sigma_x^2}$ (where σ_x^2 is the variance estimate for the station mean) can be resolved at the 90 percent confidence level and a power of 0.8 (McIntire 1963).

If $\sqrt{\sigma_x^2} \leq 0.0404$ then 0.5 phi is a reasonable contour interval for median phi. In the case of the preliminary

TABLE I

NESTED ANALYSIS OF VARIANCE TABLE (PRELIMINARY STATIONS)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Expected Mean Square		
Total	SS_{tot}	26				
Among Stations	SS_{sta}	2	MS_{sta}	σ_{sub}	$2\sigma_{sam}$	$4\sigma_{sta}$
Among Samples Within Stations	SS_{sam}	6	MS_{sam}	σ_{sub}	$2\sigma_{sam}$	
Among Sub-Samples Within Grabs	SS_{sub}	18	MS_{sub}	σ_{sub}		

TABLE II

ANALYSIS OF VARIANCE STATISTICS (PRELIMINARY SAMPLES)

SV	DF	SS	MS	F
<u>Percent Sand</u>				
Station	2	15,468.08	7,734.04	210.30
Sample	6	220.66	36.78	1.34
Subsample	18	495.33	27.52	
Total	26	16,184.08		
<u>Percent Silt</u>				
Station	2	10,170.29	5,085.16	188.34
Sample	6	162.00	27.00	1.83
Subsample	18	266.00	14.78	
Total	26	10,598.30		
<u>Median Phi</u>				
Station	2	32.24	16.12	297.42
Sample	6	0.33	0.05	2.12
Subsample	18	0.46	0.03	
Total	26	33.03		
<u>Sorting</u>				
Station	2	14.18	7.09	46.29
Sample	6	0.92	0.15	<1.0
Subsample	18	3.93	0.22	
Total	26	19.04		
<u>Skewness</u>				
Station	2	156,586.69	78,293.34	13.01
Sample	6	36,104.01	6,017.33	<1.0
Subsample	18	289,657.37	16,092.07	
Total	26	482,348.07		

samples, $\sqrt{\sigma_x^2}$ 0.04 indicating that a 0.5 phi contour interval is the closest that can be justified (see Table III).

Compared to other published work, the level of precision calculated for the preliminary samples in Tillamook Bay seems very poor. Contouring of median phi at 0.1 phi is frequently seen in the literature. None of the literature examined by the author, where median phi was contoured at close intervals, included any reference to the method used to determine contour interval. One study did calculate contour interval (Kelly and Mc Manus 1969) and used the relatively large interval of 0.75 phi units. It is probable that contouring at close phi intervals is frequently done on the basis of intuition rather than computation. High levels of variance that do not allow close interval contouring, such as found in Tillamook Bay, could cause the suspicion that the analysis is not being done with enough accuracy.

For this reason, one sample was reanalyzed and the variance for median phi estimated. This estimate was 0.21 and is in close agreement with other reported estimates as being what one could expect for experimental error (Krumbein 1934). Kelly and McManus (1969) report that sediments of the North Pacific shelf off the coasts of Oregon and Washington are variable enough to require three samples per station and three subsamples per sample

TABLE III
F RATIOS AND BETWEEN STATION MINIMUM RESOLVABLE
DIFFERENCES FOR GRANULOMETRIC VARIABLES
(PRELIMINARY SAMPLES)

Variable	F_1	F_2	MRD
Percent sand	210.36	1.34	5.31 percent
Percent silt	188.34	1.83	6.29 percent
Median phi	297.42	2.12	0.51 phi
Sorting	46.29	0.70	0.17
Skewness	13.01	0.37	11.16

$$F_1 = \frac{\text{MS among stations}}{\text{MS among samples}}$$

$$F_2 = \frac{\text{MS among samples}}{\text{MS among subsamples}}$$

to obtain enough precision to contour median ϕ at the 0.5 ϕ interval. This is based on a within-station variance of 0.22 for sediments on the North Pacific shelf.

On the basis of the foregoing preliminary data analysis the following sampling system for the bay was developed. The design of the sampling plan is determined by the degree of precision desired and the cost of obtaining and analyzing samples and subsamples. The major factor in the design was cost, including time. It was decided that a maximum of one hundred sets of data could be analyzed and samples or subsamples were equally costly.

It was also decided to stratify the bay into populations based on water depth since water depth is considered an indicator of sedimentary environment. These populations are a 2 meter population from -1 meter to -3 meter, the 4 meter population from -3 meter to -5 meter, and so forth. The depths are based on a zero datum of mean lower low water. Because of the possibility of some of the granulometric measures varying systematically from the mouth to the head of the bay, samples were taken at regular intervals from north to south.

The final sampling plan is as follows: The entire bay was divided into populations based on water depth and each population was sampled systematically along the north-south axis of the bay. The stations were sampled twice

and the samples were not subsampled.

This final sampling plan cannot be defined as random, because the samples from each population were taken in a systematic, not random manner, so the statistics describing attributes of a population or the bay as a whole must be used with caution.

Sediments were collected from thirty-five locations in the bay plus some additional samples from nearby beaches, dunes and from the rivers feeding the bay (Figure 2). Samples were collected from a nineteen foot skiff with a small crane system installed to lower and retrieve the sampler. The sampler was a United States Geological Survey grab sampler type BM 54 (Figures 4a and 4b), which takes a half cylindrical sample of about 500 cubic centimeters, depending on depth of penetration. The sample-taking apparatus is housed in a streamlined cast iron housing which weighs approximately 70 pounds. The weight and streamlined shape allow the sampler to operate in quite high currents without tipping or failing to reach the bottom. This feature is quite valuable in estuaries as current strengths can be considerable.

The trip system on the sampler required that most of the weight be off the cable to operate the release and take the sample. Because of this, samples taken in soft mud might not be surface samples since the sampler might sink into the mud before activating. The sampler did

Figure 4a. B. M. 54 sampler ready to take sample.

Figure 4b. B. M. 54 sampler after taking sample.

seem to preserve sediment orientation and every effort was made to transfer samples from the sampler to the storage container without destroying this orientation.

With sample orientation preserved, only the top layer was removed for analysis in the hope that only one sedimentation unit would be sampled.

Sampling was completed during August of 1971. It is believed that the time involved was short enough that no significant changes occurred in the sediments of the bay during the sampling period.

II TEXTURAL ANALYSIS

Samples were kept in a moist state and no disaggregation was done in an attempt to maintain the sediment in its natural state. To obtain the material from the sample for analysis, approximately 25 cubic centimeters was carefully removed from the top of each sample. Every effort was made to analyze only one sedimentation unit (Otto 1928), however, it is believed that this was not always successful. The inability to examine a single sedimentation unit, as will be noted later, causes difficulty in interpreting the results of the granulometric analysis.

The 25 cubic centimeters from each sample was wet sieved through a 63 micron sieve. The coarser-than 63 micron fraction was dried and sieved in a Ro-Tap. The

finer than 63 micron fraction was analyzed by pipette. The resulting data were combined for plotting on graph paper.

III HEAVY MINERAL ANALYSIS

Heavy minerals were separated from selected samples by using tetrabromoethane which has a specific gravity of 2.96 at 20°C. After removal of the magnetic fraction with a hand magnet, the remainder was ground in a mortar to -200 mesh. This powder was mixed with Duco cement as a slurry and mounted on petrographic microscope slides for X-ray diffraction (Pryor and Hestor 1969). The mounted samples were irradiated at a scan rate of $4^{\circ} 2 \theta$ per minute from 10° to $50^{\circ} 2 \theta$. The purpose of this technique is to provide an X-ray diffraction "fingerprint" of the heavy mineral assemblage, not to identify individual heavy minerals. The technique provides a rapid method of comparing the heavy mineral assemblage of any two locations.

IV CLAY MINERAL ANALYSIS

Two samples of the less than 2 micron suspended sediment from the bay were mounted for electron microscope observation. To make the mount for observation, a thin layer of polyvinyl chloride was placed on a 200 wire per inch copper grid. A drop of the sample suspension was

put on the grid with a pipette and allowed to dry. The sample was then placed in a high vacuum chamber and a thin layer of carbon was evaporated over the sample. The samples were then placed in the microscope for observation.

V GRANULOMETRY

Analysis of Variance

To obtain the data for analysis, the size characteristics of the sediments were plotted on probability graph paper. The measures used, percentage of sand, percentage of silt, median phi, sorting and skewness, were derived graphically. Sorting and skewness used are the Inclusive graphic standard deviation (σ_I) and Inclusive graphic skewness (Sk_I) of Folk (1968). Where $\sigma_I =$

$$\frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6} \text{ and } Sk_I = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} +$$

$$\frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_5)}.$$

These two statistics are not totally

independent and when using graphic measures they are not completely independent of the median. Consequently, caution should be used when interpreting these statistics.

Analysis of variance was computed using the hierarchy in Table IV. Computations for the variance analysis were done on an IBM 1130 computer. The results for the bay as a whole are summarized in Table V.

Ranking the F values shows that median phi is the measure most capable of discriminating between stations

TABLE IV

NESTED ANALYSIS OF VARIANCE TABLE (POPULATION TOTAL)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Expected Mean Square
Total	SS_{tot}	69		
Between Station	SS_{sta}	35	MS_{sta}	$\sigma_{sam} + 2\sigma_{sta}$
Between Samples Within Stations	SS_{sam}	34	MS_{sam}	σ_{sam}

TABLE V
ANALYSIS OF VARIANCE STATISTICS (POPULATION TOTAL)

SV	DF	SS	MS	F
<u>Percent Sand</u>				
Station	34	33,253.16	978.03	6.92
Sample	35	4,943.50		
Total	69	38,196.66		
<u>Percent Silt</u>				
Station	34	30,467.37	896.10	7.35
Sample	35	4,265.50		
Total	69	34,732.87		
<u>Median Phi</u>				
Station	34	52.93	1.56	8.73
Sample	35	6.63	0.19	
Total	69	59.55		
<u>Sorting</u>				
Station	34	16.52	0.486	3.59
Sample	35	4.74	0.135	
Total	69	21.26		
<u>Skewness</u>				
Station	34	5,433,242.01	159,801.22	4.50
Sample	35	1,242,734.25	35,506.69	
Total	69	6,675,976.26		

within the populations. Skewness has a higher F ratio than sorting; this is reversed from the preliminary sample data.

The column labeled MRD (Minimum Resolvable Difference) in Table VI is the minimum value that will give an appropriate T-test at the 90 percent confidence level. For the total population, as shown with the preliminary data, using median phi as an example, one can distinguish between two stations if $D = (2.612) (\sqrt{\sigma_x^2})$ where σ_x^2 is the estimator of the station variance and D = difference. Inserting the appropriate value and computing for D shows that the minimum resolvable difference for median phi is 0.80 phi units. Accordingly, median phi was contoured at a 1 phi interval (Figure 5). The reasons for choosing 1 phi rather than 0.8 phi are a desire for simplification in the display and a feeling that contours labeled 0.8, 1.6, 3.4, and so forth, would create the mistaken impression that the figure is significant at 0.1 phi units.

Even though the minimum resolvable difference is not a very powerful statistic, it was chosen in order to allow some geologic interpretation. A much more powerful statistic would be the minimum significant difference of the Tukey method (Sheffé 1959). This test yields values of nearly 2 phi for median phi and values with this order of magnitude for the other measures also.

Figure 5. Distribution of median grain size of sediments in Tillamook Bay. Contour interval 1 phi.

The minimum significant difference means that while it is possible to distinguish between two stations in Tillamook Bay which differ in median phi by 0.8 phi, there really is no significant difference unless the stations are separated by at least 2 phi. Interpretations using the Tukey test are almost impossible but the implications of minimum significant difference versus minimum resolvable difference should not be overlooked.

Looking at Figure 5, a strong linear trend can be seen, with a coarser median size found to the north and finer to the south. This indicates that in summer, when the study was conducted, higher average energies are present in the northern part of the bay than in the southern part. Higher energy should be expected in the northern part of the bay during the winter, too.

The minimum resolvable difference for percentage of sand and percentage of silt was calculated also. Table VI shows the variance for both these measures to be quite high. The percentage of sand, silt and clay was plotted on Figure 6, using the classification of Folk (1968). When viewing this areal distribution of sediment type, it should be remembered that some of the boundaries cannot be justified at the 90 percent confidence level. This figure was included because even with its limitations it, in some ways, displays sediment type better than median grain size. Median grain size and sediment type

Figure 6. Distribution of sediment type in Tillamook Bay. (Sediment type after Folk, 1954)

are not necessarily correlated. A very well sorted sediment with a median size of 4.5 phi could be classified as silt and poorly sorted sediment with the same median size of 4.5 phi could be a sandy mud.

The pattern in the western central part of the bay (zS) is partly a result of sand being washed into the bay when the spit was breached in 1952. A pattern of sand can be seen in the primary drainage channels in the bay.

Skewness and Sorting

Skewness and sorting showed areal patterns, accordingly these parameters were contoured into major subdivisions (Figure 7).

Samples from the few coarse skewed areas were plotted on a CM diagram (Passega 1957) (Figure 8). All of these samples plotted in the beach deposit field. Friedman (1967) and Passega (1957 and 1964) both indicate a beach deposit should be relatively free of "fines" or skewed to the coarse. All of the areas with coarse skewed sediments are areas of cut or erosion (Figure 3). It seems quite likely that erosion has, in these areas, exposed a previously covered beach deposit from an earlier time.

A CM diagram is a plot of the size class containing the coarsest 1 percentile (C) versus median grain size (M). The value C is representative of the minimum

Figure 7. Distribution of skewness and sorting of sediments in Tillamook Bay.

Figure 8. Plot of the coarsest 1 percentile versus median grain size for those stations that were skewed to the coarse. All stations plot in the beach field of Passega. (after Passega 1957)

competence of the transporting medium and M is representative of the range of particles being transported. Few workers have utilized CM relationships to interpret environments of deposition and transport. Bull (1962) used CM patterns in analyzing alluvial fan deposits and Royse (1968) indicated a general validity and usefulness of CM relationships but felt wider testing necessary.

The area of 0 skewness, very well sorted, in the northern part of the bay is an area of high sand percentage (Figure 6). Samples from this area plot on a CM diagram in and around the tractive current or bed load field on the diagram. Currents in this part of the bay can be quite high and, as they are primarily tidal, flow in two principal directions. Sedimentation in this area can be considered to be dominantly marine with tidal currents the major factor in determining sediment type.

The 0 skewness, moderately sorted, area in the southern part of the bay seems to be largely an area that is quite shallow and is frequently exposed at lower tides. Because of this, wave stirring and carrying away of fines is reduced. If this were not the case, it would be expected that the sediment would be skewed to the coarse as wave action can be considerable in the southern part of the bay in the summer. Qualitative observation of near surface water in this area during sampling indicated that the water can be quite turbid. The sampler

frequently could not be seen deeper than one meter.

The central part of the bay with fine skewness and mixed sorting seems to be a transition zone between the north and south. Mixed sorting in this case means sorting that ranged from well sorted to poorly sorted with no areal pattern evident. This central part of the bay is where the majority of flora and fauna likely to influence sedimentation are found. Large areas of eel-grass, Zostera, are found in this part of the bay. The grass functions as a trap for fines by locally reducing current velocity. This same central area also supports a large burrowing animal population. Some noted by the author were: cockle, Clinocardium, gaper or horseneck clams, Schizothaerus nuttallii, softshell clams, Mya arenaria, and sand shrimp, Upogebia pugettensis, to name a few. In some areas it was apparent that bioturbation was such that no stratification remained in the sediments. In these areas no undisturbed surface could be seen; the entire surface was either material thrown up around a burrow or the hole itself.

Subpopulation Statistics

Table VII is a summary of the pertinent statistics developed when the bay was divided into populations defined by water depth. The table shows mean square, F ratio, and minimum resolvable difference. When

TABLE VI
F RATIOS AND BETWEEN STATION MINIMUM RESOLVABLE
DIFFERENCES FOR GRANULOMETRIC VARIABLES
(TOTAL POPULATION)

Variable	F	MRD
Percent sand	6.92	21.95 percent
Percent silt	7.35	20.37 percent
Median phi	8.23	0.80 phi
Sorting	3.59	0.68 phi
Skewness	4.50	0.35

TABLE VII

F RATIOS AND BETWEEN STATION MINIMUM RESOLVABLE
DIFFERENCES FOR GRANULOMETRIC VARIABLES
(SUBPOPULATIONS DEFINED BY WATER DEPTH)

	MS	F	MRD
<u>-2 Meter Depth</u>			
Sand	34.00	54.72	15.55
Silt	98.50	35.34	26.48
Median Phi	0.13	26.29	0.95
Sorting	1.30	0.03	0.96
Skewness	76.74	30.69	0.07
<u>0 Meter Depth</u>			
Sand	42.94	27.70	12.43
Silt	25.06	40.65	9.49
Median Phi	0.06	30.49	0.45
Sorting	0.13	4.13	0.66
Skewness	39.02	3.62	0.37
<u>2 Meter Depth</u>			
Sand	268.29	1.68	31.56
Silt	219.87	1.50	28.59
Median Phi	0.44	2.11	1.28
Sorting	0.13	3.80	0.70
Skewness	24.19	7.04	0.30
<u>4 Meter Depth</u>			
Sand	193.80	1.37	29.07
Silt	205.80	1.06	29.93
Median Phi	0.03	1.62	0.36
Sorting	0.17	2.72	0.87
Skewness	34.93	10.04	0.39

comparing this data with that found in Table V and Table VI, some strong differences are noted. Looking at F ratio rank we find in the population as a whole, sorting and skewness are the two poorest statistics for discriminating between stations. However, in the 2 meter (6 feet) and 4 meter (12 feet) populations these are the best measures. Median phi in all the depth populations seems to hold constant in F ratio ranking while the percentages and the higher moments trade about. When looking at the minimum resolvable difference no significant gain in minimum resolvable difference can be seen at any depth population when compared to the population as a whole.

Cumulative Curves

The statistics, median phi, sorting and skewness, are at their best when used to describe curves or distributions that are normal or nearly normal. As the distribution departs from normal, the statistics do an ever poorer job of describing the distribution. In the case of the sediments in Tillamook Bay, some station granulometric data are very near normal while others depart from normal significantly. The author has subjectively divided the cumulative size frequency curves into three classes or types. These types are shown in Figure 9 as found in Tillamook Bay.

Figure 9. Sediment cumulative curve types in Tillamook Bay. Type 1, straight or normal. Type 2, S curved. Type 3, humped. (Probability ordinate)

The curves are drawn with probability as the ordinate and phi units on the abscissa. With these scales a straight line would be a normal distribution and the slope of the line would indicate standard deviation or sorting. The visual appearance of these curves almost compels one to think of attempting to describe the curves as mixtures of two or more normal curves. Type 2 curves are frequently found with the lower part of the S truncated giving an inverted L shape. These truncated type 2 curves seem to be a combination of two normal populations, one being a well sorted sand and the other a poorly sorted mud.

Type 3 curves seem a little more complex. If each change in slope represents a mode then these curves are polymodal and truncated type 2 curves are bimodal.

An attempt was made to synthesize a type 2 curve. On the basis of intuition, a mixture of 70 percent well sorted sand, median phi 1.5, and 30 percent poorly sorted mud, median phi 5.5, was combined mathematically. The resulting curve, Figure 10, is not a totally satisfactory match, but is close enough to show the method has promise. Muller (1966) and Oser (1972) have successfully synthesized curves of this type by using an analog computer. It would seem that a digital computer could be programmed to do this type of problem, also.

Figure 10. Synthesized curve derived from two normal curves. The normal curves are the straight lines. The S shaped curve is the composite of the two normal curves.

The geologic significance of polymodal sediment distributions has been discussed by several authors. Pettijohn (1957) summarizes most of the ideas. They can be stated as follows:

1. Sediments naturally tend to have a bimodal distribution. (Udden 1914)
2. Fines have a tendency to infiltrate into interstices of a previous deposit. (Fraser 1935 and Plumley 1948)
3. Incomplete mixing of two sediments by a transporting agent results in bimodality. (Swensen 1941 and Rittenhouse 1943)
4. Faulty sampling procedure resulting in sampling two different units could also result in bimodality. (Bagnold 1941)

More recently Visher (1969) has suggested that each mode could represent a different method of transport; the coarse mode, traction or bed load; the intermediate mode, saltation; and the fine mode, suspension. Not all samples contain all three modes and some samples contain more than one mode in an area representing one type of transport.

Visher does not attempt to synthesize his curves and because of this fails to point out the influence of one subpopulation on the shape of the total cumulative curve. For instance, changing the amount of the fine or suspended

population will change the shape of the traction and bed load parts of the curve.

Sonu (1972) found that beach sediments have two unimodal populations associated with winter and summer beach profiles. The beach sediments become bimodal as the profile changes from summer to winter with winter and summer modes evident. The process continues until the winter mode is the only one present, then reverses itself until summer.

Most of the stations that have a well sorted type 1 (one population) curve are in the northern part of the bay. It seems that the current energy is quite high here (up to 1.5 meters per second) and the entire curve represents saltation material. The other locations have curves that are complex enough to require separation of each mode to analyze.

It is the author's opinion that in Tillamook Bay the causes of polymodality in the sediments are the differences in energy of the transporting medium as well as different modes of transport for the sediment at any given energy. Further, by isolating each mode it should be possible to determine which factors are responsible at each location. To further aid the geologic interpretation, mineralogy of each population should be investigated. This could be done by examination

of that size class containing the median of the population to be studied.

The existence of more than one normal population in the cumulative curve also leads to the idea that the high variance noted earlier is a reflection of different amounts of each population in each sample. Separation into constituent populations before describing them statistically should reduce the variance to a very low level.

VI MINERALOGY

Heavy Mineralogy

The results of the X-ray diffractions of whole heavy mineral fractions are shown in Figure 11 and Figure 12. Figure 11 shows the diffraction patterns from samples in the northern part of Tillamook Bay with the top pattern representing the Miami River assemblage and the bottom two patterns beach and older dune "fingerprints." The beach and older dune samples were collected from the beach and dune of the northern part of the spit. The intervening traces are from northern bay samples arranged in geographic sequence, east at the top, west at the bottom. Traces are easier to compare by placing the full size patterns over each other on a light table.

Some of the samples were irradiated at a slower scan rate of $2^{\circ} 2 \theta$ per minute. These traces show considerably

Figure 11. X-ray diffraction "fingerprints" of heavy mineral samples from the northern part of Tillamook Bay. The easternmost locations are at the top and westernmost at the bottom.

Figure 12a. X-ray diffraction "fingerprints" of heavy mineral samples from four rivers that flow into Tillamook Bay.

Figure 12b. X-ray diffraction "fingerprints" of heavy mineral samples from the southern part of Tillamook Bay with two river traces for comparison.

less "noise" and patterns are much more distinct. Future work should be done with scan rates no faster than 2° 2 θ per minute.

When these traces are compared, a progressive change from east to west can be seen. The most easterly bay sample shows a marked resemblance to the Miami River sample. The most westerly bay sample seems to be a composite pattern with the characteristics of both the beach and older dunes. Figure 12a shows the X-ray diffraction patterns of heavy minerals of four of the rivers feeding into Tillamook Bay, the Miami, the Wilson, the Kilchis and the Trask.

Each river can be seen to have a somewhat distinctive pattern. Figure 12b shows two patterns from the middle of the bay with the Kilchis and Miami Rivers for comparison. The bay traces seem to be combinations of the two rivers. When the western parts of the bay are examined, the traces become difficult to match. This is an indication of thorough mixing in the southern and western parts of the bay.

The traces from the Kilchis, Trask and Wilson Rivers seem somewhat similar while the trace from the Miami River is different. The Miami River flows through an area of the Cowlitz Formation and perhaps this is enough to give the distinctive mineralogy. Kulm and others (1968) report essentially no differences in the heavy mineral

composition of any of these rivers, except that the Trask River has 6 percent Titanaugite. Kulm's investigation did not include opaques and it is possible that the difference is in these minerals.

One other aspect of this type of technique needs consideration for future studies. Variability or variance at each sample location needs to be assessed. Two or three samples from each location should be processed and compared. Further, the technique of comparison of curves by eye is unnecessarily crude. Curves should be compared by a factor analysis or Fourier Analysis technique. This would require access to a computer for rapid comparisons.

Even with the limitation of the "noisy" traces due to high scan speeds, the method shows promise in rapidly evaluating source areas of sediments. It seems that the beach and dunes of Tillamook spit are not primarily composed of sediments derived from Tillamook Bay as their X-ray diffraction "fingerprints" are distinctly different. The heavy mineral X-ray diffraction "fingerprints" show that the sediment source for the majority of the bay is from the rivers feeding into the bay. That part of the bay near the mouth, however, seems to have sediments derived from the beach and older (Pleistocene ?) dunes on the spit. The hooked shape of the spit also indicates a net inflow of sediments at the mouth of the bay.

Clay Mineralogy

Two electron photomicrographs, Figure 13a and Figure 13b, show some of the -2 micron suspended sediment in the bay water. Most of the material seems to be amorphous or organic. In Figure 13a some of the plate like material looks like montmorillonite or illite and one object on the right side seems to have a hollow center or in other words is tubular. If this is not organic, it would likely be halloysite.

A sample of -2 micron material from this location was mounted for X-ray diffraction using the technique of Glenn (1968, personal communication). This X-ray diffraction pattern shows a broad peak centered at $12 \text{ \AA}^\circ$, and a smaller peak near $7 \text{ \AA}^\circ$. The $12 \text{ \AA}^\circ$ spacing is probably sodium saturated montmorillonite and the $7 \text{ \AA}^\circ$ spacing indicates halloysite. Kaolinite is ruled out by the lack of a $3.6 \text{ \AA}^\circ$ peak.

Figure 13a. Electron photomicrograph of a sample of the less than 2 micron suspended sediment in Tillamook Bay.

Figure 13b. Electron photomicrograph of a sample of the less than 2 micron suspended sediment in Tillamook Bay.

SUMMARY

I CONCLUSIONS

It can be seen that any sampling plan needs an input of sample variance. If no estimate of sample variance is known, a small pilot study will give a value which can be used to design the sample plan. If variance is not taken into account, for any study that utilizes sampling, it is likely that a greater degree of precision than is justified will be attributed to the results.

Geological data is frequently displayed by use of contour or isopleth maps as this type of display increases the ease of geologic interpretation. The choice of contour intervals depends on the degree of precision of a station value and the density of stations. The first factor is not so well recognized as the second if published work is used as an indicator.

Granulometric data of sediments, when plotted on probability graph paper, frequently show attributes of being composed of more than one sedimentary population. Analysis of these individual populations would shed more light on the sedimentary process.

The technique of X-ray "fingerprinting" of heavy minerals is a rapid method of identifying sediment source

areas and, while it should not replace the petrographic microscope, it could be used to guide the direction of petrographic examination.

Electron microscopy for clay mineralogy is probably not justified except for special applications. X-ray diffraction is much quicker and gives good results usually.

The sedimentary facies in Tillamook Bay can be divided into three major categories using skewness and sorting as parameters. A small portion of the bay near the mouth has zero skewness and is very well sorted. Near the head of the bay an area of zero skewness and moderate sorting is found with most of the remainder of the bay containing sediments that are finely skewed and sorted from poor to well sorted.

When looking at sediment type (Folk 1954) the zero skewness, very well sorted area is mostly sand. The remainder of the bay is dominantly sandy silt. The area to the east of the old break in the spit is silty sand.

Median grain size is coarse (less than 2 phi) near the mouth of the bay. The finer median grain sizes are found to the south, away from the mouth.

The history of Tillamook Bay from the earliest recorded time is one of filling. The filling at the present time is primarily from streams flowing into the bay with only a minor contribution from the ocean near the mouth of the bay. The rate of fill and whether filling is

accelerating or not is not known. The future of Tillamook Bay is one of continual filling unless steps are taken to reduce the input of sediment to the bay or a method found to remove sediment from the bay.

II FUTURE STUDIES

Variance estimates for Tillamook Bay may or may not be typical of other bays, but a small pilot study such as the one done for this project could provide a rough estimate of variance to compare with this and other studies to see if extrapolation is possible. As previously noted, variance estimates for Tillamook Bay coincide fairly closely with those found by Kelley and McManus (1969) for continental shelf sediments.

In this study median phi seemed the most diagnostic measure for differentiating between stations, while sorting and skewness seemed the poorest. For a rapid determination of sediment type, one might choose percentage of sand and percentage of silt. Even though they are not quite as diagnostic, one could probably complete three or four samples for percentage of sand and percentage of silt, thereby increasing precision, in the same time required for one complete granulometric analysis.

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APPENDIX

GRANULOMETRIC DATA FOR SAMPLES FROM TILLAMOOK BAY.
LOCATION MAP WITH STATION IDENTIFICATION ON LAST
PAGE OF APPENDIX. STATIONS TABULATED FROM
NORTH TO SOUTH.

Station	5 Percentile	16 Percentile	50 Percentile	80 Percentile	95 Percentile	Sorting	Skewness	Percent Sand	Percent Silt	Percent Clay
80	1.04	1.20	1.44	1.75	1.92	0.27	0.091	100		
59	1.48	1.62	1.94	2.22	2.42	0.29	-0.023	100		
81	1.50	1.68	1.98	4.22	5.50	1.24	0.762	82	04	14
60	1.50	1.60	1.97	4.12	6.70	1.42	0.763	83	15	02
82	0.98	1.42	2.00	2.48	7.00	1.18	0.280	92	05	03
61	1.18	1.54	1.92	2.36	3.15	0.50	0.136	97	02	01
83	1.40	1.60	1.92	2.22	2.42	0.31	-0.163	100		
62	1.54	1.72	2.00	2.22	2.35	0.25	-0.128	100		
84	1.46	1.64	1.44	2.22	2.40	0.29	0.028	100		
63	1.59	1.74	1.95	2.20	2.35	0.25	0.062	100		
85	1.38	1.55	1.82	2.10	2.28	0.27	0.020	100		
64	1.36	1.54	1.85	2.12	2.30	0.29	-0.013	100		
86	1.40	1.56	1.80	2.10	2.30	0.27	0.110	100		
65	1.42	1.58	1.84	2.08	2.24	0.25	0.032	100		
87	1.45	1.62	1.90	2.20	2.40	0.29	0.043	100		

Station	5 Percentile	16 Percentile	50 Percentile	80 Percentile	95 Percentile	Sorting	Skewness	Percent Sand	Percent Silt	Percent Clay
66	1.55	1.72	1.99	2.25	2.40	0.26	-0.027	100		
88	1.40	1.54	1.86	2.10	2.30	0.28	0.028	100		
67	1.50	1.66	1.92	2.20	2.35	0.26	0.024	100		
90	1.20	1.68	2.00	2.44	3.22	0.40	0.271	97	03	
69	1.05	1.60	2.30	4.06	7.04	1.67	0.465	84	12	04
89	1.20	1.70	2.12	2.68	7.10	1.14	0.415	91	08	01
68	1.08	1.74	2.05	2.34	4.30	0.64	0.182	94	06	
37	1.55	1.72	2.08	2.78	10.00	1.55	0.597	87	06	07
36	1.60	1.78	2.06	2.84	2.65	0.42	0.298	98	02	
77	1.64	1.92	2.30	2.70	4.40	0.61	0.274	94	03	03
38	1.92	1.96	2.09	2.48	2.85	0.28	0.549	97	03	
78	1.38	1.55	1.84	2.22	2.52	0.34	0.163	98	02	
39	1.65	1.82	2.36	5.44	6.50	1.64	0.705	54	46	
41	2.10	2.42	2.75	5.82	7.88	1.73	0.790	74	21	05
40	2.10	2.40	2.90	5.95	8.16	1.81	0.727	66	18	06
43	1.68	1.84	2.15	2.44	2.66	0.30	-0.003	99	01	
42	1.68	1.86	2.16	2.45	2.65	0.29	-0.001	99	01	
45	0.64	1.46	1.88	2.26	2.54	0.49	-0.178	99	01	
44	0.62	1.54	1.94	2.28	2.52	0.50	-0.231	99	01	
47	2.00	2.46	3.30	5.02	6.66	1.35	0.393	67	31	02

Station	5 Percentile	16 Percentile	50 Percentile	80 Percentile	95 Percentile	Sorting	Skewness	Percent Sand	Percent Silt	Percent Clay
46	2.10	2.50	3.28	5.40	7.18	1.49	0.499	71	27	02
49	1.25	1.75	2.25	2.50	2.72	0.41	-0.347	99	01	
48	1.64	2.04	2.30	2.56	2.75	0.30	-0.114	100		
51	1.56	2.16	2.74	4.48	7.00	1.40	0.318	78	10	02
50	1.65	2.18	2.74	4.70	8.20	1.62	0.612	76	09	05
53	1.70	2.42	3.34	5.95	9.60	2.08	0.531	61	31	08
52	1.34	2.00	2.75	4.98	6.36	1.51	0.567	76	23	01
28	1.96	2.12	2.32	4.95	7.55	1.55	0.865	82	15	03
29	1.50	1.66	1.96	2.24	2.54	0.30	0.041	98	02	
31	1.70	1.92	2.56	5.54	8.40	0.92	0.695	70	24	06
30	2.04	2.26	2.62	2.86	3.50	0.37	0.144	96	04	
10	1.64	1.88	2.25	4.06	7.95	1.50	0.504	84	11	
11	1.56	1.78	2.12	2.46	3.20	0.42	0.159	96	04	
12	1.58	1.80	2.12	2.50	4.34	0.59	0.347	95	04	01
13	1.60	1.86	2.22	2.62	4.20	0.58	0.274	95	04	01
14	1.50	1.80	2.24	2.65	3.42	0.50	0.097	96	03	01
15	1.60	1.84	2.16	2.56	4.10	0.56	0.391	95	03	02
16	1.64	1.90	2.30	3.02	6.50	1.03	0.500	90	07	03
17	1.64	1.84	2.18	2.64	4.86	0.69	0.407	93	06	01
18	1.54	1.80	2.22	2.66	4.55	0.67	0.290	94	05	01

Station	5 Percentile	16 Percentile	50 Percentile	80 Percentile	95 Percentile	Sorting	Skewness	Percent Sand	Percent Silt	Percent Clay
33	2.04	3.84	5.25	7.00	8.40	1.75	0.049	19	74	07
32	1.28	1.58	2.04	2.50	4.84	0.77	0.292	93	05	02
35	1.98	2.56	4.36	6.35	8.20	1.89	0.155	42	52	06
34	1.90	2.42	3.66	5.30	7.25	1.53	0.240	58	44	04
79	1.64	2.12	2.45	3.90	6.65	1.20	0.653	84	13	03
58	1.78	2.00	2.44	4.15	6.30	1.22	0.649	83	16	01
57	0.44	1.12	1.78	2.36	2.74	0.66	-0.115	100		
56	0.38	1.02	1.72	2.28	2.60	0.65	-0.159	100		
1	0.30	1.00	1.80	2.72	7.60	1.54	0.260	91	05	04
2	0.62	1.36	2.12	5.03	9.00	2.19	0.614	80	14	06
3	0.44	1.50	2.05	6.24	11.00	2.79	0.731	78	10	12
4	0.30	1.00	1.86	2.92	5.80	1.31	0.359	90	06	04
5	0.62	1.25	2.40	6.08	9.50	2.55	0.561	73	19	06
6	0.46	1.20	2.14	5.30	9.50	2.39	0.585	79	12	09
7	0.58	1.26	2.05	3.42	7.85	0.64	0.432	87	08	05
8	0.90	1.50	2.25	4.44	8.08	1.82	0.557	82	13	05
9	0.50	1.26	2.15	4.15	9.50	2.09	0.509	83	10	07
91	2.96	3.96	4.75	7.16	8.80	1.69	0.446	15	76	09
70	3.25	4.50	5.38	6.26	6.80	0.98	-0.100	09	91	
92	3.75	3.95	4.26	6.50	8.45	1.35	0.769	20	73	07

Station	5 Percentile	16 Percentile	50 Percentile	80 Percentile	95 Percentile	Sorting	Skewness	Percent Sand	Percent Silt	Percent Clay
71	3.86	4.12	5.00	6.26	6.88	0.99	0.211	06	94	
19	2.65	3.44	4.64	7.50	12.50	2.51	0.402	34	52	14
20	2.68	3.45	4.72	7.50	12.00	2.43	0.467	31	55	14
21	2.55	3.45	4.74	7.84	12.00	2.53	0.469	30	55	15
22	2.18	2.94	4.09	6.65	9.90	2.10	0.443	48	42	10
23	2.20	3.20	4.46	7.30	12.00	2.50	0.462	36	51	13
24	2.34	3.24	4.64	7.40	14.00	2.81	0.466	36	51	13
25	2.15	3.14	4.45	7.00	12.30	2.50	0.433	38	49	13
26	2.25	3.14	4.30	7.62	11.20	2.48	0.512	42	44	14
27	2.08	2.98	4.12	7.00	10.50	2.81	0.474	46	41	13
93	-0.28	0.40	1.16	1.90	2.38	0.78	-0.048	98	02	
72	-0.14	0.44	1.38	2.05	2.55	0.81	-0.149	98	02	
95	-2.50	-1.30	0.60	1.74	2.50	1.52	-0.245	97	03	
74	-1.11	-0.28	0.92	1.62	2.04	0.95	-0.276	98	02	
97	0.29	1.02	1.96	2.75	3.50	0.92	-0.063	97	03	
76	0.24	1.06	2.14	3.25	4.82	1.13	0.093	91	08	01
96	1.26	1.92	3.06	4.14	7.24	1.46	0.186	78	18	04
75	1.46	2.14	3.40	4.76	6.00	1.34	0.092	68	31	01

Location map of stations by number in Tillamook Bay

**GRANULOMETRIC ANALYSIS OF RECENT SEDIMENTS
OF TILLAMOOK BAY, OREGON**

by
GENNARO WILLIAM AVOLIO

**A thesis submitted in partial fulfillment of the
requirements for the degree of**

**MASTER OF SCIENCE
in
EARTH SCIENCE**

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