1978

A study of estuarine sedimentation in South Slough, Coos Bay, Oregon

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Recommended Citation

Baker, Charles Allen, "A study of estuarine sedimentation in South Slough, Coos Bay, Oregon" (1978). *Dissertations and Theses.* Paper 2867.
https://doi.org/10.15760/etd.2858

AN ABSTRACT OF THE THESIS OF Charles Allen Baker for the Master of Science in Geology presented August 24, 1978.

Title: A Study of Estuarine Sedimentation in South Slough, Coos Bay, Oregon.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

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R. O. Van Atta, Chairman

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A. G. Johnson

Sediments in the South Slough Estuarine Sanctuary, Coos Bay, Oregon, were sampled and studied in order to determine the sources, dispersal systems and depositional facies of sedimentation. The purpose of the study was to establish baseline measurements and observations on the existing sediment conditions within the relatively undisturbed South Slough Estuarine Sanctuary.

South Slough is located in the axis of a northerly trending syncline. Tertiary sandstones and mudstones of the Coaledo, Bastendorff, and Empire Formations, overlain by Quaternary marine terrace sands, underlie the region of the South Slough watershed.

Sediment samples were analyzed for texture and composition. Granulometry was done using sieve and pipette analysis. Mean, median, sorting, skewness, and kurtosis were determined using Trask, Inman, Folk and Ward, and Moment statistical parameters for each sample.

Most of the sediments of the slough are a bimodal mixture of medium to fine sand (+2.00 ∅) and coarse to medium silt (+5.00 ∅). Fluvial input is the major source of silt sized material. Lateral sedimentation from the terrace deposits supplies most of the sand. The fluvial input is poorly sorted, however, more information is needed to determine the extent of the fluvial input. Possibly the poorer sorting may be the result of hydraulic forces acting on floccules and not individual grains.

The changes in the derived statistical parameters with sediment transport, and in their interrelationships, determined using binary plots of the parameters, are probably a simple function of the ratio between the various modes of the sediments.

Textural distribution patterns of the bottom sediments reflect the energy distribution which is controlled by the bottom topography of the estuary. The transportation processes determined by CM analysis also reflect the energy distribution. Tidal currents carry sediments in traction, saltation and suspension over the tidal flats and differentiate their load inland as a result of the decreasing velocity which brings about a reduction in capacity and competence. As a result, the sediments found in the channels are characteristically coarse grained, well sorted, and near symmetrical to fine skewed, while tide flat sediments are finer grained, poorly sorted and strongly fine skewed. Tidal currents and wave action are ineffective in removing fines from the tide flats, possibly due to lag effects, and in addition are ineffective in sorting. The dominant positive skewness of the sediments implies the slough is at present an area of deposition.

Sediment composition in South Slough is essentially uniform. Epidote, hornblende, clinopyroxene, garnet, hypersthene, zircon, and clinozoisite are the commonest heavy minerals. Feldspar and quartz make up almost all of the light fraction. Areal differences in mineral composition within South Slough are attributed to a difference in the character of the source materials. X-ray heavy mineral analysis indicates that sediment movement is generally seaward, deposition occurring where movement is obstructed, such as by Vallino Island, and in regions of large cross sectional area. Mineralogy of the sediments is independent of the grain size.

The clay mineral assemblage of South Slough is dominated by montmorillonite and kaolinite, with small amounts of chlorite, glauconite, and possibly illite and/or mica. The abundance of montmorillonite reflects the volcanic-rich character and immature weathering of the source materials. Kaolinite increases down-estuary. A possible cause is increasing lateral addition of terrace sands. Fractionation during sedimentation is a possible alternative to lateral sedimentation but sufficient information is lacking to support that conclusion. No longitudinal diagenetic changes down estuary were indicated.

A STUDY OF ESTUARINE SEDIMENTATION IN

SOUTH SLOUGH, COOS BAY, OREGON

by

CHARLES ALLEN BAKER

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

MASTER OF SCIENCE
in
GEOLOGY

Portland State University

1978

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

The members of the Committee approve the thesis of Charles Allen Baker presented August 24, 1978.

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ACKNOWLEDGMENTS

I wish to acknowledge the encouragement and aid in the development and completion of this study by my advisor, Dr. R. O. Van Atta, Earth Sciences Department, Portland State University. I would also like to thank the members of my thesis committee, Dr. Ansel G. Johnson and Dr. Paul E. Hammond, Earth Sciences Department, and Dr. Daniel M. Johnson, Geography Department, Portland State University, for their constructive criticism and valuable suggestions.

Special thanks go to Gene Pierson, Staff Geologist, Portland State University, for his invaluable help during my studies at Portland State University.

My appreciation also goes to Dr. Delane Munson, Manager, South Slough Estuarine Sanctuary, for providing equipment and use of the Oregon Institute of Marine Biology facilities for this study.

I would also like to acknowledge several other people who have given support to this study: first, Dave Simpson, U. S. Army Corps of Engineers, Rivers and Harbors Division, for valuable information concerning hydraulic characteristics of South Slough; Don Chitwood, Tektronix, Inc., for his time and expertise in use of the scanning electron microscope; Mike Moran and Jim Anderson assisted in writing and debugging the computer program which calculates the textural statistics; Tom St. Marie and my brother, John Baker, who spent considerable time and effort slogging through the mud; and to Virginia Pfaff, who typed the final manuscript. To these individuals and to all those persons who contributed to this study, I am deeply grateful.

Finally, I would like to thank my wife, Dianna, who inspired me to finish my thesis. She provided the emotional support and assistance in every aspect of this study which made the completion possible.

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INTRODUCTION

Man has always exhibited a natural affinity for the bays and river mouths which form Oregon's estuaries. The unique advantages provided by estuaries make them one of the more important of our natural resources. The advantages provided by the estuarine resource include transportation, water supply, waste disposal and a unique biological setting at this interface between land and sea.

Estuarine environments are rapidly changing due to the mounting intensity of public, commercial, and industrial use. With the increased public interest and emphasis on development of estuaries, studies are needed to provide comparative data against which future changes in the estuarine ecosystem can be measured.

Selected estuaries are being set aside to insure the protection of significant wildlife habitat and to provide for research and educational needs. South Slough Estuarine Sanctuary, part of one arm of Coos Bay, Oregon, has been established under the Coastal Zone Management Act of 1972 for these reasons.

The purpose of this investigation is to identify and define the existing sediment conditions within the relatively undisturbed South Slough Estuarine Sanctuary. Previous studies in Oregon estuaries which could provide the necessary data for proper management have most often been conducted where problems of mismanagement already exist.

This study contributes to the data base on which effective estuarine management depends. Sources, dispersal systems, and depositional patterns of sedimentation are examined utilizing textural and compositional variations in sediment type.

GEOGRAPHY AND GEOLOGIC SETTING

LOCATION AND ACCESSIBILITY

Coos Bay is located on the western slopes of the southern Coast Range in Coos County, Oregon (Figure 1). The Coast Range merges into the Klamath or Siskiyou Mountains south of the study area in the general vicinity of the Coquille River. Coos Bay is located about 320 kilometers south of the mouth of the Columbia River. The entrance to Coos Bay lies a few kilometers north of Cape Arago and is bounded by Coos Head and North Spit. Just inside the entrance to Coos Bay, the town of Charleston lies at the entrance to South Slough which extends to the south.

The study area includes the southern half of South Slough and its drainage basin within the estuarine sanctuary. The drainage basin of South Slough is bounded by the Seven Devils Road on the west and to the south, where the Seven Devils Road connects with U. S. Highway 101 which lies to the east of the western margin of the basin. The area is easily accessible from U. S. Highway 101 or the Seven Devils Road. Dirt roads and jeep trails crisscross the area, but most are impassable during wet weather. The slough is readily accessible by boat.

REGIONAL PHYSIOGRAPHY

The surface features of the Coos Bay area can be grouped into three major categories: the lowlands, terraces, and uplands (Beaulieu

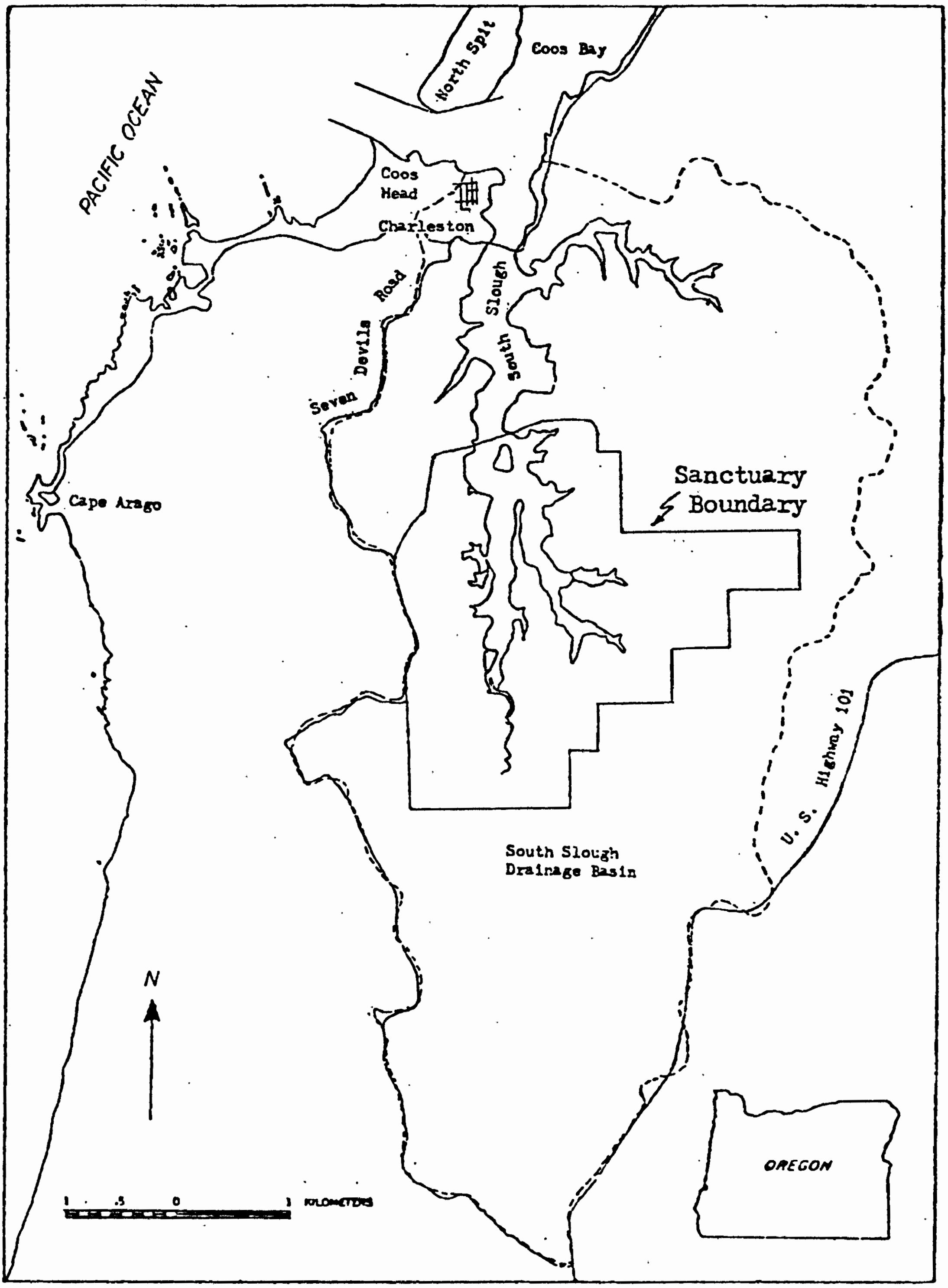


Figure 1. Index map showing the location of the South Slough area and associated drainage basin.

and Hughes, 1975). The geomorphic features of much of this part of the southern Oregon coast are formed as a consequence of Pleistocene to Recent eustatic changes in sea level superimposed on a regional uplift of the Coast Range which continued from late Pliocene into the Pleistocene (Allen and Baldwin, 1944). Pleistocene wave erosional and depositional marine terraces occur at elevations of approximately 15, 75, 150, 305, and 455 meters (50, 250, 500, 1000, and 1500 feet), giving a flat topped appearance to many of the ridges. The terraces at high elevations have been modified extensively by erosion and are difficult to observe, while terraces at elevations less than 150 meters (500 feet) are generally well developed. Terraces lower than 150 meters form a narrow strip along the coast up to six kilometers in width between the Pacific Ocean and the Coast Range to the east (Allen and Baldwin, 1944).

The hills and higher elevations to the east are associated with the Coast Range. The uplands rising from the back of the coastal plain to elevations greater than approximately 455 meters (1500 feet) are rugged and highly dissected with a relief of more than 305 meters (1000 feet) (Allen and Baldwin, 1944).

The coastline to the south of the entrance to Coos Bay consists of a series of narrow ocean beaches separated by resistant headlands. Beaches are backed by sea cliffs of Tertiary sedimentary rocks capped by terrace deposits. Immediately north of South Slough, coastal features are dominated by Coos Bay, the drowned mouth of the Coos River. Another prominent feature is the Coos Bay dune sheet on North Spit. Other coastal features include flood plains, marsh and tidal flats of Coos Bay and its tributaries.

SOUTH SLOUGH PHYSIOGRAPHY

South Slough is a north-south trending drowned stream valley system. Irregular terrace surfaces surround the slough for a distance of more than 16 kilometers in a north-south direction, 4-6 kilometers from east to west, and from 15 to approximately 75 meters in elevation. The terrace surfaces are well developed along the western side of the slough but are less distinct to the east, where they have been extensively altered by erosion and have assumed a gentler slope which rises toward uplands on the east. The terrace surfaces are continuous from north of the study area to Cape Arago, extending along the eastern side of a 120-185 meter ridge between South Slough and the Pacific Ocean (Griggs, 1945).

South Slough reaches inland a distance of about eight kilometers, with an average width of about one kilometer. The slough is divided into Winchester and Sengstacken arms by Long Island Point. Major tributaries draining the area around South Slough include Day and Elliot Creeks on the east side, John B and Talbot Creeks draining into the southern end of the Sengstacken arm, and Winchester Creek which drains into the Winchester arm. South Slough drains a total of about 68 square kilometers (Munson, 1977).

Within the sanctuary, South Slough covers about 2.4 square kilometers (Munson, 1977). The slough is quite shallow and consists primarily of intertidal flats. The greatest depths are in the larger meandering main channels. Numerous smaller tidal channels branch off the main channels of the slough. Channel depths show some variability, but in general gradually decrease towards the head of the slough as the width of the channel decreases.

Several major marshlands are located inside the slough. The largest areas are located in the Elliot Creek area and at the end of the Sengstacken arm of the slough. Marshlands border the slough in many other places (Munson, 1977). Lost wetlands include area claimed through fill, dikes, draining or accretion. Diked agricultural land occupies several of the inlets of South Slough (U. S. Army Corps of Engineers, 1975). The important morphological features and bathymetry are indicated on Figure 2. These are: (1) main channels, (2) intertidal areas, (3) marshlands, and (4) lost wetlands.

CLIMATE

The climate of the Coos Bay area is mid-latitude marine, with cool wet winters and warm, dry summers with only very light precipitation (U. S. Department of Commerce, Weather Bureau, 1963). Annual precipitation for the three summer months is only four percent of the annual average.

The temperature difference between warmest and coldest months is less than 9°C, brought about by the Pacific Ocean. The coldest month of January averages about 7°C. The highest monthly temperature occurs in August, with an average of 15°C. Temperature extremes vary from 9°C to 38°C.

The seasonal wind regime has been summarized by Cooper (1958). Summer winds are characterized by onshore winds from the north-northwest and have the greatest average velocity with winds in excess of 24 kilometers per hour. Winter winds are predominantly offshore and of low velocity. However, infrequent onshore winds from the south-southwest accompanying winter storms moving inland from the Pacific have the highest velocities. Fall and Spring conditions alternate between those of Winter and Summer (Cooper, 1958).

HYDROGRAPHY

Estuaries can be classified on the basis of their mode of formation. On that basis, Coos Bay is classified as a drowned river valley type of estuary, formed during the Holocene rise in sea level. Some of the distinguishing characteristics of drowned river valley estuaries include: (1) V-shaped cross section, (2) relatively shallow and gently sloping bottoms, and (3) a fairly uniform increase in depth towards the mouth (Schubel, 1971). These characteristics hold true for Coos Bay and South Slough.

A more useful classification, developed by Pritchard (1955), and applied to Oregon's estuaries by Burt and McAlister (1959), is based on circulation patterns and salinity distributions. Division of estuarine types is determined by measurement of salinity distributions within the estuary. Circulation patterns, controlled by the relative magnitudes of the river flow, the tidal flow, and the geometry of the estuary, promote different degrees of mixing between land derived fresh water and sea water, controlling the salinity distribution. The dominant agent which promotes mixing may be either the river, tide, or wind. These factors control the position an estuary occupies in the sequence of circulation pattern types, ranging from the highly stratified, type A, to the well mixed estuary, type D. Intermediate types B and C are described as partially mixed and vertically homogeneous, respectively (Pritchard, 1955).

Using this system Burt and McAlister (1959) classified Coos Bay as essentially well mixed, type D, throughout the year. High tidal range, low runoff, and a shallow, narrow topography allow thorough lateral and vertical mixing, producing a homogeneous salinity distribution. Mixing is primarily due to tidal forces, which are dominant over the river and wind. The mean tidal range for Coos Bay is 1.6 meters. The energy present in a tidal cycle available for mixing is proportional to the square of the tidal range (Burt and McAlister, 1959). In comparison with Mid-Atlantic and Gulf Coast estuaries the tidal range is large and compares with New England estuaries (Hayes, 1971).

With this type of circulation pattern there is a slow net drift seaward at all depths over a tidal cycle (Burt and McAlister, 1959). A recent numerical model of tidal hydraulics produced by the U. S. Army Corps of Engineers for South Slough indicates a net ebb flow at the South Slough entrance. The U. S. Army Corps of Engineers were unable to relate the larger ebb velocity to a difference in tidal range, fresh water input or wind action.

CLIMATIC INFLUENCE ON HYDROGRAPHY

During periods of high river flow, the relative magnitudes of river flow to tidal flow increases enough to change the mixing pattern within Coos Bay. The estuary becomes partly mixed in November (Burt and McAlister, 1959). A similar change in mixing patterns was shown by Kulm and Bryne (1966) in Yaquina Bay, which lies to the north along the Oregon coast at Newport. They attribute the change to changes in river discharge, because tidal ranges and basin configuration remain constant throughout the year. Seasonal variations in precipitation account for the increase in precipitation during October, which is not reflected by a change in salinity until a month later. Similarly, an increase in mean monthly precipitation increases the flow of rivers into Coos Bay, decreasing the salt content of the bay. However, in the case of Coos Bay, winter time precipitation peaks during January (U. S. Department of Commerce, Weather Bureau, 1963) with no resultant change in classification (Burt and McAlister, 1959). Reported surface areas for Coos and Yaquina Bays measured at mean high water are approximately 44 and 17 square kilometers, respectively. Stream gauging stations on tributaries of both estuaries are limited and monthly discharges unavailable. The normal flow rate for the Yaquina River has been estimated at about 31 cubic meters per second and at 62 cubic meters per second for the Coos River (Percy and others, 1974). The ratios of surface areas and normal flow rates for the tributaries for both estuaries are comparable, although the discharge of the Coos River relative to the surface area of Coos Bay is slightly higher than for the Yaquina River in comparison with Yaquina Bay surface area. Apparently other factors which are not well known must influence the pattern of mixing.

South Slough may not undergo changes in the mixing pattern in November similar to Coos Bay as a whole. Assuming the precipitation over the area is uniform, the ratio of drainage basin area to water surface area is much smaller for South Slough than for Coos Bay. This might suggest a much smaller relative influx of fresh water in South Slough, which allows greater mixing.

Another important climatic influence on sedimentation may be resuspension by wind waves during periods of storm activity or during fair weather. Most of the storms move across the coastline from the Pacific during late Fall, Winter, and early Spring months. Onshore winds from the south-southwest accompany Winter storms. The slough is oriented north-south, allowing a considerable distance for the waves to reach wavelengths necessary to "feel" the bottom. However, South Slough is protected from much influence of the south-southwest winds by the forested hills on the south and west. Summer winds from the north-northwest have the greatest average velocity and are more likely to cause resuspension due to wave base interference with the bottom. Resedimentation may also take place at low tide with tide flats exposed to wind action, but this is unlikely because of the fine grain size, cohesion, and algal material acting as a binder (Van Atta, oral communication, 1978).

GEOLOGY

South Slough is located in the axis of the northerly trending South Slough syncline. Tertiary sandstones and mudstones of the Coaledo, Bastendorff, and Empire Formations, overlain by Quaternary marine terrace deposits, underlie the region of the South Slough watershed (Figure 3).

The oldest formation in the area is the Coaledo Formation. The Coaledo Formation is divided into coal bearing lower and upper members, composed primarily of sandstone, and a predominantly shaley middle member which is not coal bearing. The lower member is described by Allen and Baldwin (1944) as follows:

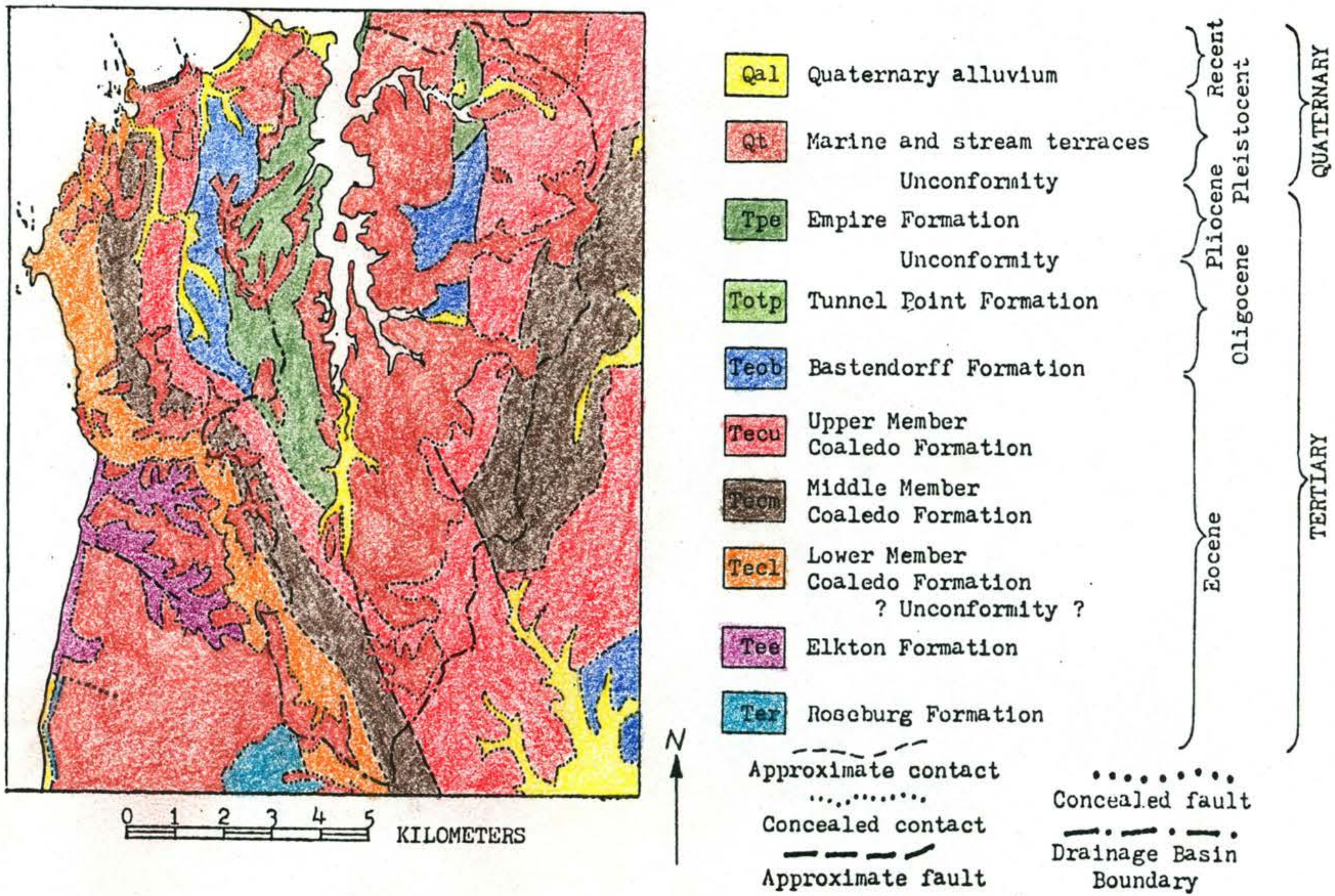


Figure 3. Geologic map of the South Slough area.

> Blue-gray medium to coarse-grained nodular sandstone predominates, with some grit and intercalated fine-grained sandy shale beds which are usually darker in color than the sands. The sandstone, which weathers to a characteristic buff color, is tuffaceous, and many of the pebbles in the few conglomeratic lenses are of fine-grained basaltic material.

The middle member of the Coaledo Formation is described as a "medium-gray tuffaceous shale and some sandy lenses" (Baldwin, 1964).

The upper member of the Coaledo Formation is described by Dott (1966) as similar in lithology and appearance to the lower member. "The Coaledo sandstones are texturally submature to immature: feldspathic micaceous, and carbonaceous lithic (volcanic) arenites; more poorly sorted ones are lithic (volcanic) wackes" (Dott, 1966).

The Coaledo Formation lies unconformably over the Roseburg, Lookingglass, and Flournoy Formations, but is not known to be in contact with the middle Eocene Tyee Formation. Contact with the Elkton Siltstone (upper middle Eocene) which overlies the Tyee Formation is obscure, but it is likely that the Coaledo Formation is unconformable over the Elkton Siltstone (Baldwin and Beaulieu, 1973). The Tyee and Elkton Formations are included in the regional stratigraphic pile but are not included in the South Slough stratigraphic record. The Coaledo Formation is considered to be of late Eocene age.

The Coaledo Formation grades abruptly upwards into the Bastendorff Formation, which is predominantly argillaceous and silty material like the middle Coaledo. "The Bastendorff beds are made of dark-gray to medium-gray shale and siltstone with some thin, white tuffaceous layers" (Baldwin, 1974). Microfossils studied by Stewart (1957) and by earlier authors suggest an age of late Eocene to early Oligocene. However, as stated by Baldwin (1974), McKeel (1972) considers it all Eocene.

The late Oligocene Tunnel Point Formation is conformable over the Bastendorff and is overlain in turn by the Empire Formation with marked angular unconformity. The Tunnel Point Formation is not exposed in the South Slough basin.

The Empire Formation occupies the center of the South Slough syncline and "is made up of as much as 3,000 feet of massive, poorly-bedded sandstone with minor interbeds of siltstone and at least one prominent fossiliferous conglomeratic lens which crops out at Fossil Point" (Baldwin, 1974). The highly conglomeratic lens is a member of the Empire Formation and is named the Coos Conglomerate. The sandstone of the Empire Formation is described by Armentrout (1967) as a feldspathic graywacke.

Pleistocene terraces, as previously described, are made up of unconsolidated sands and gravels. Terraces are considered physiographic features and are not assigned formational names (Baldwin and Beaulieu, 1973).

PREVIOUS WORK

Bottom sediments in the upper part of the South Slough arm of Coos Bay have not been studied in enough detail to delineate facies and sediment dispersal patterns. Arneson (1976) conducted grain size analysis of selected samples within South Slough as part of a larger study involving most of Coos Bay.

Some previous studies of the biological parameters and hydraulic characteristics have been conducted by the Oregon Institute of Marine Biology in Charleston, Oregon, and the Schools of Engineering and Oceanography, Oregon State University. The United States Army Corps of Engineers has constructed a numerical model of tidal hydraulics.

Baseline study of sedimentation in South Slough was begun by R. O. Van Atta in February 1976, including sampling and analysis of sediments. In February, April, August, and November 1976, and February, March, and June 1977 a series of sediment samples was taken at selected sites, including repeated sampling at four sites within South Slough, a few tributary streams, and from the margins of the slough.

INVESTIGATIVE PROCEDURES

SAMPLING METHODS AND PROCEDURES

Field work was undertaken during August, September, and early October 1977. The plan was to take all the samples in as short a time as possible to avoid seasonal variations. No major storms occurred during this time. All samples from South Slough were taken at ebb tide in order to take advantage of the greatest exposure and accessibility to the sediments.

Considerable natural variations in materials, boundary, and energy conditions were anticipated, requiring a fairly high sampling density. Sediment samples in the South Slough Estuary were collected from over 250 locations, from which selected samples were chosen for this study. Sediment samples in deeper water, mainly channels, were collected with a U. S. G. S. BM 54 grab sampler which can be operated from a small open vessel. Additional grab samples from tide flats, the margins of the slough, ocean beaches, source rocks and soils, and the rivers feeding the slough were collected by hand. Samples were collected from the top 0.5-1.0 centimeter in an attempt to sample only the most recent sedimentation unit. The location of samples collected from South Slough and the surrounding area are shown in Figure 2.

Bottom topography is often the principal factor in controlling recent sediment distribution patterns (Krumbein and Caldwell, 1939; Allen, 1970). Greater variations in bottom topography along cross channel profiles than along longitudinal profiles in South Slough suggested a need for a higher sampling density cross channel. With that in mind, samples were collected along traverses cross channel at approximately 30 meter intervals, with a between-traverse distance much broader and yet close enough to define the natural variations in sediment conditions. Between-traverse distances were about 300 meters.

Krumbein (1934) estimated field sampling error, even under the best conditions, of at least eight times any error introduced in the laboratory during mechanical analysis. The greatest error is introduced in sampling soft muds with a grab sampler (Avolio, 1973). Penetration well into the mud before it closes nullifies the attempt to sample a single sedimentation unit (Otto, 1938). Fine material may also be partially washed out of the sandier material as the sampler is pulled through the water. Having to fight strong currents to maintain a position during sampling from a skiff can be avoided for most samples by sampling during ebb tide by hand. Sampling at ebb tide by hand offsets some of the error that is introduced through the use of the grab sampler. However, greater difficulty was experienced in crossing tide flats during sampling. Greater mobility was gained through the use of snow shoes.

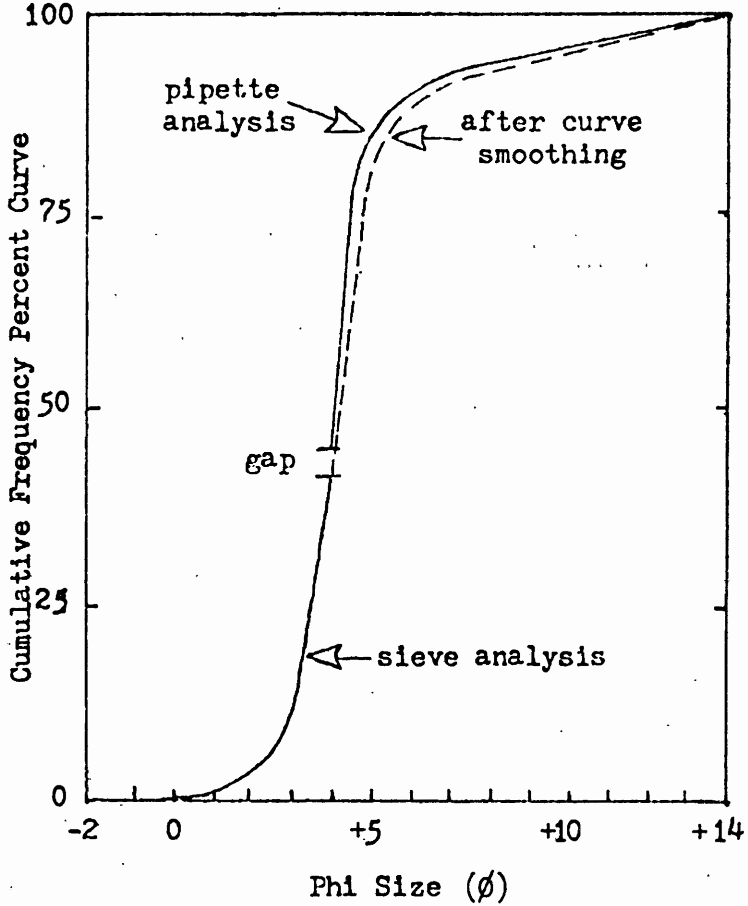
TEXTURAL ANALYSIS

In the laboratory, samples were air dried, weighed, and wet sieved to separate the sediment into fractions coarser and finer than +4.00 ø. The coarser material is then sieved, each nest of sieves being shaken for 15 minutes on a Ro-tap using eight inch Tyler screens. The fraction finer than +4.00 ∅ is divided into size grades by pipette analysis. Most samples contained a large mud fraction and/or gravel fraction, and required separate splits of appropriate size for accurate work. The weight of each mud and/or gravel fraction was then multiplied by the splitting factor (Folk, 1974), and the weights cumulated together with the sand portion of the analysis.

The sieves used for analyzing sand ranged from -2.00 ∅ to 0.00 ∅ in 1.00 ∅ intervals, and from 0.00 ∅ to +4.00 ∅ in $\frac{1}{4}$ ∅ intervals. Samples with a notable gravel fraction were analyzed at -2.65 ∅, -3.65 ∅, -4.25 ∅, and -4.65 ∅ sizes. Pipette size grades were broken down into $\frac{1}{2}$ ∅ intervals from +4.00 ∅ to +6.00 ∅, and 1.00 ∅ intervals from +6.00 ∅ to +9.00 ∅.

The various size fractions are weighed within one milligram. The weights are then adjusted on the basis of the amount of aggregate present (Folk, 1974). Additional manipulations prior to processing the data include extrapolation of the data beyond the last data point, +9.00 ∅, to +14.00 ∅ at 100 percent. Extrapolation to 100 percent is necessary or the computer program will compute anomalous values for the derived statistical parameters. In order to obtain grain size parameters a smooth continuous curve must be drawn through all points.

A gap exists between the +4.00 ∅ fraction measured by sieve and pipette (Figure 4). No standard method exists for dealing with this error, which may be the result of the difference in what is actually being measured by sieve and pipette, a scarcity in natural material around +4.00 ∅, operator error, or other reasons. The discrepancy is most likely inherent in the pipette analysis. Sieving is more repro-



Explanation:

(B) Gap/10=0.209

Phi Size	Value (g)	(C)	(D)
4.00	28.872	+(0.209 X (14.00- 4.00))=	30.960
4.50	12.148	+(0.209 X (14.00- 4.50))=	14.132
5.00	7.910	+(0.209 X (14.00- 5.00))=	9.789
5.50	5.820	+(0.209 X (14.00- 5.50))=	7.595
6.00	4.690	+(0.209 X (14.00- 6.00))=	6.360
7.00	3.277	+(0.209 X (14.00- 7.00))=	4.739
8.00	2.317	+(0.209 X (14.00- 8.00))=	3.570
9.00	1.752	+(0.209 X (14.00- 9.00))=	2.796
10.00	1.402	+(0.209 X (14.00-10.00))=	2.237
11.00	1.051	+(0.209 X (14.00-11.00))=	1.677
12.00	0.701	+(0.209 X (14.00-12.00))=	1.119
13.00	0.350	+(0.209 X (14.00-13.00))=	0.559
14.00	0.000	+(0.209 X (14.00-14.00))=	0.000

Figure 4. Cumulative curve for sample 96 illustrating curve smoothing.

ducible than pipetting, where results easily vary ten percent of reported pipetted values (Roysce, 1970). In order to compensate for this error, curve smoothing is done by taking the difference between calculated sieve and pipette values for the weight of material finer than +4.00 ø (A), and dividing by 10 (B), the number of whole phi units between +4.00 ø and +14.00 ø at 100 percent. The value obtained is then multiplied by the difference between each pipette phi size and +14.00 ø (C), and subsequently added to the fraction weight at that phi size (D). The value obtained replaces the weight obtained from the pipette analysis. This method weights the correction factor so a greater change in the pipetted values occurs at coarser size grades where error is more likely.

HEAVY MINERAL SEPARATIONS

Heavy mineral separations were made with tetrabromoethane (Sp. gr. 2.95 at 25°C) on splits of the +2.00 ø to +4.00 ø fractions of selected samples. A Franz Magnetic Separator was used to remove the abundant opaques prior to mounting. Standard line counts were used to identify 300 to 500 grains for heavies (nonopaque, nonmicaceous) and lights. Traverses across the grain mounts were made at intervals from 1-5 millimeters, which allowed enough grains to be counted while sampling the entire mount. Mineral identification was done with a petrographic microscope. Light minerals were identified with the aid of staining techniques described by Carver (1971).

Heavy minerals were also separated for X-ray analysis (Pryor and Hestor, 1969), and these required further treatment. Samples for X-ray analysis were separated in tetrabromoethane from splits of the +2.00 ϕ to +5.00 ϕ size range, washed with acetone, and ground uniformly using an automatic pulverizing device. Prior to pulverizing samples, carbonates were removed by boiling for two minutes in concentrated hydrochloric acid, flushed with water, then acetone. Apatite is also lost during treatment with hydrochloric acid. Magnetically susceptible minerals were removed with a hand magnet and a Franz Magnetic Separator to reduce iron fluorescence during X-raying. The ground material was mounted on a glass slide in a Duco cement slurry. Diffraction patterns were produced at a scan rate of 2° 2θ per minute in the range from 10° 2θ to 50° 2θ. The purpose of this technique is to characterize a larger number of samples and group them according to their X-ray diffraction patterns so as to facilitate selection of representative samples for petrographic analysis. Variations in the diffraction patterns from each group were used directly in provenance determination.

CLAYS

All samples for clay mineral study were prepared for X-ray diffraction analysis following standardized methods developed by the Soil Science Laboratory at Oregon State University (Van Atta, oral communication, 1978). Pretreatment included removal of soluble salts, organic matter, and iron removal on the less than 400 mesh fraction. Each sample was then dispersed in anhydrous Na_2CO_3, and separated into 2.0 to 0.2 microns and less than 0.2 micron size fractions by centrifuging and flocculation with a saturated calcium chloride solution. Following saturation with calcium chloride samples were washed repeatedly with water and then with methanol. A portion of the suspension of fine grained material was then mounted on a ceramic tile by drawing the liquid portion of the clay suspension through the tile by means of a vacuum, which leaves an oriented coating of clay on the tile (Gibbs, 1965). X-ray diffraction patterns were made with a General Electric XRD-5 X-ray diffractometer. X-ray patterns were made of each clay fraction. In order to complete identification of clay mineral components, additional patterns were made after the tiles were treated with ethylene glycol, heated to 550°C for one hour, and cleaned with HCl.

Selected samples were also prepared for the scanning electron microscope (SEM) by placing a drop of dilute clay suspension on the SEM mounting stub. Samples were sputtered with gold palladium prior to examination.

ORGANICS

Selected samples were analyzed to estimate total organic matter. The technique employed involved oxidation of the organic material with 30 percent hydrogen peroxide (H_2O_2), and the estimation of its original abundance by comparing initial and final weights (Carver, 1971).

PROCESSING DATA AND STATISTICAL PARAMETERS

The raw data in the form of individual fraction weights were processed on the Harris 220 Computing System at the Computing Services Center of Portland State University. The program used for grain size analysis is based on two programs by E. E. Collias and M. R. Rona (Technical Report No. 87, 1963, of the Department of Oceanography, University of Washington).

Input for the grain size analysis program consists of the starting weight for the sample, the sample number, and the weight of each individual fraction obtained in the analysis. After calculation of individual fraction percentages, cumulative weights, and cumulative percentages, the computer interpolates between the cumulative percentages to arrive at the seven percentiles used in calculating the various statistical parameters. The seven percentiles are the 5th, 16th, 25th, 50th, 75th, 84th, and 95th. The computer program then calculates three types of statistical parameters from the percentile values (Table I), including those of Trask (1932), Inman (1952), and similar parameters derived by Folk and Ward (1957). In addition, the true statistical moment measures are calculated utilizing the individual fraction percentages. Tabulated statistical output is included in Appendix A. Computation of these derived statistical parameters facilitates comparison of the results with a large number of previous studies involving grain size analyses and aids in correlation between sediment types and their environment.

The different types of statistical parameters (Table I) used to describe the character of the particle size distributions assume that the sediment size distribution is lognormal, and are intended to approximate the moment measures used in statistics. According to Inman (1952), the term "moment" has its origin in mechanics, where the moment of a force is defined as the product of the force and the perpendicular distance from the axis to the line of action of the force. In statistics the frequency of the distribution replaces the force of mechanics.

TABLE I

DESCRIPTIVE MEASURES

Measure	Trask (1932)	Inman (1952)	Folk and Ward (1957)	Moments (Inman, 1952)
Median	$Md=\phi^{*}_{50}$	$Md=\phi_{50}$	$Md=\phi_{50}$	$V_k=(\sum_{i=1}^{h}(((X_i-X_0)/C)^k \times f_i))/100$ C = class interval h = number of classes f_i= class frequency of the ith class X_0= class mark near the mean of the distribution X_i= class mark (value of the mid-point of the class interval) of the ith class V_k= moments about X_0 (converted to the appropriate moments about the origin and mean of the distribution by the following equations:
Mean	$M_q=\frac{\phi_{25}+\phi_{75}}{2}$	$M_\phi=\frac{\phi_{16}+\phi_{84}}{2}$	$M_z=\frac{\phi_{16}+\phi_{50}+\phi_{84}}{3}$	$m_1= M = CV_1+X_0=$ Mean
Sorting	$S_o=\sqrt{\phi_{75}/\phi_{25}}$	$\sigma_\phi=\frac{\phi_{84}-\phi_{16}}{2}$	$\sigma_I=\frac{\phi_{84}-\phi_{16}}{4}+\frac{\phi_{95}-\phi_5}{6.6}$	$m_2= C^2(V_2-V_1^2)$ $\sigma=\sqrt{m_2}=$ Standard Deviation
Skewness	$Sk_g=\frac{\phi_{25}\phi_{75}}{Md^2}$	$\alpha_\phi=\frac{M_\phi-Md_\phi}{\sigma_\phi}$ $\alpha_{2\phi}=\frac{1/2(\phi_5+\phi_{95})-Md_\phi}{\sigma_\phi}$	$Sk_I=\frac{(\phi_{16}+\phi_{84})-2\phi_{50}}{2(\phi_{84}-\phi_{16})}+\frac{(\phi_5+\phi_{95})-2\phi_{50}}{2(\phi_{95}-\phi_5)}$	$m_3= C^3(V_3-3V_1V_2+2V_1^3)$ $\alpha_3=m_3/\sigma^3=$ Skewness
Kurtosis	$K_{qa}=\frac{\phi_{75}-\phi_{25}}{2(P^{**}_{90}-P_{10})}$	$\beta_\phi=\frac{(\phi_{95}-\phi_5)-\sigma_\phi}{\sigma_\phi}$	$K_G=\frac{\phi_{95}-\phi_5}{2.44(\phi_{75}-\phi_{25})}$	$m_4= C^4(V_4-4V_1V_3+6V_1^2V_2-3V_1^4)$ $\beta_2=m_4/\sigma^4=$ Kurtosis

$*\phi_i$ = phi value corresponding to the ith percentile

$**P_i$ = particle size of the ith percentile

The computer program utilized for calculating the statistical parameters calculated data moments (Inman, 1952) which are less exact than theoretical moments, because the data is classified by dividing the size distribution into class intervals and is not based on a continuous distribution. Moment measures may be used if the entire distribution is known (Friedman, 1961). The dependence of moment measures on the entire distribution is a limitation of their practical application, since mechanical analysis often results in open ended curves (failure to attain the 100th percentile in the last cumulation). As described previously in this section the fine tail of the curve may be closed by extrapolating from the last measured value to 100 percent at +14.00 ∅ (Folk, 1974). The effect of normalizing the fine tail of the curve varies with different samples depending on the percentage of the sample normalized and the character of the entire distribution and must be viewed with caution (Roysce, 1970).

Trask's (1932) quartile measures do not take into consideration a sufficient portion of the total sample, since they are based on only the central 50 percent of the sediment distribution. In addition Trask's sorting measure is geometric rather than arithmetic, making it difficult to visualize relative degrees of sorting.

Inman (1952) and Folk and Ward (1957) measures are analogous to true moment measures and consider a larger portion of the curve, making them better for polymodal size distributions (Roysce, 1970).

SOUTH SLOUGH SEDIMENTS

GRAIN SIZE PARAMETERS

The usefulness of grain size parameters in differentiating depositional environments has been investigated by many workers. Studies by Friedman (1961, 1967), Mason and Folk (1958), Visher (1969), Passega (1957, 1964), and others have dealt with the relationship between varying modes of transport and transport conditions and the textural response of the sediment being transported.

Bottom sediment patterns are closely related to hydraulic circulation, tidal current velocities, bottom topography, and sediment source area (Hayes, 1971). The complex relations between these variables and their effect on textural parameters must be understood to delineate distinct environmental patterns.

The sediments of South Slough range in size from gravel to clay. The sediments can be divided into five types, ranging from pure sand to pure silt at the other extreme (Folk, 1974). Figure 5 depicts the distribution of bottom sediments in the South Slough Estuary. The gravel portion is ignored here for two reasons: (1) the gravel fraction, generally much less than one percent of the total sample, consists predominantly of wood and shell fragments which show no apparent relationship when plotted against the derived statistical parameters, and (2) only two samples have a significant gravel content, and those are related to unnatural conditions.

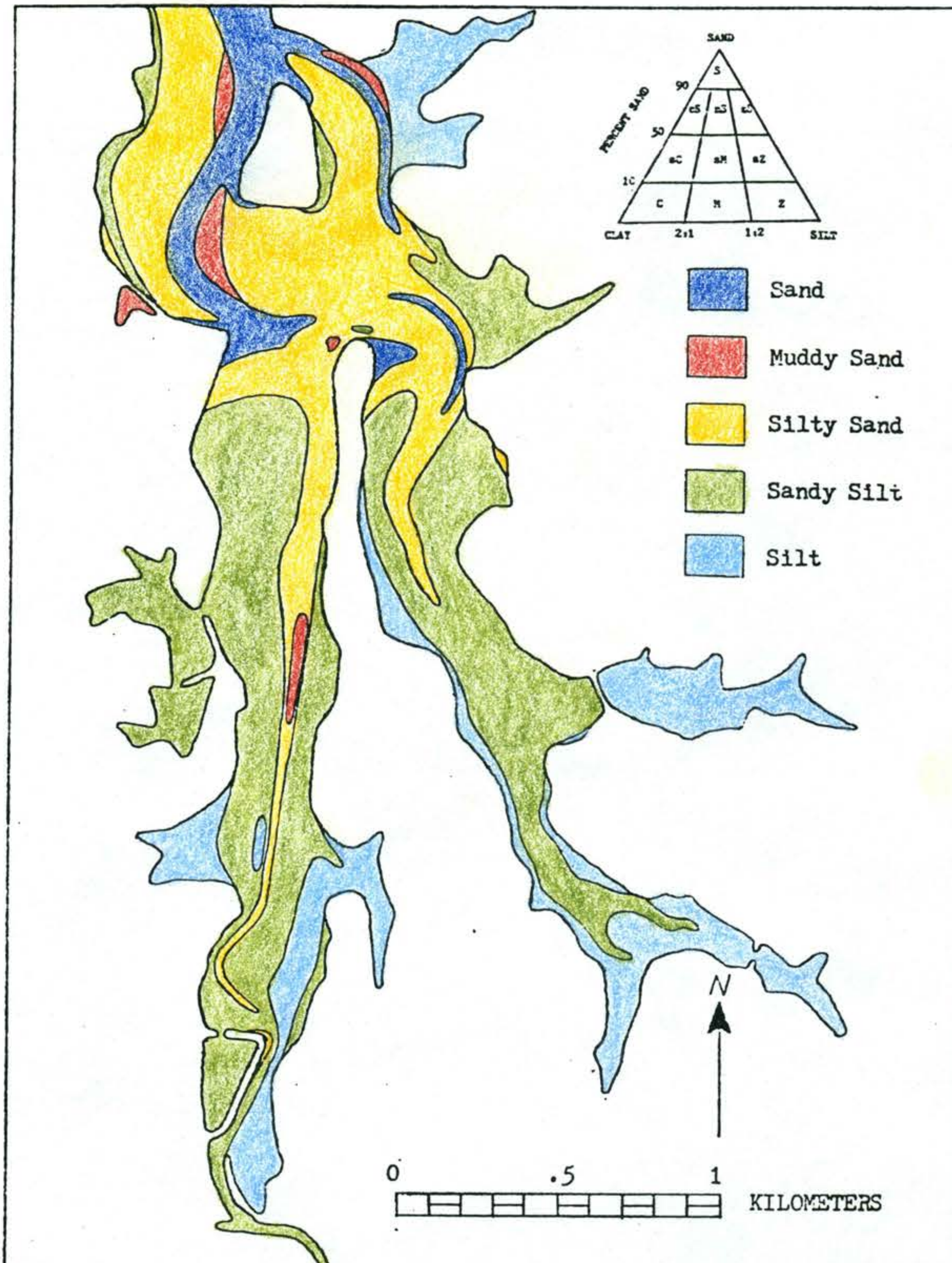


Figure 5. Distribution of bottom sediments in the South Slough Estuary. Classification scheme after Folk (1974).

The average characteristics of each sediment type are listed in Table II for convenience in interpreting the map. The distribution of sediments in South Slough closely parallels the depth contours in Figure 2 considering the much lower sampling density for sediments compared to depth soundings. In general, the distribution of the coarsest and best sorted sands agrees well with the main channel. Additional sands extend laterally from actively eroding terrace sands on Vallino Island, Long Island Point, and west of Long Island Point.

TABLE II

AVERAGE CHARACTERISTICS OF BOTTOM SEDIMENT TYPES

Sediment Type	Symbol	Average Phi Median	Average % Sand	Average % Silt	Average % Clay
Sand	S	1.91	95.18	2.73	1.77
Muddy Sand	mS	2.63	81.09	11.00	7.85
Silty Sand	zS	3.07	69.25	23.66	7.13
Sandy Silt	sZ	4.32	26.25	62.24	10.60
Silt	Z	4.73	6.00	80.82	13.14

The sands grade into finer grained muddy sands and silty sands. The muddy sands have subequal amounts of silt and clay, and the silty sands have at least twice as much silt as clay. In terms of the apparent energy distribution in the slough, and areally, the muddy sands lie between sand and silty sand. Local areas of muddy sand lie near the channels in areas of shallower water, where the fines can settle out.

The silty sands might be termed the average sediment type for South Slough. They are the dominant sediment type sampled (32 percent), and are widely distributed over the tide flats and in the channels towards the head of the slough. The sands grade into silty sand in the channels as the current strength diminishes.

The shallowest parts of the slough are composed of sandy silt and silt. These sediments are found bordering the slough, away from the main channel, and up either arm. Silty sands in the channels grade into sandy silts across the tide flats and similarly in the channels at the head of the slough. The farthest reaches of the slough are generally composed of silt.

Mean Grain Size

The mean grain size of both tide flat and channel deposits becomes increasingly finer towards the head of the slough. The grain size varies in two directions, decreasing abruptly from channel to tide flat and along the length of the slough. Figure 6 clearly depicts the close relationship between bathymetry and mean grain size. The dominance of tidal currents and apparent lack of coarse sediment from major streams entering the slough are the primary influences in establishing the environmental pattern for mean grain size.

Mean grain size for all environments ranged from +1.46 ∅ to +6.24 ∅ (.36 mm to .01 mm). Samples had a mean M_z value of about +3.91 ∅ and a standard deviation of about 1.24 ∅. The greatest clustering of mean values occurs about values of +4.00 ∅ and +5.00 ∅, with other prominent groupings around +1.75 ∅ and +3.25 ∅ (Figure 7A).

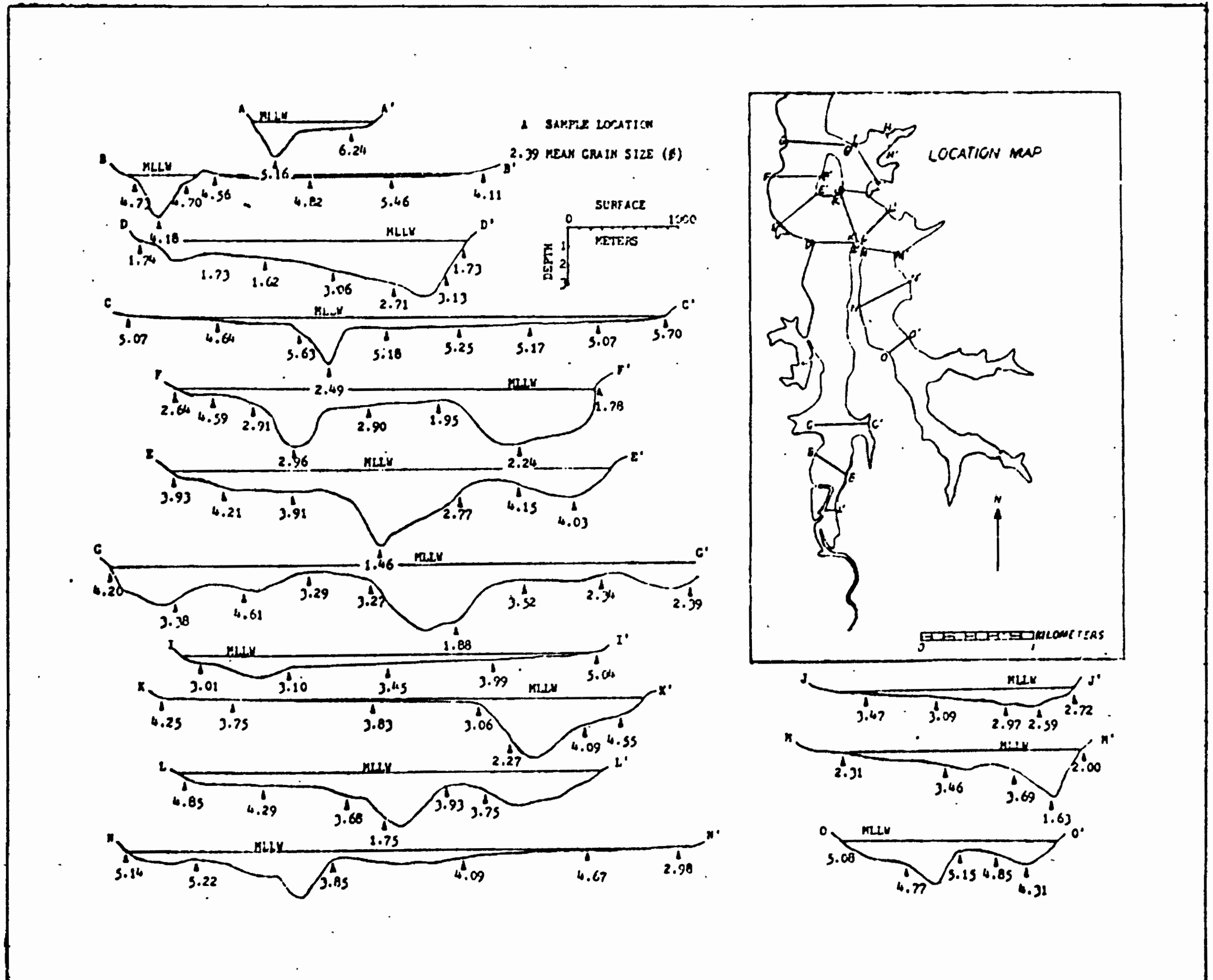


Figure 6. Cross channel bottom profiles of the South Slough Estuary.

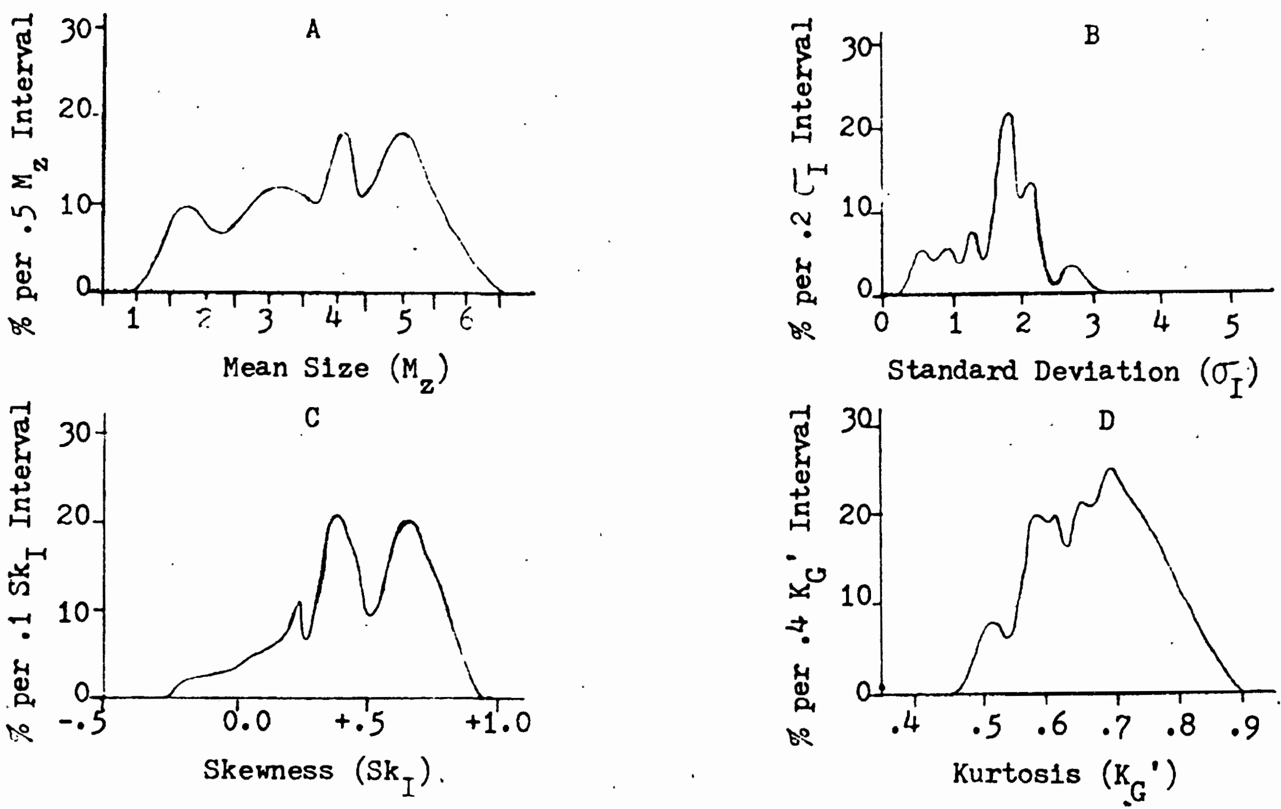


Figure 7. Frequency distribution of mean size, standard deviation, skewness, and kurtosis values for South Slough sediments. The ordinate gives the percentage of the analyzed samples falling in the given interval (e.g., the curve for standard deviation is 21 percent at σ_I=1.75; this means that 21 percent of the samples had σ_I values between 1.65 and 1.85).

Grain size distributions are commonly mixtures of two or more component populations (Visher, 1969; Passega, 1957). The component modes are produced by varying transport conditions, largely independent of each other (Doeglas, 1946), and often showing little or no variation in modal diameter in an area (Folk, 1974). The prominent modes in Figure 7A suggest a multiple source for the sediments.

Small variations from the basic pattern described above can be found. For instance, the east end of line N-N' (Figure 6) and west side of line D-D' are coarser near shore, decrease to a low on the tide flat, then increase again toward mid-channel. From observations made in the field these areas occur where smaller creeks empty into the slough, and where marginal sources of sediment, through bank erosion, are present. Marginal sources actively sloughing material into the slough are predominantly terrace sands. In addition, lag deposits of gravel, coarser sands, and shell resulting from erosion of small creeks across the tide flats, and of the terrace sands bordering the slough, were found but not sampled.

Standard Deviation

Inclusive graphic standard deviation (sorting) values (Folk and Ward, 1957) for South Slough are highly variable, ranging from 0.33 ∅ to 2.99 ∅, except for two samples with extreme values of 3.48 ∅ and 4.52 ∅. Verbal limits placed on sorting by Folk (1974) vary from very well sorted ($\sigma_I < 0.35$ ∅) to extremely poorly sorted ($\sigma_I > 4.00$ ∅) on the other end of the scale. Inclusive graphic standard deviation values show a nearly normal distribution (Figure 7B) averaging 1.73 ∅ with a standard deviation of 0.68 ∅. This indicates that the central two thirds of the samples have inclusive graphic standard deviation values ranging between 1.05 ∅ and 2.41 ∅.

The areal distribution pattern of inclusive graphic standard deviation values (Figure 8) follows the topographic pattern as with mean grain size, better sorting values corresponding to greater depth. A gradient of variable but generally increasing sorting values coincides with the main channels. The sorting values for channel samples increases from a minimum of 0.34 ∅ just west of Vallino Island to a maximum of 2.99 ∅ and 2.29 ∅ for west and east channels, respectively. The tidal flat sediments are more poorly sorted except in the southern end of both arms, where a reversal of this pattern, with more poorly sorted values corresponding to channel samples and better sorting on the tide flats, can be seen. Variations on this general pattern for tide flat samples are probably due to lateral input from terrace sands and streams feeding the slough. An area of extremely poorly sorted sediments is found bordering the slough southwest of Vallino Island, where material is flushed through a broken tidal gate at low tide.

Skewness

Skewness values ranged widely from -0.19 to +0.87. Symmetrical curves have a Sk_I=0.00 and a theoretical maximum of +1.00 or -1.00. Greater than 95 percent of the samples are positively skewed or skewed toward the fine sizes. Skewness is a measure of the departure of the mean from the median or the asymmetry of the frequency distribution. The skewness sheds light on the source. Sediments from multiple sources are commonly bimodal and strongly skewed. The processes and character of the depositing agent are also reflected in the asymmetry of the curve

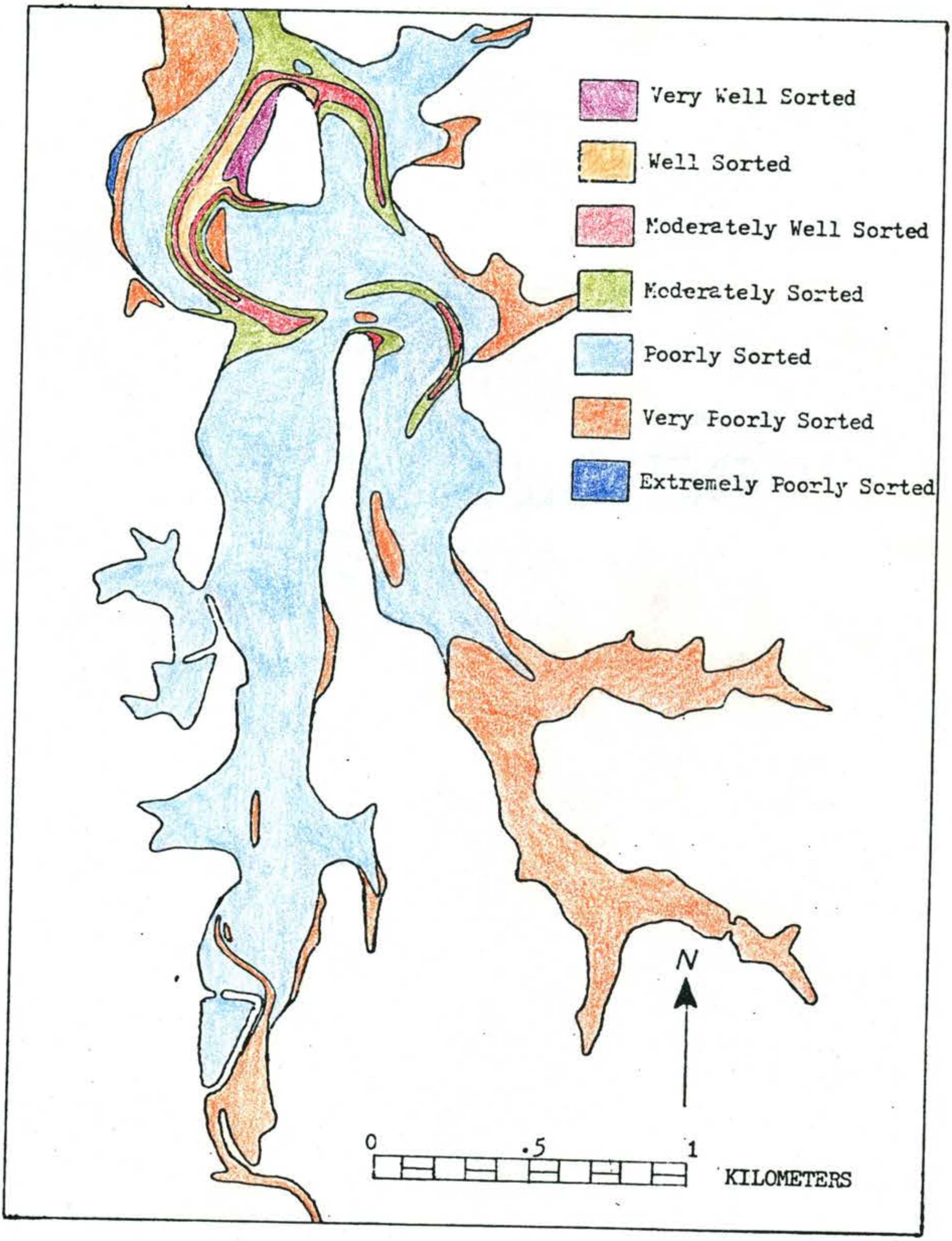


Figure 8. Distribution of sorting values. Classification scheme after Folk (1974).

(Folk, 1974). Skewness values, though polymodal, appear to approach a somewhat normal distribution, grouped about a mean skewness of +0.46 with a standard deviation of 0.24 (i.e., two thirds of the samples have skewness values between +0.22 and +0.70) (Figure 7C).

The areal distribution pattern of skewness values is indistinct. However, when the verbal limits of Folk (1974) are applied a pattern emerges (Figure 9). In general, tide flats are strongly positively skewed (Sk_I values ranging from +0.30 to +1.00), except where terrace sands are actively sloughing material into the slough. Terrace sands are near symmetrical (Sk_I values ranging from -0.10 to +0.10). Tide flat sediments adjacent to the eroding terrace deposits are fine skewed (Sk_I values ranging from +0.10 to +0.30). Channel samples, on the other hand, are near symmetrical to fine skewed near Vallino Island, changing to fine skewed and then strongly fine skewed towards the head of the estuary. Only two samples south of the end of Long Island Point were not strongly fine skewed.

Kurtosis

Folk (1974) reports the distribution of K_G values in nature to be strongly skewed, with most sediments around 0.85 to 1.40. For graphical or statistical analysis the kurtosis distribution must be normalized using the function $K_G'=K_G/K_G+1$. Transformed kurtosis for normal curves is $K_G'=0.50$, with most sediments falling between 0.40 to 0.65. Kurtosis values are computed by taking the ratio between sorting in the tails and sorting in the central portion of the curve.

The distribution of kurtosis values is nearly normal (Figure 7D) with a mean K_G' of 0.66 (corresponding to K_G=2.17) and a standard devia-

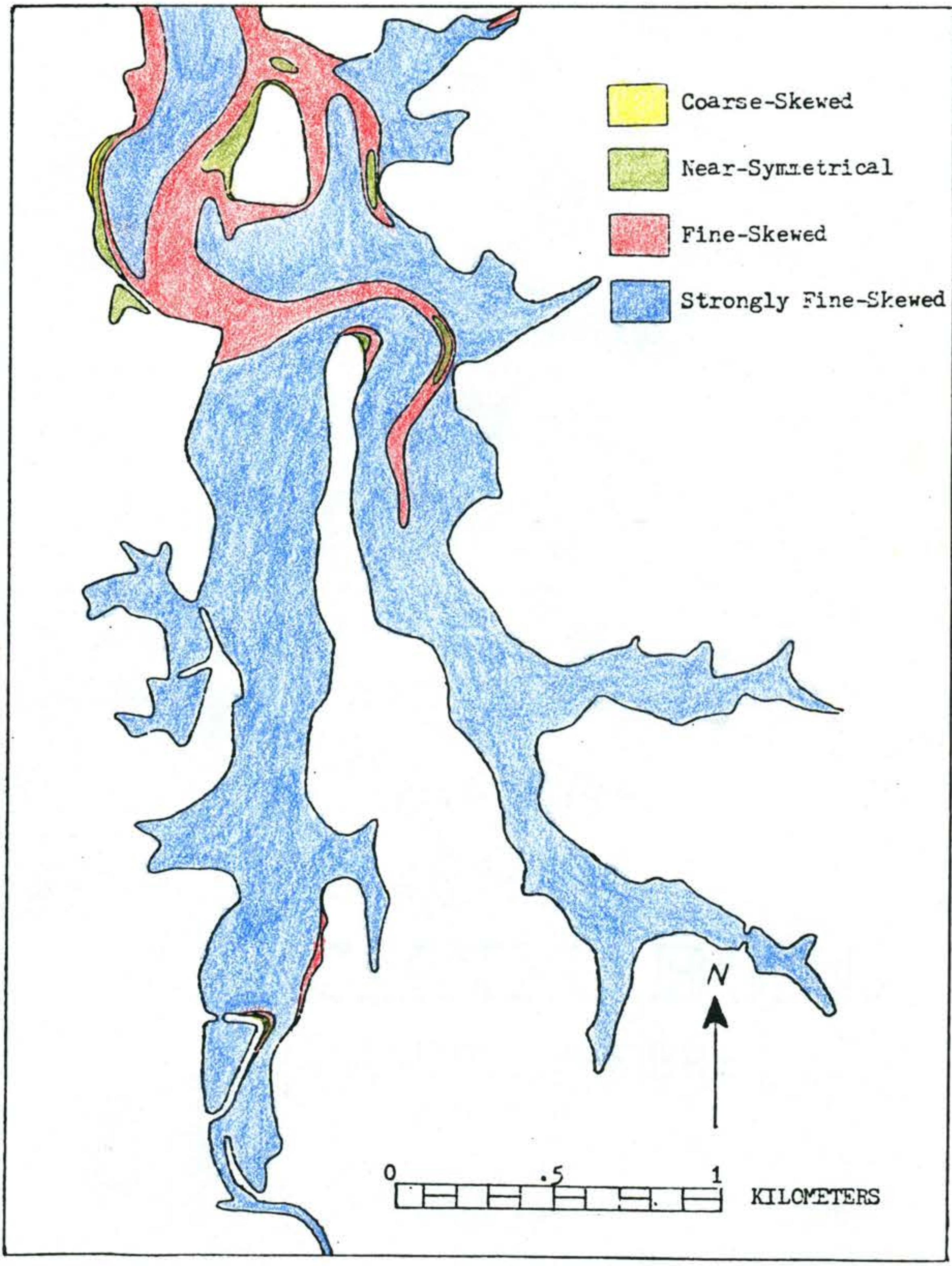


Figure 9. Distribution of skewness values. Classification scheme after Folk (1974).

tion of 0.08 (i.e., two thirds of the samples have K_G' values between 0.58 and 0.74, corresponding to K_G values ranging from 1.32 to 3.02 with a standard deviation of 0.85). Kurtosis values (K_G') vary between 0.49 and 0.86 or from mesokurtic (K_G' between 0.53 and 0.60) to leptokurtic (K_G' over 0.75) (Folk, 1974). These samples, for the most part then, are excessively peaked, with better sorting in the central portion of the curve than in the tails. The larger portion of the samples fall outside the normal range of K_G' values for natural sediments, with nearly 55 percent greater than 0.65.

In analyzing the areal distribution of kurtosis values no distinct depositional patterns or trends are revealed.

INTERRELATIONSHIP BETWEEN PARAMETERS

It is not always possible to interpret a single sample from its size data, or to interpret a series of samples from a single derived statistical parameter. To unravel the complex of physical, chemical, and biological conditions under which a sediment accumulates requires understanding the geological significance of variations in parameters across the environment as well as their interrelationships.

Mean Size Versus Standard Deviation

Figure 10 indicates a general increase in standard deviation values with decreasing mean size. Minimum standard deviation values generally correspond to prominent modes in the sediment and vice versa (Folk and Ward, 1957). The highest σ_I values should be obtained by sub-equal proportions of sand and silt, halfway between the two modes if the sediment is bimodal. Prominent modes in South Slough sediments corres-

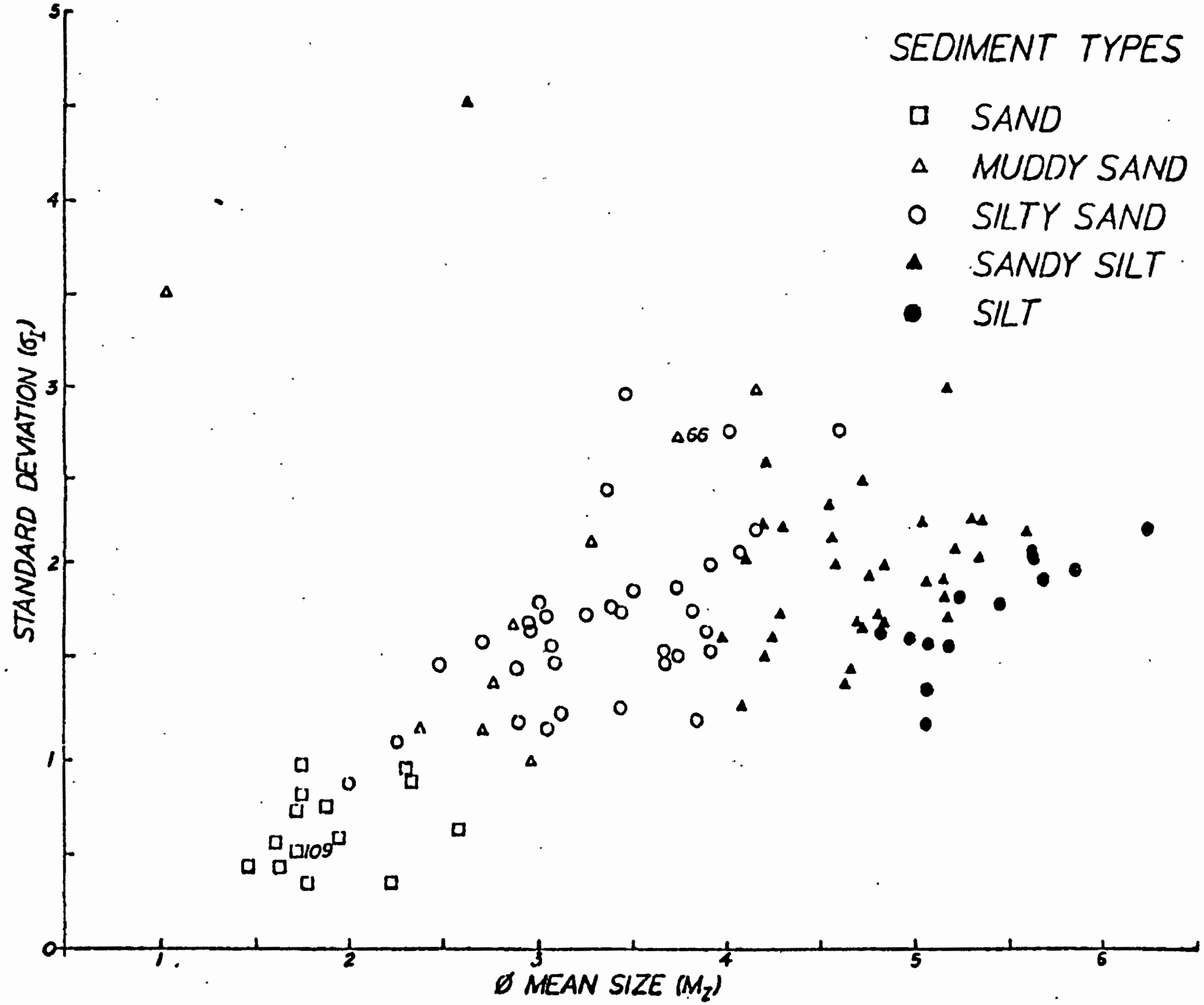


Figure 10. Scatter plot of graphic mean size (M_z) versus inclusive graphic standard deviation (σ_I) (sorting).

pond to sand from the terrace deposits, and silt, which appears to be related to the upland contribution. The pattern in Figure 10 appears to level out as it approaches the silt size particle range (+4.00 ø to +8.00 ø); however, the σ_I values do not decrease to the level of the sand mode. Folk and Ward (1957), in a similar study, have pointed out this may be the result of the type of material supplied by the source area. Apparently the terrace sands have inherently better sorting than material being supplied by the present creeks. A comparison of sample 109, which is located at the base of an actively eroding terrace deposit, and sample 66 from Winchester Creek support that possibility (Figure 10). Furthermore, a plot of inclusive graphic standard deviation versus less than 62 micron percent (Figure 11) shows poorer sorting in the nearly pure silt fraction (100 percent less than 62 microns). Folk and Ward (1957) found a pattern similar to Figure 10 for Brazos River bar sediments by the same mechanism of adding two modal distributions. Folk and Ward (1957) also indicate that with a wide range of grain sizes the pattern is probably a sine curve, with minimum values of σ_I corresponding to the various modes present in the sediment.

Channel sands are separated from tide flat sediments in Figure 10, although a large overlapping of the two fields occurs. The overlap is suggestive of a wide range in energy conditions both laterally and longitudinally in South Slough, with energy decreasing towards the margins and towards the head of the estuary.

Mean Size Versus Skewness

A graph of mean grain size as a function of inclusive graphic skewness (Figure 12) shows a sinusoidal relationship exists between the

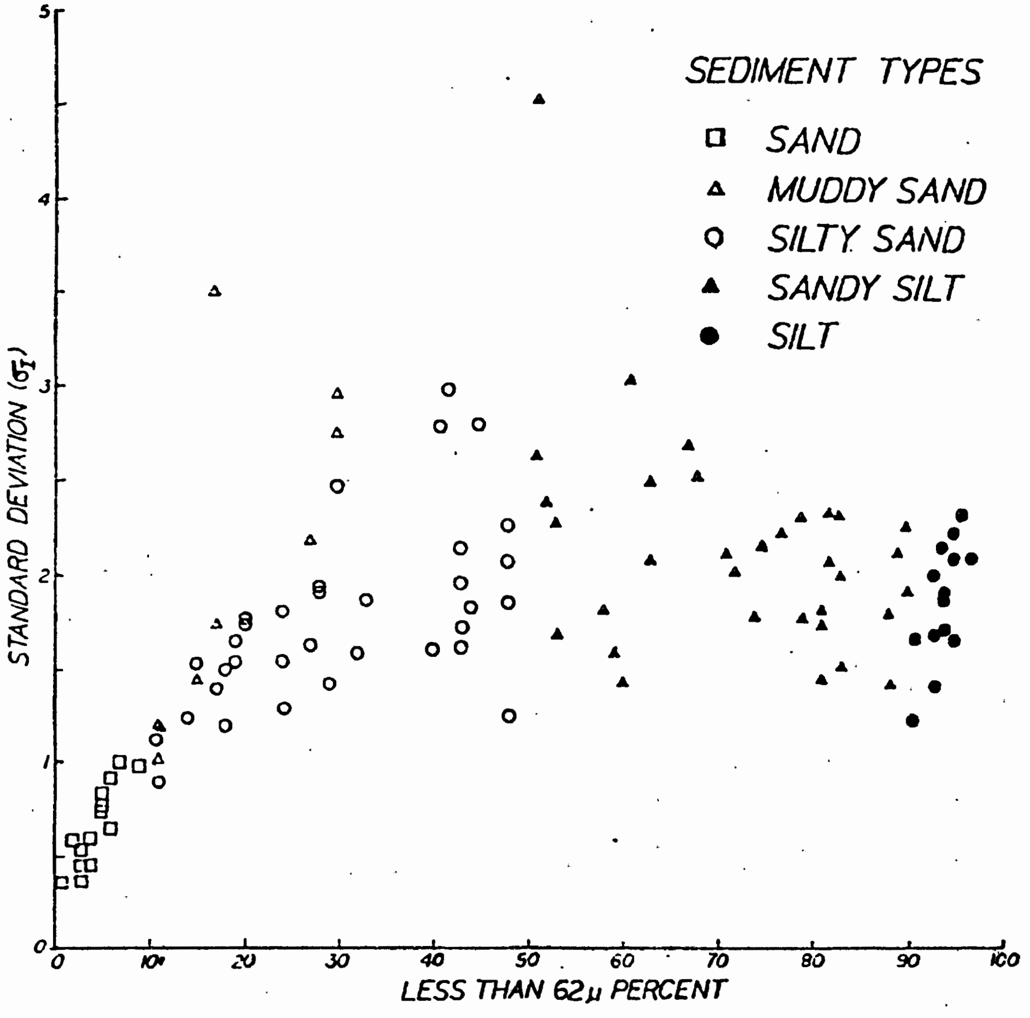


Figure 11. Scatter plot of less than 62 micron percent versus inclusive graphic standard deviation (σ_I).

asymmetry of the distribution and mean grain size. Comparison with Folk and Ward (1957) indicates a similar relationship in Brazos River bar sediments. Again, Folk and Ward (1957) were able to explain a markedly sinusoidal relationship on the basis of mixed modes. The distinctiveness of the two modes is more apparent than in Figure 10. Prominent modes again correspond to sands with a mean size of about +2.00 ∅ and silt with a mean size greater than +5.00 ∅.

In Figure 12, the addition of fine material to the coarser sand mode (at a mean size of about +2.00 ∅) changes the sediment from a near normal distribution to strongly fine skewed with a mean size of about +3.00 ∅. As more silt is added the two modes become subequal and skewness again becomes near symmetrical at about +4.00 ∅. As the amount of silt becomes greater than sand, the addition of fine material causes the pattern to become once again strongly fine skewed at a size of +5.00 ∅. However, in at least one sample (117) a negatively skewed distribution is produced. Winnowing out finer sized particles in the sediment and lagging of coarser sands results in both improvement in sorting and development of negative skewness.

Plotting inclusive graphic skewness versus less than 62 micron percent (Figure 13) reinforces the results obtained from Figure 12. The progressive change from one sediment type to another can be followed as the pattern develops through mixing modes. Channel sands grade into muddy sand and silty sands laterally and towards the head of the estuary. Tidal flat silty sands grade into sandy silt and silt as the tidal currents diminish over the tide flats and lengthwise, as fines settle out in abundance towards the head of the estuary.

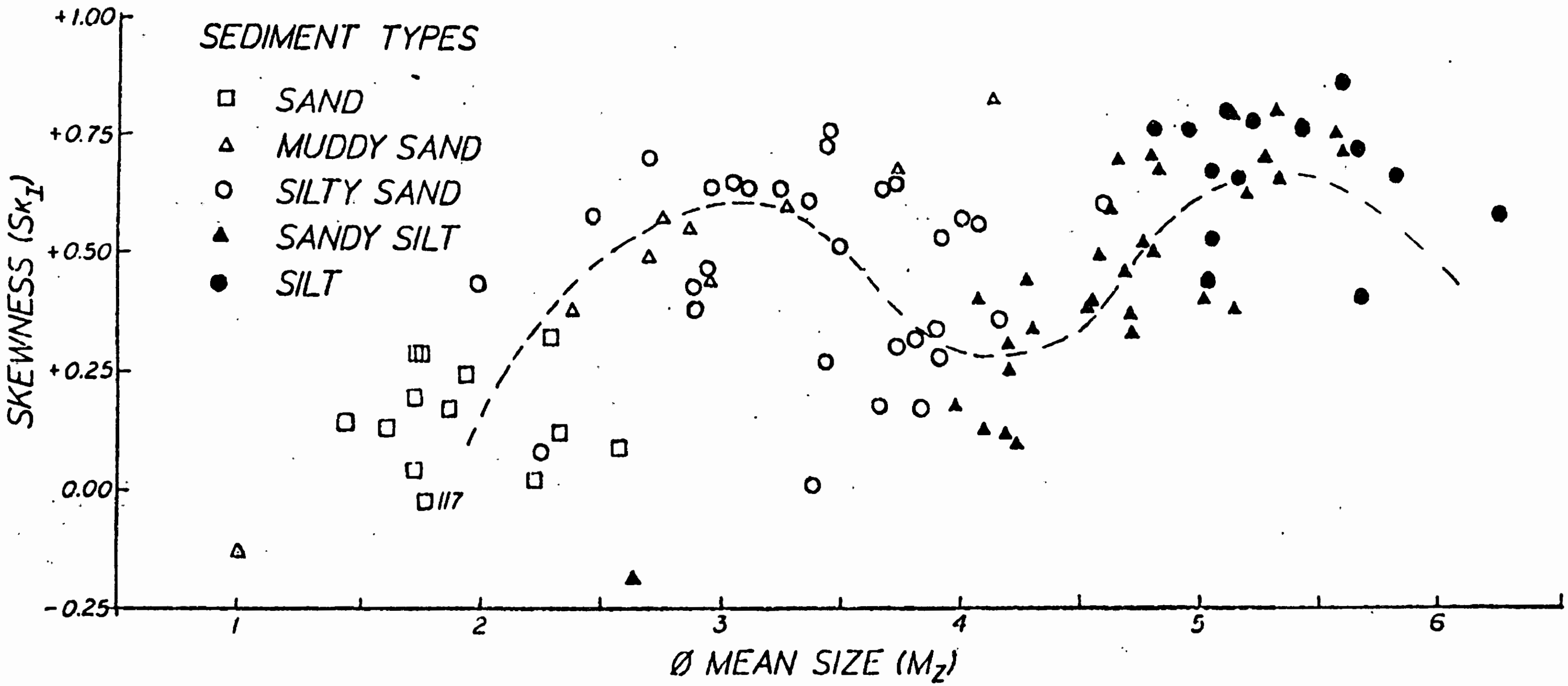


Figure 12. Scatter plot of graphic mean size (M_z) versus inclusive graphic skewness (Sk_I). Trend line is discussed in the text.

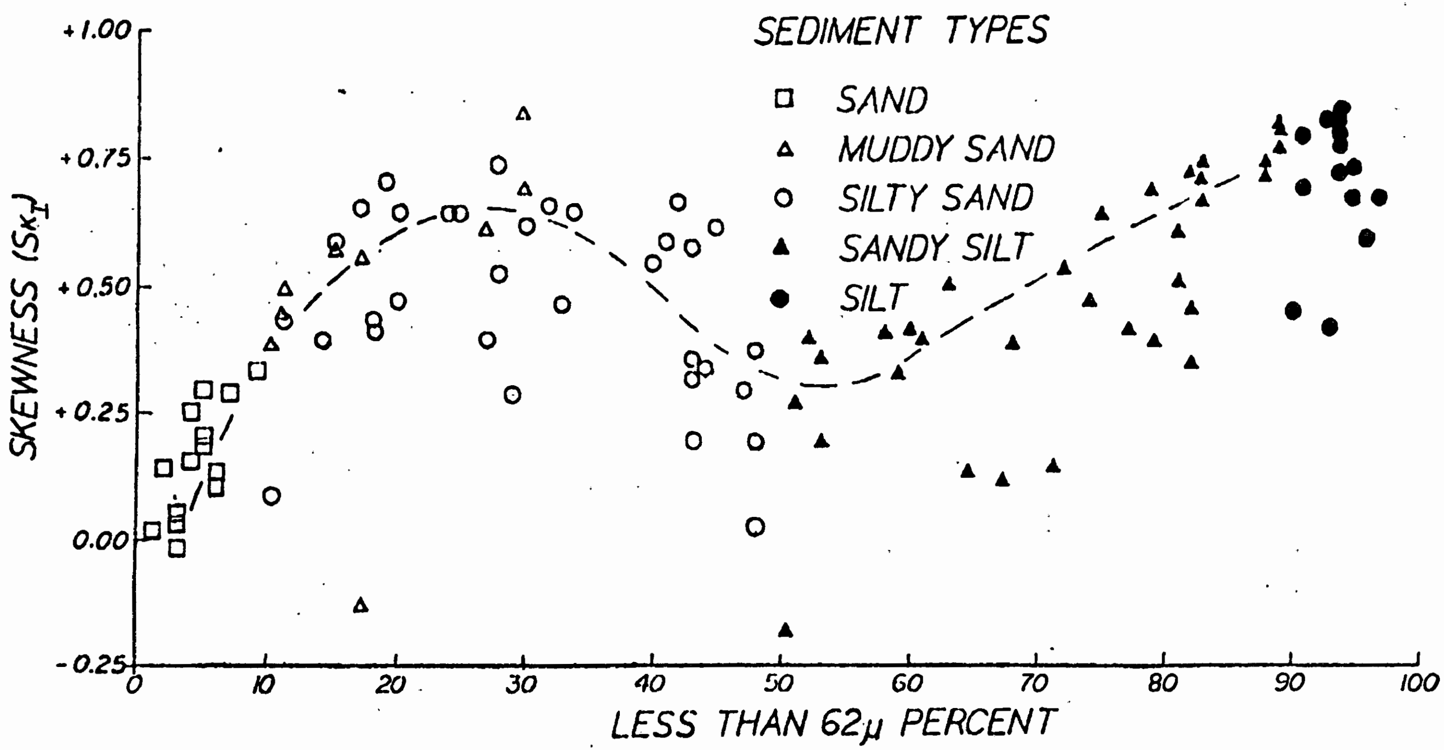


Figure 13. Scatter plot of less than 62 micron percent versus inclusive graphic skewness (Sk_I). Trend line is discussed in the text.

In Figures 10-13 the patterns suggest the tidal currents are ineffective in sorting. Apparently the source area(s) liberates a wide range of fine sand to coarse silt size particles (sorting remains relatively constant from +3.00 ∅ to +6.00 ∅ - poorly sorted) at a rate too high to be efficiently sorted. Another important influence on sorting is the current characteristics, fluctuating currents being inefficient sorting agents (Folk, 1974).

Mean Size Versus Kurtosis

The relationship between kurtosis and mean grain size (Figure 14) is complex. Comparison with Figure 12 shows that high positive skewness is generally associated with lower kurtosis values. On closer examination of Figure 14 this relationship between skewness and kurtosis is not directly applicable. There is a shift in the positions of prominent peaks and troughs of the trends, with highest positive skewness values not in direct coincidence with lower kurtosis values, and vice versa. Figure 15 sheds some light on the relationship between kurtosis and sediment type. The purer sand and silt modes at either end of the diagram (0 and 100 percent less than 62 microns) do not correspond to the highest kurtosis values. The purer modes, in fact, give nearly normal curves (K_G'=0.50), sand generally somewhat closer to normal than silt. Folk and Ward (1957) discovered that the slight addition (3 to 10 percent) of another mode to the purer end members worsened the sorting in the tails while sorting in the central portion of the curve remained good, producing curves which were very leptokurtic. They further concluded that additional material from the new mode gives rise to a bimodal distribution. Numerous authors including Folk and Ward (1957),

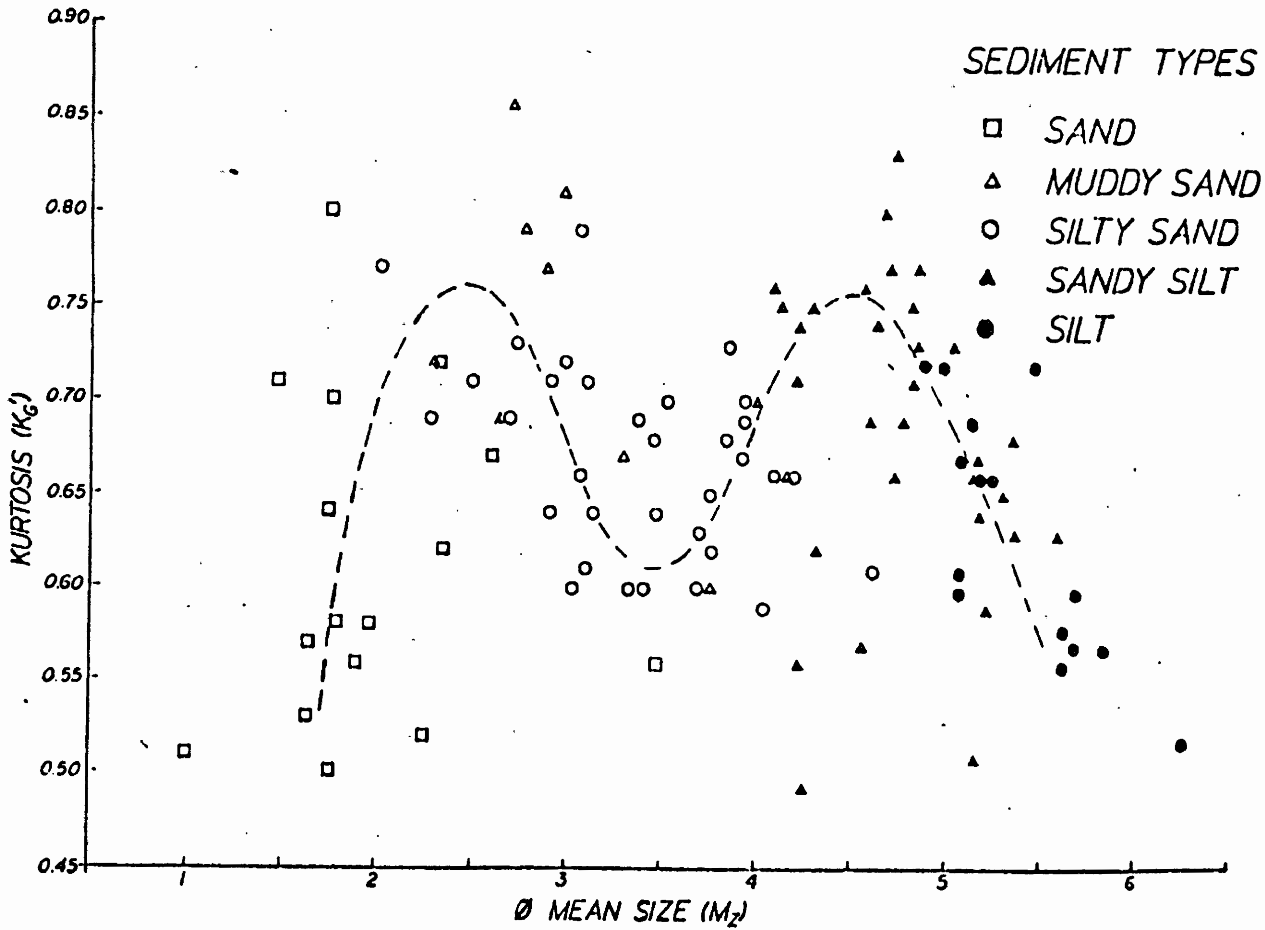


Figure 14. Scatter plot of graphic mean size (M_z) versus normalized graphic kurtosis (K_G'). Trend line is discussed in the text.

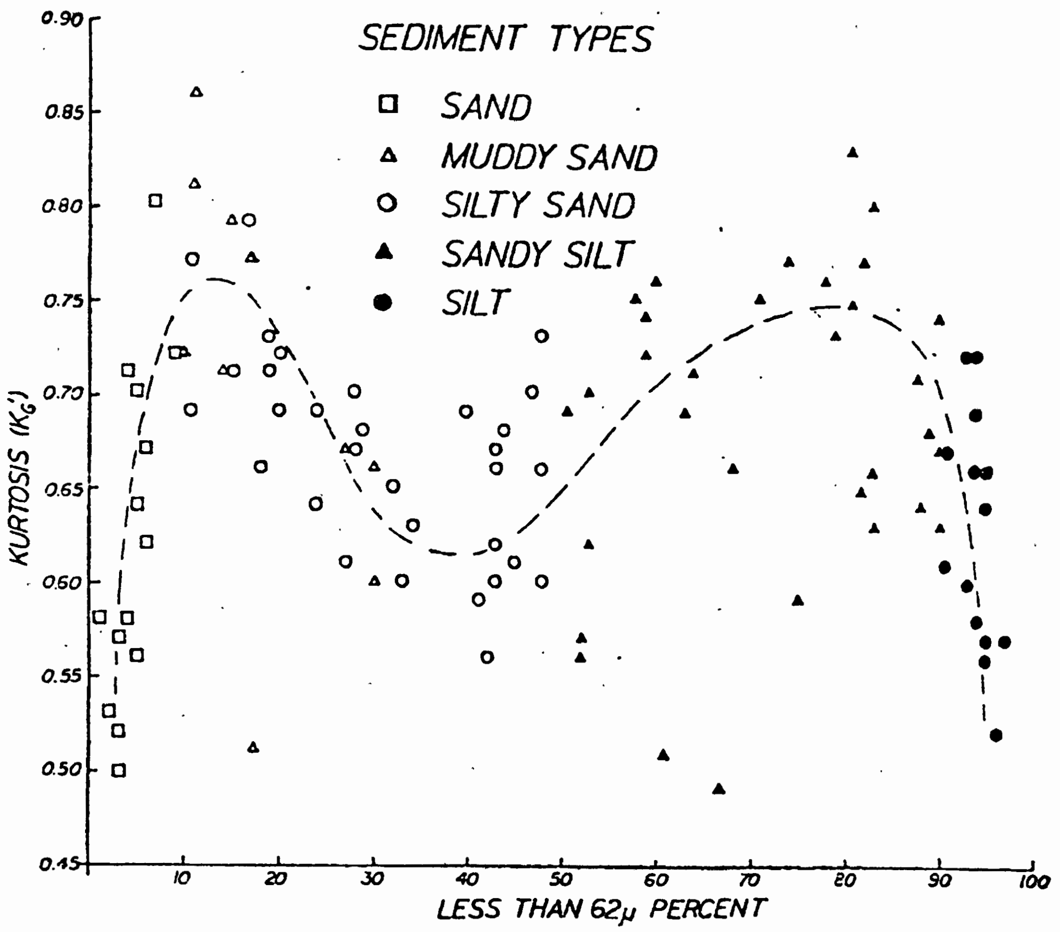


Figure 15. Scatter plot of less than 62 micron percent versus normalized graphic kurtosis (K_G'). Trend line is discussed in the text.

Folk (1974), and Friedman (1961, 1967) have pointed out that strongly bimodal sediments tend to be platykurtic. The trend from leptokurtic back toward a more normal curve as the modes become more equal can be seen in Figure 15. The transition from silty sand to sandy silt away from the main channel and near the head of the estuary corresponds to this portion of the pattern. The highest kurtosis values are reached with approximately 10 and 80 percent silt, at M_z=+2.70 and M_z=+4.75, respectively. Samples corresponding to these silt percentiles can be found bordering the slough and in near channel deposits. The lowest kurtosis values in the central portion of the pattern shown in Figure 15 do not coincide with 50 percent less than 62 microns, as expected with a bimodal sediment. The shift towards lesser amounts of mud corresponding to the low point in the trend again makes it evident that the silt fraction has poorer relative sorting.

Standard Deviation Versus Skewness

A plot of inclusive graphic skewness against inclusive graphic standard deviation shows very little overall trend between skewness and standard deviation (sorting), except that coarser sands generally show near symmetrical curves and are well sorted. Friedman (1967) in a similar plot suggested groupings into river and beach deposits. The boundary proposed by Friedman (1967) for dividing beach and river deposits is superimposed on Figure 16. The line shows near terrace and channel sands closer to the beach field designated by Friedman (1967) with the rest of the sediment types departing farther from the line. The basis for the division proposed by Friedman (1967) relates to the important differences between fluvial and longshore transport. The basic differ-

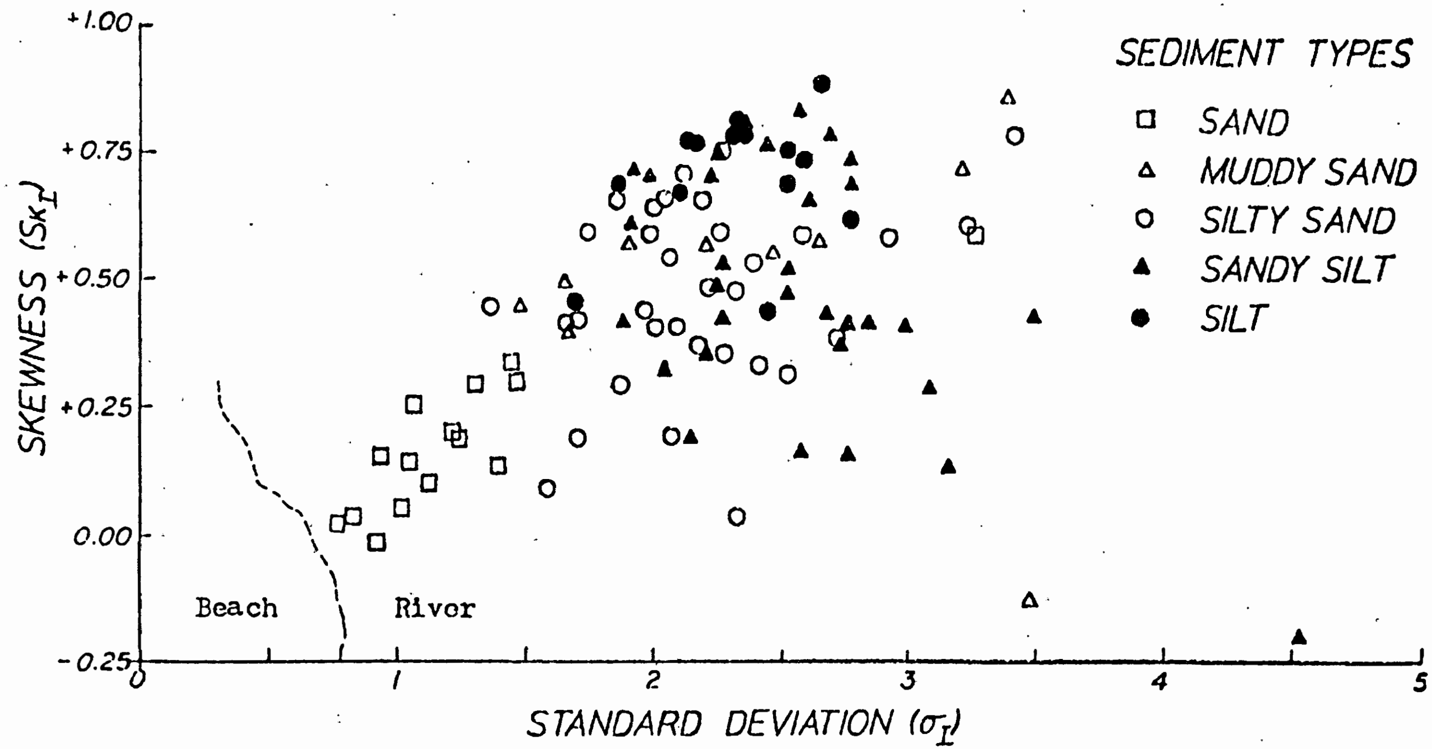


Figure 16. Scatter plot of inclusive graphic standard deviation (σ_I) versus inclusive graphic skewness (Sk_I). Demarcation line separates beach and river fields proposed by Friedman (1967).

ences being oscillatory flow on beaches compared to unidirectional flow in the river environment. Oscillatory flow results in removal of the fines, producing a high degree of sorting and negative skewness in the beach environment. River sediments in comparison were shown to be predominantly positively skewed and to have poorer sorting values, there being no way to remove fines from river transport except during flood stage through overbank deposits.

In South Slough, the channel sands lie immediately to the right of the beach/river boundary and the tide flat sediments farther to the right. Only one sample has negative skewness and lies near the boundary proposed by Friedman (1967). The association of negative skewness with an environment where active winnowing takes place (Duane, 1965) suggests that tidal currents and wave action in South Slough, except near the north end of the study area in the main channels, are ineffective in removing fines from the sediment.

The sands do not appear to retain their inherent texture for any great distance from their source. Mixing of sediments is either quite complete or finer material is trapped in the sediments derived from the terrace deposits. Poorly sorted and strongly fine skewed sediments are found near actively eroding terrace deposits.

Standard Deviation Versus Kurtosis

In Figure 17 inclusive graphic standard deviation is plotted against graphic kurtosis. Kurtosis has been shown to be a function of mean grain size, and standard deviation is also very much a function of mean grain size, making it evident that kurtosis and standard deviation should exhibit some relationship. The relationship, although indis-

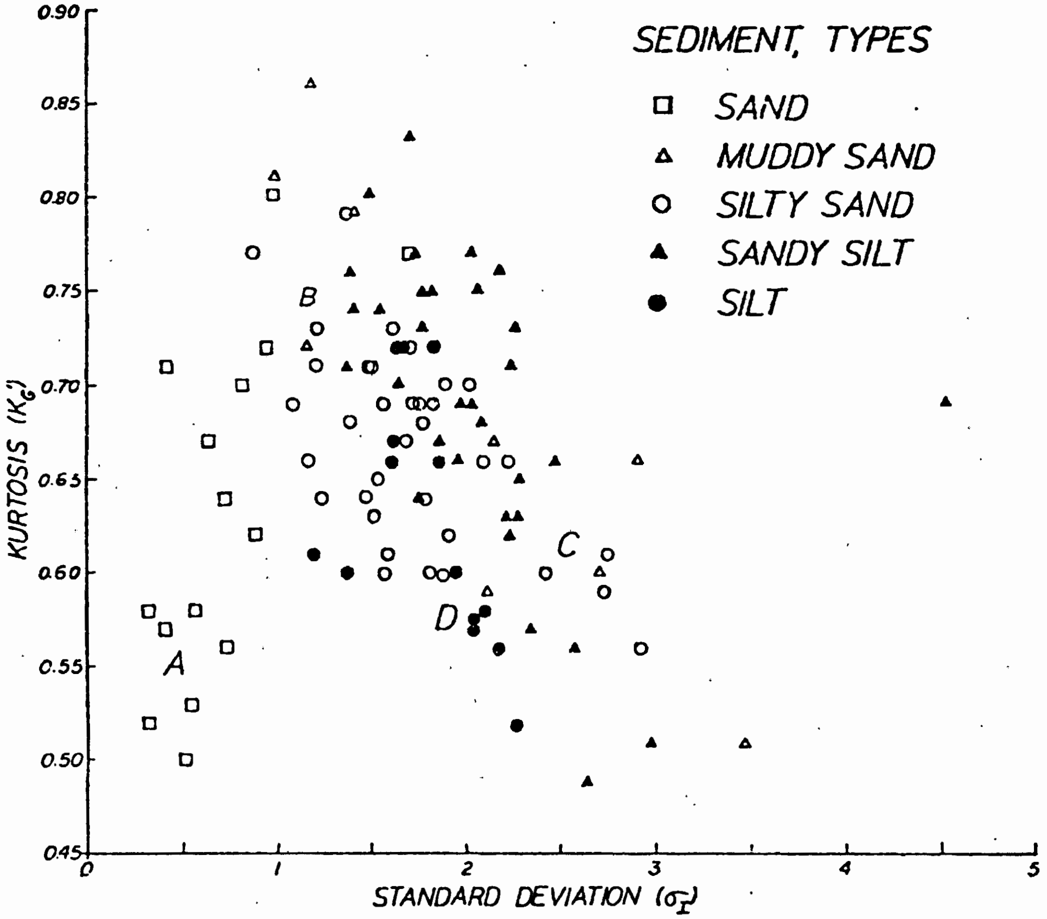


Figure 17. Scatter plot of inclusive graphic standard deviation (σ_I) versus normalized graphic kurtosis (K_G').

tinct, can be traced from one sediment type to another as the relative proportions of the prominent modes varies. Purer sands with low σ_I and K_G' values change drastically to the highest kurtosis values with the addition of subordinate amounts of mud (10 percent). As the two modes become subequal (1:3 to 3:1) with the addition of more mud, samples exhibit poorer sorting and very low kurtosis values. As more mud is added, becoming the dominant mode, the kurtosis and standard deviation values change back toward moderate sorting values and high kurtosis, returning to lower K_G' values with mud predominant (more than 80 percent). The progressive change is complicated by the dominant modes themselves, as their distributions do not entirely follow normal curves.

In order of decreasing size, samples follow a regular progression from pure sands (A) to muddy sands (B) to subequal sand and mud (silty Sand) towards C. A reversal of the pattern occurs as the silt mode increases, back to B (sandy Silt) and ending at D (Silt).

Skewness Versus Kurtosis

In Figure 18 inclusive graphic skewness is plotted against graphic kurtosis. Mason and Folk (1958), in a study of sands from Mustang Island, Texas, found the plot of skewness versus kurtosis to be most effective in differentiating between environments. Few studies other than Mason and Folk (1958) have succeeded in differentiating between environments utilizing skewness and kurtosis in binary plots. Friedman (1961) considered skewness sensitive to environmental influences, whereas kurtosis was insensitive in distinguishing beach, dune, and river sands.

In Figure 18 very little overall trend between skewness and kur-

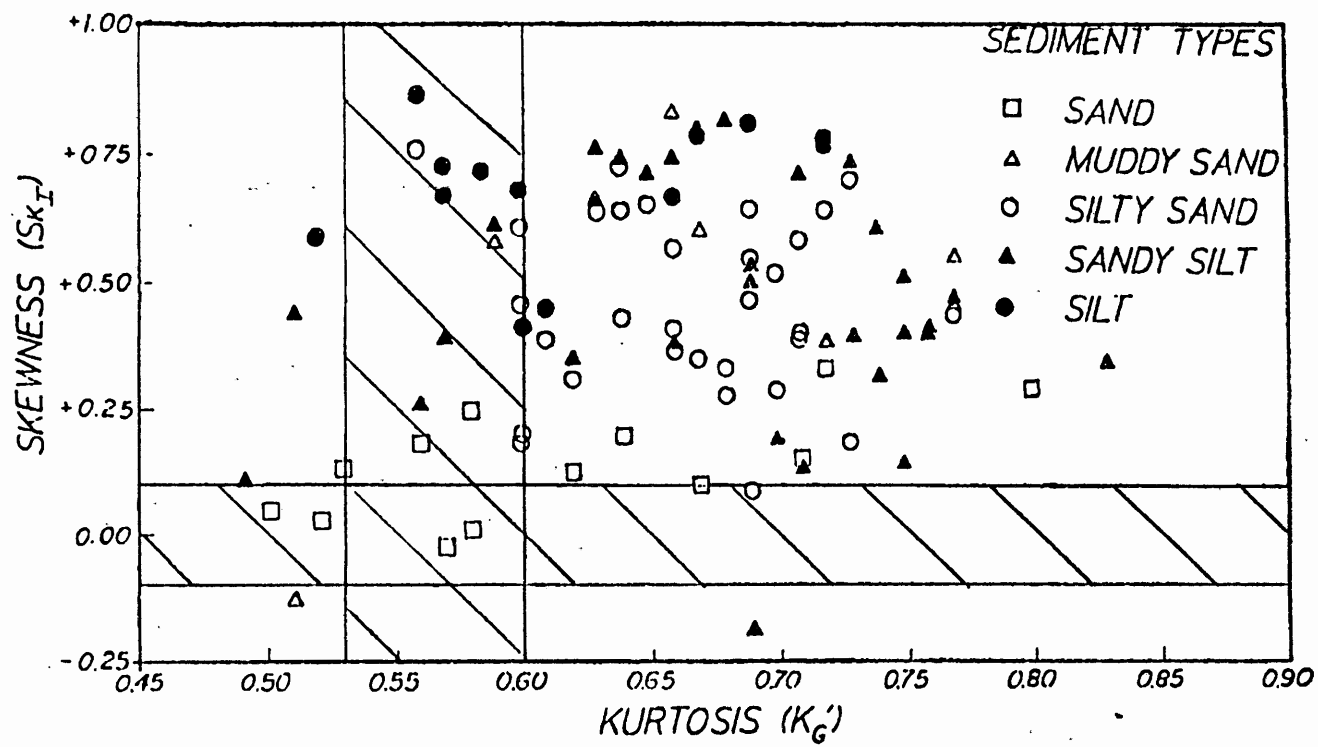


Figure 18. Scatter plot of normalized graphic kurtosis (K_G') versus inclusive graphic skewness (Sk_I). Areas defined as within the range of the normal curve are shown by diagonal line patterns.

tosis is indicated. However, as indicated by Folk and Ward (1957), both properties are dependent on the relative proportions of the prominent modes, and should therefore follow a regular path as the proportions change.

Starting with nearly pure sands with low positive skewness and low kurtosis values, and changing proportions of the modes, the progression from one sample type to another traces a counterclockwise path through the cluster of points, nearly twice repeated, and ending with near normal kurtosis and high positive skewness. Folk and Ward (1957) also indicate that there were very few analyses which fall into the range for normal curves (Figure 18). Wide separation between modes and ineffective sorting of the depositional environment were deemed responsible for the departure from normality. Similar conclusions are suggested for South Slough sediments.

CM Analysis

Samples plotted on a CM diagram (Passega, 1957, 1964) are shown in Figure 19. A CM diagram is a binary plot of the 1st percentile (C) versus median grain size (M). The 5th percentile is used rather than the 1st percentile as the C value, which is representative of the minimum competence of the transporting medium. The choice of a percentile larger than the 1st percentile value may reduce or eliminate significant depositional variations, but was necessary to reduce sampling errors mentioned previously with nonterrigenous materials (shell and wood fragments). The value M expresses the average coarseness of the sediment. The idea behind CM diagrams is that certain processes of transportation and deposition act to differentially concentrate varying size distribu-

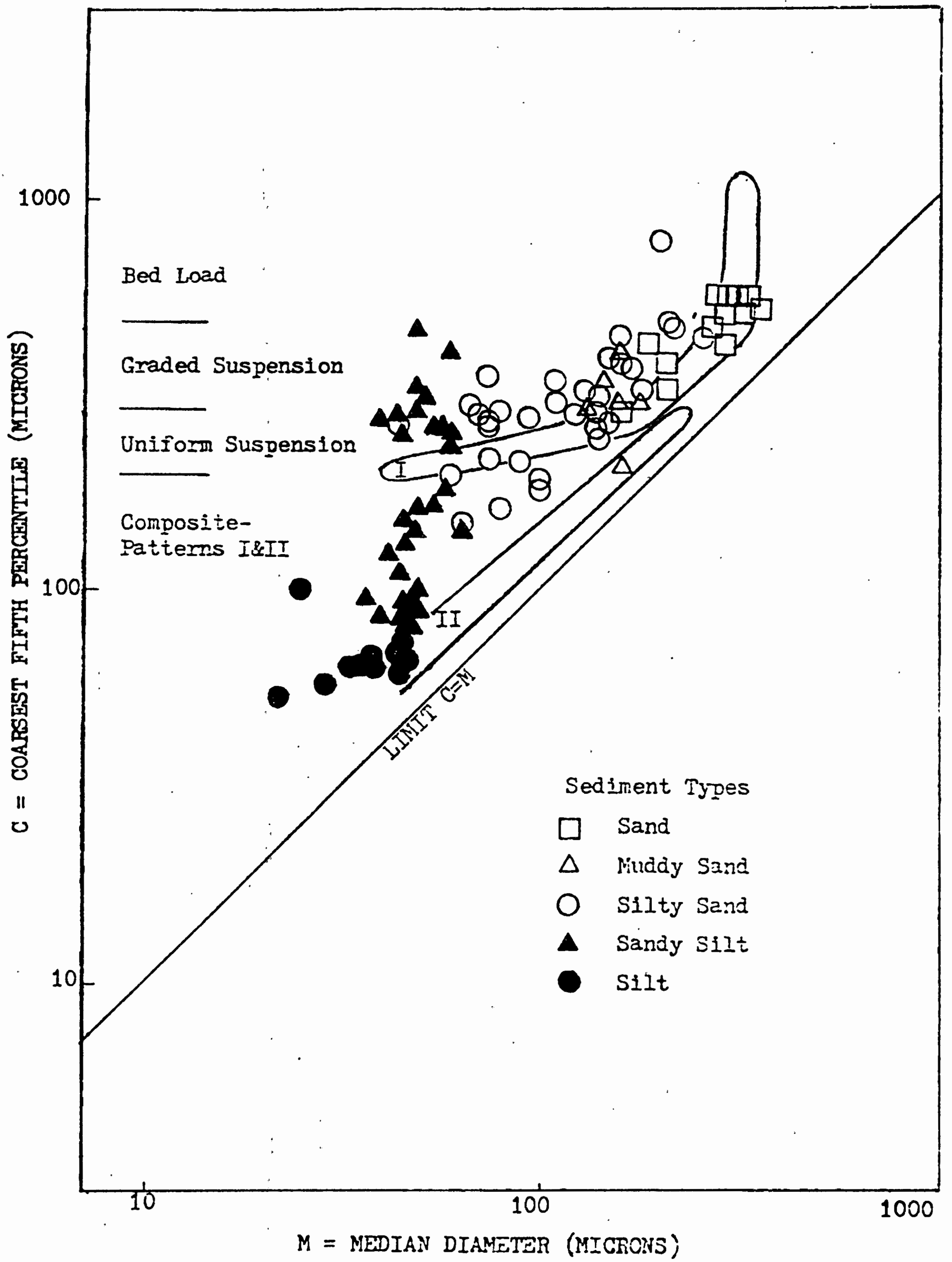


Figure 19. CM diagram for sediments in the South Slough Estuary (modified from Passega, 1957).

tions.

In comparison with the CM patterns of Passega (1957) sample analyses with a C value larger than 200 microns form a river pattern. Passega (1957), using data from a variety of sources, indicated that as depositional agents, shallow marine currents are similar to rivers. A similar pattern to the river pattern, for example, was discovered by Passega (1957) for tidal flat sediments in Holland. Passega (1957) applied the name tractive currents to these currents which have the ability to transport sediment by traction and closely follow bottom topography.

The crescent shaped pattern formed by sample analyses with a C value larger than 200 microns is divisible into three segments by the bends in the pattern. Sample analyses with C values larger than 500 microns represent coarser sands transported by traction. The coarse particles form a somewhat scattered pattern for the few analyses larger than 500 microns. The coarsest particles transported by traction generally form only a small part of the total sample (Passega, 1957).

That part of the pattern limited by values of C between 500 and approximately 300 microns, and to the right of 100 microns (M), parallels the limit C=M. The upper and lower limits of this segment are an indication of the maximum and minimum turbulence of the current at the bottom assuming a wide size range of material is available for transport (Roysce, 1970). The material represented by this segment is small enough to be carried in suspension by tractive currents. Particles are transported part of the time in the bed load and otherwise in suspension (Passega, 1957).

That segment of the river pattern between approximately 200 and 300 microns (C) with median values less than 100 microns, relates to the finest sediments transported in suspension by tractive currents in areas of low velocity. Turbulence of the transporting medium is always sufficient to carry particles smaller than the lower limit of the pattern for this segment. Complete river patterns are rarely observed. Patterns which are complete represent considerable lateral variation in conditions of flow and deposition (Passega, 1957).

Sample analyses plotting below 200 microns (C) seem to be a combination of patterns I and II of Passega (1957). Pattern II can be formed by turbidity currents as well as by tractive currents which lose speed gradually and uniformly enough that the suspension remains graded near the bottom. Passega (1957) indicated that a sequence of locally swift currents and slow uniform currents would form such a pattern. Nearly all the samples in this range are located near the head of the slough or away from the channels where these flow conditions may exist. The areal distribution of transport mechanisms is shown in Figure 20.

DISCUSSION - PROCESSES OF TRANSPORTATION AND DEPOSITION

The environmental patterns which have been shown to be impressed into the various parameters discussed above reflect the morphology of the estuary. Circulation patterns, resulting from tidal changes which are influenced by local variations in shoreline and bottom configurations, appear to control the bottom sediment distribution.

The sediments deposited within South Slough, from the various external, internal, and marginal sources (to be discussed in a later sec-

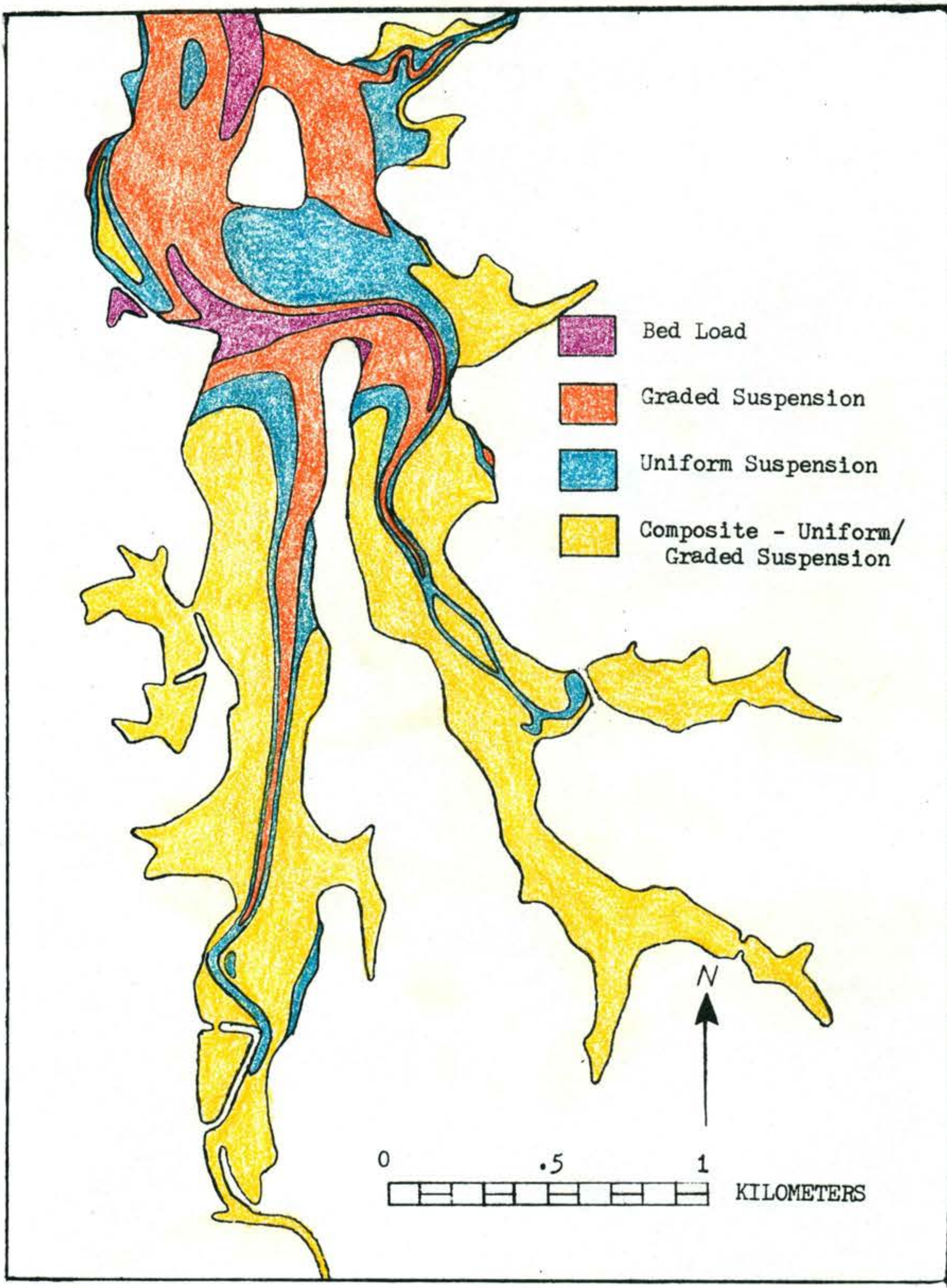


Figure 20. Distribution of transport mechanisms determined by CM analysis (Passega, 1957).

tion) are acted on by various processes. The tidal currents carry sediments in suspension, traction, and saltation (Figure 19). The decrease in average grain size passing inland results from the gradually decreasing velocity of the tidal currents and a reduction in their capacity and competence. A gradual differentiation of the material in transport results. Coarser sands are transported by strong tractive currents in the channels where winnowing action removes fine sands and mud. Away from the channels as the currents weaken, coarser material is lagged behind and the fine fraction makes up the greater percentage of the sediment. Muddy sands and silty sands are transported by graded suspension and uniform suspension. Sandy silts and silts are deposited out of suspension through a gradual uniform reduction in current velocity in the farthest reaches of the slough. The coarser sand cannot reach the shallow parts of the slough while the fine fraction can. The net reduction in grain size occurs in two directions, both laterally over the tide flats and along the length of the slough. Samples which exhibit seemingly anomalous grain size values are the result of inherited textural characteristics from the terrace sands. The primary control for the decrease in grain size is a reduction in the average and maximum current velocities.

Another phenomenon which appears to be of primary importance in the accumulation of fine grained material towards the head of the estuary is the "lag effect" (Postma, 1967; Straaten and Kuenen, 1957). This mechanism, which repeats itself during every tidal cycle, relates to two processes: settling lag of suspended material and scour lag of deposited material. Settling lag results when the flood tides decrease in velocity towards the time of slack water at high tide, and material which can no longer be held in suspension sinks to the bottom. There is a time lag between the moment when the current is no longer able to hold the material in suspension and the moment when the material reaches the bottom. Therefore the mud is deposited farther in the flood direction than if it had dropped straight to the bottom. As a consequence the material is deposited where the average velocity is less than at the point when the material began to settle, assuming a decrease in current velocity landward. The water mass which deposited the material on the incoming tide does not reach the minimum velocity at which the same material can be eroded. The ebb current as a result is unable to remove all the material deposited by the flood currents (scour lag). Additional energy is required to resuspend this material (Postma, 1967). This model assumes the ebb and flood tides are equal in magnitude and duration. The ebb currents are slightly stronger than the flood currents (U. S. Army Corps of Engineers, 1978); however, flood current velocities are generally greater near the bottom and ebb currents stronger at the surface for most estuaries (Ippen, 1966). Insufficient hydrographic data is available to evaluate these complications. But, the data suggest lag effects are important to sedimentation in South Slough.

Another significant factor in controlling sediment distributions pointed out by Straaten and Kuenen (1957) is the action of wind and waves. As pointed out by Straaten and Kuenen (1957) the influence of wind is twofold: to generate waves and to change the flow direction and velocity of tidal currents. Mud churned up by wave activity should result in a great loss of mud from the tidal flat areas, especially when summer winds from a north-northwesterly direction raise the water level at the south end of the slough. Water piled up during flood tide increases the amount of discharge during ebb tide, and hence ebb currents can reach higher velocities, carrying the increased suspension seaward. The prevailing wind patterns described previously can alter the character of the sediment transporting medium most effectively in shallow water (Einstein and Krone, 1961), wave energy being inversely proportional to water depth (Allen, 1970).

Wave action, however, does not appear to be an important factor, at least during the time the majority of samples for this study were collected. The fine fraction, settling out of suspension at high tide, would be sorted out of the tide flat sediments if wind generated wave action were great. The greatest amount of fine material is present in sediments near the head of the estuary, consequently wave action appears limited as a modifying influence to any great extent. No measurements of suspended load over a complete tidal cycle, or more important, during storm activity, have been carried out.

The variations in derived statistical parameters have been shown to be the result of mixing predominant modal fractions in the sediments. Extreme values of skewness and kurtosis in particular imply less than effective sorting energy. Sediments are characteristically leptokurtic and positively skewed, suggesting the prominent modes are transported with their size characteristics essentially unmodified, but diluted with the other modes (Folk and Ward, 1957). Positive skewness further indicates tidal currents are not an active winnowing agent, and South Slough is at present an area of deposition (Duane, 1965).

Biodeposition may also be important in initiating deposition of suspended solids in estuaries (Haven, 1969). Filter feeders remove particulate matter from suspension and extrude ingested material in the form of fecal pellets. During examination of material being sieved, pellets which resisted fragmentation during sample preparation were observed in the coarser fraction of numerous samples. Other organisms also extrude ingested material, but in effect only compact material already present into fecal pellets and do not add to the material removed from suspension (Evans, 1965).

X-RAY HEAVY MINERAL ANALYSIS

Sediment distribution patterns were analyzed using X-ray diffraction patterns of heavy mineral assemblages from 32 samples, including bedrock, stream, and selected samples within South Slough. The results of sample grouping of X-ray diffraction patterns are shown in Figures 21 and 22. Figure 21 shows the diffraction patterns for bedrock samples collected from outcrops along the coast, except for the terrace sands. The Upper Coaledo trace is representative of all three members of the Coaledo Formation. MacIlvaine and Ross (1973), in a similar study, concluded that X-ray analysis over-complicates the picture and optical analysis over-simplifies the results. For this reason, and due to the uncertainty in experimentally induced error with this unfamiliar method, minor peak intensity differences between Coaledo members were ignored. Heavy mineral separates from the Bastendorff Formation were inadequate, the most reproducible results being obtained from the highest concentration of powdered material on the mount. The most intense peaks occur-

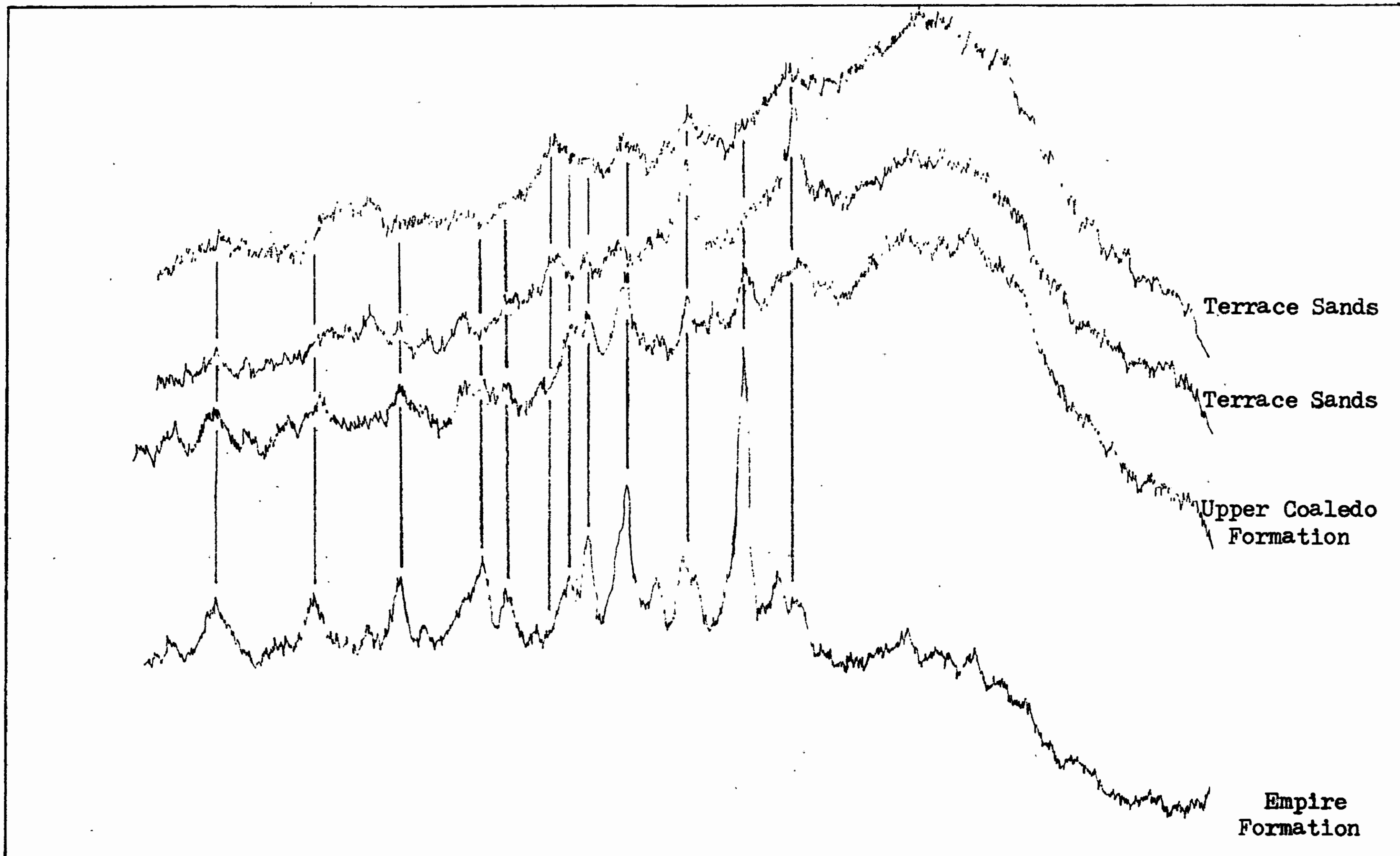


Figure 21. X-ray diffraction patterns of heavy mineral samples from the bedrock units within the South Slough drainage basin.

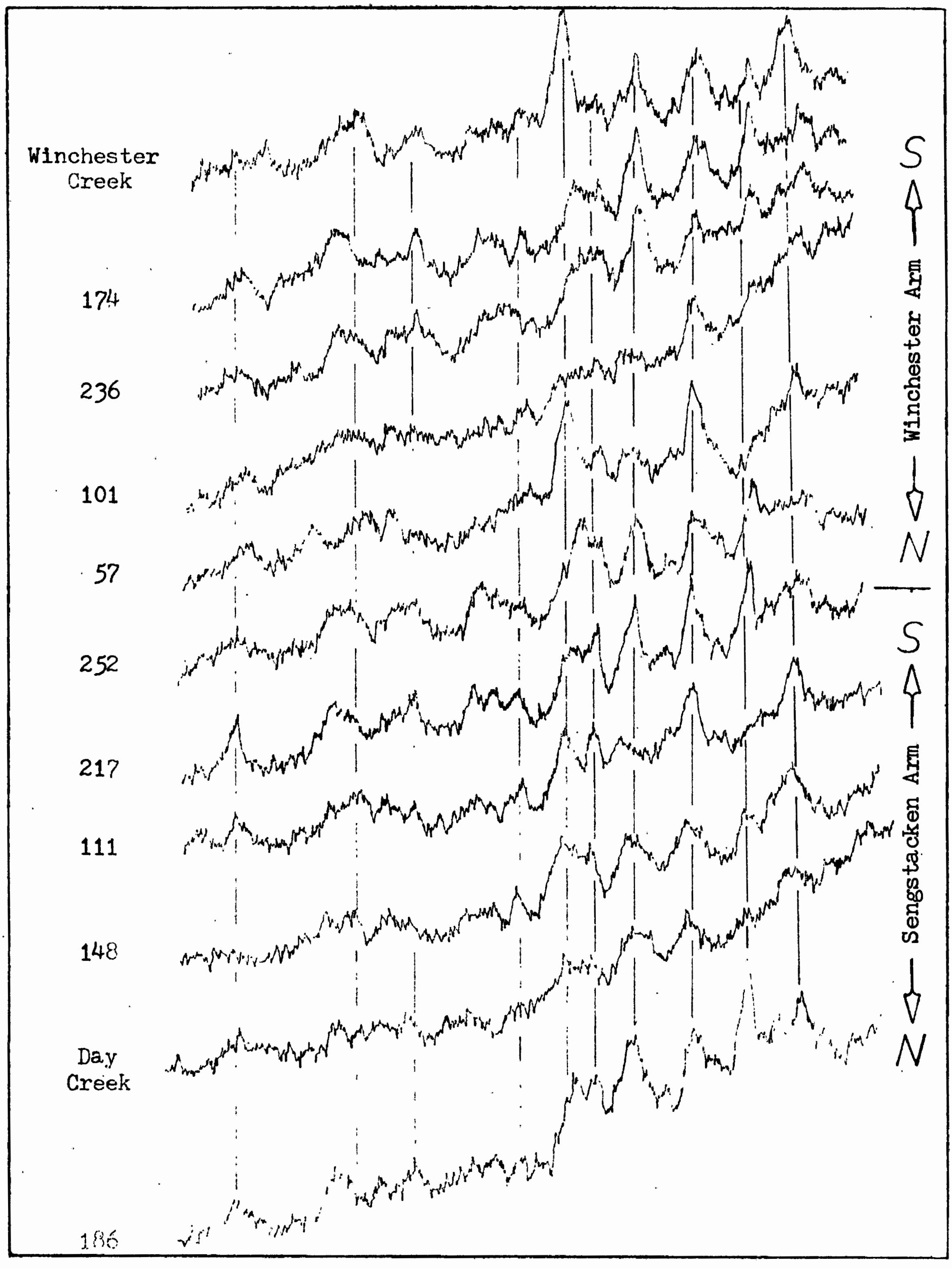


Figure 22. X-ray diffraction patterns of heavy mineral samples from estuarine sediments in South Slough.

ring in the Empire Formation trace in Figure 21 were produced with the highest concentration of heavies.

In Figure 21, the bedrock samples show some distinct variations in relative peak heights, and also the absence of peaks in some traces which are common to others. Two terrace sand samples, from north and south ends of the study area, are shown as a control for experimental error. Some minor variations exist, but in this case separate identities for the terrace sand samples would defeat the purpose of this analysis since compositional variations in the terrace sands have not been delineated in the literature. The traces are easier to compare when the diffraction patterns are superimposed on a light table.

Figure 22 illustrates the variations in mineralogic composition for major streams and estuarine samples in geographic sequence from south to north for the Winchester and Sengstacken arms of the slough. There were only minor variations between tide flat and channel samples collected along the same traverse, so only the trace having the highest peak intensities is illustrated. The Winchester Creek sample, at the head of the Winchester arm, shows a good correlation with the terrace sands. Minor peak intensity differences also suggest the influence of the Coaledo and/or Empire Formations. Winchester Creek drains the largest portion of the South Slough basin, with the entire South Slough stratigraphic section exposed. Samples 174 and 236, from the Winchester arm, are quite similar, with major peak positions and relative peak intensities common to both. Sample 101, farther to the north along the Winchester arm, demonstrates a greater influence from the terrace sands, and similarly with sample 57. A progressive change can be seen from south to north, with a greater terrace sands input to the north.

Samples 252 to 111 (Figure 22) in the Sengstacken arm also demonstrate a similar progressive change from the composite pattern exhibited by 252 (Coaledo influence greater than terrace sands) to predominantly terrace sands at sample 111. Diffraction patterns for John B, Talbot, and Elliot Creeks were indistinct due to a lack of heavy minerals for analysis and were omitted. Sample 217 near Elliot Creek varies from this trend with no apparent differences from the Upper Coaledo trace.

The traces from Day Creek and sample 148, east of Vallino Island, are similar while sample 186 located between them is different. On the basis of relative peak intensities, sample 186 compares with the Empire trace. The geologic map published by Beaulieu and Hughes (1975) shows no Empire Formation in the Day Creek drainage. However, Allen and Baldwin (1944) show Day Creek flowing through an area underlain in part by the Empire Formation. Allen and Baldwin (1944) did not map the terrace sands, shown by Beaulieu and Hughes (1975) throughout the Day Creek drainage. The Empire Formation may in fact be exposed where terrace deposits have been highly dissected by Day Creek or its tributaries, or deposited from suspended material transported from another source area. On the basis of the foregoing analysis samples were selected for detailed petrographic analysis by grouping similar patterns.

PETROGRAPHY

The sediments of South Slough have essentially uniform mineral composition. The homogeneity indicates that some agent is active in dispersing sediments over the entire area or that all sources have similar composition.

The light fraction of the samples studied (Appendix B) contained quartz (32 to 54 percent), the dominant mineral in the +2.00 ∅ to +4.00 ∅ fraction for most samples, potassium feldspar (11 to 27 percent), and plagioclase (27 to 47 percent), with a few grains of volcanic glass, rock fragments, and glauconite in most samples. Quartz and feldspar usually occur in nearly a 1:1 ratio, yet in some samples feldspar is almost twice as abundant, reflecting the mineralogical immaturity of the sediments. The potash:plagioclase feldspar ratio averages 0.54, varying from 0.25 to 1.01.

Glauconite values (not shown) were determined by counting 100 grains using a binocular microscope, for all samples collected in this study. Glauconite is present in nearly all samples within South Slough. Highest concentrations (5 to 10 grains) occur west of Vallino Island along the western margin of the slough, and near Day Creek on the eastern margin.

The heavy minerals from the selected samples within South Slough make up from 0.8 to 1.9 percent by weight for the +2.00 ∅ to +4.00 ∅ size range. A large number of heavy minerals was found in the South Slough sediments. This assemblage is presented in Appendix C. These sands have a characteristic mineral assemblage dominated by ubiquitous hornblende, epidote, clinopyroxene, and tremolite-actinolite. More than half of the nonopaque, nonmicaceous suite is composed of hornblende and epidote. Other commonly occurring heavies in some, but not all, samples include garnet, hypersthene, zircon, clinozoisite, and minor but persistent amounts of glaucophane. Random grains of other mineral species are indicated in Appendix C.

Opaque minerals identified include magnetite, ilmenite, chromite, hematite, and leucoxene. Additional particles identified but not counted include fragments of shell and wood, plant debris, foraminifera tests, fecal pellets, and furruginous aggregates.

Varietal analyses of hornblende were made in an attempt to reflect differences in source area lithology and establish significant trends or patterns of variability in South Slough sediments. In addition, areal variations in the abundance of all mineral species and along a profile from the mouth of the estuary to the head of the estuary were looked at with no systematic variation established.

No differentiation of the mineral assemblages could be established on the basis of selective sorting, weathering, or mechanical destruction during transport. The importance of modification of the heavy mineral assemblage by weathering has been emphasized by many authors (e.g., Van Andel, 1959). A study conducted by Van Andel (1959) showed the most pronounced weathering of heavy minerals in very permeable sands and gravels above the water table, in intensely weathered podzolic soils in the temperate zone. Terrace sands surrounding South Slough are intensely weathered (Beaulieu and Hughes, 1975) (Clay Mineralogy) even though the compositionally diverse and immature mineral assemblage (pyroxene, hornblende, epidote) present in South Slough suggests rapid mechanical erosion. Variations in mineralogy related to weathering include etched C-axis terminations of clinopyroxene grains in the terrace sands. Etched C-axis terminations of clinopyroxene grains were looked at in an attempt to relate the relative percentages of etched grains to terrace sand contributions to South Slough sediments. No consistent variations between near terrace sands samples and others was found, nor did the less stable components (pyroxene, hornblende, epidote) show a corresponding decrease relative to the stable components (kyanite, zircon, tourmaline) in any direction.

Modification of the heavy mineral assemblage by sorting during transportation and deposition is limited. However, anomalously high values for green-brown hornblende (45 percent) were discovered in South Slough sediments at the end of the Sengstacken arm. John B, Talbot, and Elliot Creeks were low at 15, 15, and 6 percent, respectively, suggesting mixing of sediments from varying sources. Hornblende may be included in the preferred size range for material deposited by lag effects, and in fact is highest in samples which show improved sorting over channel samples along the same traverse.

CLAY MINERALOGY

The clay fraction of four South Slough Estuary bottom samples were analyzed by X-ray diffraction and scanning electron microscope (SEM) to determine clay mineral content and to note any diagenetic changes in the clays as they were introduced into a brackish to salt water environment.

All four samples contained an overwhelming amount of montmorillonite with a subordinate amount of kaolinite, traces of chlorite, and possibly glauconite and/or mica and illite.

Montmorillonite when air dried has a basal spacing of 14-15 Å. This increases to 17-18 Å with ethylene glycol treatment and collapses to 10 Å when heated to 550°C. Kaolinite basal spacing is 7 Å. This remains unchanged after glycolation but is destroyed by heating to 550°C.

Chlorite is difficult to distinguish from kaolinite when both are present in a clay mineral assemblage. This is because of similar d spacings of kaolinite (001) and chlorite (002) at 7 Å, and with kaolinite (002) and chlorite (004) at 3.5 Å. Chlorite can be distinguished by the presence of a relatively weak first order peak at 14 Å. The chlorite present in these samples is masked by the overwhelming abundance of montmorillonite. A slight shoulder at 14 Å is visible after ethylene glycol treatment shifts the montmorillonite peak to 17-18 Å. Heat treatment at 550°C removes the kaolinite peaks but also weakens or removes the higher order chlorite reflections, further complicating analysis. The distinction can also be made by preferentially dissolving chlorite in dilute hydrochloric acid; however, no change was observed. Uncertainties exist in this method due to variations in chlorite composition and crystallinity. Illite has a 10 Å spacing which is unaffected by ethylene glycol or heat treatment, which is also true of glauconite and mica. Figure 23 illustrates patterns which clearly indicate the presence of montmorillonite, kaolinite, chlorite, and possibly glauconite, illite and mica. All of the 2.0 to 0.2 micron samples gave patterns similar to those of Figure 23. X-ray diffraction patterns for the less than 0.2 micron fractions for all samples showed predominantly montmorillonite. The anomalous appearance of calcium carbonate found in the less than 0.2 micron size fraction of sample 57 is probably related to a breakdown of shell material, which is abundant in South Slough.

Electron photomicrographs were required to resolve the identification of the 10 Å clay(s) and to further document the presence of montmorillonite and kaolinite. Figures 24 and 25 clearly indicate clays

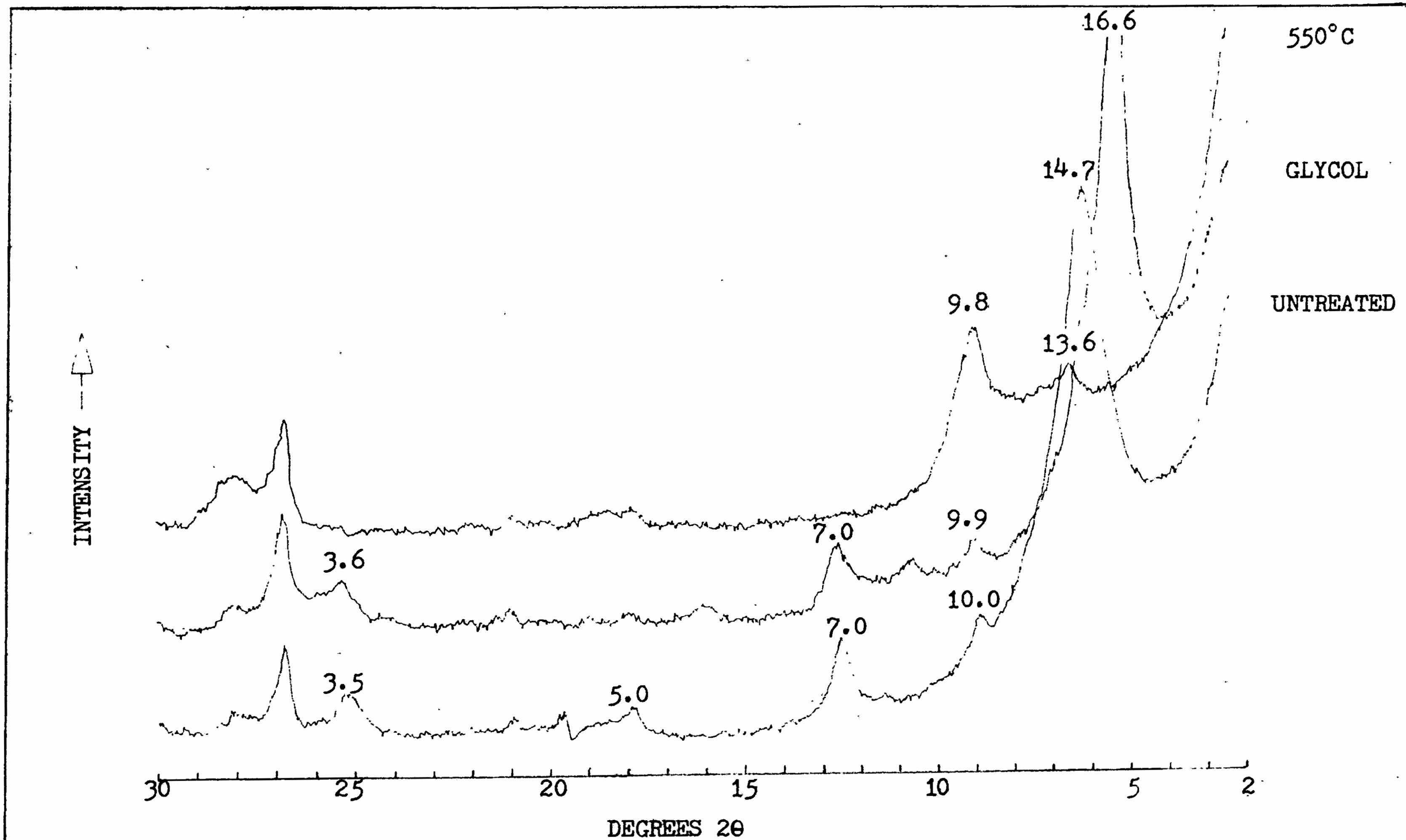


Figure 23. X-ray diffraction patterns of the 2.0-0.2 micron fraction from the Winchester Creek sample. Patterns show diffraction effects ascribed to the South Slough clay suite (d-spacings in angstroms).

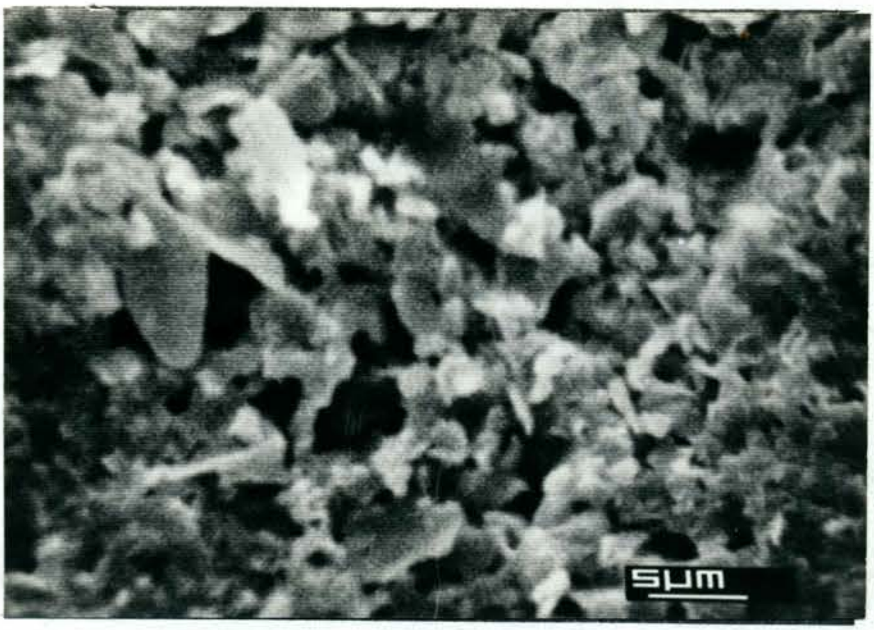


Figure 24. Electron photomicrograph of the 2.0-0.2 micron fraction of the Winchester Creek sample.

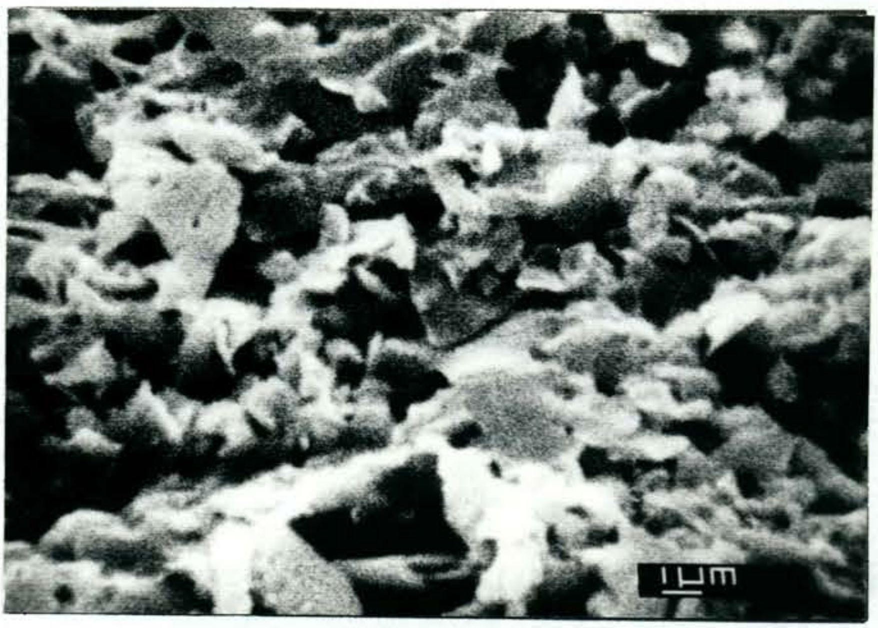


Figure 25. Electron photomicrograph of the 2.0-0.2 micron fraction of sample 195.

with platey morphology, indicative of chlorite, kaolinite, and mica. The hexagonal morphology of kaolinite is not readily apparent, but imaginable. The electron photomicrograph of montmorillonite is that of an amorphous material, shown in Figures 26 and 27. Figure 26 also shows a vermicular morphology for the larger grain in the upper right corner, with an elongate form having micaceous cleavage perpendicular to the direction of elongation. Glauconite exhibits a similar external morphology (Triplehorn, 1961). The cubic morphology of grains in Figures 26 and 27 are likely non-clay minerals, possibly pyrite. Pyrite has been observed directly by other workers (Slotta and others, 1974) in South Slough sediments.

The Winchester Creek sediment carried into the saline environment does not show any significant changes in clay mineralogy, except for a notable increase in kaolinite content relative to montmorillonite in a downstream direction. Similarly the 10 Å clays increase relative to montmorillonite, and kaolinite increases relative to the 10 Å clays. These trends are shown in Figure 28, in which the peak height ratios of the first order peaks are plotted against position in the estuary. The results of this technique are semiquantitative. The intensity of the X-ray diffraction peaks varies with grain size, degree of orientation of clay particles, and other factors, so that it requires large variations in reflection intensities to see significant trends or changes in clay mineral content (Carver, 1971). Various models, including marine diagenesis, various sources, and fractionation by sedimentation were applied to explain the clay mineral distribution.

The importance of diagenesis in controlling the clay mineral dis-

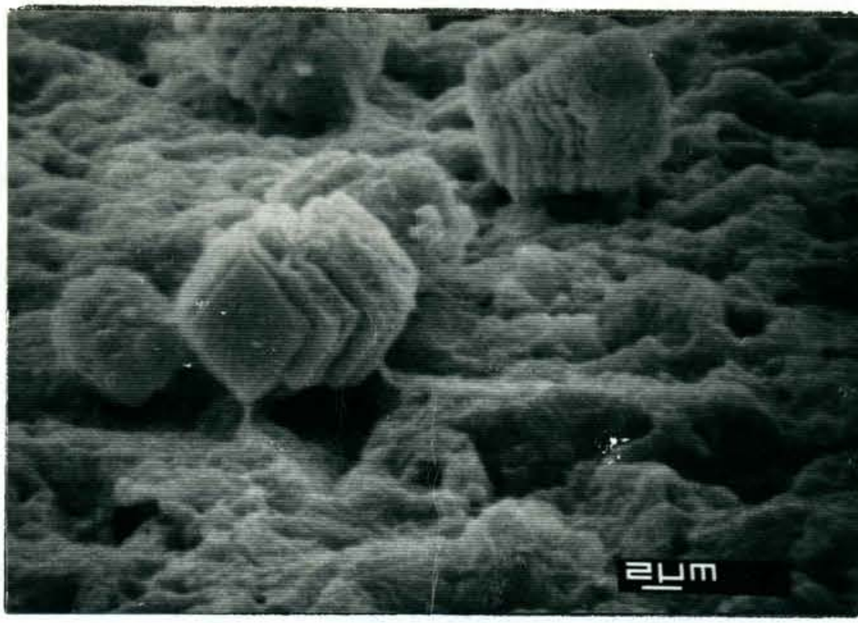


Figure 26. Electron photomicrograph of the less than 0.2 micron fraction of the Winchester Creek sample.

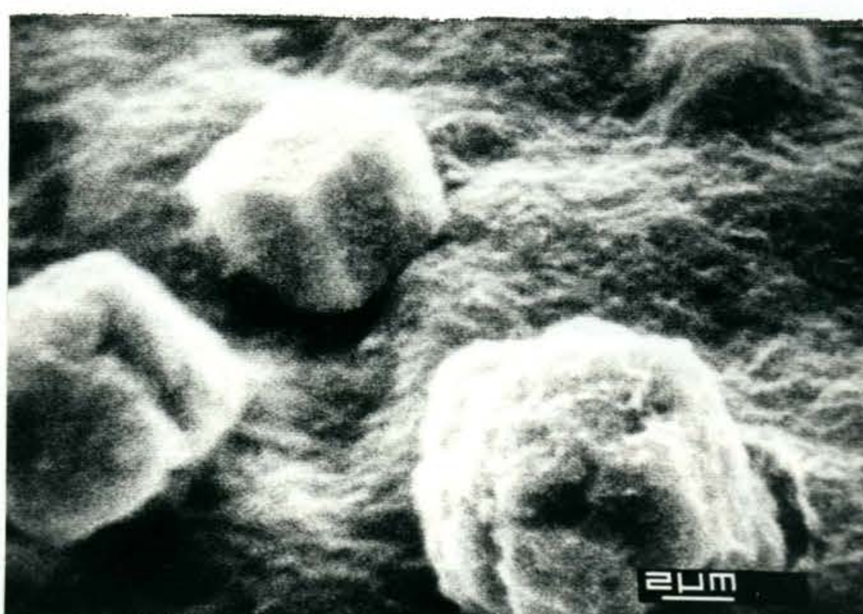


Figure 27. Electron photomicrograph of the less than 0.2 micron fraction of sample 195.

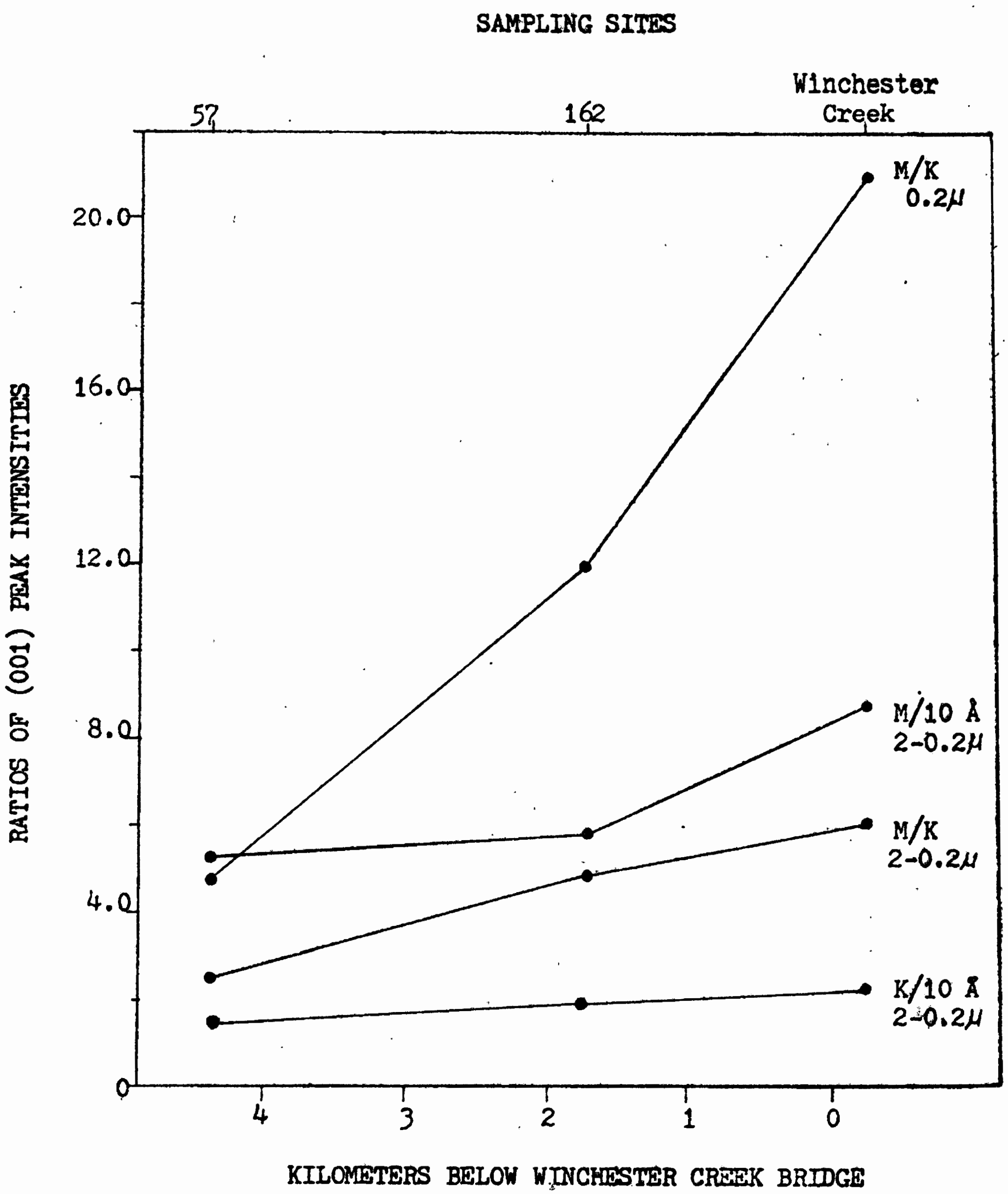


Figure 28. Ratios of intensities of (001) clay mineral peaks in South Slough Estuary samples. Ratios are identified by the following symbols: M=montmorillonite, K=kaolinite, 10 Å=glauconite and illite and/or mica.

tribution is most certainly minor. In areas of active sedimentation the clay mineral assemblage is primarily controlled by the character of the source area. Climatic conditions of the source area may be the most important factor in determining the clay minerals in recent sediments (Grim, 1953; Milne and Earley, 1958). Clay minerals are sensitive to environmental changes but require sufficient time to reach equilibrium with their new environment. Alteration of unstable clay minerals in a depositional area is expected where the sedimentation rate is low and sufficient time is available. Under these conditions montmorillonite should alter to form illite or chlorite in a marine environment (Grim, 1953; Millot, 1970). Less montmorillonite would be expected in the marine sediments than in their nonmarine equivalent. This occurs in South Slough, but the change is not attributable to diagenesis, as little or no increase in illite or chlorite was found. Kaolinite as well should disappear as you advance down the estuary.

The difference in clay mineral abundance can be related to fractionation of the clay minerals as the conditions of transportation and dispersal of sediment in the slough varies. Studies of particle aggregation and settling rates in sediments of the Pamlico River Estuary by Edzwald and O'Melia (1974) indicate that kaolinite would be expected to aggregate more slowly and be deposited downstream from montmorillonite, which is in agreement with the observed clay mineral distribution in South Slough. However, Dobbins and others (1970), in another study of Pamlico River estuarine sediments, suggests kaolinite has a smaller negative electrostatic charge density than montmorillonite and is coarser grained, causing flocculation out of the river's suspended load earlier and deposition relative to other clay minerals farther upstream. It seems likely that this discrepancy arose from the differences in theory and actual clay distribution reported by Edzwald and O'Melia (1974) for Pamlico River estuarine sediments.

The distribution of kaolinite remains somewhat puzzling, and as suggested previously, may be related to differences in the clay minerals being deposited. The distribution of montmorillonite in recent sediments is associated with volcanism (Grim, 1953). The predominance of montmorillonite reflects the volcanic rich character of the bedrock units within the drainage basin, as pointed out by Dott (1966). Dott (1966) analyzed the clay size fraction of the Coaledo Formation:

> . . . all samples, regardless of stratigraphic position or apparent mode of deposition, contain an overwhelming amount of montmorillonite with only traces of illite, chlorite, and sporadic kaolinite or vermiculite; this is true even of one supposed coal underclay. And sandstone matrix shows no appreciable difference from interstratified mudstones. The abundance of montmorillonite reflects the extreme volcanic-rich character of the source materials.

Sediments derived from the source rocks and soils may alter to clay minerals during weathering that are stable in this environment. Under existing conditions in Oregon's coastal drainages, source areas are characterized by high relief and rapid mechanical weathering (Kulm and others, 1968).

In contrast to the immature fluvial input the flat topped ridges formed by terrace deposits inhibit erosion and promote deep weathering. Permeability is generally high for the terrace deposits, promoting leaching and more intense weathering than in other bedrock and surficial materials in the area. The various soil units of western Coos County are the acidic leached products of weathering in a moist temperate climate. Terrace soils, dominant in the study area, are characterized by slow to moderate runoff, and slight to moderate erosion potential, with high erosion potential on steep slopes (Beaulieu and Hughes, 1975).

Ground water movement through the terrace deposits promotes sloughing of material into the slough (Beaulieu and Hughes, 1975). Terrace sands can be seen actively sloughing material into the slough on and around Vallino Island, and Long Island Point, and are also suggested as a major marginal sediment source by granulometry and X-ray analysis of heavies.

The clay minerals introduced into the slough have not been significantly altered from the similar dominant montmorillonite clays found in the source of the sediments. Kaolinite, however, is more abundant in South Slough sediments than reported by Dott (1966) for the bedrock units within the South Slough drainage. Kaolinite should be most abundant in the terrace sands which lack volcanic materials and are deposited in more porous beds which might undergo more intense leaching than in the Tertiary formations. No data is available on the clay mineral content of the terrace sands. The terrace sands, as previously described, are located where lateral addition of sediment can explain the longitudinal distribution of the clays.

The possible presence of glauconite in the clay size fraction is probably the result of rapid weathering and breakdown during transportation and deposition of larger glauconite pellets in the source rocks. Triplehorn (1961) found most glauconite weathers rapidly and is destroyed during transportation in fresh water. Glauconite is present in all bedrock units in the study area to some degree. In addition, at least some of the important conditions which normally attend glauconite formation exist in South Slough; it is marine in origin, tends to occur in water shallower than 2000 meters, forms during periods of slight detrital sedimentation, and is facilitated by the presence of decaying organic matter (Triplehorn, 1961).

ORGANICS

The content of organic matter varies from 0.00 to 19.77 percent, and is greatest in the fine grained silts and sandy silts of the tide flats, and least in the sands found in the channels. As with most recent sediments, a general parallelism of grain size and organic content exists, both being deposited under similar conditions (Kulm and Bryne, 1966; Evans, 1965). Organic matter is subjected to the same sedimentological forces which are acting on sediments of low density and small size. It seems both are functions of the quietness of the water. In addition, another important factor may be the relationship between filter feeding organisms which can extract matter from the water, and their close association with fine grained sediments (Evans, 1965).

SEDIMENT SOURCES AND DISPERSAL PATTERNS

The effect of variations in source rocks within the South Slough drainage basin which supply the sediment requires an understanding of the geology of the area. Figure 3 shows the distribution of source materials present in the South Slough drainage basin. The sediments entering the estuary are introduced by external, marginal, and internal sources (Schubel, 1971).

Published heavy mineral analyses of bedrock units present in the South Slough drainage basin and of recent sediments along the Oregon coast are available for comparison with the results from this study. Unfortunately, no direct comparisons can be made since different methods of sample preparation and various fractions have been sampled by different authors (Griggs, 1945; Dott, 1966; Kulm and others, 1968; Rottman, 1970).

It appears that most of the sediments available for transportation and deposition within the South Slough drainage basin are derived ultimately from the metamorphic rocks of the Klamath Mountains. Epidote, zoisite, clinozoisite, abundant garnet, blue-green hornblende, tremolite-actinolite, glaucophane, and kyanite present in South Slough sediments reflect the strong metamorphic character of the source. Dott (1966) and Rottman (1970) have concluded that the non-blueschist metamorphic rocks of the Klamaths were the major source of the detritus for the Coaledo Formation. However, Rottman (1970) also suggested that a considerable portion of the detritus was of more local origin because of the occurrence of brown hornblende (oxyhornblende) considered to be basaltic in origin.

No published heavy mineral analyses of the Bastendorff and Empire Formations are available for comparison. Bedrock samples were collected and analyzed because of the lack of data on petrology for most of the Tertiary formations present in the South Slough drainage basin. The bedrock and stream samples analyzed in this study are listed in Appendix D. Notable variations shown in Appendix D between Coaledo and post Coaledo strata include the absence of glaucophane, kyanite, and hypersthene from the Coaledo Formation, and as pointed out by Rottman (1970):

> . . . glaucophane and hypersthene are conspicuously absent from the Lower Coaledo. If Dott's reconstruction of Coaledo paleogeography as a deltaic complex deposited by a river or rivers draining northwestward from the Klamath highland is correct, then the blueschist source bodies for the glaucophane were either not yet exposed or not yet formed in the upper Eocene. The hypersthene, derived from the Cascade volcanic province, post-dates Coaledo sedimentation.

Glaucophane and kyanite are absent from the Bastendorff and Empire Formations as well.

In another paper by Rottman (1972) discussing the heavy mineralogy of the terrace sands:

> This heavy mineralogy is very similar to that of the recent southern Oregon shelf sediments (Kulm and others, 1968) and to that of the lower Coaledo (Rottman, 1970). However, the latter does not contain glaucophane and kyanite, two minor minerals of the terrace sands. This similarity of mineralogy is additional evidence that the Coaledo was the probable major source of terrace sediment. Yet, the presence of additional minerals indicates one or more additional sources. The exposure to shelf currents of either an offshore or an open beach depositional environment would account for the minor occurrence of these minerals.

In this study the presence or absence of indicator minerals did not provide a means of evaluating provenance or dispersal patterns within South Slough. The mineralogy suggests a mixed origin of the sediments because glaucophane, kyanite, and hypersthene are widely dispersed. The terrace deposits do not contain glauconite, present in the underlying formations. The highest glauconite concentrations occur to the west of Vallino Island along the western margin of the slough, and near Day Creek. There is a sharp decrease in the glauconite concentration away from these areas, with only a trace of glauconite present in the rest of the slough. The dark, rounded, polished nature of the glauconite indicates that it is a mature form, and is probably derived from deposits of the material eroded subaerially (Triplehorn, 1961). Glauconite along the western margin of the slough is associated with fragments of reworked sedimentary rocks (anomalous gravel fraction in samples 84 and 98) suggesting that glauconite bearing sedimentary rocks (Empire Formation) served as a source for much of the detrital material west of Vallino Island along the margin of the slough, and probably in the Day Creek area.

Several other lines of evidence, including X-ray heavy mineral analysis, texture, and clay mineralogy, are suggestive of significant trends useful in evaluating provenance and dispersal patterns. Summarily, the diffraction patterns of the heavy minerals showed: (1) the Coaledo Formation contributes more detritus than the terrace sands in the southern end of the Sengstacken arm, (2) sediments near Elliot Creek show a definite affinity for the Coaledo Formation, (3) terrace deposits are the major source of sediment in Winchester Creek, and (4) a general increase in the terrace sand contribution through lateral erosion towards the north end of the study area. Clay mineralogy and textural analysis provide further evidence of a major marginal contribution of material into the slough on and around Vallino Island and Long Island Point.

Prominent modes determined by textural analysis further suggest a multiple source for the sediment. External sources include contributing streams and tidal input during flood tide. A marine origin is not expected for South Slough sediments since the net transportation direction is seaward in a well mixed estuary. However, accumulation of fine grained suspended material is possible by lag effects in tidal flat areas. Most of the sediments appear to have had their source in sediments made available through weathering and erosion of the Tertiary sedimentary rocks within the South Slough watershed. The dominant silt sized material in these sediments is probably carried in suspension by the creeks emptying into South Slough, particularly during flood stage. In most estuaries which have been studied in detail, rivers are the dominant source (Schubel, 1971). No conclusive evidence of a marine contribution can be reached on the basis of mineralogy or texture, or on the exact nature of the upland contribution, without further study.

Biological activity and resuspension by wind waves and tidal scour all contribute to sedimentation internally, but are probably not the major source of sediment. Agglomeration of fine grain suspended material by filter feeding organisms may be an important factor (Schubel, 1971) and also by ciliary mucous feeders in the plankton (Van Atta, oral communication, 1978).

CONCLUSIONS

The following conclusions can be drawn from the present study:

1. Tidal currents carry sediment over the tide flats and differentiate their load passing inland as a result of the decreasing velocity of the tidal currents and a reduction in their capacity and competence. The result is a general correlation of the sediment parameters and bottom topography.

2. Textural parameters reflect the energy distribution. The sediments found in the channels are characteristically coarse grained, well sorted and near symmetrical to fine skewed, while tidal flat areas are finer grained, poorly sorted and strongly fine skewed. The presence of the fine tail in the size distribution reflects the transportation ability of the tidal currents. Tidal currents and wave action are ineffective in removing fines from the tide flats, possibly due to lag effects.

3. The tidal currents carry sediments in traction, saltation, and suspension. Wave activity is limited allowing material transported by tidal currents to settle from suspension and dilute the sand fraction throughout the slough. The mineralogy corroborates this, there being little or no variation in mineralogy between near terrace sediments and the rest of the South Slough sediments. The fine fraction can accumulate only where wave action is not great. The greatest amount of fine material accumulates near the head of the estuary as a result.

4. The tidal currents are shown to be ineffective in sorting, possibly due to a high rate of influx of sediments compared with efficiency of

the tidal currents. Few analyses produced skewness and kurtosis values which fall into the normal range for sediments, which is further suggestive of inefficient sorting.

5. Prominent modes are suggestive of multiple sources. Fluvial input appears to be a major source of silt sized material, while lateral sedimentation from the terrace deposits supplies most of the sand.

6. The fluvial input is poorly sorted, shown by plots of mean size versus kurtosis, mean size versus standard deviation, less than 62 microns percent versus standard deviation, and a comparison of samples from Winchester Creek and the terrace sands. Sufficient information is not available to determine the extent of the fluvial input, and it is possible the poor sorting may be the result of hydraulic forces acting on floccules and not individual grains.

7. The changes in the derived statistical parameters with sediment transport are probably simply a function of the ratio between the various modes of the sediments, those being sand at about +2.00 Ø and silt at +5.00 Ø.

8. The overlapping fields of the various sediment types shown in the binary plots is suggestive of a wide range in energy conditions laterally and longitudinally in South Slough. The complete river pattern in the CM diagram adds merit to that conclusion.

9. The dominantly positive skewness implies the slough is at present an area of deposition. Negative skewness is produced by winnowing action in the channels.

10. A great variety of minerals occur in South Slough estuarine sediments. The sediments of South Slough have essentially uniform mineral

composition. The most abundant mineral species or mineral groups are epidote, hornblende, clinopyroxene, garnet, hypersthene, zircon, and clinozoisite, in the heavy fraction, and feldspar and quartz in the light fraction. Areal differences in mineral composition within South Slough are attributed to a difference in the character of the source materials.

11. The areal distribution of certain selected minerals and results of X-ray heavy mineral analysis indicate that sediment movement is generally seaward, deposition occurring where their movement is obstructed by obstacles like Vallino Island, and where regions of large cross sectional area occur. Mixing of sediments appears thorough because of the essentially homogeneous mineral composition. Mineralogy of the sediments is independent of grain size parameters.

12. The clay mineral assemblage of South Slough is dominated by montmorillonite and kaolinite, with only small amounts of chlorite, glauconite, and possibly illite and/or mica. The abundance of montmorillonite reflects the volcanic rich character and immature weathering of the source materials. Kaolinite increases in a downstream direction, with increasing lateral addition of terrace sands as a possible source. Fractionation during sedimentation is a possible alternative to lateral sedimentation but sufficient information is lacking to support that conclusion. No longitudinal diagenetic changes down estuary were indicated.

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APPENDIX A

TEXTURAL STATISTICS

SAMPLE	TRASK			INMAN				FOLK AND WARD					MOMENTS			
	M_q	QD_a	SK_a	M_ϕ	σ_ϕ	α_ϕ	β_ϕ	M_z	σ_I	Sk_I	K_G	K_G'	M	σ	α_3	β_2
SS-47	0.094	0.049	0.033	4.12	1.83	-0.13	1.42	4.20	2.25	0.13	2.41	.71	4.59	2.46	1.58	6.08
SS-49	0.282	0.163	0.052	3.75	2.12	0.53	1.16	3.38	2.44	0.61	1.53	.60	3.64	2.80	1.72	5.60
SS-51	0.144	0.081	0.024	5.10	2.49	0.59	1.00	4.61	2.76	0.61	1.58	.61	4.65	2.99	1.34	4.36
SS-53	0.218	0.146	0.062	3.54	1.59	0.48	1.80	3.29	2.15	0.60	2.00	.67	3.71	2.65	2.01	6.81
SS-55	0.177	0.142	0.066	3.50	1.25	0.54	2.02	3.27	1.77	0.64	2.18	.69	3.69	2.40	2.25	8.18
SS-57	0.367	0.283	0.198	1.90	0.66	0.13	1.06	1.88	0.74	0.18	1.26	.56	2.02	1.47	3.47	22.83
SS-59	0.157	0.111	0.059	3.70	1.34	0.39	2.03	3.52	1.90	0.52	2.35	.70	3.93	2.43	2.16	7.54
SS-61	0.276	0.190	0.144	2.32	0.65	-0.12	1.91	2.34	0.89	0.13	1.65	.62	2.63	1.68	3.89	21.00
SS-63	0.268	0.200	0.147	2.42	0.67	0.14	3.01	2.39	1.16	0.38	2.55	.72	2.78	1.94	3.35	15.44
SS-66	0.254	0.155	0.039	4.28	2.49	0.64	0.96	3.75	2.72	0.68	1.49	.60	3.91	2.99	1.61	4.79
SS-68	0.052	0.045	0.012	5.81	1.94	0.69	1.21	5.36	2.28	0.66	1.69	.63	5.52	2.51	1.43	4.86
SS-69	0.129	0.042	0.008	5.46	2.88	0.31	0.77	5.16	2.99	0.39	1.06	.51	5.39	3.06	0.93	3.26
SS-71	0.043	0.022	0.005	6.60	2.11	0.51	0.91	6.24	2.28	0.59	1.09	.52	6.42	2.55	1.16	3.77
SS-73	0.330	0.290	0.257	1.78	0.29	-0.03	1.09	1.78	0.33	0.02	1.39	.58	1.86	0.76	6.60	63.21
SS-75	0.248	0.213	0.179	2.24	0.31	0.03	1.00	2.24	0.34	0.03	1.07	.52	2.40	1.22	5.98	44.61
SS-77	0.322	0.272	0.211	1.99	0.51	0.22	1.03	1.95	0.57	0.25	1.38	.58	2.15	1.45	4.79	30.83
SS-79	0.249	0.157	0.098	3.01	1.18	0.28	1.47	2.90	1.48	0.43	1.79	.64	3.13	1.98	2.84	12.55

SAMPLE	TRASK			INMAN				FOLK AND WARD					MOMENTS			
	M_q	QD_a	SK_a	M_ϕ	σ_ϕ	α_ϕ	β_ϕ	M_z	σ_I	Sk_I	K_G	K_G'	M	σ	α_3	β_2
SS-81	0.226	0.151	0.086	3.08	1.19	0.29	2.13	2.96	1.73	0.47	2.19	.69	3.35	2.27	2.57	10.06
SS-82	0.183	0.143	0.099	2.96	0.79	0.19	2.42	2.91	1.21	0.39	2.49	.71	3.26	1.91	3.29	15.19
SS-83	0.084	0.055	0.029	4.79	1.55	0.39	1.69	4.59	2.04	0.50	2.23	.69	4.87	2.41	1.90	6.41
SS-84	0.262	0.073	0.040	2.06	4.51	-0.38	0.66	2.64	4.52	-0.19	2.24	.69	3.26	4.19	0.08	2.89
SS-86	0.218	0.109	0.031	4.44	2.50	0.50	0.99	4.03	2.75	0.58	1.44	.59	4.27	2.97	1.52	4.61
SS-88	0.188	0.162	0.041	4.91	2.73	0.84	0.88	4.15	2.92	0.83	1.90	.66	4.23	3.17	1.62	4.43
SS-90	0.219	0.171	0.134	2.88	0.85	0.39	2.82	2.77	1.41	0.57	3.75	.79	3.17	2.13	2.93	11.86
SS-92	0.411	0.356	0.329	1.45	0.27	-0.14	2.63	1.46	0.43	0.15	2.45	.71	1.70	1.30	4.95	32.52
SS-94	0.122	0.074	0.048	3.99	1.30	0.18	1.63	3.91	1.69	0.35	2.07	.67	4.23	2.13	2.28	8.94
SS-96	0.084	0.057	0.042	4.25	1.03	0.12	2.32	4.21	1.55	0.32	2.80	.74	4.52	2.09	2.09	9.18
SS-97	0.131	0.068	0.046	3.95	1.50	0.05	1.83	3.93	2.04	0.29	2.31	.70	4.32	2.43	1.93	6.98
SS-98	3.533	0.313	0.154	0.66	3.47	-0.29	0.66	1.00	3.48	-0.13	1.04	.51	1.23	3.49	0.62	3.86
SS-99	0.356	0.292	0.251	1.73	0.42	-0.11	5.06	1.74	0.98	0.29	4.11	.80	2.14	1.81	4.02	20.22
SS-101	0.387	0.302	0.245	1.73	0.55	0.01	1.63	1.73	0.72	0.20	1.80	.64	1.91	1.29	3.80	25.10
SS-103	0.425	0.334	0.265	1.64	0.54	0.10	0.71	1.62	0.55	0.14	1.11	.53	1.71	0.99	5.10	44.02
SS-105	0.177	0.153	0.114	3.24	0.92	0.58	2.25	3.06	1.37	0.65	3.82	.79	3.34	1.97	2.89	12.14
SS-107	0.184	0.160	0.138	2.74	0.45	0.20	5.80	2.71	1.16	0.49	5.99	.86	3.20	2.00	3.37	14.49
SS-108	0.169	0.143	0.071	3.29	0.86	0.56	2.12	3.13	1.25	0.64	1.76	.64	3.49	1.91	2.96	13.02
SS-109	0.377	0.310	0.235	1.75	0.51	0.11	0.63	1.73	0.51	0.05	1.00	.50	1.89	1.29	5.24	37.48
SS-111	0.265	0.203	0.161	2.31	0.51	0.02	3.53	2.31	0.95	0.33	2.60	.72	2.70	1.81	3.69	18.09
SS-114	0.167	0.139	0.052	3.77	1.33	0.69	1.78	3.46	1.79	0.73	1.81	.64	3.81	2.36	2.29	8.09
SS-116	0.141	0.105	0.051	3.91	1.19	0.55	1.54	3.69	1.51	0.64	1.69	.63	4.01	2.07	2.39	9.28
SS-117	0.380	0.315	0.273	1.62	0.38	-0.13	1.03	1.63	0.42	-0.02	1.32	.57	1.79	1.16	6.07	48.20
SS-118	0.303	0.263	0.212	2.04	0.47	0.24	3.46	2.00	0.87	0.44	3.30	.77	2.35	1.62	3.83	20.79

SAMPLE	TRASK			INMAN				FOLK AND WARD					MOMENTS			
	M_q	QD_a	SK_a	M_ϕ	σ_ϕ	α_ϕ	β_ϕ	M_z	σ_I	Sk_I	K_G	K_G'	M	σ	α_3	β_2
SS-119A	0.274	0.049	0.020	4.19	2.58	-0.06	0.74	4.25	2.65	0.11	0.97	.49	4.53	2.73	0.98	4.15
SS-121A	0.167	0.080	0.053	3.80	1.54	0.11	1.48	3.75	1.92	0.31	1.89	.62	4.09	2.35	1.99	7.31
SS-125A	0.137	0.076	0.050	3.88	1.26	0.13	2.01	3.83	1.79	0.33	2.13	.68	4.20	2.26	2.17	8.14
SS-128A	0.173	0.134	0.087	3.14	0.89	0.28	1.67	3.06	1.17	0.41	1.97	.66	3.32	1.73	3.23	15.88
SS-129A	0.283	0.204	0.154	2.25	0.66	-0.06	2.81	2.27	1.09	0.09	2.35	.69	2.49	1.85	2.75	15.51
SS-131A	0.142	0.085	0.041	4.35	1.68	0.47	1.47	4.09	2.10	0.57	1.90	.66	4.40	2.50	1.87	6.30
SS-132A	0.140	0.058	0.022	4.76	2.13	0.30	0.98	4.55	2.35	0.39	1.30	.57	4.64	2.55	1.51	5.14
SS-135	0.135	0.101	0.052	3.97	1.19	0.55	1.64	3.75	1.55	0.65	1.88	.65	4.08	2.13	2.42	9.15
SS-136	0.116	0.080	0.050	4.07	1.14	0.38	1.91	3.93	1.57	0.54	2.21	.69	4.28	2.12	2.42	9.25
SS-138	0.377	0.303	0.245	1.77	0.53	0.08	2.33	1.75	0.81	0.29	2.35	.70	1.99	1.73	3.86	22.18
SS-139	0.144	0.075	0.041	3.65	1.11	-0.08	2.05	3.68	1.58	0.19	1.53	.60	4.11	2.13	2.14	8.96
SS-141	0.086	0.058	0.041	4.39	1.20	0.24	2.24	4.29	1.78	0.40	2.96	.75	4.64	2.24	2.09	7.67
SS-143	0.059	0.046	0.027	5.05	1.36	0.45	2.28	4.85	2.04	0.45	3.27	.77	4.99	2.39	1.72	6.23
SS-144	0.329	0.224	0.031	4.12	2.71	0.72	0.93	3.47	2.94	0.76	1.25	.56	3.87	3.21	1.41	4.19
SS-146	0.200	0.130	0.060	3.16	1.16	0.18	1.92	3.09	1.60	0.39	1.59	.61	3.55	2.16	2.47	10.05
SS-148	0.154	0.136	0.110	3.01	0.48	0.28	4.19	2.97	0.99	0.44	4.18	.81	3.27	1.70	3.54	17.50
SS-149	0.202	0.161	0.139	2.57	0.46	-0.15	1.87	2.59	0.63	0.10	2.00	.67	2.85	1.46	4.52	27.16
SS-150	0.280	0.227	0.143	3.00	1.29	0.67	1.50	2.72	1.62	0.70	2.71	.73	2.90	2.12	2.63	10.63
SS-151	0.044	0.029	0.009	6.22	1.86	0.61	0.99	5.85	2.05	0.67	1.34	.57	6.00	2.27	1.59	5.12
SS-152	0.046	0.026	0.011	5.90	1.63	0.38	1.31	5.70	1.96	0.42	1.49	.60	5.81	2.20	1.37	5.60
SS-154	0.057	0.043	0.021	5.32	1.20	0.64	1.16	5.07	1.38	0.68	1.47	.60	5.32	1.90	2.14	8.07
SS-156	0.055	0.047	0.018	5.56	1.36	0.84	1.88	5.17	1.87	0.80	2.00	.67	5.45	2.28	1.92	6.35
SS-158	0.052	0.045	0.018	5.64	1.59	0.75	1.24	5.25	1.87	0.79	1.91	.66	5.47	2.21	1.95	6.44
SS-160	0.056	0.045	0.019	5.53	1.43	0.74	1.40	5.18	1.76	0.74	1.77	.64	5.38	2.12	1.98	6.86

SAMPLE	TRASK			INMAN				FOLK AND WARD					MOMENTS			
	M_q	QD_a	SK_a	M_ϕ	σ_ϕ	α_ϕ	β_ϕ	M_z	σ_I	Sk_I	K_G	K_G'	M	σ	α_3	β_2
SS-162	0.295	0.229	0.141	2.67	1.09	0.50	1.89	2.49	1.50	0.58	2.43	.71	2.77	2.06	2.85	12.23
SS-163	0.048	0.037	0.020	5.23	0.95	0.48	1.50	5.07	1.20	0.45	1.57	.61	5.16	1.52	2.01	9.43
SS-165	0.058	0.050	0.031	4.80	0.93	0.51	2.36	4.64	1.41	0.60	2.81	.74	4.94	1.95	2.57	9.93
SS-167	0.056	0.036	0.012	6.06	1.91	0.67	0.99	5.63	2.11	0.72	1.39	.58	5.77	2.34	1.69	5.24
SS-169	0.097	0.052	0.043	4.04	1.50	-0.14	1.90	4.11	2.07	0.14	3.01	.75	4.52	2.40	1.71	6.95
SS-171	0.046	0.038	0.021	5.83	1.48	0.76	1.46	5.46	1.84	0.77	2.63	.72	5.54	2.24	1.92	6.38
SS-174	0.056	0.048	0.029	5.05	1.02	0.67	1.82	4.82	1.38	0.71	2.47	.71	5.06	1.95	2.41	9.08
SS-177	0.053	0.055	0.024	4.75	1.69	0.33	1.61	4.56	2.19	0.41	3.13	.76	4.93	2.41	1.64	6.05
SS-178	0.063	0.045	0.033	4.81	1.15	0.29	2.35	4.70	1.74	0.47	3.31	.77	5.06	2.22	2.16	7.61
SS-179	0.136	0.068	0.040	4.33	1.86	0.24	1.32	4.18	2.23	0.37	1.98	.66	4.40	2.50	1.74	6.07
SS-180	0.053	0.044	0.033	4.85	1.05	0.34	2.72	4.73	1.71	0.34	4.84	.83	4.90	2.14	1.83	7.60
SS-181	0.212	0.075	0.049	3.23	1.32	-0.38	1.91	3.40	1.82	0.02	1.48	.60	3.84	2.31	2.07	8.22
SS-182	0.080	0.051	0.021	4.95	2.22	0.30	1.05	4.73	2.49	0.38	1.96	.66	4.93	2.57	1.42	5.04
SS-183	0.053	0.048	0.024	5.29	1.14	0.79	2.13	4.99	1.65	0.77	2.53	.72	5.21	2.21	1.73	7.32
SS-184	0.155	0.060	0.020	4.30	2.38	0.10	0.94	4.21	2.59	0.26	1.29	.56	4.44	2.72	1.28	4.73
SS-185	0.050	0.038	0.019	5.42	1.21	0.58	1.76	5.19	1.62	0.67	1.95	.66	5.42	2.10	1.99	7.37
SS-186	0.051	0.046	0.025	5.01	1.25	0.47	2.06	4.82	1.78	0.51	3.02	.75	5.07	2.16	1.99	7.39
SS-187	0.056	0.034	0.011	6.10	1.76	0.69	1.19	5.69	2.05	0.73	1.35	.57	5.82	2.38	1.62	5.08
SS-188	0.053	0.046	0.021	5.04	0.88	0.69	3.65	4.83	1.68	0.77	2.55	.72	5.43	2.47	1.98	6.12
SS-189	0.059	0.044	0.025	5.31	1.97	0.41	1.15	5.04	2.27	0.39	2.76	.73	5.08	2.40	1.38	5.33
SS-192	0.107	0.061	0.047	3.96	1.21	-0.06	1.86	3.99	1.65	0.19	2.38	.70	4.29	2.04	2.41	10.12
SS-195	0.134	0.094	0.058	3.47	0.92	0.07	2.35	3.45	1.39	0.28	2.09	.68	3.79	1.88	2.63	11.83
SS-198	0.176	0.126	0.081	3.15	0.98	0.17	2.45	3.10	1.51	0.40	2.49	.71	3.51	2.10	2.84	11.71
SS-200	0.243	0.147	0.055	3.13	1.29	0.28	2.08	3.01	1.84	0.46	1.52	.60	3.55	2.41	2.17	8.16

SAMPLE	TRASK			INMAN				FOLK AND WARD					MOMENTS			
	M_q	QD_a	SK_a	M_ϕ	σ_ϕ	α_ϕ	β_ϕ	M_z	σ_I	Sk_I	K_G	K_G'	M	σ	α_3	β_2
SS-201	0.053	0.047	0.020	5.50	1.41	0.77	1.66	5.14	1.84	0.81	2.23	.69	5.38	2.31	1.94	6.45
SS-203	0.062	0.046	0.014	5.61	1.92	0.61	0.99	5.22	2.12	0.63	1.46	.59	5.37	2.31	1.62	5.51
SS-204	0.223	0.170	0.100	3.19	1.20	0.53	2.06	2.98	1.71	0.64	2.62	.72	3.34	2.36	2.47	9.29
SS-207	0.059	0.050	0.036	4.85	0.87	0.62	3.00	4.67	1.49	0.70	3.97	.80	4.99	2.09	2.48	9.01
SS-211	0.085	0.062	0.047	4.14	0.82	0.17	2.95	4.09	1.39	0.41	3.14	.76	4.51	1.98	2.71	10.93
SS-215	0.096	0.065	0.052	3.80	0.62	-0.23	3.76	3.85	1.21	0.19	2.71	.73	4.29	1.90	2.96	12.53
SS-216	0.056	0.046	0.021	5.41	1.13	0.86	2.12	5.08	1.63	0.79	2.03	.67	5.26	2.13	1.97	7.37
SS-217	0.068	0.051	0.024	5.01	1.50	0.48	1.69	4.77	1.98	0.53	2.24	.69	5.01	2.31	1.87	6.50
SS-218	0.062	0.047	0.020	5.52	1.56	0.72	1.49	5.15	1.96	0.74	1.92	.66	5.34	2.31	1.92	6.26
SS-219	0.061	0.049	0.029	5.10	1.24	0.61	1.96	4.85	1.74	0.68	2.73	.73	5.12	2.20	2.16	7.43
SS-219A	0.141	0.059	0.030	4.43	1.83	0.19	1.39	4.31	2.24	0.35	1.62	.62	4.53	2.52	1.72	5.95
SS-223	0.053	0.041	0.013	6.10	1.91	0.78	1.18	5.60	2.22	0.76	1.69	.63	5.71	2.50	1.61	4.90
SS-236	0.055	0.047	0.019	5.82	1.75	0.81	1.28	5.35	2.09	0.81	2.14	.68	5.47	2.40	1.88	5.77
SS-238A	0.242	0.171	0.131	3.05	1.18	0.42	2.10	2.88	1.71	0.55	3.40	.77	3.21	2.33	2.57	9.62
SS-252	0.051	0.045	0.009	6.20	2.00	0.86	0.96	5.63	2.19	0.87	1.26	.56	5.91	2.47	1.50	4.51
SS-256	0.057	0.049	0.015	5.77	1.89	0.75	1.35	5.30	2.29	0.71	1.86	.65	5.49	2.55	1.53	4.93

SAMPLE	PHI SIZES AT PERCENT LEVELS OF								PERCENTAGES OF			
	1	5	16	25	50	75	84	95	GRAVEL	SAND	SILT	CLAY
SS-47	0.90	1.61	2.29	3.41	4.35	4.91	5.95	10.45	0.00	35.62	54.93	9.45
SS-49	0.66	1.18	1.63	1.82	2.62	4.26	5.87	10.31	0.30	69.65	20.28	9.77
SS-51	-1.14	1.78	2.61	2.80	3.63	5.38	7.59	11.76	1.17	54.12	30.13	14.58
SS-53	0.77	1.54	1.95	2.19	2.77	4.02	5.13	10.46	0.46	72.67	17.62	9.25
SS-55	1.13	1.85	2.25	2.50	2.82	3.92	4.75	9.41	0.46	75.16	16.49	7.89
SS-57	-1.43	0.78	1.24	1.45	1.82	2.34	2.57	3.50	1.52	93.96	3.00	1.53
SS-59	1.17	1.73	2.35	2.67	3.17	4.09	5.04	9.87	0.00	71.94	19.42	8.64
SS-61	0.85	1.24	1.67	1.86	2.39	2.79	2.97	5.00	0.00	93.93	3.27	2.80
SS-63	0.87	1.31	1.74	1.90	2.32	2.77	3.09	6.72	0.01	89.99	5.64	4.36
SS-66	0.74	1.31	1.79	1.98	2.69	4.67	6.77	11.08	0.01	70.22	16.45	13.32
SS-68	1.35	2.92	3.87	4.26	4.47	6.34	7.75	11.53	0.01	17.47	67.91	14.62
SS-69	0.82	1.87	2.58	2.95	4.56	6.91	8.35	12.10	0.15	38.97	42.86	18.02
SS-71	2.28	4.21	4.48	4.54	5.52	7.58	8.71	12.29	0.00	4.10	74.44	21.46
SS-73	0.97	1.22	1.49	1.60	1.79	1.96	2.07	2.44	0.00	98.51	1.04	0.45
SS-75	1.14	1.64	1.93	2.01	2.23	2.48	2.54	2.86	0.00	96.85	1.79	1.37
SS-77	0.79	1.14	1.48	1.63	1.88	2.25	2.50	3.21	0.27	95.60	2.19	1.94
SS-79	1.03	1.43	1.82	2.00	2.67	3.35	4.19	7.29	0.01	82.31	13.18	4.49
SS-81	0.96	1.39	1.88	2.15	2.73	3.54	4.27	8.86	0.10	80.13	13.77	6.01
SS-82	1.15	1.69	2.17	2.45	2.81	3.34	3.75	7.09	0.04	86.26	9.32	4.37
SS-83	1.68	2.60	3.24	3.57	4.19	5.10	6.34	10.95	0.03	37.10	51.46	11.40
SS-84	-4.14	-3.70	-2.44	1.93	3.78	4.66	6.57	11.23	23.95	28.44	36.25	11.36
SS-86	1.01	1.53	1.94	2.20	3.20	5.02	6.94	11.46	0.04	59.18	27.70	13.08
SS-88	1.14	1.71	2.18	2.41	2.63	4.62	7.64	11.98	0.00	70.01	14.94	15.04
SS-90	1.25	1.72	2.03	2.19	2.54	2.90	3.73	8.23	0.00	85.26	9.37	5.36

SAMPLE	PHI SIZES AT PERCENT LEVELS OF								PERCENTAGES OF			
	1	5	16	25	50	75	84	95	GRAVEL	SAND	SILT	CLAY
SS-92	0.50	0.95	1.18	1.28	1.49	1.61	1.72	2.89	0.09	95.72	3.25	0.95
SS-94	1.62	2.12	2.69	3.03	3.75	4.38	5.29	8.96	0.00	56.78	36.56	6.65
SS-96	1.42	2.46	3.22	3.58	4.12	4.58	5.28	9.29	0.66	40.31	52.22	6.80
SS-97	1.18	1.86	2.45	2.93	3.88	4.44	5.45	10.37	0.07	52.85	37.99	9.09
SS-98	-4.46	-3.94	-2.81	-1.82	1.68	2.70	4.13	7.57	31.38	51.92	12.31	4.40
SS-99	0.68	0.99	1.31	1.49	1.77	2.00	2.15	6.08	0.00	93.40	3.18	3.41
SS-101	-0.16	0.84	1.18	1.37	1.73	2.03	2.29	3.74	0.67	94.62	3.54	1.17
SS-103	0.50	0.83	1.10	1.24	1.58	1.92	2.18	2.67	0.02	97.76	1.66	0.56
SS-105	1.24	1.90	2.32	2.49	2.71	3.14	4.16	7.88	0.01	82.75	12.45	4.79
SS-107	1.57	1.97	2.29	2.44	2.65	2.86	3.19	8.11	0.01	88.63	6.23	5.13
SS-108	1.70	2.07	2.42	2.56	2.80	3.81	4.15	7.46	0.04	76.31	19.57	4.08
SS-109	0.52	0.84	1.24	1.41	1.69	2.09	2.26	2.51	0.02	96.73	2.06	1.19
SS-111	0.98	1.45	1.80	1.92	2.30	2.64	2.81	6.02	0.00	90.88	5.58	3.53
SS-114	1.48	1.97	2.43	2.58	2.85	4.26	5.10	9.39	0.02	72.12	19.56	8.30
SS-116	1.77	2.42	2.72	2.82	3.26	4.29	5.10	8.47	0.00	66.11	27.30	6.60
SS-117	0.67	0.97	1.24	1.39	1.67	1.87	2.00	2.50	0.00	97.35	1.47	1.18
SS-118	0.80	1.18	1.57	1.72	1.93	2.24	2.51	5.36	0.00	89.19	8.77	2.04
SS-119A	0.72	1.13	1.61	1.87	4.35	5.68	6.77	10.12	0.00	33.17	56.85	9.98
SS-121A	1.32	1.81	2.27	2.59	3.64	4.24	5.34	9.43	0.00	56.86	35.31	7.83
SS-125A	1.46	1.97	2.62	2.87	3.72	4.33	5.14	9.58	0.01	56.04	36.23	7.73
SS-128A	1.30	1.80	2.25	2.53	2.90	3.52	4.03	6.56	0.00	82.40	14.11	3.49
SS-129A	-1.53	0.37	1.60	1.82	2.29	2.70	2.91	5.38	2.17	89.77	5.42	2.64
SS-131A	1.48	2.20	2.67	2.81	3.56	4.60	6.03	10.49	0.10	56.90	32.66	10.34
SS-132A	1.38	1.94	2.63	2.84	4.12	5.49	6.90	10.38	0.00	48.04	40.73	11.22

SAMPLE	PHI SIZES AT PERCENT LEVELS OF								PERCENTAGES OF			
	1	5	16	25	50	75	84	95	GRAVEL	SAND	SILT	CLAY
SS-135	1.79	2.51	2.77	2.89	3.31	4.26	5.16	8.81	0.00	67.83	25.36	6.80
SS-136	1.79	2.61	2.93	3.10	3.64	4.33	5.21	9.25	0.00	59.85	33.44	6.71
SS-138	-1.28	0.81	1.23	1.41	1.72	2.03	2.30	4.38	1.39	93.31	2.92	2.38
SS-139	1.33	1.91	2.54	2.80	3.74	4.61	4.76	8.68	0.23	56.44	37.33	6.01
SS-141	1.65	2.36	3.19	3.55	4.10	4.62	5.59	10.15	0.04	41.64	49.14	9.17
SS-143	1.58	1.99	3.69	4.09	4.43	5.21	6.42	10.93	0.00	18.44	70.94	10.63
SS-144	0.72	1.06	1.41	1.60	2.16	5.02	6.83	11.50	0.04	58.30	29.07	12.59
SS-146	1.14	1.61	2.00	2.32	2.95	4.06	4.31	8.36	0.06	73.34	21.09	5.51
SS-148	1.34	1.88	2.53	2.70	2.88	3.19	3.49	6.84	0.05	88.71	7.44	3.80
SS-149	1.30	1.78	2.11	2.31	2.64	2.85	3.03	4.41	0.00	93.85	3.78	2.36
SS-150	0.77	1.29	1.71	1.83	2.14	2.81	4.29	7.73	0.03	81.41	14.14	4.42
SS-151	3.12	4.09	4.36	4.50	5.10	6.76	8.09	11.48	0.00	3.22	79.83	16.95
SS-152	1.71	3.27	4.27	4.44	5.28	6.51	7.54	10.82	0.04	6.65	80.28	13.04
SS-154	2.76	3.83	4.13	4.14	4.55	5.58	6.52	9.00	0.00	7.25	82.36	10.40
SS-156	2.41	3.48	4.20	4.19	4.41	5.79	6.91	11.30	0.00	10.01	78.35	11.64
SS-158	2.87	3.85	4.06	4.26	4.46	5.78	7.23	10.96	0.00	6.49	80.83	12.67
SS-160	2.74	3.55	4.10	4.16	4.46	5.75	6.97	10.43	0.00	11.78	76.81	11.41
SS-162	0.61	1.09	1.58	1.76	2.13	2.82	3.75	7.38	0.00	85.21	10.55	4.24
SS-163	2.91	3.40	4.28	4.37	4.77	5.62	6.18	8.17	0.00	9.70	84.39	5.91
SS-165	2.72	3.36	3.87	4.10	4.33	5.01	5.73	9.61	0.00	18.58	73.62	7.80
SS-167	3.15	3.93	4.14	4.16	4.78	6.41	7.97	11.54	0.00	5.77	78.38	15.85
SS-169	0.25	1.70	2.54	3.36	4.25	4.55	5.55	10.42	0.14	29.08	62.40	8.38
SS-171	2.38	3.93	4.35	4.43	4.71	5.57	7.31	11.22	0.01	5.67	81.13	13.18
SS-174	2.68	3.65	4.03	4.16	4.37	5.11	6.07	9.41	0.01	12.20	78.67	9.13

SAMPLE	PHI SIZES AT PERCENT LEVELS OF								PERCENTAGES OF			
	1	5	16	25	50	75	84	95	GRAVEL	SAND	SILT	CLAY
SS-177	1.39	1.93	3.06	4.23	4.19	5.38	6.44	10.77	0.03	22.62	66.36	10.98
SS-178	2.13	3.13	3.66	3.98	4.47	4.93	5.96	10.84	0.01	25.57	64.33	10.09
SS-179	1.07	1.76	2.47	2.88	3.89	4.66	6.18	10.37	0.01	52.21	37.83	9.95
SS-180	1.25	1.92	3.80	4.25	4.50	4.91	5.90	9.74	0.01	18.94	72.67	8.38
SS-181	0.93	1.51	1.91	2.24	3.73	4.35	4.55	9.17	0.00	52.29	40.88	6.83
SS-182	1.11	1.81	2.73	3.64	4.28	5.54	7.16	10.90	0.00	31.72	55.45	12.83
SS-183	0.20	3.48	4.15	4.25	4.39	5.40	6.43	10.61	0.37	6.24	83.52	9.87
SS-184	0.36	1.33	1.92	2.69	4.05	5.61	6.68	10.56	0.24	49.17	40.75	9.84
SS-185	1.88	3.90	4.21	4.32	4.72	5.73	6.63	10.61	0.00	5.34	85.03	9.63
SS-186	1.85	2.72	3.77	4.29	4.43	5.32	6.26	10.35	0.00	18.70	72.19	9.11
SS-187	2.80	3.97	4.34	4.17	4.88	6.50	7.85	11.68	0.00	5.10	79.61	15.29
SS-188	1.99	3.78	4.16	4.25	4.43	5.56	5.91	11.94	0.00	5.67	81.22	13.11
SS-189	1.35	1.87	3.34	4.09	4.50	5.34	7.28	10.34	0.04	20.83	65.90	13.22
SS-192	1.55	2.10	2.76	3.22	4.04	4.41	5.17	9.00	0.00	47.04	47.38	5.58
SS-195	1.37	1.86	2.55	2.90	3.41	4.11	4.39	8.01	0.06	70.74	24.18	5.02
SS-198	1.29	1.77	2.17	2.51	2.99	3.62	4.13	8.52	0.00	81.44	12.77	5.78
SS-200	0.80	1.35	1.85	2.04	2.77	4.18	4.42	9.28	0.03	66.80	26.23	6.94
SS-201	2.20	3.85	4.09	4.24	4.42	5.61	6.90	11.32	0.07	5.54	82.30	12.09
SS-203	2.10	3.12	3.69	4.00	4.44	6.15	7.54	10.76	0.00	24.91	63.58	11.52
SS-204	0.77	1.67	1.99	2.16	2.56	3.31	4.39	9.01	0.28	79.61	13.51	6.60
SS-207	2.14	3.53	3.98	4.09	4.31	4.81	5.73	10.51	0.00	16.83	74.58	8.59
SS-211	1.93	2.86	3.32	3.56	4.00	4.41	4.96	9.33	0.01	40.48	52.91	6.61
SS-215	2.09	2.80	3.18	3.38	3.94	4.28	4.42	8.70	0.04	52.18	41.80	5.99
SS-216	1.90	3.44	4.28	4.16	4.44	5.58	6.53	10.47	0.03	8.56	81.41	10.00

SAMPLE	PHI SIZES AT PERCENT LEVELS OF								PERCENTAGES OF			
	1	5	16	25	50	75	84	95	GRAVEL	SAND	SILT	CLAY
SS-217	1.74	2.61	3.51	3.87	4.30	5.35	6.52	10.71	0.00	27.80	61.13	11.07
SS-218	2.42	3.46	3.96	4.01	4.40	5.67	7.08	11.24	0.00	17.09	71.15	11.76
SS-219	2.40	3.39	3.86	4.02	4.34	5.13	6.34	10.76	0.01	21.41	67.63	10.95
SS-219A	1.32	1.93	2.59	2.83	4.08	5.04	6.26	10.69	0.04	47.14	42.85	9.97
SS-223	2.56	3.56	4.19	4.24	4.60	6.27	8.01	11.89	0.03	10.18	73.76	16.04
SS-236	2.69	3.61	4.07	4.18	4.41	5.71	7.58	11.61	0.00	11.37	74.76	13.87
SS-238A	0.88	1.41	1.86	2.05	2.55	2.94	4.23	8.76	0.00	83.21	10.28	6.52
SS-252	3.25	4.01	4.20	4.29	4.48	6.84	8.20	11.85	0.00	4.73	77.60	17.68
SS-256	1.36	2.87	3.88	4.14	4.35	6.09	7.65	11.75	0.05	17.91	67.54	14.50

APPENDIX B

LINE COUNT SUMMARY OF SOUTH SLOUGH SEDIMENTS

SAMPLE	% QUARTZ	% PLAGIO-CLASE	% K-SPAR	TOTAL FELDSPAR	% ROCK FRAGMENTS	% GLASS	% HEAVIES	QUARTZ/ FELDSP.	K-SPAR/ PLAG.
SS-53	37.9	39.2	21.7	60.9	-	0.3	1.0	0.6	0.55
SS-61	47.3	27.2	23.2	50.4	0.5	-	1.8	0.9	0.85
SS-88	53.8	28.6	15.8	44.4	-	-	1.9	1.2	0.55
SS-96	49.2	37.9	10.7	48.7	0.5	-	1.6	1.0	0.28
SS-103	44.1	27.1	27.4	54.5	0.6	-	0.8	0.8	1.01
SS-114	45.5	33.8	19.5	53.3	-	-	1.2	0.9	0.58
SS-125	51.5	29.8	17.1	46.9	-	0.2	1.3	1.1	0.57
SS-148	50.7	27.4	18.8	46.3	2.1	-	1.0	1.1	0.69
SS-174	32.1	47.6	17.7	65.4	0.6	0.6	1.3	0.5	0.37
SS-185	47.2	35.6	14.5	50.2	1.3	0.4	1.6	0.7	0.41
SS-211	40.2	44.3	13.2	57.6	1.1	-	1.1	0.7	0.30
SS-223	39.8	43.9	11.0	54.9	3.7	0.4	1.2	0.7	0.25
SS-238	41.5	33.5	22.7	56.3	0.3	0.5	1.4	0.7	0.68
SS-252	40.3	40.3	16.2	56.4	1.9	-	1.5	0.7	0.40

APPENDIX C

PERCENT HEAVY MINERAL SPECIES IN SOUTH SLOUGH SEDIMENTS

SAMPLE \ MINERAL	green-brown hornblende	blue-green hornblende	brown hornblende	epidote	hypersthene	tremolite-actinolite	clinopyroxene	clinozoisite	apatite	sphene	zoisite	tourmaline	glaucophane	kyanite	olivine	enstatite	pink garnet	white garnet	zircon
SS-53	28.2	10.2	7.3	17.0	6.6	10.2	6.3	3.4	-	-	0.5	0.2	0.5	0.5	-	-	4.6	2.4	1.7
SS-61	18.2	9.6	1.8	17.3	11.9	7.2	10.0	1.2	0.6	0.3	-	-	0.3	0.3	-	-	6.0	9.6	6.0
SS-88	26.0	8.1	7.4	12.3	10.5	14.4	6.0	0.7	-	1.4	-	-	0.7	-	0.4	-	4.2	5.6	2.5
SS-96	34.2	7.8	3.6	16.6	6.2	4.9	12.7	6.8	0.7	-	-	-	1.0	-	-	-	0.7	4.9	-
SS-103	12.6	11.0	7.1	34.1	7.4	2.5	10.4	2.2	0.5	0.5	-	-	0.3	0.3	0.3	-	3.0	6.3	1.4
SS-114	28.8	8.1	7.1	15.2	11.1	12.6	6.1	-	-	0.5	0.5	-	1.0	1.0	-	-	2.0	4.5	1.5
SS-125	31.7	6.9	7.4	17.5	1.6	10.1	7.9	4.5	1.3	0.5	0.3	-	0.5	0.3	0.5	-	5.8	2.1	1.1
SS-148	33.1	7.2	6.3	15.7	3.6	6.0	14.5	1.2	0.9	1.2	-	-	0.6	0.3	-	-	3.6	3.6	2.1
SS-174	48.3	9.4	6.3	13.5	5.6	5.6	5.9	1.0	-	-	0.3	-	0.7	0.3	-	-	0.3	1.4	1.4
SS-185	10.1	18.4	0.9	23.7	3.9	14.9	6.1	1.3	-	-	-	-	-	0.9	-	-	7.9	5.3	7.0
SS-211	39.9	6.8	8.7	13.6	9.6	8.0	6.8	1.2	-	-	0.6	-	0.3	-	-	0.6	0.6	1.9	1.2
SS-223	44.9	1.9	6.7	23.2	-	7.3	5.4	3.5	1.6	-	1.9	-	0.6	-	0.6	-	-	-	2.2
SS-238	36.4	18.1	10.8	8.2	7.6	3.5	6.7	-	-	0.6	-	-	0.6	-	-	-	2.9	3.8	0.9
SS-252	45.0	3.6	4.5	19.6	5.4	3.3	6.9	2.7	0.6	-	-	-	-	-	-	-	5.4	1.8	0.9

APPENDIX D

PERCENT HEAVY MINERAL SPECIES IN SOURCE MATERIALS

SOURCE \ MINERAL	green-brown hornblende	blue-green hornblende	brown hornblende	epidote	hypersthene	tremolite-actinolite	clinopyroxene	clinozoisite	apatite	sphene	zoisite	tourmaline	glaucophane	kyanite	olivine	enstatite	garnet	zircon
Lower Coaledo Formation	5.0	18.0	-	18.0	-	-	6.0	4.5	0.5	0.5	1.0	0.5	-	-	-	-	42.0	4.0
Middle Coal-edo Formation	2.7	9.5	10.8	28.4	-	2.7	6.6	5.4	1.4	-	4.1	4.1	-	-	-	-	21.6	1.4
Upper Coaledo Formation	39.1	13.2	1.7	30.7	-	0.9	7.7	3.4	-	0.4	0.9	-	-	-	-	-	2.1	-
Bastendorff Formation	29.5	6.8	-	15.9	9.1	6.8	13.6	6.8	2.3	-	-	-	-	-	-	-	9.1	-
Empire Fm.	53.5	3.7	1.2	16.6	8.3	4.9	6.5	2.8	0.6	-	0.9	0.3	-	-	-	-	-	0.6
Terrace Sands	12.0	15.8	2.5	40.0	0.9	6.6	5.4	5.4	1.6	0.6	-	-	0.6	0.3	-	-	6.9	1.3
Bastendorff Beach	4.2	19.7	5.8	36.9	12.0	8.4	3.9	2.9	-	-	-	-	-	0.6	-	-	5.5	-
Talbot Creek	15.2	7.9	4.8	23.1	9.0	1.1	10.7	5.6	0.6	0.8	1.1	-	-	0.3	-	-	18.0	1.7
John B Creek	15.2	2.3	5.9	32.7	11.9	4.6	6.9	0.7	-	-	1.0	0.3	-	0.3	-	-	17.2	0.7
Elliot Creek	5.8	2.6	10.1	19.6	16.4	6.9	11.1	9.0	3.7	2.1	3.2	1.6	-	1.6	-	-	1.1	5.3
Day Creek	34.7	3.4	0.8	31.7	4.6	5.7	4.6	2.7	0.4	-	-	0.8	0.4	1.1	-	0.4	6.5	2.3
Winchester Creek	46.0	7.4	7.0	19.1	1.0	1.3	10.4	-	0.7	0.3	0.7	0.3	0.3	0.7	-	-	2.3	2.3