ABSTRACT OF THE THESIS OF

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Title SEDIMENTS OF YAQUINA BAY, OREGON

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(Major Professor)

Three realms of deposition, Marine, Fluviatile, and Marine-Fluviatile, are recognized in Yaquina Bay, Oregon, on the basis of sediment texture and mineralogy. The Marine Realm extends 1.5 miles into the entrance of the estuary and is typified by normal marine salinity and vigorous tidal action. Sediments of this realm are similar to those of the adjacent beach and coastal dune sands and consist of well-sorted, subangular to subrounded, fine to medium sand. The immature arkosic sands in this realm are distinguished by the marine suite of heavy minerals which include abundant pyroxenes, primarily hypersthene and diopside, and such metamorphic minerals as kyanite, sillimanite, and staurolite. The Fluviatile Realm occurs at the fresh-water head of the estuary and reaches to a point 6 miles from the entrance, where brackish water conditions prevail. The poorly sorted, angular to subangular sediments of this realm range in grain size from silt to coarse sand. They are somewhat more arkosic than the sands of the Marine

Realm and are represented by the fluviatile suite of heavy minerals. This assemblage includes such diagnostic minerals as biotite and muscovite, and hematite and limonite. Diopside is absent, hypersthene is restricted, and there is a marked decrease in the abundance of garnet and the number of metamorphic species, compared with the Marine Realm. The Marine-Fluviatile Realm lies between the Fluviatile and Marine Realms and contains admixtures of sediments of the other two realms.

The chief sources of Recent sediments in the Yaquina Bay area are the Tertiary rocks of the central Oregon Coast Range, the Pleistocene marine terrace sands and estuarine deposits near the bay mouth, and the Recent transitory beach and dune sands that flank the bay entrance.

Marine sand from the adjacent ocean beaches is transported into the estuary by strong tidal currents to Oneatta Point 6 miles from the entrance. Nearby coastal dune sands are blown into the tidal channel near the mouth of the estuary and onto the southwestern shore of Southbeach Tidal Flat by strong onshore winds. Suspended sediments are contributed by the Yaquina River during periods of high runoff.

The type of estuarine system is dependent upon seasonal and annual climatic conditions. Generally, from June to October the system is well-mixed, but it may alternate between a well-mixed to partly-mixed system from November to May. Precipitation recorded at Newport apparently reflects the type of estuarine system present during each month of the year for any given year.

Deposition in Yaquina Bay appears to be largely seasonal. Maximum deposition probably occurs in the winter and early spring when river runoff is highest, the littoral drift is from south to north, and the highest velocity winds are from the southwest. At this time, the partly-mixed estuarine system is effective in transporting drifting beach sands into the entrance of the estuary. During the summer, deposition is slight because of the low runoff, southward littoral drift, and northwest winds. The well-mixed estuarine system inhibits the transportation of sediments into the estuary.

Known areas of shoaling occur on the bar, in the main channel, and in the turning basin. The shoaled areas have maintained a fairly constant position from 1950 to 1961. Estimated average rate of deposition in the dredged channel is 9.1 inches per year. Marine sand is the principal shoaling material. As a result of jetty construction in 1888, and through subsequent additions, extensive deposition has occurred on the southern ocean beach behind the south jetty. An average estimate of 274 cubic yards of material accumulated annually during the past 73 years.

SEDIMENTS OF YAQUINA BAY, OREGON

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INTRODUCTION

Because of their diverse hydrographic properties and accessibility, estuaries afford an excellent opportunity to study the relationship of sedimentation to the many phases of oceanography. In an estuarine environment it is often possible to examine the processes that occur as a result of the mixing of fresh and saline water, and to correlate these processes directly with their sedimentary counterparts. Many variables that are incalculable in an ancient lithified sedimentary environment can be measured in a Recent environment. Periodic and non-periodic changes may occur within the environment during a single day or be extended over a longer period of time. Facies changes may be expected in the sediments of an estuary in relatively short distances. The hydrographic system controls, to a great extent, the distribution of the sediments in an estuary and frequently has a marked effect upon the composition of the estuarine sediments.

Numerous estuaries indent the relatively straight coastline of Oregon. Yaquina Bay is one of these estuaries. It is bordered on its ocean front by gently sloping beaches and flanked on its southwestern shore by transitory coastal dunes. The estuary extends 23 miles inland and undergoes mixed semi-diurnal tides characteristic of the North Pacific Ocean.

The objective of the present study is to determine the nature and origin of the Recent sediments of Yaquina Bay and the associated coastal beaches and dunes, and to show the relationship of the sediments to the hydrography of the estuary. This investigation is based primarily on sediment textural and mineralogical analyses. Additional information was obtained from geomorphic and hydrographic observations in the estuary and nearshore areas. Post-depositional processes were best evaluated by means of piston cores collected from the estuary.

The first and only investigation of the mineralogy and physical composition of the Recent sediments in the Yaquina Bay area prior to the present one was done by Twenhofel (42, p. 21-36). This study was limited to the coastal dunes, to the southwestern shore of the tidal flat in the vicinity of Southbeach, and to the ocean beach adjacent to the municipal pavilion at Newport.

Geography

Yaquina Bay, including the estuary, adjacent ocean beaches, and nearby coastal dunes, is located between 44° 34' and 44° 40' north latitude and 123° 51' and 124° 04' west longitude. Yaquina estuary lies on the western flank of the central Oregon Coast Range and and crosses the Yaquina and Toledo Quadrangles (Figure 1).

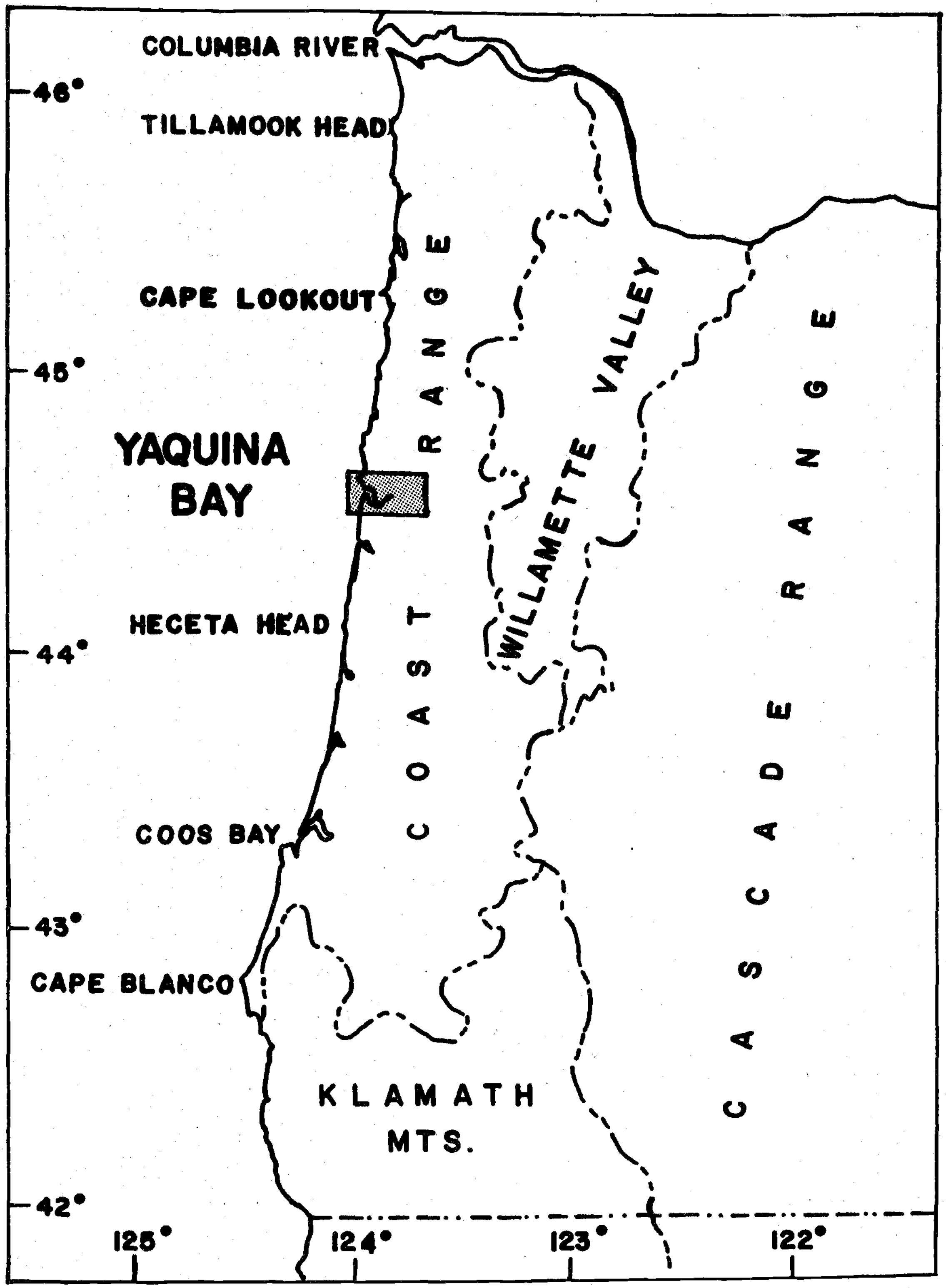

Figure 1. Location map showing Yaquina Bay, Oregon.

Access to the area may be gained by two paved highways, U. S. 101 and U. S. 20, which enter from the north and south, and east respectively. Within the area, a gravel road parallels the Yaquina River valley for more than 30 miles from its intersection with U. S. 20 at Chitwood to the town of Toledo. The area may also be entered from the sea through the port of Newport, noted for the foreign export and domestic transport of lumber products.

GENERAL

The present coastline of central Oregon is relatively straight except where it is interrupted by erosionally resistant headlands and indented by estuaries. Several uplifted marine terraces have been recognized along the coast. Eustatic changes of sea level and general regional uplift resulted in the formation of the terraces. The Late Quaternary rise of sea level inundated the coastal river mouths resulting in the creation of the estuaries and enhancing the formation of extensive alluvial flats in central and northern Oregon.

The Yaquina River drainage basin extends from the ocean to the crestline of the central Oregon Coast Range. Although the crestline of the Coast Range is about 1500 feet in elevation, the summit of the passes in the Yaquina River drainage is somewhat lower at 800 feet. Headward erosion by coastal streams has shifted the summit of the passes to the east of the center of the range (4, p. 5).

CLIMATE

The climate in the Yaquina Bay area is classified as (Csb) in the Köppen classification of climate (20, p. 28). This type of climate is characterized by extremely dry summers and wet winters. At Newport, seasonal fluctuations of precipitation during 1960 ranged from less than 0.5 inch during July to about 16 inches during November (51). The mean annual precipitation recorded at Newport is 64.87 inches (53); however, deviations of 20 inches or more from the mean value are not uncommon. Seasonal changes in air temperature are moderate. The Yaquina Bay area is marked by warm summers and mild winters, and has a mean annual temperature of 51.1 degrees Fahrenheit.

Fog frequently blankets the bay and nearshore coastal waters during the summer and fall, making navigation hazardous. The fog commonly occurs during periods of upwelling when cold water brought to the surface cools the warm moist surface air.

Data on the seasonal wind regime has been compiled by Cooper (10, p. 14-17) from wind velocities and directional frequencies during July and January from 1936 to 1942 for Newport, Oregon. During the month of July, which is typical of summer conditions, onshore winds predominate. The highest frequency of winds with velocities of 4 m. p. h. and more is from the north, parallel to the coast, with a somewhat lower frequency occurring from the north-northwest to northwest. For winds 16 m. p. h. and more, the greatest frequency of occurrence is also from the north, parallel to the coast. During the month of January, representative of winter conditions, there is a preponderance of offshore winds, which have velocities in excess of 4 m. p. h. but less than 16 m. p. h.. Winds with velocities greater than 16 m. p. h. , however, have their highest frequency from the south, parallel to the coast or slightly seaward of the coastal trend. The less frequent south to south-southwest winter winds have the highest velocities; this is in marked contrast to the more frequent but much lower velocity offshore winds. Fall and spring winds are transitional. Fall winds alternate between winter and summer types. In the spring, the north to northwest winds reappear and alternate with the high frequency low velocity offshore breezes and the high velocity less frequent south to southwest winter winds.

General Physiography and Areal Geology

The central Oregon Coast Range is a north-south trending ge-anticline composed of more than 15,000 feet of Middle Eocene to Middle Miocene sandstones, siltstones, and mudstones. This sequence of rocks overlies Lower Eocene volcanics consisting of a series of flows, tuffs, and breccias. Above the volcanic core, the Siletz River Volcanic Series, lies the most widespread formation exposed in the Coast Range, the Middle Eocene Tyee Formation. The Tyee Formation consists of rhythmically bedded, micaceous and arkosic sandstones and siltstones. Both the Tyee Sandstone and the Siletz River Series are cut by numerous basic and syenitic intrusives considered to be Late Oligocene to Early Miocene in age (4, p. 19-20).

The thickest section of sedimentary rocks (Figure 2) in the central Oregon Coast Range occurs along the Yaquina River (4, p. 11). These rocks include the Toledo Formation (Moody Shale Member and Upper Sandy Member), Yaquina Sandstone, Nye Mudstone, and Astoria Formation, and range in age from Late Eocene to Middle Miocene. Middle Miocene volcanic rocks rest upon the Astoria beds at Yaquina Head.

Erosion during or subsequent to Late Cenozoic uplift stripped the younger sediments from this region and superimposed the present drainage system on the older sedimentary rocks. No sediments of Pliocene age have been found in the central Coast Range.

On the coast, in the vicinity of Yaquina Bay, the Tertiary rocks are overlain by a narrow belt of Pleistocene estuarine and marine terrace deposits.

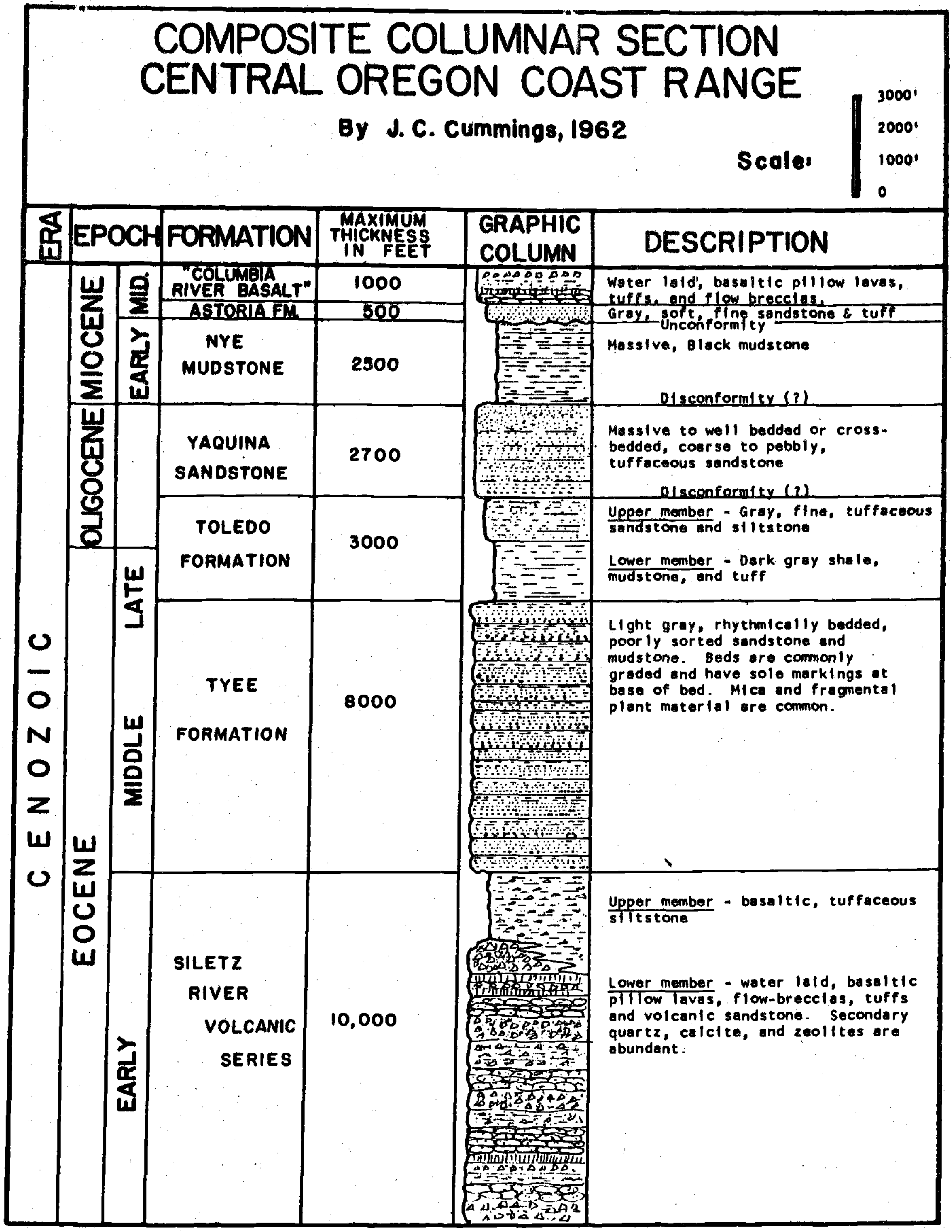

Figure 2. Stratigraphic section at Yaquina Bay, Oregon. (Courtesy of Jon C. Cummings, Department of Geology, Oregon State University)

GEOMORPHOLOGY

General

The Pleistocene geologic history of the Newport area and vicinity is known largely through the studies of Diller (11, p. 480-483) and Baldwin (2, p. 40, and 3). During the Pliocene and Pleistocene, the Yaquina River excavated its present valley as the Coast Range was being slowly uplifted. Two cycles of downcutting (glacial stages) and alluviation (interglacial stages) in Late Pleistocene time have been described for the Yaquina Bay area by Baldwin (3).

Isolated fluviatile deposits, correlated by Baldwin (3) with the Coquille River sediments of southern Oregon, underlie the marine terrace deposits in the vicinity of Newport. These sediments suggest that the alluvial fill deposited following the first stage of downcutting probably occurred in the Yaquina River valley during the last interglacial stage (3). Then followed relative emergence of the land accompanied by stillstands of the sea during which the marine terraces were formed. The lowest and most prominent marine terrace in the bay area is the wave-cut platform of the "Elk River" terrace, which is presently about 65-85 feet above sea level along Nye Beach and on the south side of Yaquina Head. This platform is overlain by sand deposits correlated with the Elk River beds, first described by

Diller (13, p. 30-31) along the southern Oregon coast. During the formation of the Elk River terrace, the Coquille Formation and the older surrounding rocks were truncated by the sea.

The second and final stage of downcutting occurred after the formation of the Elk River terrace, further enhancing the removal of Coquille sediments. Finally, the last rise in sea level following the Wisconsin stage of glaciation resulted in the drowning of the Yaquina River valley and its tributaries. Contemporaneous with post-Wisconsin drowning was the formation of the present-day flood plain deposits and tidal flats.

Yaquina Bay

Yaquina estuary reaches to a point 23 miles inland in the vicinity of Elk City, where fresh-water conditions prevail. Included in the lower estuary are the two large tidal flats, Sallys Tidal Flat and Southbeach Tidal Flat, both marginal to the main channel. The river channel and sloughs from the bay mouth to the vicinity of Elk City, however, comprise the major portion of the estuary. The segment of the ocean beach north of the bay entrance included in this study lies between the north jetty and Jump-off-Joe, a small headland, 1.7 miles to the north. The southern ocean beach for 2 miles south from the south jetty has been included. A series of transitory coastal dunes lie adjacent to Southbeach near Yaquina Bay and extend southwestward along the shoreline for 1. 5 miles.

The most distinctive geomorphic feature in this area is the estuary of the Yaquina River. Although the estuary reaches to a point 23 miles inland measured through the sinuous Yaquina River, its fresh-water head is only about 10 miles due east of the shoreline. The estuary reaches a maximum width of 2 miles in a northeast-southwest direction across its two channel-bordering tidal flats in the vicinity of Newport. Upstream from the tidal flats, the Yaquina River channel and valley decrease gradually in width to the head of the estuary near Elk City.

In the lower portion of the estuary, between the tidal flats and Toledo, the river channel is flanked by numerous sloughs and small tidal flats. Between Toledo and Elk City, grass covered flood plain deposits blanket the narrow valley floor. In this area, fairly well-developed natural levees rim the channel and extend about 5 miles upstream from Elk City.

BATHYMETRY

The bathymetry of Yaquina Bay has been altered through man's efforts to industrialize the area. A comparison of two bathymetric charts published in 1868 and in 1953 demonstrates the topographic changes brought about by man and by normal geologic processes (Figures 3 and 4).

In 1868 the bathymetry was vastly different from that of today especially on the bar and in the area now designated the turning basin. The old channel had numerous holes and elongate depressions between 12 and 17 feet in depth bordering the position of the present-day channel, which is currently dredged to 20 feet. The deepest depressions in the estuary are found in the turning basin adjacent to McLean Point and along the north side of the dredged channel underneath the highway bridge at Newport. A channel 12 feet deep is now being maintained upstream to Toledo for navigational purposes.

The geomorphology of the northern shore of Southbeach in Yaquina Bay has been altered considerably since 1868. In 1868, a large sand bar north of the beach was separated from the beach by a narrow channel 8 feet in depth. During subsequent years the bar was joined to the beach and formed an extensive continuous sand spit. The spit has been lengthening and changing in shape to the present.

In the 1868 survey of Sallys Tidal Flat, only a small intertidal channel, Sallys Slough, drained into the main channel, but between 1868 and 1953 another lateral channel, Center Slough, formed and the initial channel lengthened. At the present time it appears that both channels will join, forming an isolated flat adjacent to the main

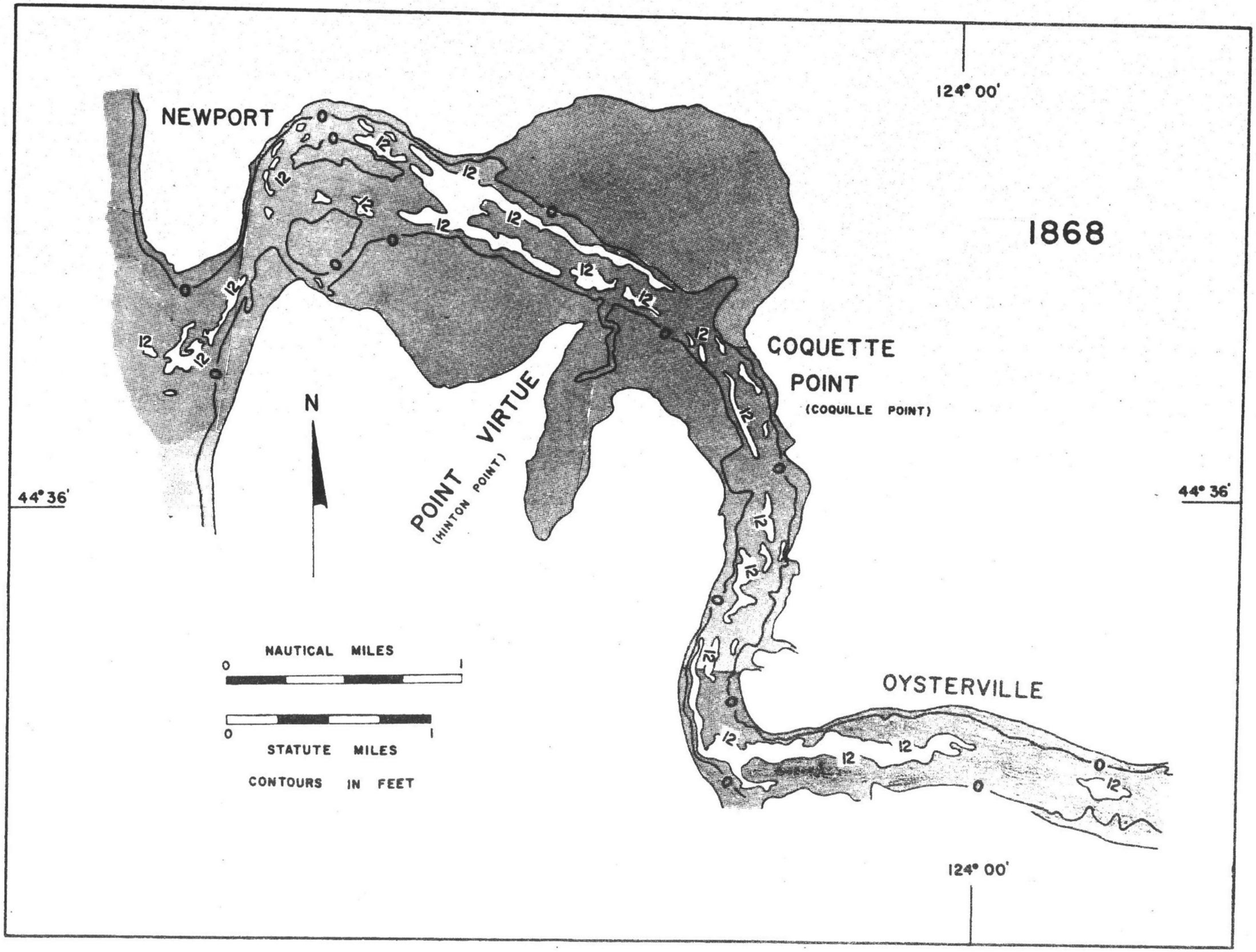

Figure 3. Bathymetry of Yaquina Bay. Contours compiled from 1868 U.S. Coast and Geodetic Survey smooth sheets. Contour interval 12 feet. Datum mean lower low water.

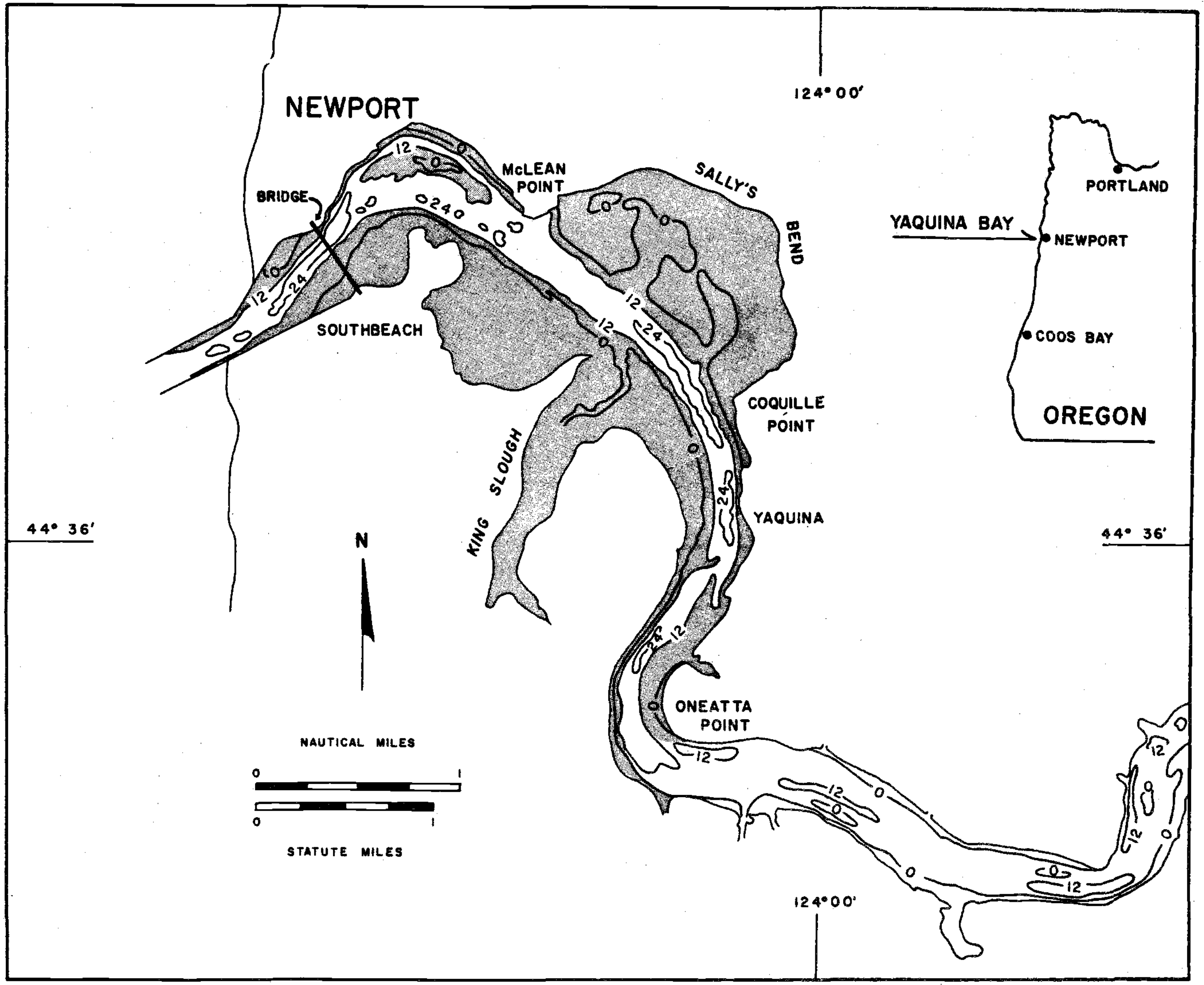

Figure 4. Bathymetry of Yaquina Bay. Contours compiled from 1953 U. S. Coast and Geodetic Survey smooth sheets. Contour interval 12 feet. Datum mean lower low water.

channel. Evidently the abrupt lowering of the water level in the main channel during ebb tide, results in currents instrumental in the downcutting and lateral erosion of the channels.

Recent changes in the geomorphology and bathymetry in Yaquina Bay that are not directly attributed to dredging (removal and dumping of shoaling material) probably stem from changes in hydrography which result from physiographic alterations through dredging and jetty construction.

DRAINAGE

The relatively small drainage basin of the Yaquina River is comprised of approximately 240 square miles of maturely dissected, moderately high hills on the western flank of the central Oregon Coast Range (Figure 5). The Yaquina River is the major stream draining the area and is affected by tides at its lower end. Elk Creek, which flows into the Yaquina River in the vicinity of Elk City, is the only other permanent stream of consequence.

Although relief in the drainage basin rarely exceeds 1000 feet, steep-sided valley walls adjacent to the river valley frequently create rugged topography leading to rapid erosion during periods of high rainfall.

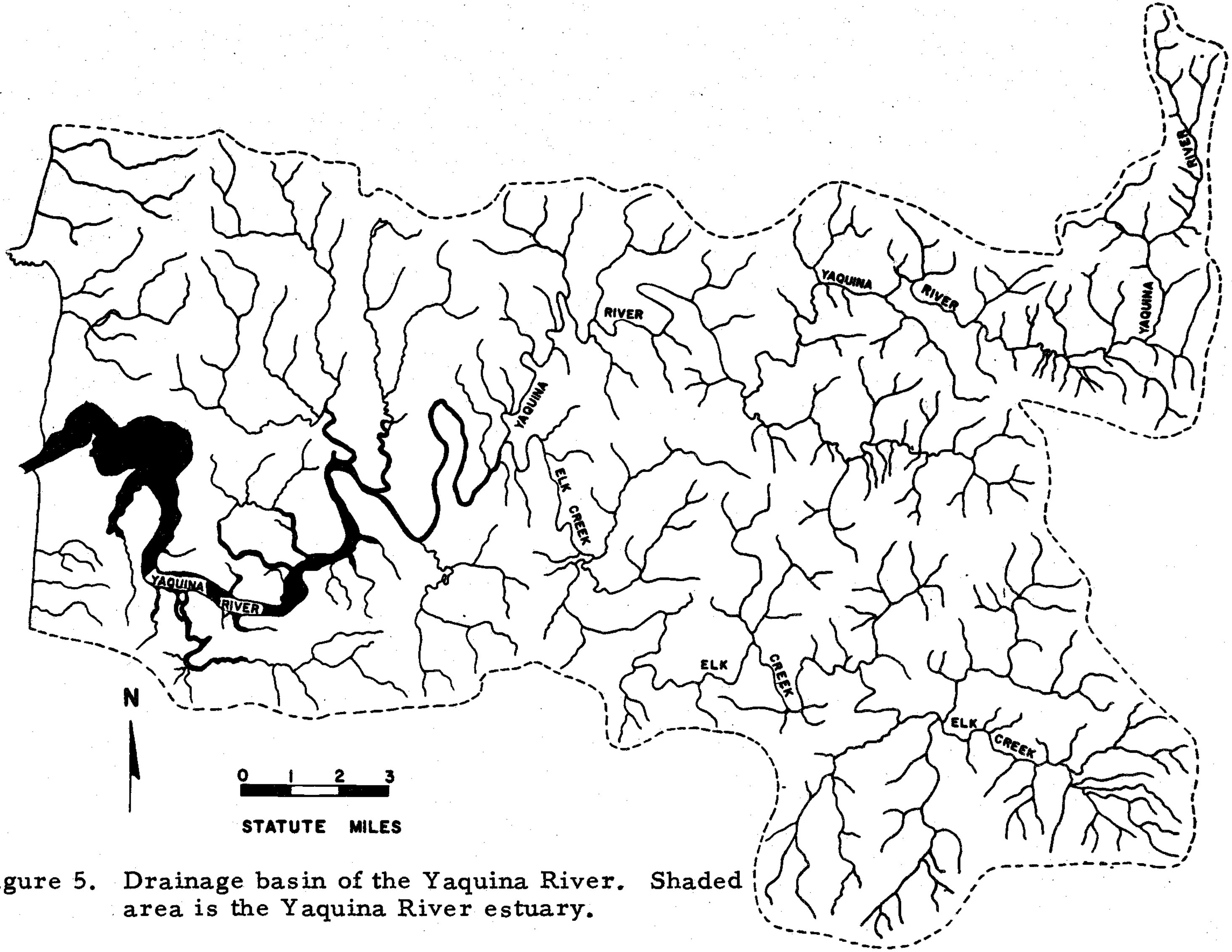

Figure 5. Drainage basin of the Yaquina River. Shaded area is the Yaquina River estuary.

Between Toledo and Newport several small creeks empty into sloughs along both sides of the estuary. Most of these sloughs are semi-diurnally exposed and inundated at high tide. The largest of these, King Slough, has a rather extensive tidal flat and a shallow channel. On the north side of the Yaquina River channel halfway between Toledo and Oneatta Point, Boone Slough and Nute Slough occupy an abandoned meander of the Yaquina River.

Many shifts in the mouths of Oregon coastal rivers have been described by Baldwin (2, p. 39-42), Cooper (10, p. 82), and Snavely (39). According to Baldwin and Cooper, the mouth of the Yaquina River was once located south of its present position.

Baldwin (3) suggests that the former channel flowed across the area now occupied by Southbeach and the present migrating coastal dunes. However, the author believes, as does Cooper (10) that the original stream outlet was even farther south, at the base of the present landward curving bluff, and that the stream cut across the area now occupied by the dunes. Eventually the channel shifted northward to its present posititION, which has been stabilized by the jetties and the dredging of the U. S. Army Corps of Engineers.

Beaches and Dunes

The coast north of the bay entrance consists of a narrow sand beach backed by moderately high (50-100 feet) sea cliffs cut in Tertiary sedimentary rocks and capped by a thin accumulation of Quaternary terrace deposits. The sea cliffs extend along the coast for some distance north of Newport and in places are transected by a few small creeks of low discharge. Three and one-half miles north of the bay the continuity of the coastline is broken by Yaquina Head, a terraced volcanic headland, which projects seaward about 1 mile and serves as a barrier to southward littoral drift.

In the vicinity of Jump-off-Joe, 1. 7 miles north of the bay, spectacular erosion by landsliding in 1961 resulted in sizable losses of real estate. Minor slumping occurs all along this northern beach. This segment of the coast is being actively eroded landward by wave action during winter storms. Because of the high precipitation, the water saturated Oligocene shales and mudstones serve as sliding planes for the overlying seaward dipping Tertiary formations and flat lying Quaternary deposits.

The coastline south of the bay is relatively straight for approximately 1. 6 miles. It extends south for many miles without interruption by headlands. The Tertiary formations south of the bay entrance are not exposed immediately behind the shoreline, as they are north of the bay entrance, but lie obscured beneath a relatively thick sequence of Quaternary deposits landward of the shoreline. These deposits consist of Pleistocene marine terrace sands and gravels, in places underlain by estuarine sediments.

An undulating surface of recently migrating coastal dunes presently covers portions of the marine terraces and low hills to the east of the shoreline (Figure 6) of the southern ocean beach. The dune sands apparently were derived from the reworked material of the terrace and estuarine deposits and Recent beach sands. At present, the migrating coastal dunes are encroaching inland into the forested low lying hills and northeastward onto the south shore of Yaquina Bay.

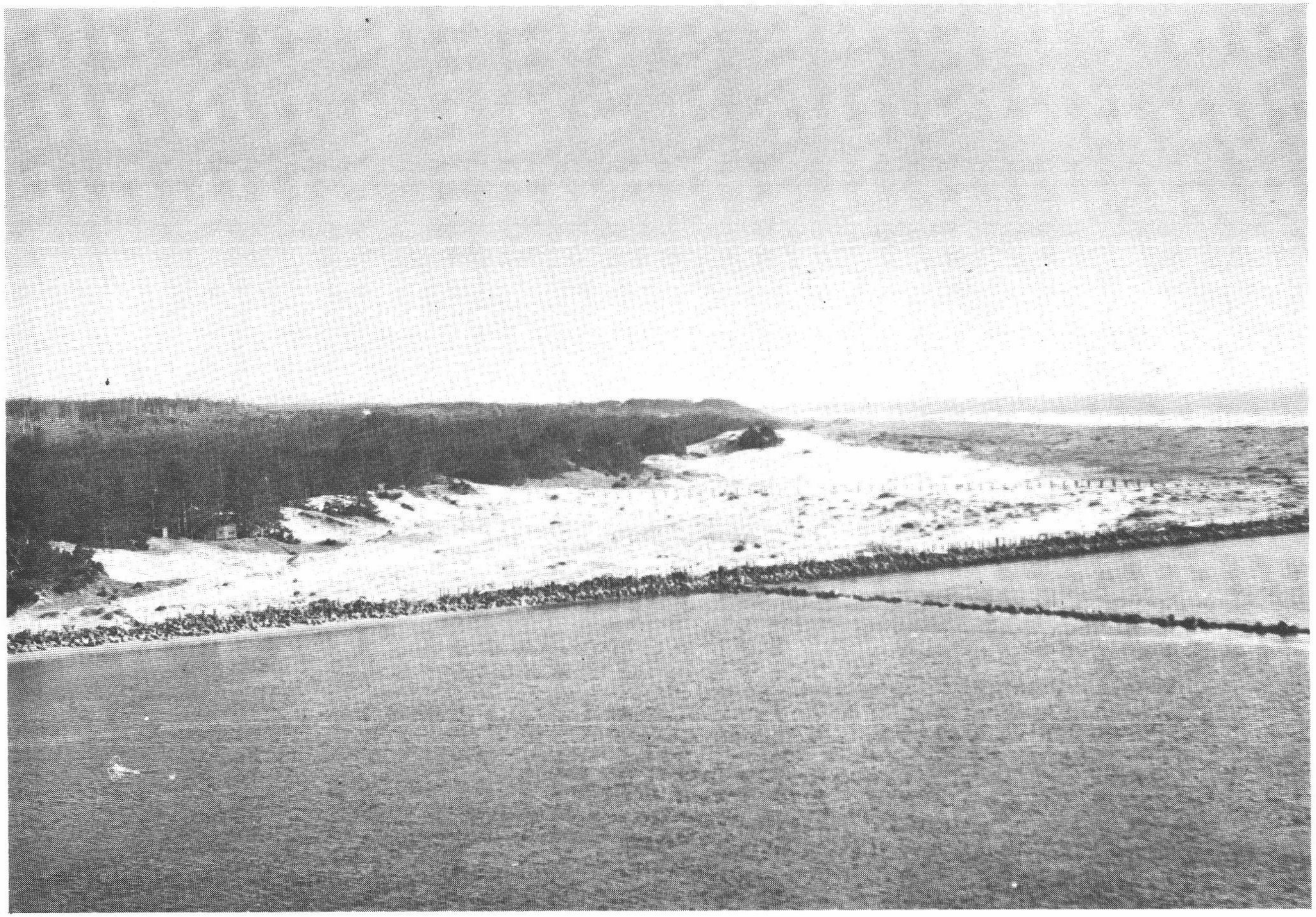

Figure 6. Coastal dunes bordering the south shore of the bay entrance.

PHYSICAL OCEANOGRAPHY AND CLIMATIC CONTROL

Estuaries are characterized by unique hydrographic properties. In coastal waters, the changes in the physical, chemical, and biological properties of the water are much greater than in the open sea due to tidal variations, fresh-water runoff, and meteorological conditions. Accompanying these variations, many of which are seasonal, are changes in the rate and location of sediment deposition. The climate and hydrography exert a pronounced influence on sedimentation in estuaries.

Classification of Estuarine Types

Oregon estuaries have been classified by Burt and McAlister (8, p. 21) on the basis of circulation patterns and salinity distributions according to the system developed by Pritchard (33). They found the following three types of systems in Oregon estuaries: Type A, two-layered or stratified; Type B, partly-mixed; and Type D, vertically-homogeneous or well-mixed. This classification is based on the salinity difference between top and bottom waters: a difference of 20 $^{o}/oo$ or more, Type A; between 4 and 19 $^{o}/oo$, Type B; and 3 $^{o}/oo$ or less, Type D. Salinities were measured at high tide at the station nearest to which mean salinity was 17 $^{o}/oo$. This is normally about half the total distance salt water penetrated since the salinity in Oregon coastal waters in approximately 34 $^{o}/oo$.

Table 1 shows the types of estuarine systems present in Yaquina Bay during each of several months of the year. The location of each station is given in nautical miles upstream from the entrance. Although these data are incomplete, they do show that the estuary is probably partly-mixed in the winter and spring and is well-mixed in the summer and fall.

Table 1. Estuarine type, Yaquina Bay, Oregon.

January	D-8	Well-mixed
February	B-9	Partly-mixed
	B-2	Partly-mixed
March		(No data)
April	B-8	Partly-mixed
May	B-8	Partly-mixed
June		(No data)
July		(No data)
August	D-12	Well-mixed
September		(No data)
October	D-16	Well-mixed
	D-16	Well-mixed
November	D-10	Well-mixed
December		(No data)

Modified after Table 1 (8, p. 22). The letter refers to the estuarine type; the number, to the distance in nautical miles upstream from the entrance of the estuary.

Relation of Hydrography to Climate

The Yaquina estuary has free tidal access to the sea through a narrow inlet channel between twin jetties. Tides are the semi-diurnal tides characteristic of the North Pacific; that is, two high and low tides of unequal duration and amplitude in a 24.8 hour period.

The mixing of fresh and saline water in the estuary is largely a function of tidal energy. This is often expressed by use of a flow ratio, which is the ratio of fresh-water discharge during a half tidal cycle of 12.4 hours to the tidal prism (the volume of water between mean high and mean low water). According to Burt and McAlister (8, p. 15), flow ratio values of 1.0 or more, 0.2-0.5, and 0.1 or less probably indicate two-layered, partly-mixed, and well-mixed estuarine circulation types, respectively. The average tide height of 5.5 feet in Oregon estuaries is conducive to mixing, especially during periods of slight river flow. Since the tidal prism remains fairly constant throughout the year for a given estuarine system, fluctuations in the fresh-water discharge account for most of the changes in the flow ratio. Average flow values of the Yaquina River were found to be only 33.5 cubic feet per second (cfs) during August 1955, whereas they were 600 cfs during February 1956 (7, p. 1386).

Other important factors affecting the observed circulation pattern are physiographic characteristics: mean depth, width, and obstructions to flow. These conditions remain nearly constant from one year to the next, unless altered by dredging or geologic processes, and do not effect changes in the circulation pattern in Yaquina Bay.

The principal factor effecting changes in the type of hydrographic system during the year, assuming constant tidal and basin characteristics, is river discharge, which is related to seasonal climatic variations.

In 1940 and 1941 the first systematic salinity measurements were made in conjunction with native oyster studies in Yaquina Bay (14). Daily readings were obtained for the top and the bottom of the estuarine channel in the vicinity of the town of Yaquina. No allowance was made for tidal inequalities. At present, a survey initiated in 1960 is being conducted in Yaquina Bay by Dr. Herbert F. Frolander of the Department of Oceanography, Oregon State University. The purpose is to correlate the physical and chemical properties of the water with biological activity. Physical and chemical data from this survey have been made available to the author by Dr. Frolander. Salinity, temperature, and oxygen measurements were made weekly for the top and bottom waters of the estuary channel at buoys 15 and 21 (in the vicinity of Coquille Point and Oneatta Point respectively).

Since the sampling was done on various phases of the tide, monthly averages have been calculated for these data and those taken in conjunction with the native oyster study in 1940 and 1941, in order to minimize tidal effects.

SEASONAL CIRCULATION PATTERNS

Since Burt and McAlister (8, Table 1, p. 22) provide results for only seven months in Yaquina Bay, the salinity measurements from the 1940-1941, 1960-1961, and 1961-1962 surveys were used to determine more adequately the seasonal and annual changes in mixing patterns. The salinity data from the afore mentioned surveys are treated in a similar manner to that used by Burt and McAlister (8, p. 21). Although all salinity measurements were not made at the same location, they are, for the most part, grouped in the same general vicinity and are believed to be a valid means of classifying the estuarine system. Also, the inherent tidal inequalities in all data have been lessened through the monthly averaging of the data.

Salinity values are plotted as the average difference in salinity, from top to bottom, for each month of the year (Figure 7). When compared with the results of Burt and McAlister (8, Table 1, p. 22), the same seasonal trends in estuarine types were noted; however, the system apparently can alter from one type to another depending

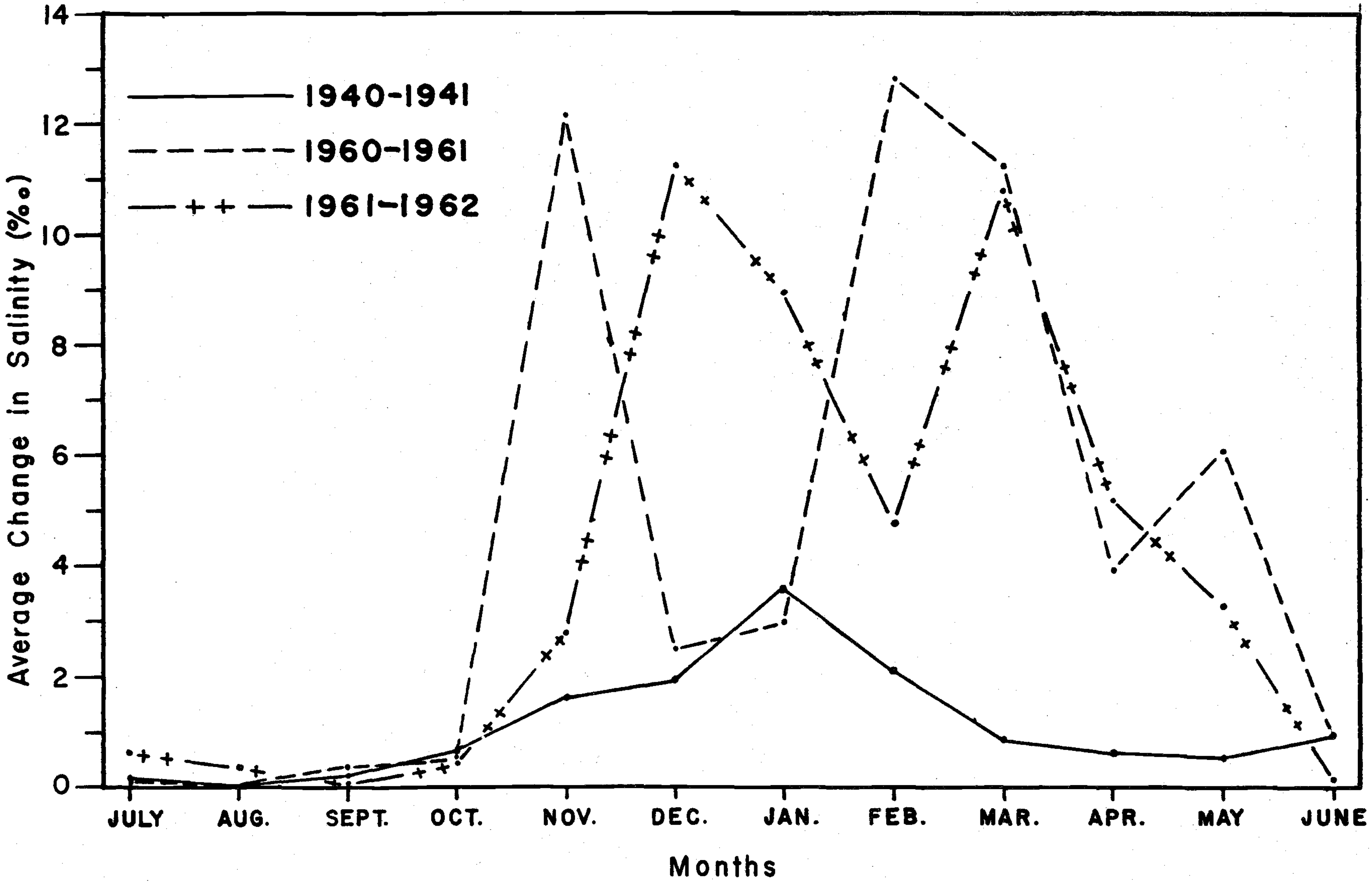

Figure 7. Average monthly difference in salinity between surface and bottom waters in Yaquina Bay.

upon the year the data are collected. For example, Yaquina Bay was well-mixed in 1940 and 1961 during the month of November, which agrees with the results presented in Table 1, but a partly-mixed system occurred during November 1960. Similar differences exist for January; there was a well-mixed system in 1961, as in Table 1, but a partly-mixed system in 1941 and 1962. In general, from June to October all existing data indicate the estuarine system is well-mixed. The estuary may alternate between a well-mixed to partly-mixed system from November to May.

CLIMATIC CONTROL

Seasonal fluctuations in precipitation can be used to illustrate the relationship between runoff and salinity change, or mixing patterns. The amount of daily precipitation is recorded at Newport, the focal center of the drainage system, by the U. S. Weather Bureau. If the average monthly difference in salinity change is expressed in parts per thousand and plotted on the same time scale as the number of inches of rainfall per month, a definite correlation between the two can be seen (Figure 8). The parallelism between salinity change and the amount of rainfall indicates strong local climatic control of the estuarine system. In this manner the various types of estuarine mixing patterns can be related to precipitation through the salinity

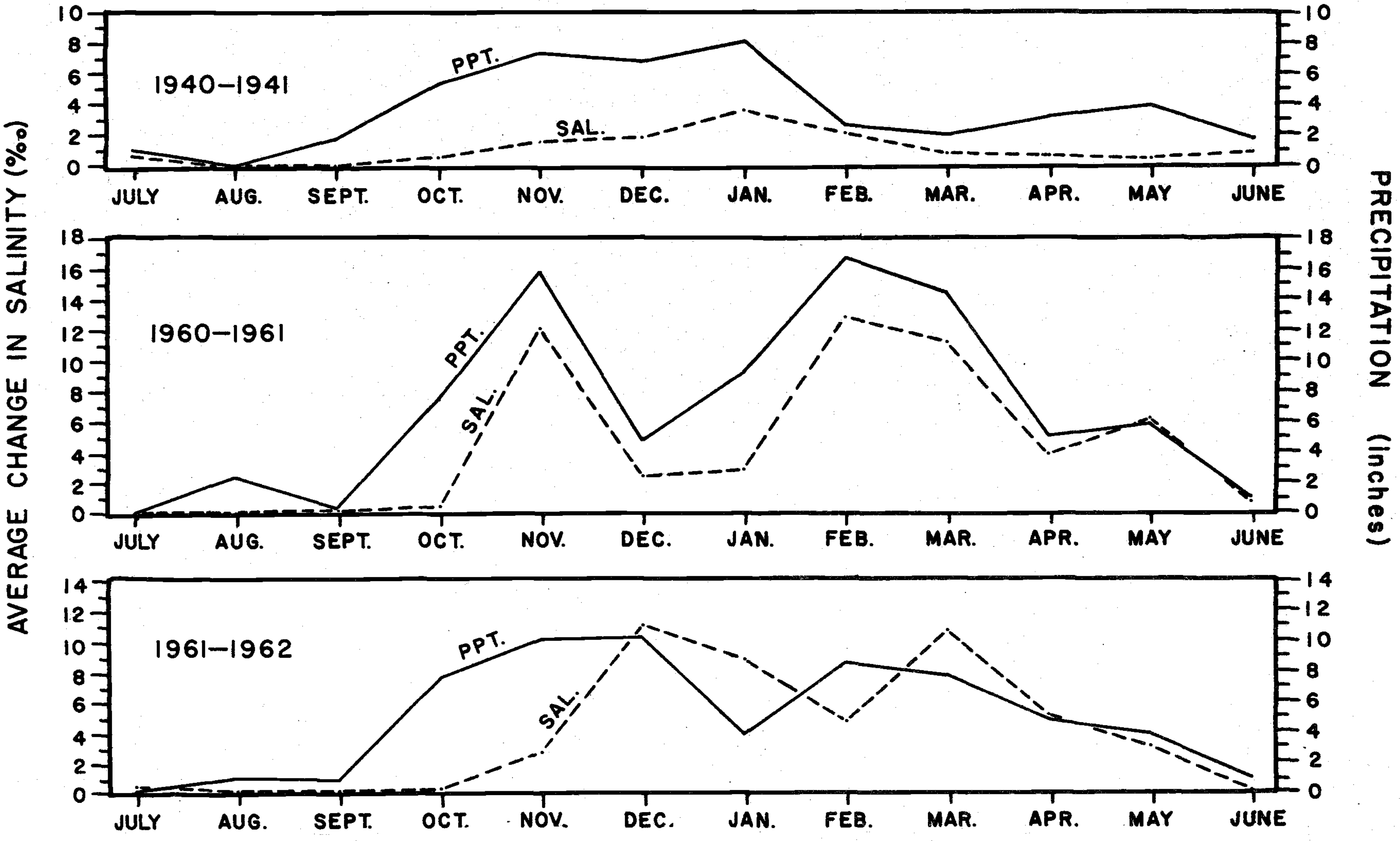

Figure 8. Correlation between monthly precipitation at Newport and the average monthly difference in salinity between surface and bottom waters in Yaquina Bay.

changes.

One of the most significant factors in the meteorological data is the marked variation in the total amount of annual precipitation. The mean annual value is 67. 4 inches (53). In the year 1940-1941, there was only 43. 40 inches of rain (49 and 50) whereas in 1960-1961 about twice this amount, 83. 35 inches (51 and 52), was recorded. The year 1961-1962 is close to the mean with 58. 41 inches (52 and 53). It is interesting to note the marked and well known annual cycle in precipitation as well as the monthly variations in the data presented. These are long term changes compared with frequent diurnal fluctuations of more than 1 inch. Extreme diurnal maxima in rainfall of up to 2. 9 inches were recorded during November and February in 1960-1961 (51 and 52).

The initial effects of runoff due to rainfall in excess of 1 inch may be expected to reach the focal point of the drainage system in about 24 hours. The time interval in which runoff is reflected in salinity change is apparently dependent upon the saturation of the soil and the rate of rainfall over a given period of time.

A time lag in salinity change is seen during the fall for the first few months after the dry summer season. The marked increase in precipitation during October in all data is generally not reflected by an increase in the average change in salinity until a month or so later. Apparently the soil in the drainage basin is undersaturated during extended dry periods in the summer and can absorb large quantities of rain water without excessive runoff.

In 1961-1962, during the months of December, January, March, and April there is an inverse correlation between salinity change and precipitation compared with 1940-1941 and 1960-1961. The chief factors that are probably responsible for these inversions are the saturated conditions of the soil and the rate of rainfall.

Salinity, Temperature, and Dissolved Oxygen Measurements

The estuarine waters of Yaquina Bay undergo marked seasonal changes as a result of the tidal mixing of fluviatile and marine waters. A remarkably good correlation exists between the physical-chemical data taken in Yaquina Bay in 1960-1961 and that collected 5 miles offshore at OSU Hydrographic Station NH-1 during the same period. Because oceanic conditions are fairly constant, the frequency and time of measurement of oceanic properties does not appear to be materially significant in correlating the two sets of data. During periods of coastal upwelling in the summer the data are somewhat difficult to correlate, because the depth at which the same water characteristics occur in the ocean is variable.

During the summer, the water properties of the bay are very homogeneous from the top to the bottom of the channel (Figure 9). In summer, high salinities (33-34 $^{o}/oo$), low temperatures (generally less than 10.0^{o}C), and low dissolved oxygen values (4.5 ml/L) are characteristic of the waters at buoy 15 near Coquille Point. These values are typical of the nearshore upwelled bottom waters off the Oregon coast. According to Wyatt and Callaway (47, p. 1), a narrow belt of upwelling may be present to about 15 miles offshore. Salinities of 33.31 $^{o}/oo$ and relatively low temperatures (10.9^{o}C) were found at the surface 5 miles from shore at NH-1. No dissolved oxygen values were cited. During July and August 1960 (48, p. 7-8), the same values of salinity, temperature, and dissolved oxygen were obtained at NH-1 at depths of 10-20 meters as occurred in the estuary at buoy 15. Surface measurements at NH-1 were not indicative of upwelled waters at this time, but subsurface waters probably reached the surface closer to shore since the ocean data indicate that upwelled waters ascend to the surface as they approach the shore.

In winter, the fluviatile influence is superimposed upon the tidal oceanic waters in Yaquina Bay. The pronounced differences of salinity, temperature, and dissolved oxygen from the top and bottom in the channel imply a lack of tidal mixing. These large variations are caused by high runoff. Bottom salinities in the estuary reach their lowest values in the winter. In February and March 1961, salinities of less than $29^{o}/oo$ were found on the bottom at buoy 15. The low salinities are comparable to those found at the surface at NH-1 during January and March (48, p. 13-14). No data are available at NH-1 for February from 1959 to 1961. Apparently the bottom salinity is controlled primarily by the tidal intrusion of oceanic waters. Low salinity values (less than $17^{o}/oo$ at the surface in the estuary during this same period appear to have little effect on the bottom salinity. This is to be expected since the tidal mixing of fresh and salt water is somewhat inhibited by the partly-mixed estuarine system.

The winter decline in surface temperature in the bay occurs in November and continues through March. Two temperature inversions occue in 1960-1961, one between October and November and the other between March andApril (Figure 9). In winter, the colder surface temperatures in the estuary (9. 6°C), coincide with the decline in air temperature in the drainage basin late in the fall. These surface waters are derived from the cold mountain streams in the central Oregon Coast Range. The warmer bottom water temperatures, which appear to be similar to the coastal surface waters at NH-1, have little effect on the surface waters in the estuary. Surface temperatures offshore are generally only slightly warmer than those on the bottom in the bay. The coldest bottom temperatures, which are characteristic of the offshore upwelled waters, occur in the estuary during the

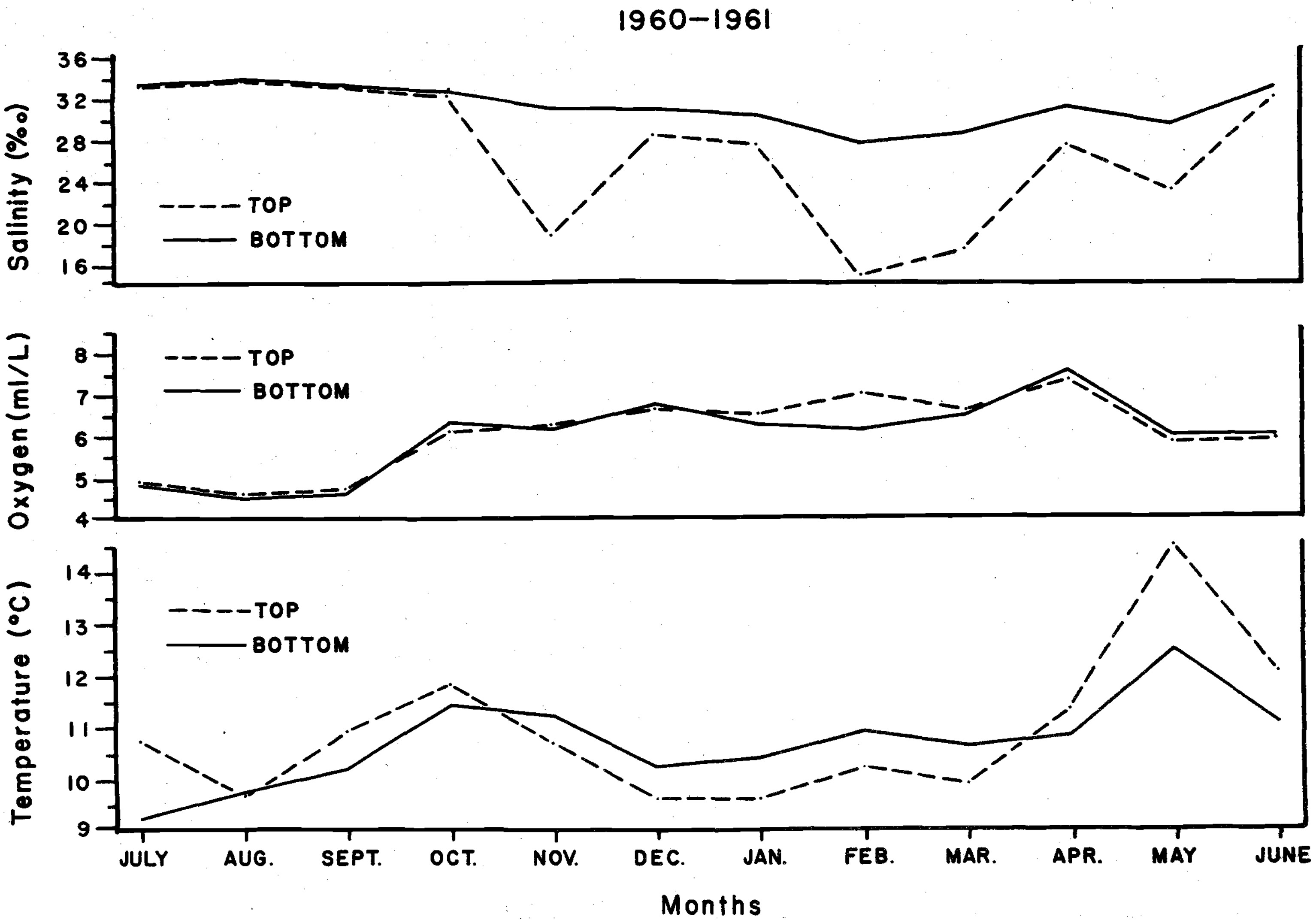

Figure 9. Salinity, temperature, and dissolved oxygen measurements in Yaquina Bay. Sampling station is located in the main channel in the vicinity of Coquille Point (Buoy 15).

summer. Bottom and surface temperatures in the estuary are highest in late fall and spring.

Dissolved oxygen increases in October to more than 6 ml/L with numerous inversions between the top and bottom of the channel. These values are maintained through the winter and spring. There is little difference between surface and bottom dissolved oxygen values except during periods of exceptionally high rainfall, such as occurred in February 1961. At this time surface oxygen was about 1 ml/L higher. The increase in dissolved oxygen is probably due to the cold fluviatile waters, which become saturated in oxygen. As a rule, the dissolved oxygen content on the bottom of the estuarine channel appears to correlate reasonably well with that at NH-1.

Currents

YAQUINA ESTUARY

Few seasonal current measurements are available for Yaquina Bay. The general current patterns, however, are known from the type of mixing patterns discussed previously. When the estuary is partly-mixed, the strongest flood currents occur near the bottom. Along the bottom there is a net upstream flow (8, p. 19-20). In contrast, a well-mixed system may be expected to have a slow net drift of water outward at all depths regardless of the superimposed tidal exchanges. A very slow net non-tidal flow was measured in Yaquina estuary when the system was well-mixed (8, p. 20). It becomes apparent that the current patterns may be seasonal or influenced by climatic conditions since they develop as a result of changes in the mixing patterns.

An estimate of the average tidal current velocity at any location in the channel can be obtained from the tidal prism and the cross-sectional area over a given period of time. The average and maximum current velocities were calculated at the entrance between the jetties assuming that the mean tidal prism enters during one-half tidal cycle or 6 hours. The cross-sectional area at the entrance is 19, 700 square feet and the mean tidal prism is 1075×10^6 cubic feet. From these values the average velocity was calculated to be 77 cm/sec and the maximum value to be 109 cm/sec.

Over a 24-hour period during August 10 and 11, 1955, at two selected channel localities, 1.1 miles and 9.7 miles from the entrance, current measurements were made with current drags (6). At 1.1 miles, bottom flood velocities reached a maximum value of approximately 75 cm/sec with an average of about 40 cm/sec; at 9.7 miles the maximum velocity dropped to 40 cm/sec with an average of about 20 cm/sec. On February 11 and 12, 1956, measurements were made at the channel adjacent to Hinton Point, 2.9 miles from the ocean. Again current drags were used to obtain a maximum bottom flood velocity of 45 cm/sec with an average of 30 cm/sec.

Current drags do not measure the current velocity at the sediment-water interface. The actual values at the bottom are probably somewhat less than those reported here. As would be expected, the bottom flood current velocities decrease rapidly with increasing distance from the bay entrance.

LITTORAL DRIFT

Although the littoral drift along the Oregon coast is thought to be seasonal, no direct measurements of the magnitude or direction of drift have been made for any given time of the year. Measurements of the magnitude of drift are difficult to make, but an approximation of the drift direction can be determined if the directions of wave propagation due to sea and swell are known.

Reliable wave hindcast data have been computed by National Marine Consultants (30) for three deep water stations off the Oregon-Washington coast. The data from one of these stations, which is located off Newport, Oregon, have been used to analyze littoral drift.

The results of the wave hindcast analysis are summarized in terms of the average monthly wave height, wave period, and wave direction frequency distributions for the three years 1956, 1957, and 1958. These data were derived from U. S. Weather Bureau synoptic weather charts and are considered to be representative of nearly average conditions.

From the wave direction frequency data, it is possible to compute the littoral drift direction. If the direction of wave travel is not normal to the shore, the accompanying discharge of water will result in a longshore component. Since the coast of Oregon trends in a north-south direction, the longshore drift, which parallels the shore, will be either in a southerly or northerly direction depending upon the prevailing direction of onshore wave travel. For example, waves with a prevailing north-northwesterly component would give rise to a southerly longshore drift; conversely, a south-southwesterly component would result in a northerly drift.

The prevailing direction of wave travel due to sea and swell was determined by dividing the data into two categories. Directions from 180° to 270° (south to west) were designated as quadrant I; directions from 270° to 360° (west to north) as quadrant II. The percentage of observations falling into each of these quadrants was obtained for both sea and swell for each month.

From Figure 10 it can be seen that only during January and February (1956-1958) does the prevailing swell come from the

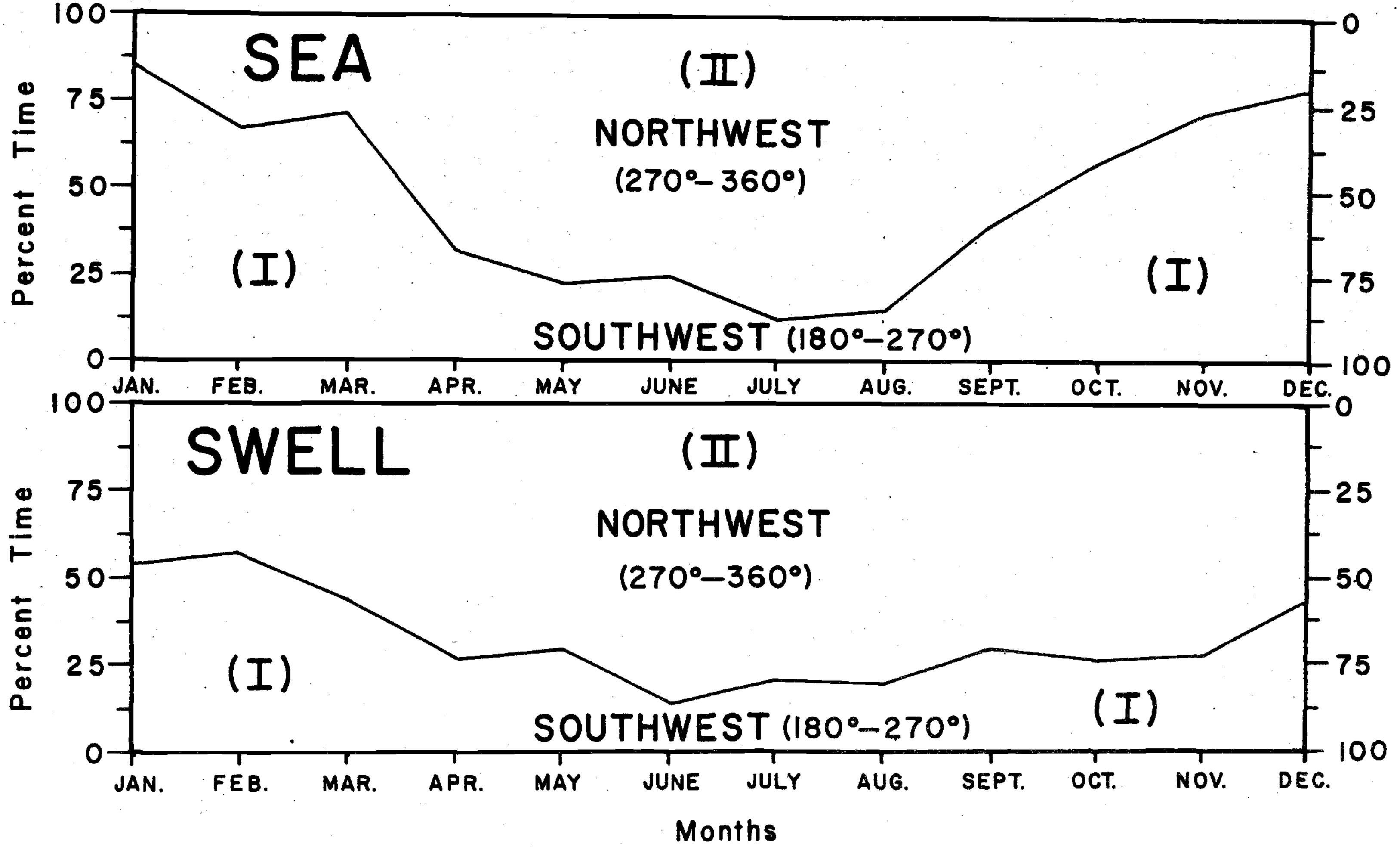

Figure 10. Prevailing directions of onshore wave advance due to Sea and Swell. Left hand scale designates the percent of time wave directions approach the shore from the southwest (quadrant I); right hand, from the northwest (quadrant II).

southwest (the mean direction of quadrant I). This infers that longshore drift due to swell is southward most of the year.

Sea conditions, due to the local wind regime, present a somewhat different picture. From October to March, the prevailing wave directions due to sea are from the southwest, which would result in a northerly longshore drift; however, from April to September, prevailing wave directions occur from the northwest (mean direction of quadrant II), indicating a southerly drift.

On the basis of both sea and swell data, it appears that from November or December to March, longshore drift is northward along the coast of Oregon, and from April to October or November, it is south. Therefore, the longshore drift is seasonal. However, southerly drift appears to be prevalent during the spring, summer, and early fall, whereas northerly drift probably occurs only in the late fall and winter. As a whole, the dominant drift along the coast in the vicinity of Newport is south.

SEDIMENTS

Sampling and Treatment of Samples

FIELD METHODS

Two major sampling trips during August and September 1960 were made to collect 133 sediment samples (Figure 11) from the Yaquina estuary, adjacent ocean beaches, and nearby coastal dunes. Bottom samples of estuarine and river sediments were collected from a small skiff where the water depth was too deep to hand sample. A messenger operated Ekman dredge and a Dietz-LaFond grab sampler were used mainly in the channel and on the tidal flats at high tide. Where sediment type permitted penetration and subsequent retention of a core, a Phleger corer with plastic liners and a home made piston corer (9) were employed.

In the estuarine channel, samples were collected at approximately one-half mile intervals along a longitudinal profile from the ocean entrance to Toledo. Upstream from Toledo the channel was sampled irregularly at one to three-mile intervals. Samples were collected along four transverse profiles at selected localities on the main channel. Other areas in the estuary, such as sloughs and tidal flats, were sampled randomly.

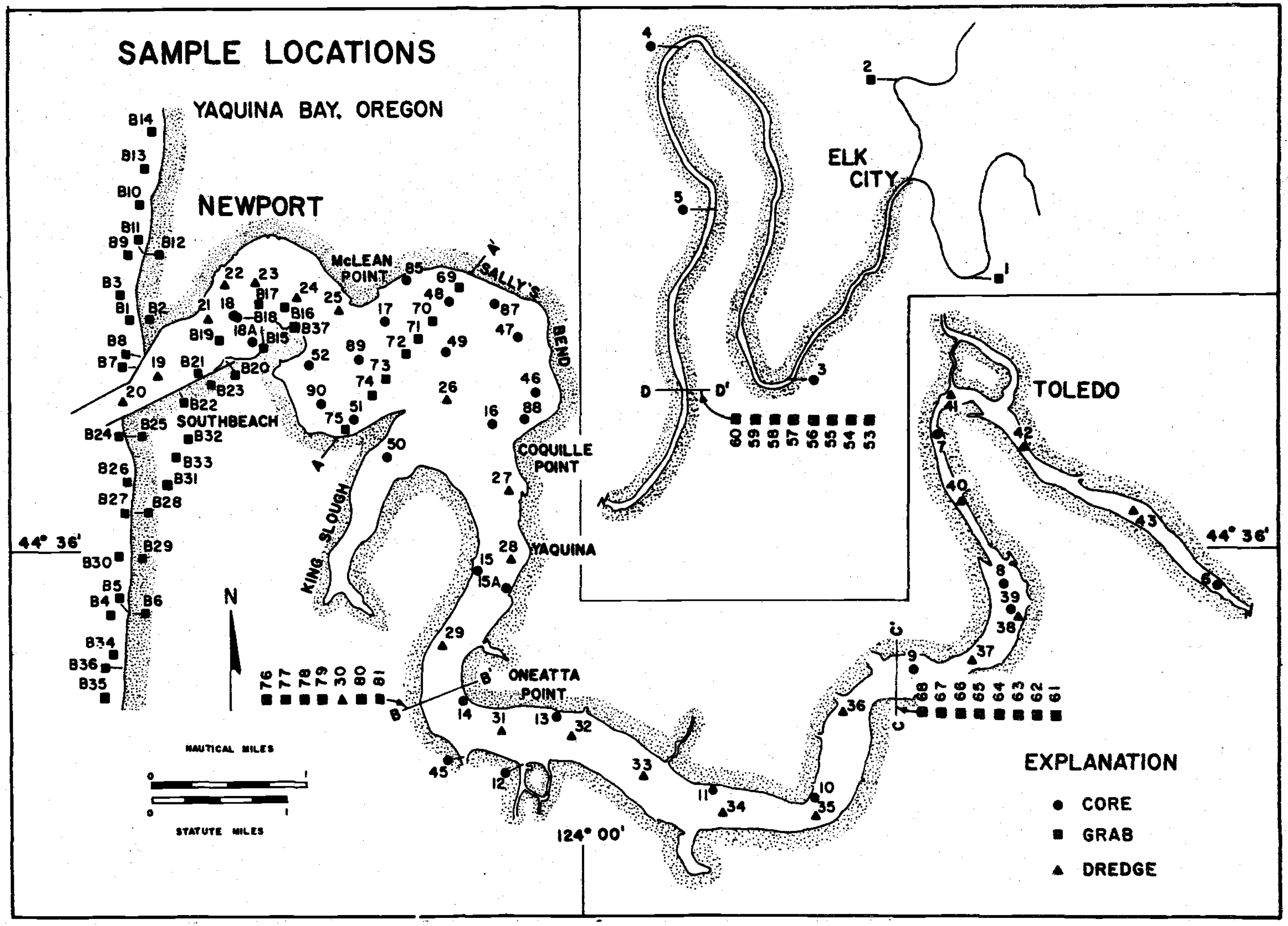

Figure 11. Sample locations in Yaquina Bay, adjacent ocean beaches, and nearby coastal dunes.

The surf zone of the beaches was sampled at approximately one-quarter mile intervals for about 2 miles on either side of the bay entrance. Both migrating upper foreshore dunes on the beaches and migrating coastal dunes were randomly sampled.

SEDIMENT ANALYSES

The grain size analyses of all sediments were carried out using particle settling velocity techniques. All sediments of sand size were analyzed with the Emery settling tube (15). Sediments containing appreciable percentages of silt and clay were dispersed with a commercial water softener called Calgon (sodium hexametaphosphate) and hand wet-sieved through a 74 micron screen into a 1000 ml graduate. The fraction greater than 74 microns remaining on the screen was analyzed with the settling tube. To further facilitate deflocculation, the saline solution was extracted from the graduate with a vacuum operated millipore filter. After extraction the graduate was again filled with dispersing agent, and the sediment was divided into very fine sand, silt, and clay with the aid of a soils hydrometer (5). The percentages of each size fraction were calculated from the total weight of sediment in the graduate, which was determined by drying and weighing a 50 ml aliquot of a homogeneous suspension of sediment. Where both particle settling velocity techniques were employed, the percentages of the respective size fractions were combined to construct the cumulative curve. From these curves Inman's (23, p. 130) median diameter, sorting, skewness, and kurtosis coefficients were calculated.

Chemical analyses included determination of carbonate (undifferentiated), organic nitrogen, and total organic matter. The percent of carbonate in the sand fraction was calculated by the weight loss of soluble sediment in dilute hydrochloric acid. Duplicate samples were used in the determination of organic nitrogen by the Kjeldahl method. Total organic matter analyses by the hydrogen peroxide method of Robinson (34) completed the chemical investigation.

Cores stored in the plastic liners as well as those taken by the piston corer were carefully extruded into a suitable receiving tray and sliced longitudinally with a violin string into identical halves. The exposed halves were photographed immediately before excessive drying could distort the textural and structural features. These features were then logged when both moist and dry.

The heavy liquid bromoform was used to separate the sand-size grains into light and heavy-mineral fractions. The heavy-mineral fractions were split with an Otto microsplitter and mounted on glass slides with Lakeside cement. Mineral species were identified optically with the aid of a petrographic microscope. Percentages of mineral species were usually determined on the basis of the identification of 200 to 400 grains per slide. Light mineral fractions were etched with hydrofluoric acid and treated with barium chloride, sodium cobaltinitrite, and potassium rhodizonate according to the procedure employed by Bailey and Stevens (1). Plagioclase feldspar stains brick red and potash feldspar yellow. The barium solution reacts with the rhodizonate solution to form insoluble red barium rhodizonate when the calcium ion of the etched plagioclase feldspar is replaced by the barium ion. This method of staining plagioclase was combined with the cobaltinitrite staining of potash feldspar originally developed by Gabriel and Cox (16). The potassium ion from the potash feldspars reacts with cobaltinitrite to form yellow potassium cobaltinitrite.

Texture

GRAIN SIZE

The grain size of sediments in terms of median diameter for Yaquina Bay and vicinity (Figure 12) ranges from coarse sand to silt according to the nomenclature of Wentworth (44, p. 381). Median diameters in millimeters were derived from the cumulative frequency curves and converted into phi units; both are given for all samples in Appendix 1.

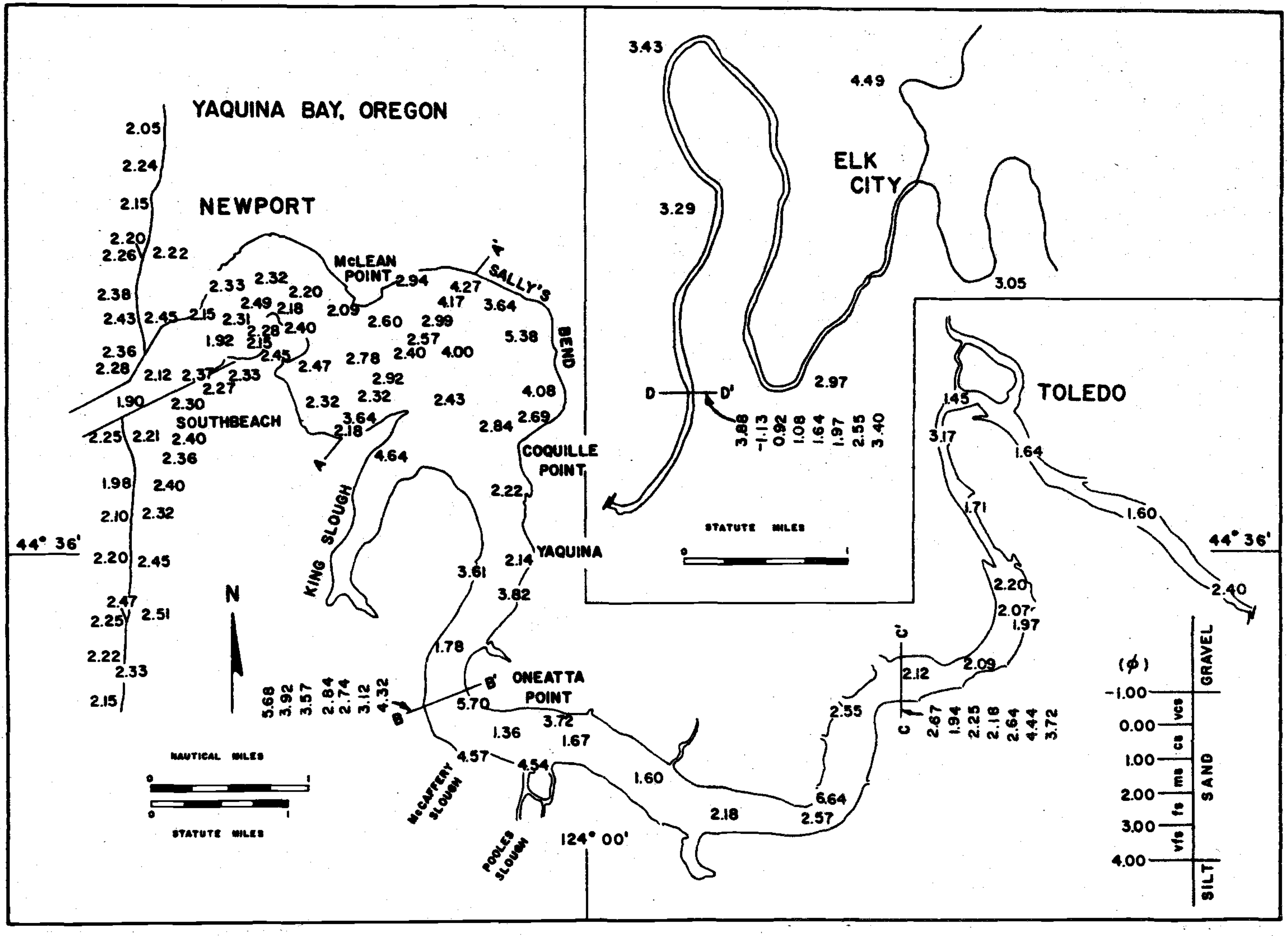

Figure 12. Distribution of phi median diameters of surface sediments of the Yaquina estuary, adjacent ocean beaches, and nearby coastal dunes.

Beach and dune deposits are composed of fine sands and show little variation in the range of grain size over the area sampled. Fine to medium sands characterize the river channel sediments with isolated coarse sand lenses occurring in the channel narrows upstream from Toledo. There is a progressive decrease in particle size outward from the river channel to the marginal banks. The lateral gradation generally is from fine and medium sand to silt. All sampled slough deposits, whose measured variation in grain size is 0.10 ϕ, consist of silts. Tidal flat sediments range from fine sand to silt but show an irregular distribution of particle sizes.

Another method for comparing the grain size distribution is by use of descriptive names for sediment types. These names are derived from the compositional triangle of Shepard (37) according to the proportions of the three end members, sand (greater than 62 microns), silt (4-62 microns), and clay (less than 4 microns). The results are analogous to those of median diameter, but sediment facies changes are more easily visualized when areas of similar sediment type are grouped together (Figure 13).

By far the most common sediment found in Yaquina Bay is sand followed by silty sand, sandy silt, sand-silt-clay, and clayey sand. As would be expected, facies changes occur laterally across the river channel. This variation is due to the progressive lateral reduction in current velocities toward the margins of the channel. The sediments of Sallys Tidal Flat are composed chiefly of silty sand and sandy silt, whereas those of Southbeach Tidal Flat are principally sand. On the basis of median diameter, the three sloughs sampled appear to have a similar grain size; however, according to Shepard's (37) classification the sediment sampled in King Slough is mainly sandy silt; those of MacCaffery and Pooles Slough are sand-silt-clay.

SORTING AND SKEWNESS

As is generally the case, sorting becomes progressively poorer for sediments coarser and finer than fine sand. Inman (23, p. 130) sorting coefficients (σ_ϕ) for the bay area range from 0.20 to 4.02 (Table 2). The best sorted sediments are found in environments of constant agitation such as the beaches, the lower foreshore and the upper foreshore dunes, and the migrating coastal dunes. Estuarine sediments are fairly well-sorted in the channel and other areas where tidal currents are strong. Sorting generally decreases with decreasing water depth except along the southwestern margins of Southbeach Tidal Flat where it increases with decreasing water depth.

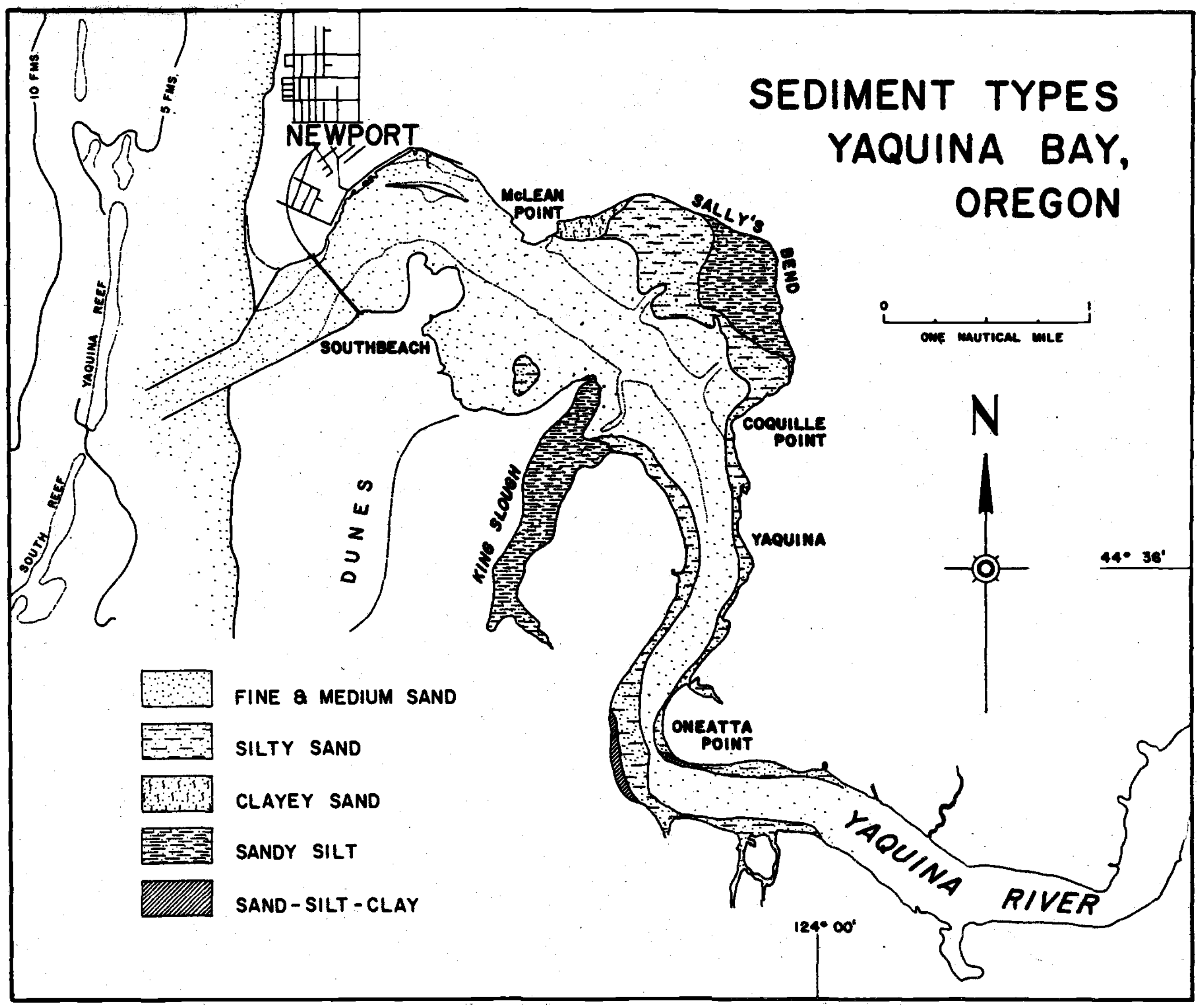

Figure 13. Sediment types in Yaquina Bay, according to the nomenclature diagram proposed by Shepard (37).

Table 2. Inman sorting and skewness coefficients for the sediments of Yaquina estuary and vicinity.

	Phi Sorting $\sigma_\phi = 1/2\,(\phi_{84} - \phi_{16})$		Phi Skewness $\alpha_{1\phi} = \frac{M\phi - Md\phi}{\sigma_\phi}$	
	Range	Average	Range	Average
Northern Ocean Beach (Lower Foreshore)	(0.24) (0.48)	0.29	(-0.17) (0.36)	-0.02
Southern Ocean Beach (Lower Foreshore)	(0.20) (0.33)	0.24	(-0.35) (0.00)	-0.13
Beach Dune (Upper Foreshore)	(0.23) (0.28)	0.26	(0.00) (0.06)	0.02
Coastal Dune	(0.16) (0.26)	0.23	(-0.23) (-0.04)	-0.12
Lower Estuary Channel (Entrance to Oneatta Point)	(0.23) (0.88)	0.39	(-0.43) (0.58)	-0.11
Upper Estuary Channel (Oneatta Point to Elk City)	(0.33) (1.03)	0.49	(-0.42) (0.68)	0.09
Southbeach Tidal Flat	(0.48) (1.94)	1.00	(0.16) (0.60)	0.41
Sallys Tidal Flat	(0.43) (4.02)	2.07	(0.02) (0.73)	0.40

Inman's skewness coefficients ($\alpha_{1\phi}$) for most sediments in Yaquina Bay and vicinity range between -0.43 to 0.83; negative values generally characterize the coarser sands of the river channel and beaches, and positive coefficients are most typical of the finer-grained sediments of a few dunes, tidal flats, and areas of quiet water deposition. However, beach, dune, and river channel sands can be skewed either to the fine or coarse fraction. The universal fine skewness in the sediments of both tidal flats is the only pronounced trend in sediment skewness over a large area.

ROUNDNESS

The measure of roundness was obtained by visual comparison with Powers' (32, p. 118) roundness chart. All determinations of roundness over the entire system were made on particles of clear quartz of approximately the same size.

For comparison of roundness values, the range and average roundness (Table 3) were estimated for each environment or type locality within a particular environment. The average roundness measures for the migrating coastal dunes show that these sands are on the average subrounded and are the best rounded of the sediments in the Yaquina Bay area. Sands from the lower foreshore and the migrating upper foreshore dunes of the beaches, the river channel,

Table 3. Particle roundness for the sediments of the Yaquina estuary and nearby coastal dunes and beaches.

Environment	Roundness (Range / Average)
Coastal Dune	A – WR / SR
Beach Dune (Upper Foreshore)	A – R / SA – SR
Beach (Lower Foreshore)	A – R / SA – SR
Lower Estuary Channel (Bay entrance to Oneatta Point)	A – WR / SA – SR
Upper Estuary Channel (Oneatta Point to Elk City)	VA – SR / A – SA
Southbeach Tidal Flat	A – WR / SA – SR
Sallys Tidal Flat	VA – SR / A – SA

VA -- Very Angular
A -- Angular
SA -- Subangular
SR -- Subrounded
R -- Rounded
WR -- Well-Rounded

from the ocean entrance to Oneatta Point, and Southbeach Tidal Flat exhibit the same average roundness. These sediments are composed of subangular to subrounded grains. The least rounded sediments are the angular to subangular sediments from Sally Tidal Flat and the river channel upstream from Oneatta Point.

Roundness of particles other than clear quartz was also noted. As a rule, the weakly resistant mudstone and siltstone fragments are well-rounded. On the other hand, clear feldspar crystals are usually angular even when found together with rounded quartz. Apparently the feldspars fracture along cleavage planes when abrasive forces are active. As a whole, the grains of the heavy mineral assemblages are fairly well rounded; however, the more resistant euhedral minerals such as zircon and tourmaline are exceptions. The pyroxenes, amphiboles, epidote, and apatite are usually well-rounded. Garnet occurs as well-rounded pink to red grains and also as pink to colorless angular grains.

SURFACE TEXTURE

Frosting, polishing, and etching are the most prominent grain surface textures on the sediments of Yaquina Bay and vicinity. The particles of each environment, beach, dune, and river, have a characteristic surface texture, but where two different environments intermix, these features are difficult to discern.

Generally the lower foreshore beach sands exhibit highly polished grain surfaces which are probably mechanically produced by gentle attrition from continual surf action.

Included in the migrating coastal dune sands are large percentages of well-rounded frosted grains. A few frosted particles also occur in the sediments along the southwestern margins of Southbeach Tidal Flat and in the river channel between the ocean entrance and Hinton Point.

Etching is easily identified on quartz grains and is most commonly found upstream from Oneatta Point. However, the sediments on Sallys Tidal Flat have much the same grain surface characteristics.

Composition

The composition of the sediments in the Yaquina Bay area can be classified as detrital and organic. The bulk of the sediments are composed of detrital sand, silt, and clay. Because of the simplicity of analysis, the light and heavy minerals of the sand fraction were used to determine the mineralogical composition. Although the light minerals are usually the dominant constituents of the sand fraction, heavy minerals often comprise more than 30 percent of the detrital sands. The organically produced portion of the sediments are subdivided into two groups, calcium carbonate and organic matter. Both groups vary in abundance according to the different sediment types. The highest carbonate concentrations occur in the detrital sands whereas the silty sediments generally contain the highest percentage of organic matter.

ORGANICALLY PRODUCED MATERIAL

Calcareous Material

The acid soluble portion of the sediment consists primarily of molluscan shell fragments and foraminiferal tests. No differentiation can be made between the different carbonate cations with this method; however, the total fraction is assumed to be calcium carbonate bearing in mind that other minor carbonate ions are probably present.

Calcium carbonate concentrations in the sediments of the estuary range from 1 to about 7 percent of the sand fraction of the sediment (Figure 14). Usually the highest percentages are found in the sandier sediments and in areas of channel confluence.

In profiles AA' and BB', the concentration of carbonate in the channel generally diminishes somewhat toward the outer margins of the tidal flats and river banks respectively. There is considerable

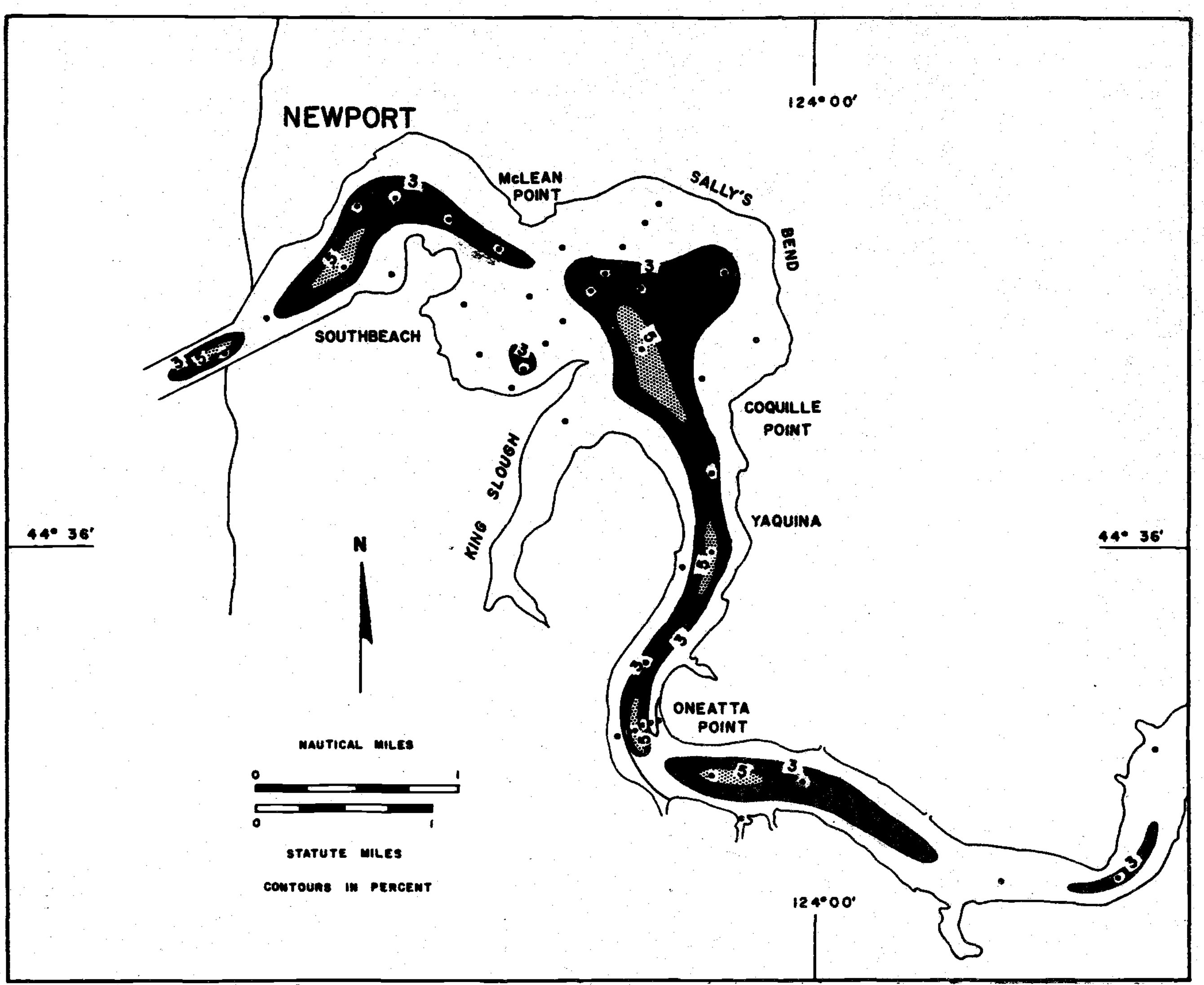

Figure 14. Distribution of calcium carbonate in the surface sediments of Yaquina Bay.

variation of carbonate content longitudinally in the stream channel. High concentrations in the form of numerous whole and broken molluscan shells accumulate in the low depressions of the river channel and also in the intertidal channels on the tidal flats (Figure 15).

Shells in the intertidal channels are probably transported seaward on the ebb tide into the topographic depressions of the main channel and are concentrated by this process in addition to the winnowing away of finer sediments.

Organic Matter

Since the organic nitrogen content reflects the total organic content, an estimate of the total organic matter can be made by multiplying the respective N_2 values by a constant factor 18 (41, p. 431). These values are given in Table 4.

Generally, as is typical in Recent sediments, the concentration of organic nitrogen increases with decreasing grain size. For the most part, the highest concentration of organic nitrogen, 2. 92 percent, is found in the quiet shallow waters of the sloughs; the lowest values, only trace amounts, occur in the fine sands of the stream channel. Some sediments, although fine-grained, have extremely low N_2 content. This is probably attributed to an absence of organic detritus or to the partial decomposition of organic matter.

Figure 15. Shell accumulation in a shallow intertidal channel on Southbeach Tidal Flat.

Table 4. Percent organic nitrogen and organic matter in the Yaquina Bay sediments. Organic matter content is obtained both from the total organic nitrogen content (N_2 x 18) and total organic matter content.

Sample No.	Nitrogen (N_2)	Organic Matter (N_2 x 18)	Organic Matter (H_2O_2 Method)	Environment
YB-12	0.1620	2.92	4.17	Slough
YB-13	0.0025	0.05	3.28	River Bank
YB-15	0.1430	2.58	4.26	River Bank
YB-16	0.0547	0.99	1.04	Tidal Flat
YB-17	0.0403	0.73	0.86	Tidal Flat
YB-25	0.0000	0.00	0.00	Estuary Channel
YB-27	0.0071	0.01	0.00	Estuary Channel
YB-46	0.0045	0.08	1.66	Tidal Flat
YB-47	0.0836	1.51	2.04	Tidal Flat
YB-48	0.1010	1.82	1.39	Tidal Flat
YB-49	0.0051	0.09	1.36	Intertidal Channel
YB-50	0.0980	1.77	1.82	Slough
YB-87	0.0037	0.07	3.22	Tidal Flat
YB-89	0.0542	0.98	1.56	Tidal Flat
YB-90	0.0000	0.00	0.14	Tidal Flat

To compare the ratio of organic nitrogen to the total organic matter, the same set of samples were analyzed by the hydrogen peroxide method. Values obtained by this method were generally higher than those computed by multiplying the organic nitrogen content by 18. Since the hydrogen peroxide method gives only approximate results, the organic nitrogen values are considered more reliable.

Included in the organic portion of the sediments in the estuarine system are large quantities of sawdust. It appears in two forms: as black burnt particles and as light brown woody stocks. The burnt particles are thought to be derived from the waste burners of sawmills in the area. Most of the sawdust particles are small and occur in greatest abundance in the finer sediments of the river banks, sloughs, and tidal flats. In these areas, concentrations of sawdust in the fraction coarser than 74 microns reach values as high as 90 percent. There is little variation in the amount of sawdust between the top and bottom of cores taken downstream from Toledo. These cores range in length from 6 to 18 inches. Upstream from Toledo the surface sediments have a low content of sawdust ranging from 1 to 5 percent, but in the cores taken from the river bank in this area, the content increases to more than 50 percent at a depth of 3 to 10 inches. An abandoned sawmill lies adjacent to the Yaquina River at Elk City and was probably the primary source of sawdust in the lower levels of the cores from this locality.

INORGANICALLY PRODUCED MATERIAL

Both light and heavy minerals are helpful in tracing the sediment to its source and in correlating the lithology of related sedimentary environments. Heavy minerals are also useful in tracing the movement of sediments into and within Yaquina Bay.

Light Minerals

In the Yaquina Bay area light minerals constitute the bulk of the sediment in the sand fraction. The light mineral assemblage consists of quartz, potash and plagioclase feldspars, rock fragments of varied composition, and glauconite. Grains of yellow quartz or yellow rock described by Twenhofel (42, p. 3, 6-7, 24, 26) in the beach sands of Oregon are characteristic of the beach and dune sands in the vicinity of Newport. All sedimentary environments investigated, beach, dune, estuary, and river, are composed of mineralogically immature , feldspathic sediments; however, the assemblage and concentration of mineral components may vary significantly from one environment to another.

Feldspar and Quartz

In order to compare the compositional characteristics of each environment, the mineralogical maturity of the sediment can be used as a common index. Maturity may be expressed as the ratio of stable/unstable minerals, in this case the quartz/feldspar ratio. Since quartz is the more stable (less resistant to abrasion and chemical weathering) of the two components, its relative abundance determines the degree of maturity. The larger the ratio the greater the maturity. Quartz/feldspar ratios (Table 5) for sediments in the estuary above Oneatta Point and those of the lower foreshore of the beach north of the bay entrance are less than one and range from 0. 28 to 0. 95. Ratios greater than one (1. 06 to 1. 33) occur in the coastal dunes, the estuarine channel below Oneatta Point, and the lower foreshore of the beach south of the bay entrance.

The high percentages of feldspar indicate that the sediments of all environments are arkosic or feldspathic in composition and very immature. According to Pettijohn (31, p. 509), these ratios are characteristic of an average arkosic sandstone.

Potash/plagioclase feldspar ratios of all environments are approximately of the same order of magnitude and range from 0. 09 to 0. 25 (Table 5). Plagioclase feldspar is the dominant feldspar group

Table 5. Quartz/feldspar and Potash/Plagioclase feldspar ratios for the sediments of the various environments of deposition in the Yaquina estuary and vicinity.

Sample Number	Quartz/feldspar	Potash/Plagioclase
YB-1 (Head of Estuary)	0.95	0.23
YB-2	0.28	0.15
YB-4	0.66	0.19
YB-38	0.94	0.25
YB-33	0.88	0.12
YB-32	0.80	0.10
(Oneatta Point) YB-29	0.60	0.13
	0.71 Average	0.17 Average
YB-26	1.33	0.12
YB-24	1.06	0.16
YB-18A	1.17	0.13
YB-19 (Mouth of Estuary)	1.09	0.17
	1.16 Average	0.15 Average
YB-B10 (Northern Ocean Beach)	0.99	0.09
YB-B7	0.64	0.85
	0.82 Average	0.47 Average
YB-B35 (Southern Ocean Beach)	1.55	0.17
YB-B29 (Coastal Dune)	1.14	0.15

as indicated by these low ratios.

The composition of the plagioclase feldspars was determined optically with a petrographic microscope. As many grains as possible were sought lying normal to the (010) cleavage plane in each slide to approximate the maximum extinction angle for a particular plagioclase. Indices of refraction were employed to differentiate positive and negative angles for plagioclase of the An_0-An_{21} range from that of the An_{21}-An_{38} range. Andesine and laboradorite appear to be the dominant feldspar members present in all sediments, but the range is generally from An_0-An_{70}. As a rule, of the potash feldspars, orthoclase is more abundant than microcline.

Both igneous and metamorphic quartz are present in most of the sediments. Igneous quartz commonly possesses uniform extinction and frequently exhibits irregular inclusions consisting of bubbles and dust trails described by Keller and Littlefield (24). Metamorphic quartz is commonly recognized by its wavy extinction and regular inclusions of minute euhedral heavy minerals.

"Yellow Grains"

Twenhofel (42, p. 3) described ubiquitous yellow quartz or yellow rock in the beach sands of Oregon. The author has carefully examined these grains with a binocular and petrographic microscope and found them to be of varied composition. In the order of decreasing abundance the yellow particles are generally feldspars (plagioclase being the most common), chert, volcanic rock fragments, and other unidentified altered particles. It is the writer's opinion that very few, if any, of the yellow grains are quartz.

In reflected light the yellow grains appear as rounded to well-rounded altered particles. The color varies from light lemon yellow to a dull, dark brownish-yellow. The darker the color the higher the degree of alteration. Initial stages of alteration tend to develop along the cleavage planes of the feldspars. In extreme cases of alteration the true identity of the particle is completely obliterated. The intensity of alteration is seen in varying degrees of opaqueness in plain light. The alteration products are tentatively identified as clay minerals on the basis of their optical properties, but positive identification is not feasible with a petrographic microscope. The clay minerals are thought to have been formed primarily by chemical weathering of the detrital grains.

Rock Fragments

Rock grains are common in the sediments of Yaquina estuary, its beaches and coastal dunes. Sediments in the estuary frequently contain more than 30 percent sandstone (including tuffaceous debris), siltstone, and shale particles. In the lower reaches of Yaquina Bay, these components are less abundant and well-rounded basaltic grains become very prominent; basaltic grains are also abundant in the beach and dune sands. Small amounts of chert, metaquartzite, schist, and felsite are generally found in all sediments in the bay area.

Glauconite

Two distinctive forms of glauconite occur in Yaquina Bay. On Sallys Tidal Flat glauconitic grains are present as light to dark green, globular, foraminiferal casts. The second form, found in the estuarine channel, is rounded to well-rounded, oxidized, dark green pellets.

Heavy Minerals

Concentration and Distribution

One of the most distinctive characteristics of the mineralogy of the sediments in the Yaquina Bay area is the high percentage of heavy minerals in the detrital sand fraction (Figure 16). Concentrations range from 1 to more than 80 percent of the total sand fraction. The heavy mineral data for each sample analyzed is presented in Appendix 2; descriptions of the minerals are included in Appendix 3.

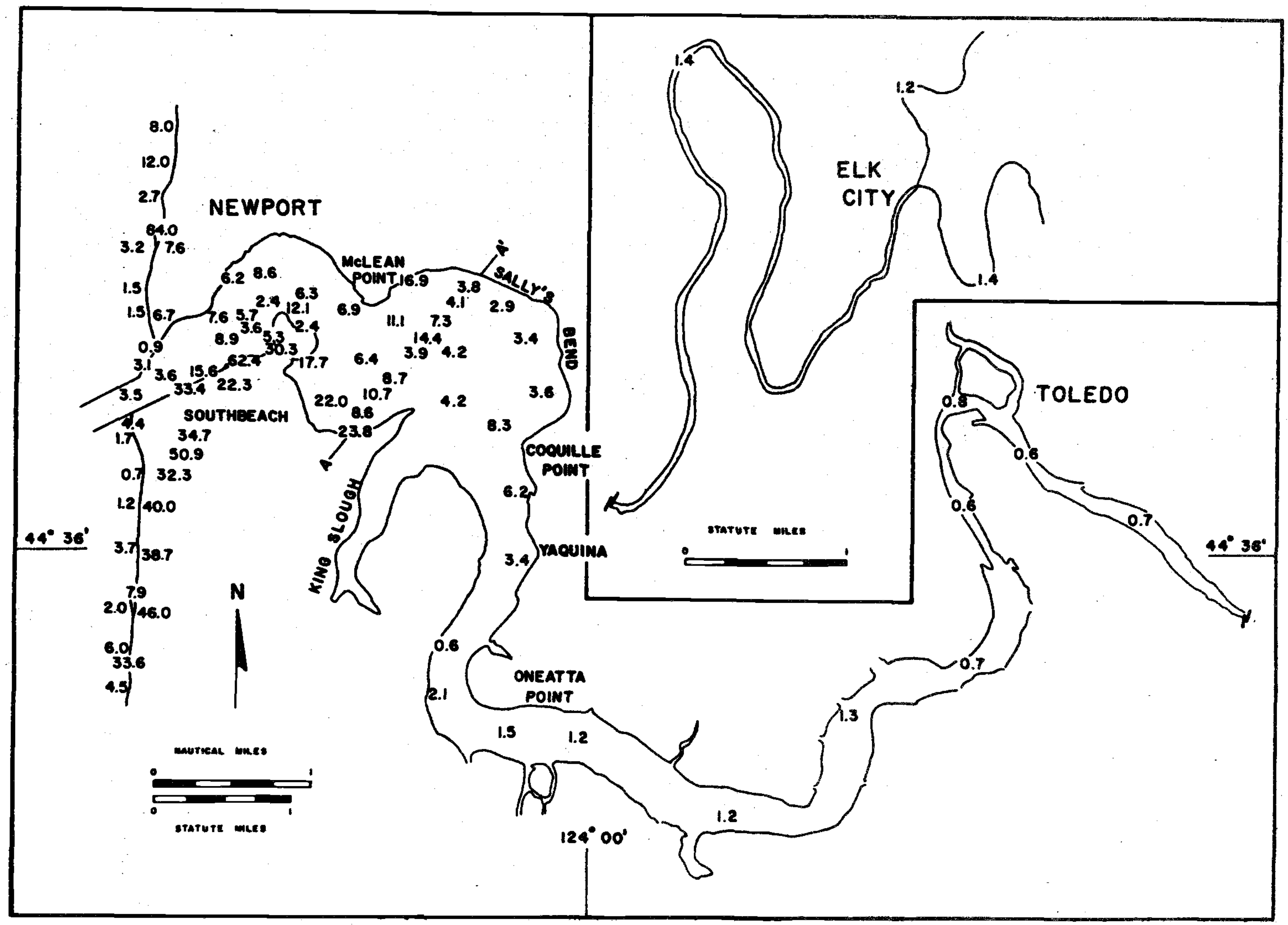

Figure 16. Percentage of heavy minerals in the sands of Yaquina estuary, adjacent ocean beaches, and coastal dunes.

The highest percentage of heavy minerals (84.0 percent) occur in the sands of the northern ocean beach. The light minerals are occasionally winnowed from the beach sands by constant wave action of an optimum intensity, but more often are sorted by small coastal streams that flow onto the beach from the shore. Small streams of ground water that seep out of the Pleistocene terrace deposits winnow out the light minerals in these sediments as well as those on the beach which are in the path of the stream flow.

Heavy mineral concentrations of 40 percent or more often occur on the windward slopes of the transitory coastal dunes in the bay area. Such high percentage of "heavies" are probably due in part to the winnowing out of light minerals by the wind.

In the Yaquina estuary channel heavy mineral concentrations range from a minimum of 1 percent at the head of the estuary to a maximum of 15 percent at the tidal entrance. Although both marginal tidal flats contain the highest percentage of heavy minerals, they exhibit an irregular distribution of "heavies." The sediments of Southbeach Tidal Flat contain higher maximum concentrations of "heavies" (23.8 percent) than those of Sallys Tidal Flat (16.9 percent). As a whole, the heavy mineral content of the sediments of Southbeach Tidal Flat is greater than that of Sallys Tidal Flat.

Heavy Mineral Suites

The heavy mineral assemblages in the sediments of Yaquina Bay and vicinity can be divided into three distinctive heavy mineral suites, marine, fluviatile, and marine-fluviatile. Each suite is defined on the basis of the following properties:

1. Presence or absence of a mineral species or group of minerals.
2. Relative abundance of a mineral species or group of minerals.
3. Textural character (grain roundness and surface texture).
4. Variable optical properties (pleochroism).
5. Particle habit and color.
6. Areal distribution of the above properties.

The marine and fluviatile suites are separate entities whereas the marine-fluviatile suite is a composite of the two basic end members. Several diagnostic mineral species for each of the two basic suites, marine and fluviatile, are listed in the order of decreasing abundance (Table 6).

Included in the marine suite are the fine sands of the beaches and coastal dunes. The fluviatile suite encompasses all sediments derived solely from the Yaquina River drainage basin. The marine-fluviatile suite is an admixture of heavy minerals from the other two

Table 6. Heavy Mineral Suites. Minerals are listed in the order of decreasing abundance.

Marine	Fluviatile
Leucoxene	Magnetite-Ilmenite-Chromite
Magnetite-Ilmenite-Chromite	Leucoxene
Hornblende	Biotite*
Hypersthene*	Muscovite*
Garnet	Augite
Diopside*	Hornblende
Augite	Garnet
Zircon	Chlorite*
Epidote	Hematite*
Sphene	Limonite*
Basaltic Hornblende*	Zircon
Tourmaline	Hypersthene**
Staurolite*	Apatite
Hematite	Epidote
Olivine*	Sphene
Rutile	Tourmaline
Kyanite*	Basaltic Hornblende**
Actinolite*	Rutile
Apatite	Monazite
Monazite	Kyanite**
Sillimanite*	
Andalusite*	

*Characteristic or present only in this environment.
**Rare and present in only one or two samples.

suites and is characteristic of the sediment in the lower reaches of the estuary.

In the marine suite, the opaque minerals magnetite-ilmenite-chromite, and leucoxene are the dominant species and comprise approximately 40 percent of the total heavy mineral assemblage. About 15 percent of the suite is composed of pyroxene, of which hypersthene and diopside are the dominant species. The amphiboles and garnets are equally represented and together constitute about 20 percent of the suite. Although the metamorphic minerals kyanite, sillimanite, staurolite, tourmaline, and epidote represent only about 5 percent of the assemblage, the first three are generally common only to the marine sediments, thus serving as diagnostic indicators of local marine sources in the Yaquina Bay area.

Although the fluviatile suite is comprised of 30-35 percent opaque minerals, it is characterized by an abundance of biotite and muscovite, which constitutes an average of about 17 percent of the heavy minerals. Pyroxenes, primarily augite, make up about 10 percent of the fluviatile assemblage. Diopside is absent, and hypersthene occurs in small percentages in only two samples. Garnets and amphiboles represent 5 and 7 percent of the suite respectively. The metamorphic minerals, tourmaline and epidote, are found in small quantities, generally less than 1 percent. The opaque minerals hematite and limonite are diagnostic of the fluviatile sediments but rarely exceed 4 percent.

Since the marine-fluviatile suite contains heavy minerals found in the marine and fluviatile assemblages, any number of mineral combinations can occur in varying percentages depending on the proximity of the sample location to the two basic sediment sources.

Environments of Deposition

Yaquina Bay comprises three distinct environments of deposition, two aqueous and one aeolian, which include the ocean beaches, Yaquina estuary, and coastal dunes respectively. The beach environment studied lies adjacent to the mouth of the estuary and extends 1. 7 miles north and 2 miles south. Landward of the southern ocean beach and adjacent to Southbeach of Yaquina Bay a series of transitory coastal dunes constitute the dune environment. The estuarine environments, which include the river channel and the tidal flats, extend from the tidal entrance of the estuary to its head in the vicinity of Elk City.

BEACH

Both ocean beaches north and south of the bay entrance can be considered together since their textural and mineralogical characteristics are similar. The beach is divided into two zones, the lower foreshore or the zone of permanent saturation affected by waves and tides, and the upper foreshore which lies beyond the zone of permanent saturation.

Lower Foreshore

All sand samples collected from the lower foreshore were taken in the surf zone at low tide. These sediments are transported to and fro on the beach by wave action and along the beach by longshore drift.

Texture

The lower foreshore of both north and south beaches is composed of fine sands with a range in particle diameter from 2.43 ϕ to 1.98 ϕ (average, 2.20). The finest sands appear to be localized in the vicinity of the jetties whereas the coarsest sands are generally found north of the jetties in the vicinity of Jump-off-Joe. The well-sorted sands (σ_ϕ average, 0.27) have a narrow range in sorting (0.20 to 0.48) and are characterized by an average coarse skewness ($\alpha_{1\phi}$) of -0.08.

Sediments of the lower foreshore have a wide range of roundness (angular to rounded) but are generally subangular to subrounded. This range in roundness is suggestive of several different sources of sediment, and the angularity of the sands indicates that the majority of the sediments have not undergone prolonged transport and abrasion. As is typical of sands in the wave zone, the grain surfaces tend to become polished and rounded due to the grinding of one particle on another from continual agitation.

Mineralogy

Mineralogically, the beach sands are immature. In the light mineral fraction quartz and feldspar generally occur in a 1:1 ratio with some local variations, but the potash/plagioclase ratio is about 1:5. These arkosic sands contain intermediate to calcic plagioclase feldspar (andesine to labradorite), and orthoclase generally predominates over microcline in the potash feldspars.

Although the bulk of the light mineral fraction is quartz and feldspar, it invariably contains about 15 percent "yellow grains" and assorted rock fragments. "Yellow grains" constitute about 10 percent of the light fraction; rock fragments about 5 percent. These two components occur in a constant 2:1 ratio over the length of beach sampled (Figure 17). The rock fragments are chiefly basalt, andesite, felsite, metaquartzite, schist, and chert. Because the yellow colored grains are such a diagnostic and easily recognizable characteristic of the beach sands, they serve as an excellent tracer for the movement of marine sands into and within other environments.

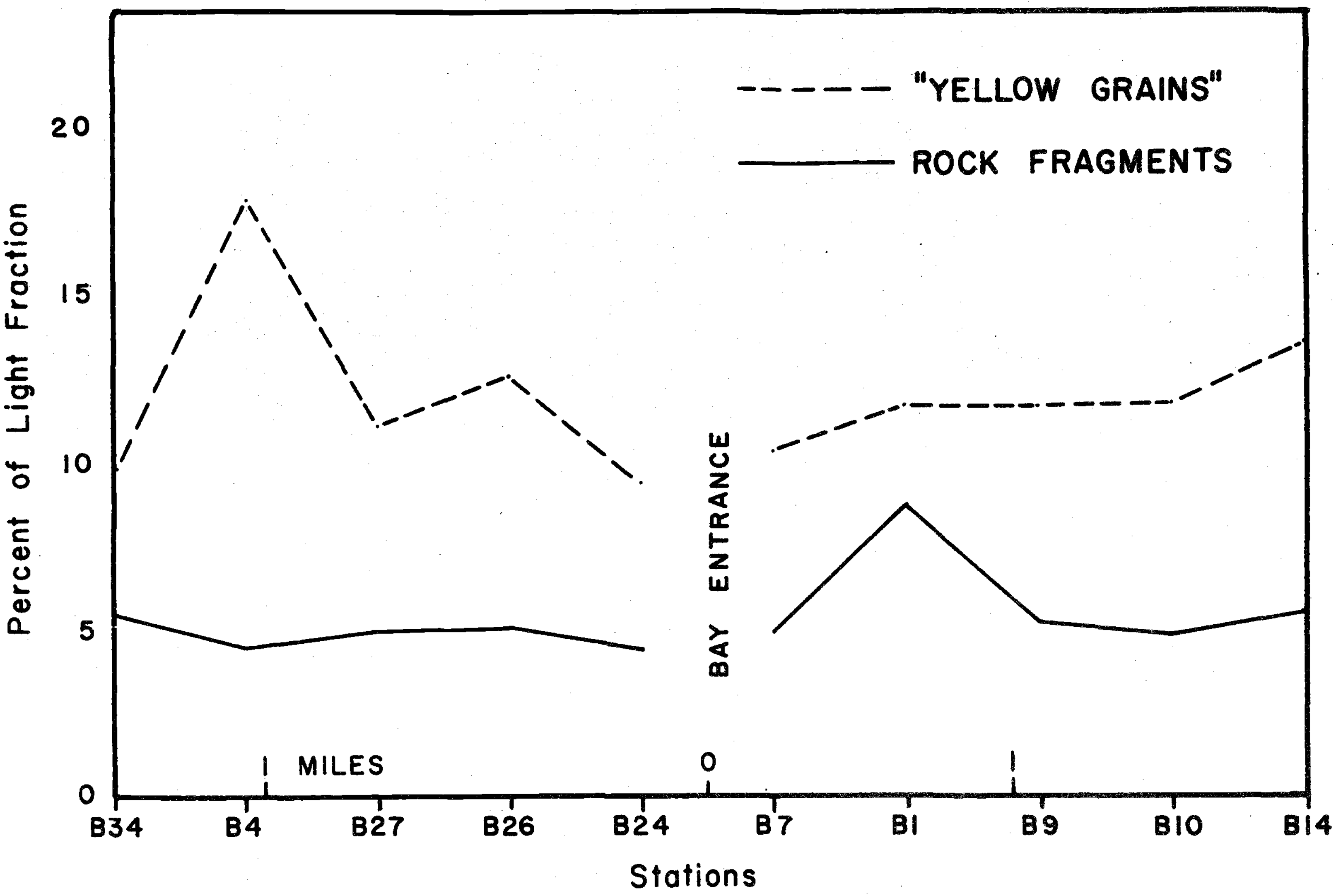

Figure 17. Relationship between "yellow grains" and rock fragments in the sediments of the ocean beaches. Station B14 is north and station B34 south of the entrance to Yaquina Bay.

The "yellow grains" and rock fragments also occur in a 2:1 ratio in the coastal terrace deposit sampled along the northern beach. The yellow colored particles in these deposits are clearly visible to the unaided eye.

Heavy mineral contents of all beach sands sampled from the lower foreshore range from less than 1 percent in the vicinity of the jetties to 12 percent near Jump-off-Joe on the northern beach; however, the average on both beaches is 3. 5 percent. The higher concentration of "heavies" in the beach sands near Jump-off-Joe may be due to the higher percentage of heavy minerals (7. 6 percent) in tne adjacent terrace sands. The heavy minerals in the terrace sands are further concentrated by small streams of ground water and local creeks that empty onto the beach. Longshore drift then distributes the "heavies" along the beach.

The marine suite of heavy minerals (Table 6), which is characteristic of the sands in the beach environment, is shown in the form of a frequency diagram in Figure 18. Four beach stations, two north and two south of the bay entrance, were selected for comparison of heavy mineral assemblages. Although the heavy mineral species of both beaches are the same, the frequency of occurrence of several species varies significantly over the stretch of beach sampled. Magnetite-ilmenite-chromite is six times more abundant in the sands of

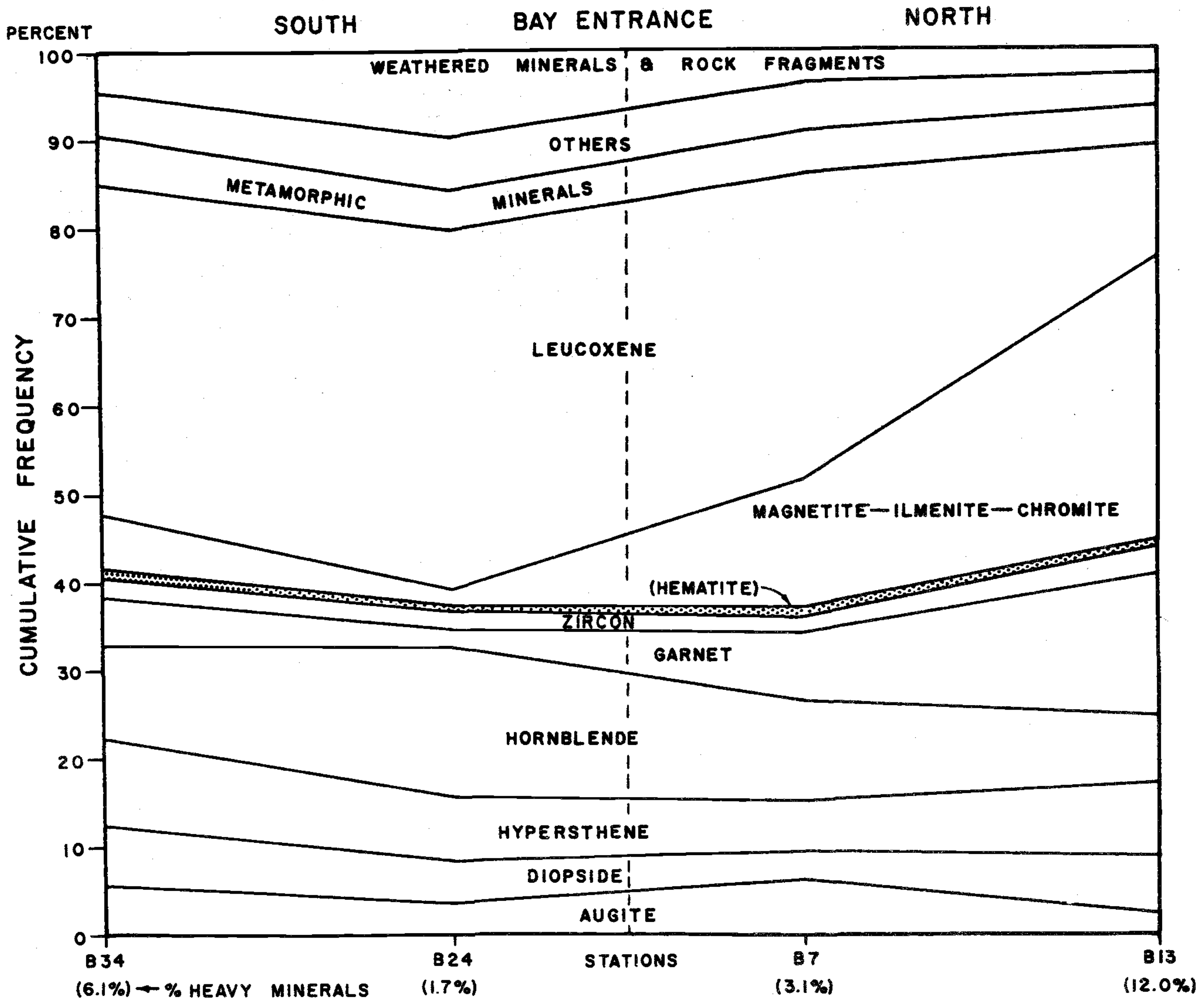

Figure 18. Heavy mineral profile of the ocean beaches flanking Yaquina Bay. Position of the bay entrance is marked by the dashed line.

the northern beach than in the southern, but leucoxene is only one-half as abundant. Even though the relative frequency of each opaque species varies along the beach the total percentage of opaque minerals remains constant. The relative frequency of non-opaque minerals is the same over most of the beaches with the exception of garnet, which is three times more abundant in the vicinity of Jump-off-Joe on the northern beach than at any other location.

From Appendix 2 it can be seen that the relative percentages of garnet and opaque minerals in the sands of the northern portion of the north beach coincide with those of the terrace deposit (YB-B12) sampled in that area. The author is hesitant to make a positive correlation between these two deposits on the basis of only one sample, but the local mixing of terrace sands with the beach sands by slumping and stream transport has been observed.

Upper Foreshore

The recently migrating upper foreshore dune sands are being derived from the often wet sands of the lower foreshore through aeolian transport by high velocity onshore winds. This zone is narrow and restricted on the northern beach because of the cliffed coastline, but extends as a wide plain over the length of the southern beach. The only sediments sampled on the upper foreshore were several recently migrating beach dunes.

Texture

The average grain size of the recently migrating upper foreshore dune sands is 2.34 ϕ whereas that of the lower foreshore sands, from which they were derived, is 2.20 ϕ. The decrease in particle size probably results from the selective sorting during aeolian transport. Likewise the skewness has changed from a coarse skewness ($\alpha_{1\phi}$) of -0.08 to a fine skewness ($\alpha_{1\phi}$) of 0.02 while the sorting has remained nearly the same.

No appreciable difference in roundness could be determined due to the transposition of sediment from one environment to another. According to Shepard and Young (38), dune sands are more rounded than beach sands because the wind tends to transport the more rounded grains more easily than the angular ones; however, their analysis was made on particular size fractions whereas this study is based on the whole unseparated fraction. These beach dunes are of Recent origin and probably have not undergone enough winnowing and abrasion for the change in roundness to be detectable with the method of determination used. Very little pitting and frosting was observed on the polished grain surfaces probably because of the short duration of transport under aeolian conditions.

Mineralogy

Although the mineralogy of the light and heavy mineral fraction is identical to that of the lower foreshore sands, there is a significant increase in the total heavy mineral content. The heavy mineral concentration of the upper foreshore dunes reaches a maximum of 40 percent of the total sediment and averages 21 percent for the 4 samples collected. However, the two upper foreshore dune samples on either side of the jetties average only about 6 percent heavy minerals, which is still appreciably higher than the content of the lower foreshore samples.

DUNE

General

The dune environment is comprised of a series of disrupted transitory and semi-stable coastal dunes that lie landward of the southern ocean beach and along the southwestern border of the estuary adjacent to Southbeach in Yaquina Bay (Figure 6). This undulating surface of separated dune ridges is being shifted progressively to the east into an adjacent forested area.

Texture

Like the upper foreshore beach dunes, the transitory coastal dunes are composed of fine sands whose average median diameter is 2.36 ϕ. They are excellently sorted ($\sigma \phi$ average, 0.23) and are skewed to the coarse fraction ($\alpha_{1\phi}$, -0.12). The few semi-stable dune masses have nearly identical textural characteristics except they are finer-grained (Mdϕ, 2.47 ϕ) than the transitory dunes. The coastal dunes are generally finer-grained and better sorted than the upper foreshore dunes, and they are coarsely skewed.

There is also a difference in particle roundness. Coastal dunes exhibit the full spectrum of rounding but for the most part are subrounded whereas the beach dunes are subangular to subrounded or slightly more angular. The higher degree of roundness of the coastal dunes may be attributed to the vigorous abrasive action of the wind over a long interval of time or to the selective winnowing of rounded particles, or both. Surface textures such as pitting and frosting that are common on dune sands are readily discernible and prominent in these sands.

Mineralogy

As was noted in the sands of the beach dunes, the coastal dunes are also exceptionally high in heavy mineral content. These sands have "heavy" concentrations that range between 22 and 62 percent of the total sand fraction. The volume distribution of "heavies" is irregular in the area sampled.

Both the light and heavy mineral assemblages of the coastal dune sands are similar to those found in the terrace deposit north of the bay entrance and in the lower foreshore sands of the beach adjacent to the bay. The mineralogical similarity suggests the recently migrating coastal dunes were probably derived from the Pleistocene terrace sands and nearby beach sands in the Yaquina Bay area.

ESTUARY

Yaquina estuary is divided into two physiographic features, the river channel and marginal tidal flats. Included with the tidal flats are the two large main flats, numerous smaller ones and several sloughs. The river channel is by far the larger of the two features and constitutes the major portion of the estuary.

Channel

The Yaquina River channel in the estuary extends from the entrance of Yaquina Bay to the vicinity of Elk City. The depth of the channel is variable because of natural and man-made pools and riffles, but decreases gradually with distance upstream. Channel width is less variable but also decreases in an upstream direction.

Texture

Sediments in the channel, from the entrance to Oneatta Point, are composed of fine to medium sand and have the same average median diameter (2.20 ϕ) as the fine sand of the lower foreshore of the beaches; however, the range in grain size is greater (2.74 ϕ to 1.78 ϕ compared with 2.43 ϕ to 1.98 ϕ respectively). These sands are not as well sorted (σ_ϕ average, 0.39) and generally are more coarsely skewed ($\alpha_{1\phi}$ average, -0.11) than the beach sands (Table 2). The channel sediments grade laterally into poorly sorted, very fine sand between Coquille Point and Oneatta Point.

In the vicinity of Oneatta Point there is a marked local gradation from the fine sand seaward of the Point to medium sand which occurs between Oneatta Point and Johnson Slough. Between Johnson Slough and the bend in the river at Toledo particle size decreases to fine sand again. But between Toledo and the bridge that crosses the estuary east of Toledo another local increase in grain size to medium sand is repeated. The sediment size distribution from the bridge to Elk City is irregular and ranges from very fine sand to gravel. In contrast to the estuary below Oneatta Point, the sediments between Oneatta Point and the vicinity of the highway bridge have a larger average median diameter (1.84 ϕ), are poorer sorted (σ_ϕ 0.49), and are generally skewed to the fine size fraction ($\alpha_{1\phi}$ 0.09).

In summary, sediments upstream from Oneatta Point are characterized by alternating longitudinal zones of fine and medium sand and as a whole are considerably coarser-grained than those of the lower reaches of the estuary. It is quite probable that insufficient sampling is responsible for the apparent alternation of zones of fine and medium sand.

Three transverse sampling profiles (BB', CC', and DD' of Figure 11) upstream from Oneatta Point show the general lateral distribution of grain size across the channel (Figure 19). Profiles BB' and CC' depict the progressive decrease in particle size from fine or medium sand in the turbulent waters of the deepest portion of the channel to silt and clay on the channel banks, where the water is relatively quiet. Poorer sorting and a finer skewness accompany this progressive decrease in particle diameter outward from the channel.

Profile DD' demonstrates the same general lateral decrease in sediment size, but the gradation is from gravel to very fine sand.

These profiles should be considered representative only of the particular area sampled, although they do emphasize the general distribution of sediments. Since the size distribution of the sediment is a relative index of the amount of energy in the transporting medium,

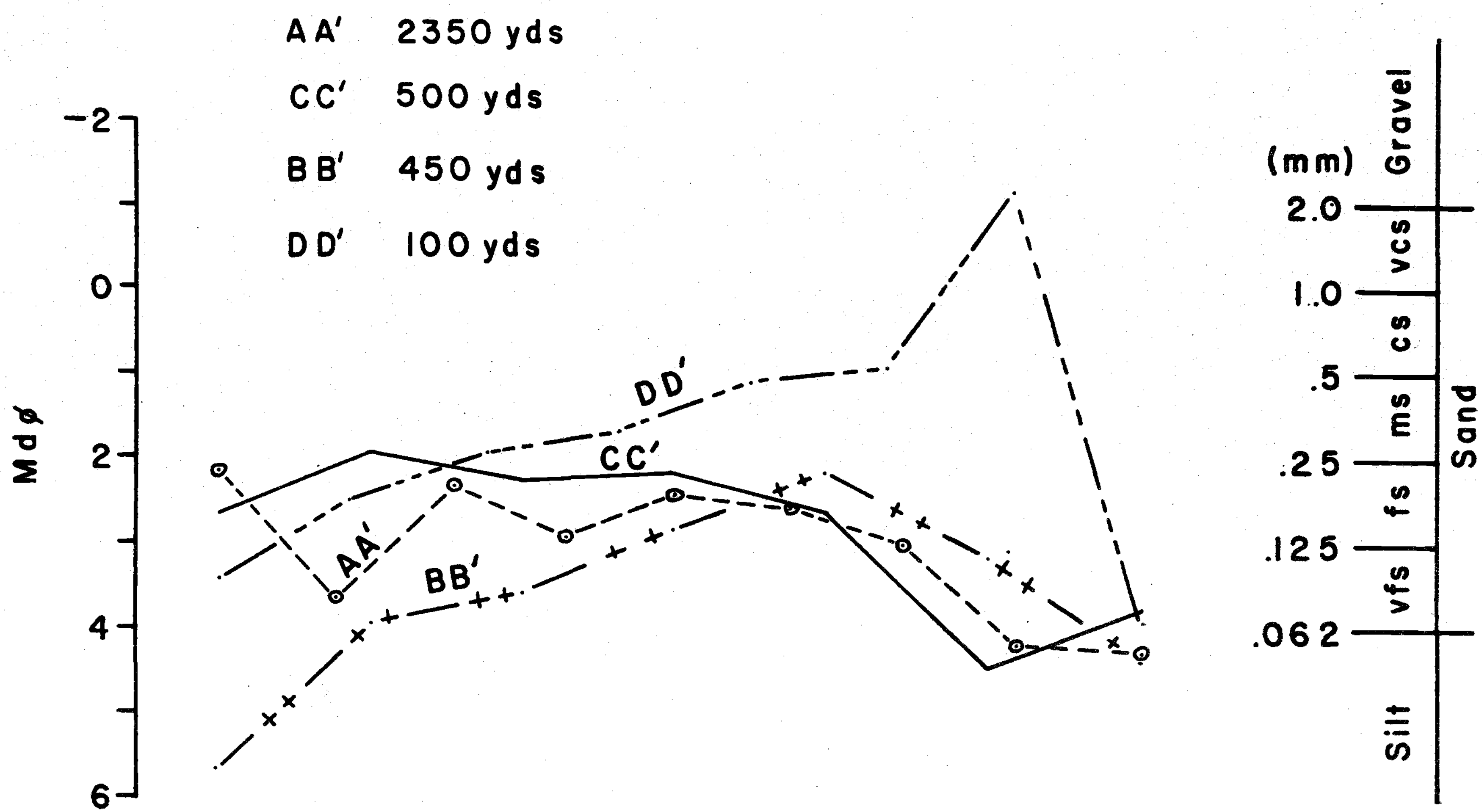

Figure 19. Grain size (phi median diameter) transverse to estuary channel. Locations of the profiles are as follows: AA', tidal flats; BB', Oneatta Point; CC', midway between Oneatta Point and Toledo; DD', upstream from Toledo. Refer to Figure 11 for exact locations.

it is apparent that the energy in the channel decreases laterally with decreasing water depth; however, the total amount of energy may vary in different segments of the channel.

Sediments between the estuary entrance and Oneatta Point are generally subangular to subrounded, but between Oneatta Point and McLean Point there is a progressive increase in particle roundness with distance downstream. Seaward of McLean Point no gross changes in roundness could be determined, but a few well-rounded grains were observed. Since the adjacent transitory coastal dunes are the only sediments in the bay area that have these grain properties, and the wind direction and velocity are favorable for the transport of dune sands into this portion of the estuary, these sediments undoubtedly contain varying admixtures of dune sands.

Landward of Oneatta Point the channel sediments are usually angular to subangular, and are therefore significantly more angular than those seaward of the Point. They are the most angular sediments in the Yaquina Bay area.

The progressive increase in particle roundness seaward of Oneatta Point is largely the result of increasing amounts of the more rounded beach and dune sands with decreasing percentages of angular fluviatile sediments.

Mineralogy

Quartz/feldspar ratios for channel sediments can be divided into two groups; those greater than one, which occur seaward of Oneatta Point, and those less than one, landward of the Point. As a rule, the difference in the ratios of these two components is not great, but a general trend does exist. The low ratios upstream of Oneatta Point reflect the arkosic composition of the central Oregon Coast Range rocks.

Quartz/feldspar ratios show that the sediments carried by the Yaquina River are much more arkosic (0. 28) than those of Elk Creek (0. 95). All other channel sediments in this region exhibit smaller ratios than those found in the sediments of Elk Creek. The higher percentages of quartz in the sediments seaward of Oneatta Point are probably due to the addition of beach and dune sands, which contain more quartz than feldspar, rather than due to the destruction of feldspars in transit with distance downstream.

As is generally the case for all sediments in the Yaquina Bay area, the potash/plagioclase feldspar ratios are low (average 0. 15) but consistent for the 23 miles of estuarine channel sediments. Both the Yaquina River and Elk Creek sediments have similar ratios.

Sandstone fragments several millimeters in diameter are common in the river channel upstream from Toledo. These micaceous rock particles appear to have been eroded from the surrounding Tyee Sandstone. Between Toledo and Oneatta Point siltstone and shale fragments characteristic of the Toledo Formation are the most abundant lithic particles in the river channel. Downstream from Oneatta Point well-rounded basalt fragments distinctive of the beach and dune sands increase in abundance seaward to the estuary entrance. Other rock fragments in this area include sandstone, siltstone, shale, chert, metaquartzite, and felsite.

The diagnostic "yellow grain" and rock fragment relationship characteristic of the beach and dune sands was also observed in the river channel sediments from the bay entrance to a point 6 miles inland at Oneatta Point (Figure 20). For about 1.3 miles upstream from the bay mouth (to YB-21) these two components occur in nearly the same ratio as those in the beach sands; the "yellow grains" predominate over rock fragments in about a 2:1 ratio. An inversion in the abundance of these two components occurs 1.5 miles upstream from the entrance (between stations YB-21 and YB-22). From station YB-22 to the turning basin (YB-24) lithic fragments predominate slightly over "yellow grains" in addition to a gradual decrease in the abundance of both upstream. From the turning basin adjacent

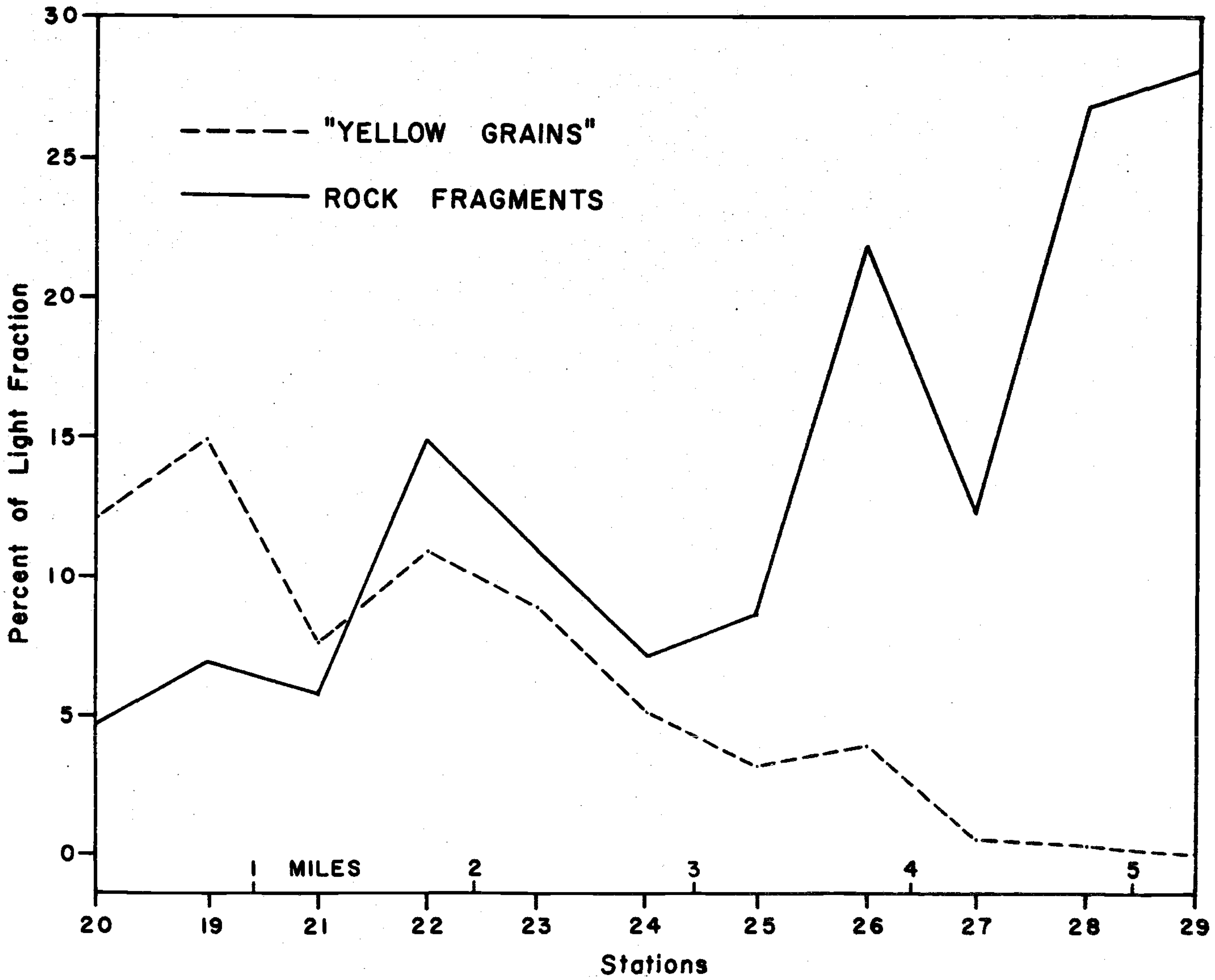

Figure 20. Relationship between "yellow grains" and rock fragments from the bay entrance to Oneatta Point. Station 20 is located at the bay entrance and station 29 near Oneatta Point.

to McLean Point to a position about 6 miles upstream (YB-29) "yellow grains" decrease gradually in abundance and finally terminate, whereas the abundance of undifferentiated lithic particles increase to about 30 percent of the light mineral fraction at station YB-29.

Heavy mineral concentrations in the sediments of the river channel range from 7.6 percent near the mouth of the estuary to less than 1.0 percent near Toledo (Figure 16). Although the volume distribution of "heavies" is somewhat irregular in the channel, there is a gradual decrease in the percentage of heavy minerals with distance upstream from the estuary entrance to Toledo. From Toledo to the vicinity of Elk City the percentage of heavy minerals increases slightly to more than 1 percent. The heavy mineral content is less than 1 percent in several places between Oneatta Point and the highway bridge at Toledo, largely as a result of the increase in grain size in this area (heavy minerals normally tending to accumulate in the finer size fractions).

Heavy mineral concentrations of more than 15.0 percent occur in the fine sands of the channel banks or sand flats that lie adjacent to Southbeach, and on the margin of the prominent sand spit that projects northeastward into the estuary. This increase in heavy mineral content is attributed to the aeolian transport of heavy minerals from the dunes to the channel banks when the wind direction is from south to southwest.

Three distinctive suites of heavy minerals, marine, marine-fluviatile, and fluviatile respectively, are recognized from the entrance of the estuary to its head near Elk City. The greatest variation in the heavy mineral assemblage in the bay area can be seen in the longitudinal profile of the 24 miles of estuarine and river drainage sampled (Figure 21).

The marine assemblage is prominent between the estuary entrance and McLean Point, and terminates where the first appearance of the micas marks the beginning of fluviatile influence. When the heavy mineral species in this portion of the channel are compared with those of the beaches, it can be seen that the gross mineralogy is the same. The ratio of leucoxene to magnetite-ilmenite-chromite, for example, is similar to that found on the southern beach.

The marine-fluviatile suite occurs between the marine inland boundary and Oneatta Point. In this segment of the channel the marine-fluviatile assemblage of heavy minerals is characterized by the presence of the micas, muscovite and biotite, and a reduction in the number of species and the abundance of such metamorphic minerals as kyanite, staurolite, and sillimanite. The inland boundary of the marine-fluviatile sediments is marked by the abrupt termination of the metamorphic minerals described and of the two pyroxenes,

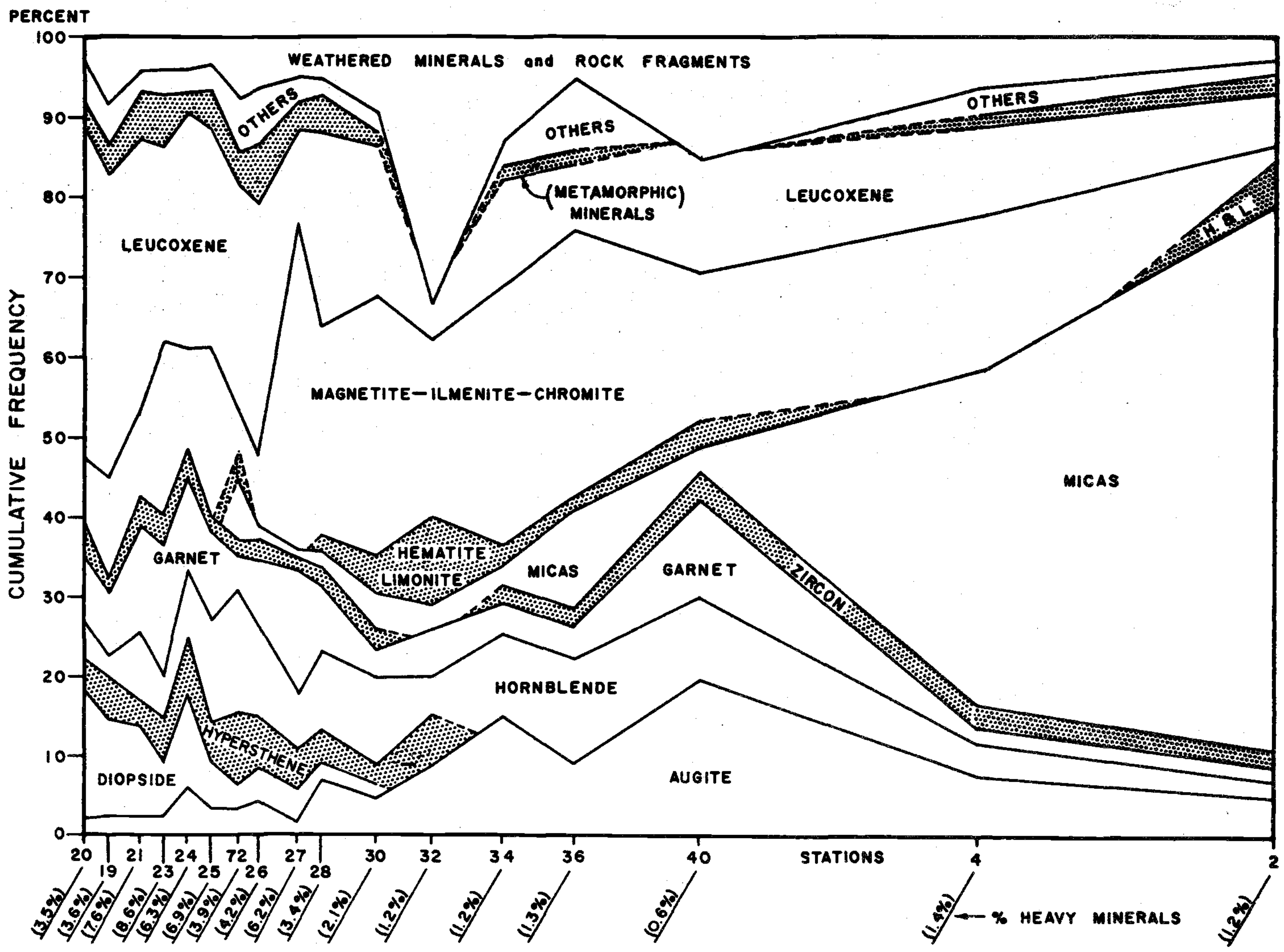

Figure 21. Heavy mineral variations along a 24-mile longitudinal channel profile, extending from the entrance of Yaquina Bay to 1 mile above the head of the estuary.

hypersthene and diopside.

The fluviatile suite extends upstream from the marine-fluviatile inland boundary in the vicinity of Oneatta Point and reaches to the head of the estuary above Elk City. This assemblage is characterized by a marked upstream increase in abundance of micas and a decrease of the opaque minerals leucoxene, and magnetite-ilmenite-chromite. Hematite and limonite are prominent in the sediments of this portion of the estuary and are diagnostic of the fluviatile sediments.

A comparison of the sediments of Yaquina River and Elk Creek on the basis of the most abundant heavy minerals (Table 7) shows that Elk Creek has more than twice the percentage of opaque minerals. In the sediments of the Yaquina River muscovite predominates over biotite while in Elk Creek the converse is true. Hypersthene and kyanite, which are distinctive of the marine sands, occur only in the sediments of Elk Creek, but in much smaller quantities than in the marine sands. Although present in the sediments of Elk Creek, both are etched and much more angular than their counterparts in the marine sediments.

In summary, the longitudinal variation in light and heavy mineral content indicates that beach sands are being transported by tidal currents 6 miles inland to Oneatta Point. Dune sands that are blown

Table 7. Comparison of percentage of selected heavy minerals from Elk Creek and Yaquina River.

Mineral	Percent heavy minerals Elk Creek (YB-1)	Percent heavy minerals Yaquina River (YB-2)
Augite	5.2	5.0
Biotite	13.4	22.0
Garnet	4.1	1.0
Hematite-Limonite	6.2	6.0
Hypersthene	2.1*	---
Kyanite	1.0*	---
Leucoxene	12.4	7.0
Magnetite-Ilmenite-Chromite	17.6	1.0
Muscovite	7.2	41.0

*Percentages determined on the basis of 1 or 2 grains per side.

into the tidal channel of the estuary are included in the marine intrusion of sediment. Seaward of the inversion point of "yellow grains" and rock fragments, unmodified marine sediments are prevalent. Between the inversion and McLean Point (station YB-24) the marine influence is still prominent, but the overlapping fluviatile influence is implied by the dominance of lithic fragments. Upstream from station YB-24 the marine influence decreases rapidly until it terminates in the vicinity of Oneatta Point where the unmodified fluviatile sediments begin. The relative abundance of specific light and heavy minerals is an indicator of the relative magnitude of sediment contribution by marine and fluviatile sources at any given location in the channel.

Oxidized Sediment

Oxidized sediment is prominent in the stream channel in a zone between Coquille Point and Toledo. The oxide coating is best developed in the channel sediments from Oneatta Point to the highway bridge in Toledo. However, upstream from the bridge it has not been noted.

The degree of oxidation appears to be related to grain size and composition. Larger grains are more highly oxidized than smaller ones; sediments finer than fine sand exhibit very little oxidation, but those coarser than fine sand are generally highly oxidized. Although oxidation itself is not confined to grains of specific composition, the clay rich rock fragments appear to be the most intensely oxidized. Evidently, currents in this area are not strong enough to transport the larger particles downstream, but are capable of moving the smaller ones by traction before they become oxidized. This zone of oxidation probably implies a slow rate of deposition in this section of the stream channel.

The iron oxide coating tentatively identified as hematite is found as patches, streaks, or a thin film. It varies in color from a light to dark Indian red, depending upon the intensity of oxidation. The soft argillaceous rock fragments between Toledo and Oneatta

Point invariably have an extremely thick, dark ambient coating. This thick oxide coating is probably due to the oxidation of iron rich clays in the shale fragments. Some of the initial oxide may be a result of weathering in the outcrop before disaggregation and deposition. Further oxidation undoubtedly takes place in the oxygenated bottom waters of the estuary.

Evidence that oxidation is occurring at the present in the channel is seen on foraminiferal tests of different genera. These Foraminifera are assumed to be living in place, because the intensity of oxidation decreases with the sequence of chamberal addition. This is best exemplified in the genus Alveolophragmium, where there is a progressive decrease in the amount of oxidation with the addition of each succeeding chamber. The most recent chamber is not oxidized in the living Foraminifera.

Through the studies of Krumbein and Garrals (26) on solubility versus mobility of oxides at various pH levels, it was found that at a pH of less than 7.0 iron oxide is soluble and will not be precipitated. They found that hematite is precipitated at pH ranges from 7.0 to 7.8 and at positive Eh values or in oxidizing conditions. No pH values in the oxidized zone have been taken.

Tidal Flats and Sloughs

Texture

A comparison of the two tidal flats on the basis of grain size shows that Sallys Tidal Flat is substantially finer-grained than Southbeach Tidal Flat (Figures 12 and 13). The channel banks bordering both flats are composed of fine sand which is moderately sorted and finely skewed. The similarity of the two flats ends here.

Southbeach Tidal Flat is composed of fine sand with the exception of one isolated area of very fine sand. The sediments of Southbeach Tidal Flat are moderately sorted (average $^{\sigma}\phi$, 1.00) and skewed to the fine fraction. In contrast the sediments of Sallys Tidal Flat grade laterally away from the channel from fine sand to silt. There is also a progressive decrease in sorting away from the channel which results from increasing admixtures of finer sediments toward the north shore of the flat. A transverse profile of the particle size distribution across the flats (AA' of Figure 19) shows the distribution of sediment across the estuary. On Sallys Tidal Flat there is the typical decrease in grain size with increasing distance from the main stream channel or from the region of maximum turbulence to areas of quiet water deposition. Conversely, on Southbeach Tidal Flat the grain size increases with increasing distance.

Three sloughs, King Slough, Macaffery Slough, and Pooles Slough, were sampled in Yaquina Bay. Although only one sample was taken in each slough near its mouth, all three samples were composed of silt with a range in grain size among them of only 0.10 ϕ (4.54 ϕ to 4.65 ϕ). They were also poorly sorted and finely skewed.

When the tidal flats are compared on the basis of particle roundness, the sediments of Sallys Tidal Flat appear to be more related to the sediments of fluviatile origin and those of Southbeach Tidal Flat to those of marine origin. The angular to subangular grains on the former flat exhibit the same degree of rounding as the sediments above Oneatta Point while the subangular to subrounded particles of the latter flat are similar to those of the beach and dune sands. As a rule, the very fine sands and silts of the marginal two-thirds of Sallys Tidal Flat are not as well rounded as the fine sands of the channel bank.

Mineralogy

The bulk of the light mineral assemblage of the tidal flats is similar to that of the river channel that separates them. There are, however, two exceptions: (1) glauconite occurs in significant quantities in the marginal deposits of Sallys Tidal Flat; (2) "yellow grains" are generally absent from the both flats except along the south shore of Southbeach Tidal Flat.

In Yaquina Bay, glauconite is restricted to the margins of Sallys Tidal Flat, stations YB-47, 69, 71, 85 and 88 (Figure 11), and to the channel between Toledo and the entrance. Glauconite constitutes approximately 3 percent of the light mineral fraction at tidal flat station YB-85; however, the concentration decreases radially away from this area onto the tidal flat. The galuconitic grains in this area are poorly sorted and light to dark green in color, and appear to be globular foraminiferal casts. They are generally delicate and exhibit little evidence of abrasion.

The glauconite particles scattered in the channel sediments, on the other hand, are characteristically rounded to well-rounded, oxidized, dark green pellets. These particles apparently become oxidized as they are transported through the zone of oxidized sediment discussed previously.

The sources of what appear to be two different types of glauconite is still somewhat undetermined. According to Baldwin (4, p. 14), numerous horizons of glauconitic sands occur in the Toledo Formation (Moody Shale Member) in the vicinity of Toledo. Although this lens has not been investigated by the author, it is the most likely source of glauconite found in the drainage channel. The source of the glauconite grains found on Sallys Tidal Flat is unknown.

"Yellow grains" occur in small percentages on the southern shore of Southbeach Tidal Flat, which is separated from the adjacent terrace deposits by a gravel road. The foundation of the road is composed of terrace sands which are the primary source of yellow particles on the southern shore of this flat. Apparently the tidal flat sediments in this area are derived in part from the adjacent terrace sands, but through the winnowing action of tidal currents the yellow particles have been, to a very large extent, depleted.

A comparison of the percentages of heavy minerals in the sand fraction of the sediments of the two tidal flats shows (Figure 16) that on Southbeach Tidal Flat the concentration of heavies (23. 8 percent) is higher than what it is on Sallys Tidal Flat (16. 9 percent). Areas of highest heavy mineral content on Sallys Tidal Flat, except near McLean Point, occur in the fine sands of the channel banks; whereas the fine sands of the south shore of Southbeach Tidal Flat contains the highest percent of heavies (23. 8 percent). In general, heavy concentrations decrease with distance from the river channel on Sallys Tidal Flat but increase with distance toward the margins on Southbeach Tidal Flat.

The profile AA' (Figure 22) shows the heavy mineral distribution and frequency across approximately 2 miles of tide flat and the intervening river channel. Although the heavy mineral assemblage

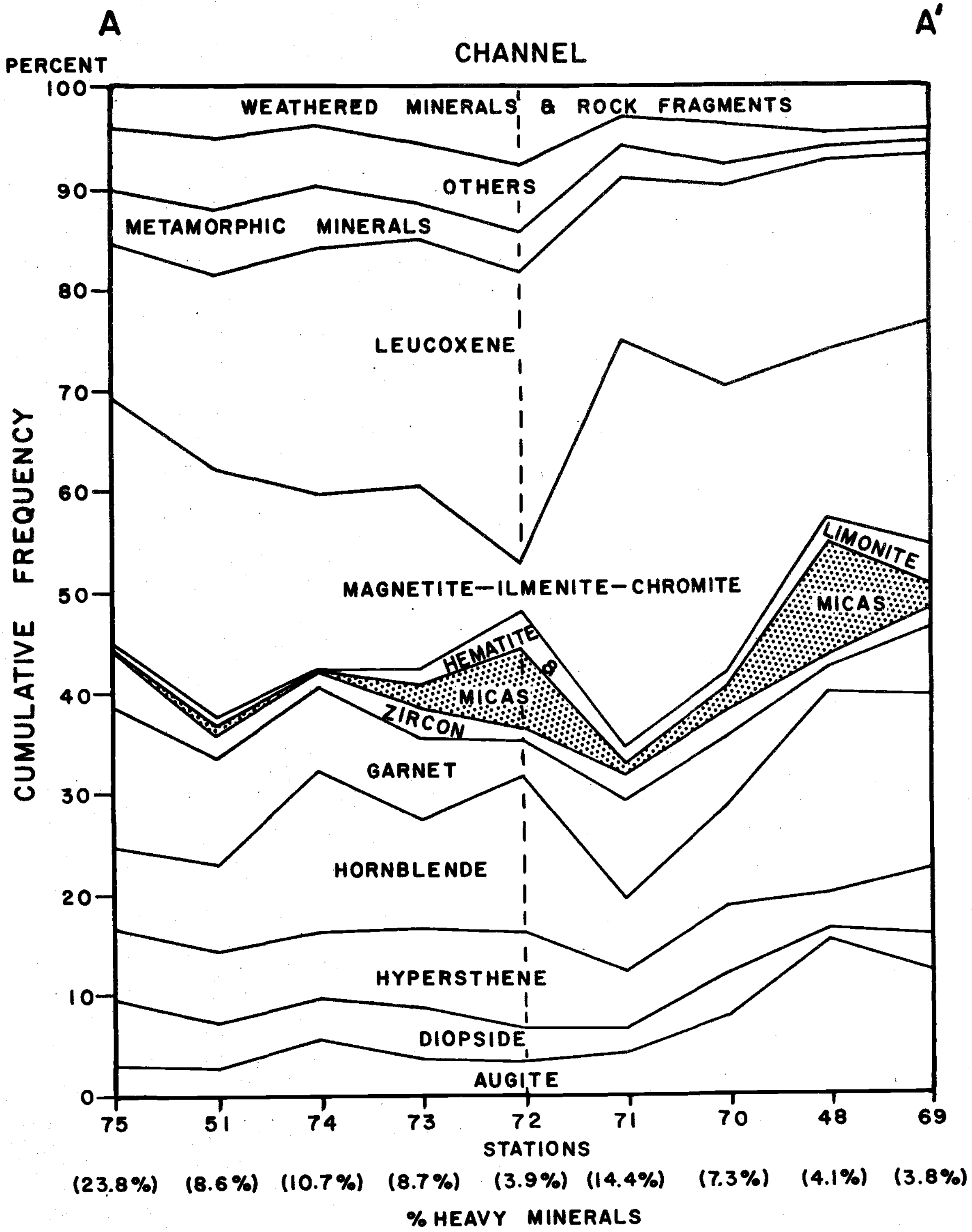

Figure 22. Transverse heavy mineral profile (AA') across Southbeach Tidal Flat and Sallys Tidal Flat in Yaquina Bay. Dashed line is the intervening river channel.

of both tide flats are characteristic of the marine-fluviatile suite, there are major differences that distinguish the two flats. For example, Sallys Tidal Flat has a significantly higher concentration of micas, muscovite predominating over biotite in a 2:1 ratio, than does Southbeach Tidal Flat. In the Yaquina River drainage muscovite also is more abundant than biotite. Also more common to Sallys Tidal Flat are augite and hornblende and the opaque minerals, hematite and limonite. There is a marked decrease and often an absence of such metamorphic minerals as staurolite, kyanite, sillimanite, and tourmaline and a noticable decline in the abundance of garnet and hypersthene on Sallys Tidal Flat as compared to Southbeach Tidal Flat.

Tidal Flat Processes

The tidal flats are the main geomorphic feature of the lower portion of the estuary. Their surfaces are semi-diurnally exposed to air and then covered by saline to brackish water. Because of daily and seasonal variations in hydrography, tidal features such as ripple marks may change with each phase of the tide or remain essentially unchanged over long periods of time.

The intertidal channels that drain the flats on the ebb tide are the most conspicuous erosional features of the tidal flats. These channels are pronounced on Southbeach Tidal Flat where they are generally less than one foot in depth and relatively straight (Figure 23). They usually increase in width near their confluence with the main channel because of the increase in the volume of discharge. In Figure 24, the fine sediments transported by these intertidal channels appear to be forming a small submarine delta at the intersection with the river channel.

Even more extensive are the very shallow intertidal channels that meander over most of the flats (Figure 25). On Sallys Tidal Flat their direction of flow and extent of meandering is often controlled by clumps of algae tentatively identified as Enteromorpha (Figure 26). This green algae flourishes in areas of brackish water, such as estuaries, and often forms dense growths.

The abundant eel grass Zostera marina, which grows in scattered patches or as an extensive mat-like cover on the tidal flats, enhances deposition by trapping the finer-grained sediments in traction or suspension near the water-sediment interface. Conversely, erosion is inhibited by this resistant cover of grasses and sediment, and the width and direction of flow of the intertidal channels is restricted in these areas (Figure 27). Generally the current direction of the last ebb tidal flow can be determined from the orientation of the grasses on the flats. As a rule, the sandy portion of the tidal flats appear to have the most dense growth of grasses.

Figure 23. Shallow intertidal channel cutting across Southbeach Tidal Flat.

Figure 24. Small ephemeral submarine delta forming at the end of an intertidal channel. Note the plume of muddy water.

Figure 25. Extensive shallow meandering intertidal channels on Sallys Tidal Flat.

Figure 26. Clumps of algae controlling the courses of meandering intertidal channels.

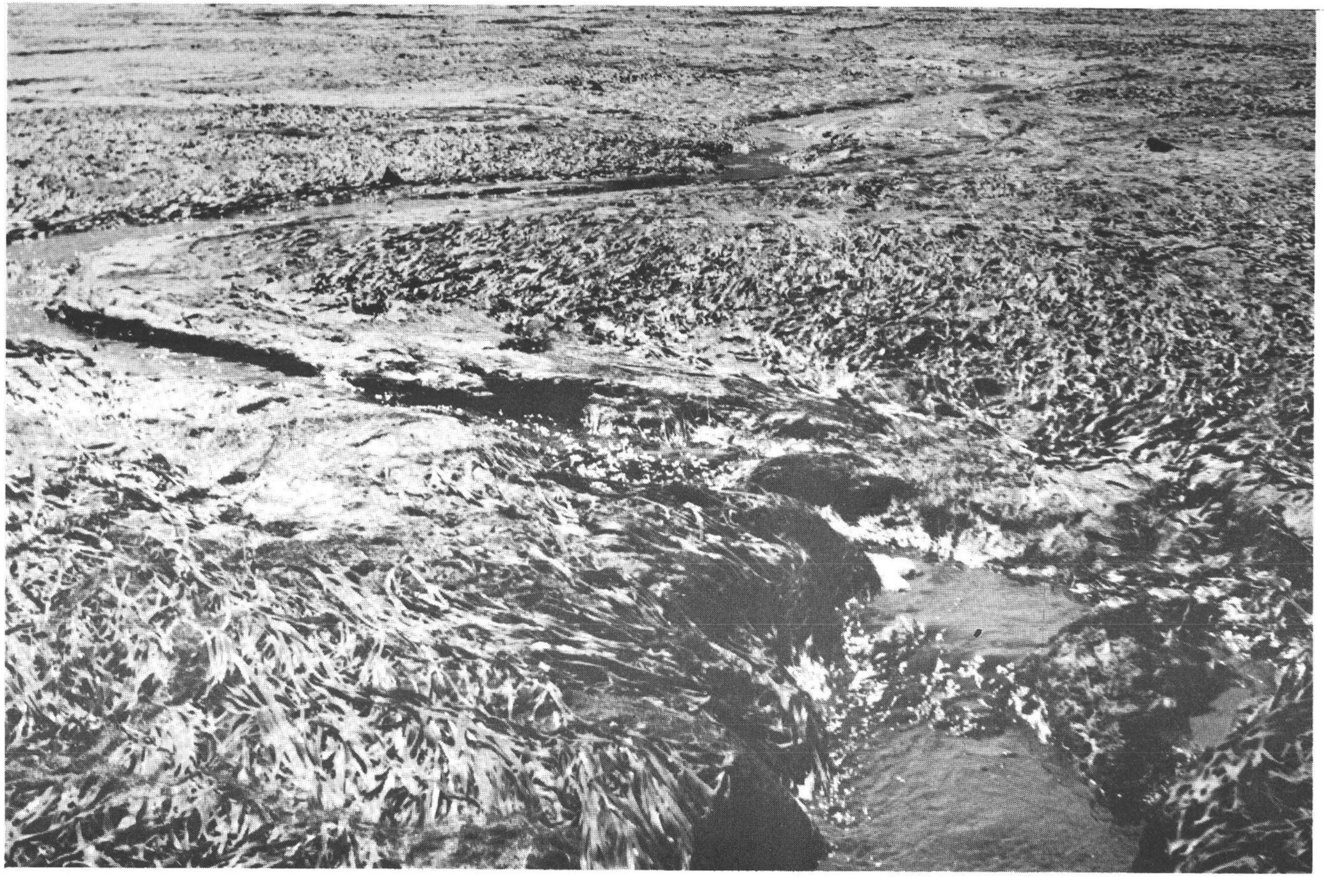

Figure 27. Dense growths of eel grass, Zostera marina, inhibiting erosion along intertidal channels.

An estimate of the relative amount of sediment reworking attributed to burrowing organisms can be ascertained from the abundance of biologically derived structures on the tidal flats. At low tide, a myriad of various sized mounds are generally present on Southbeach Tidal Flat (Figure 28). These structures are the work of burrowing clams, shrimp, and worms. Through their burrowing activities the sediment is apparently sorted into a coarser size grade through filter feeding, and mixed into a homogeneous mass. The abundance of biological structures on the surfaces of the tidal flats suggest that sediment reworking due to organisms is extensive.

The mound-like structures produced by the burrowing organisms are frequently of aid in comparing the nature of the sediment at depth with that at the surface. The slightly reddish-brown color of the surface sediments was not noticed until it was contrasted with the light to dark gray color of the extruded sediment in the mounds. The surface sediments of both tidal flats appears to be slightly oxidized; however, this property was not observed in the samples taken from the flats.

Depositional History

Piston cores afford an undistorted, three-dimensional view of the post depositional changes in the tidal flat sediments of Yaquina

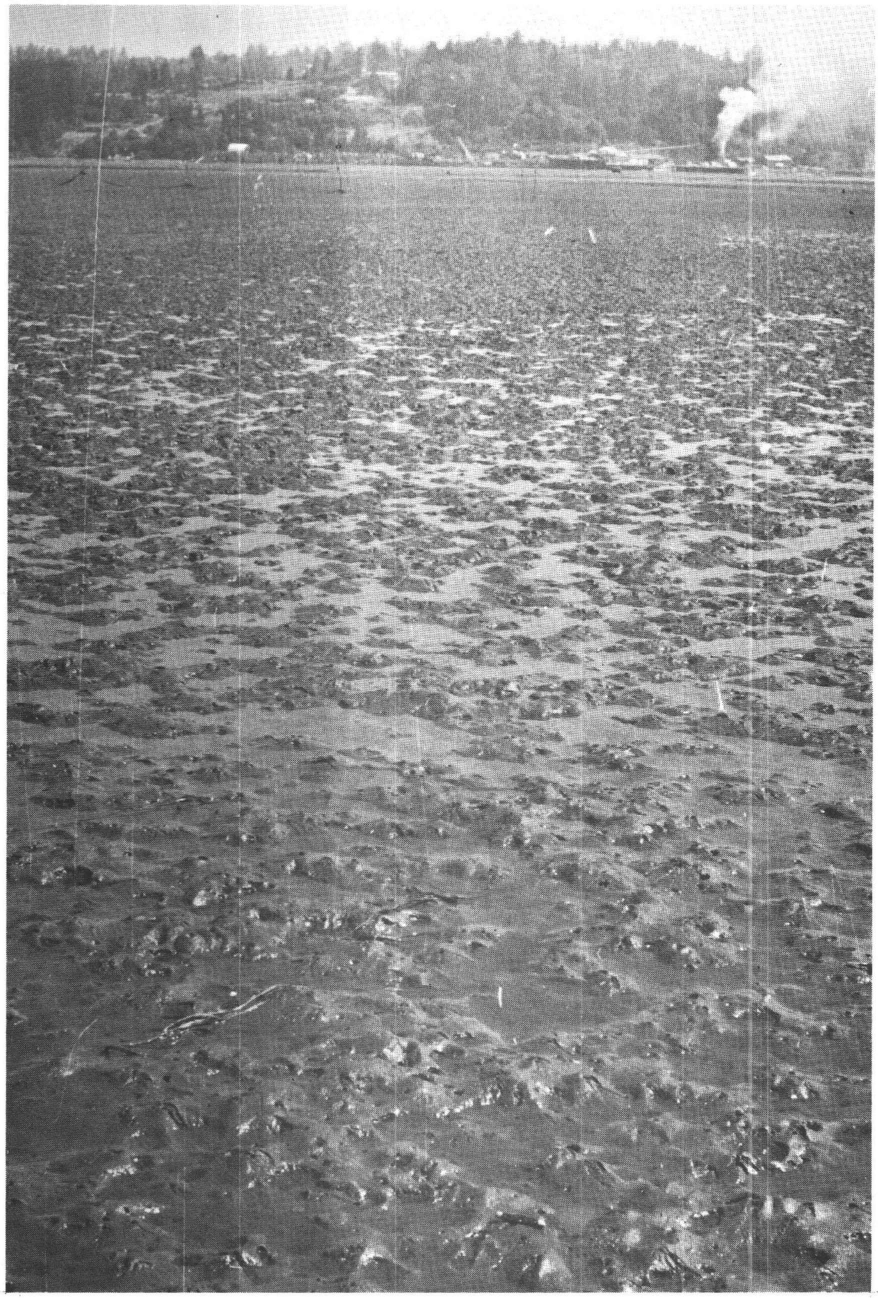

Figure 28. Burrows and mounds showing extensive activity by marine organisms.

Bay. The interval of time represented by the core, although unknown, generally increases with the length of the core. Although no detailed sediment analyses were performed on the lower levels of the cores, a visual examination reveals some of the more recent diagentic changes in the unconsolidated sediments, such as extensive reworking which results in the destruction of primary structures.

Southbeach Tidal Flat

The two piston cores (YB-89 and YB-90) taken on Southbeach Tidal Flat (Figures 29 and 30) were 4 and 2.5 feet long respectively and appear to be quite homogeneous in composition, and structureless throughout. Only along the northern shore of Southbeach Tidal Flat, at station YB-89, is there any evidence of sedimentary structures. Poorly defined discontinuous sand lenses occur about one foot from the top of the core. These sandy structures probably result from the reworking of organisms through which the larger primary structures are partly destroyed leaving the isolated lenses shown in the core.

The most conspicuous compositional feature in these cores is the abundance of whole and broken molluscan shell fragments. A particularly good example is seen in core YB-89, where numerous whole shells are concentrated in about a 6-inch interval just below

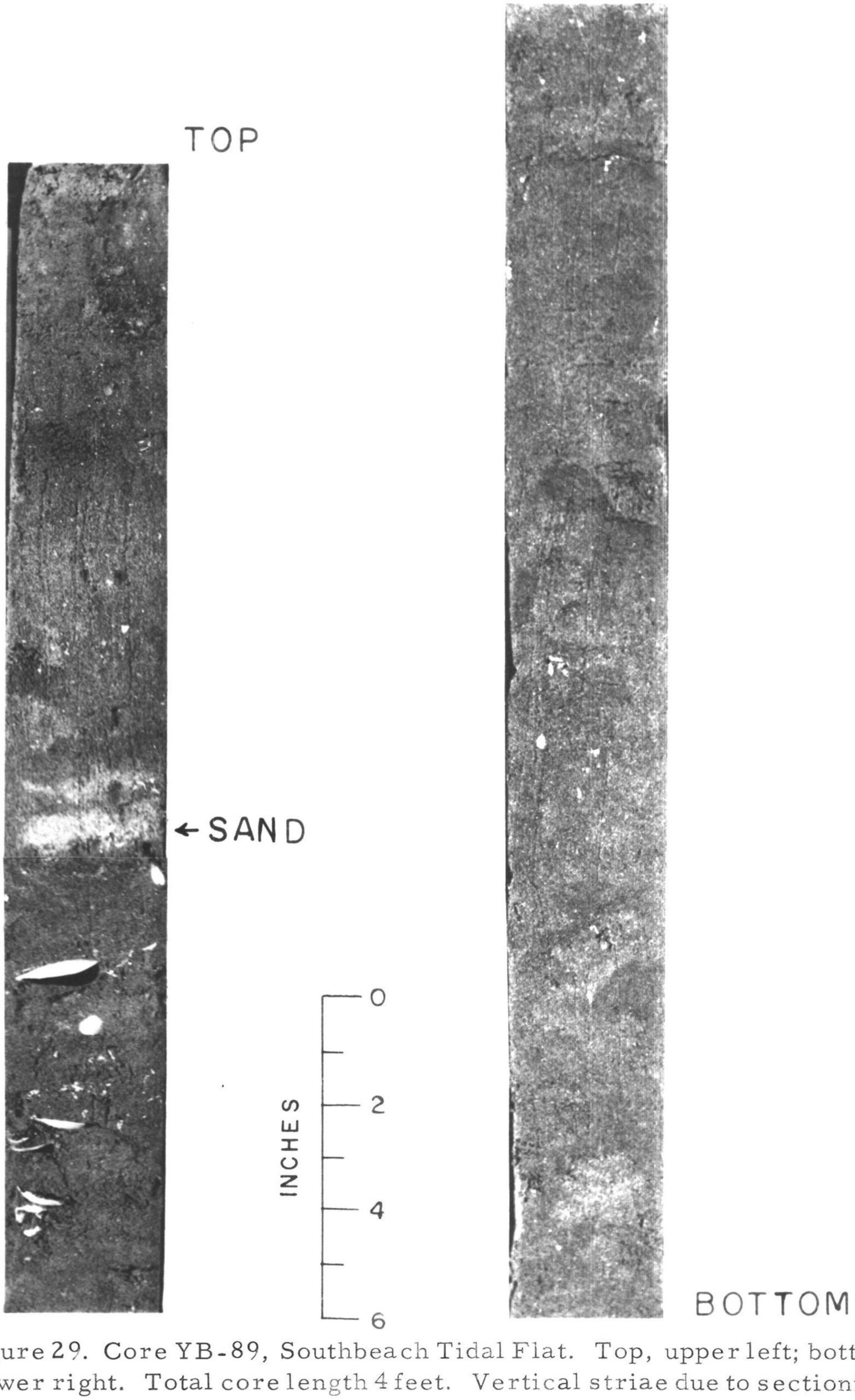

Figure 29. Core YB-89, Southbeach Tidal Flat. Top, upper left; bottom, lower right. Total core length 4 feet. Vertical striae due to sectioning.

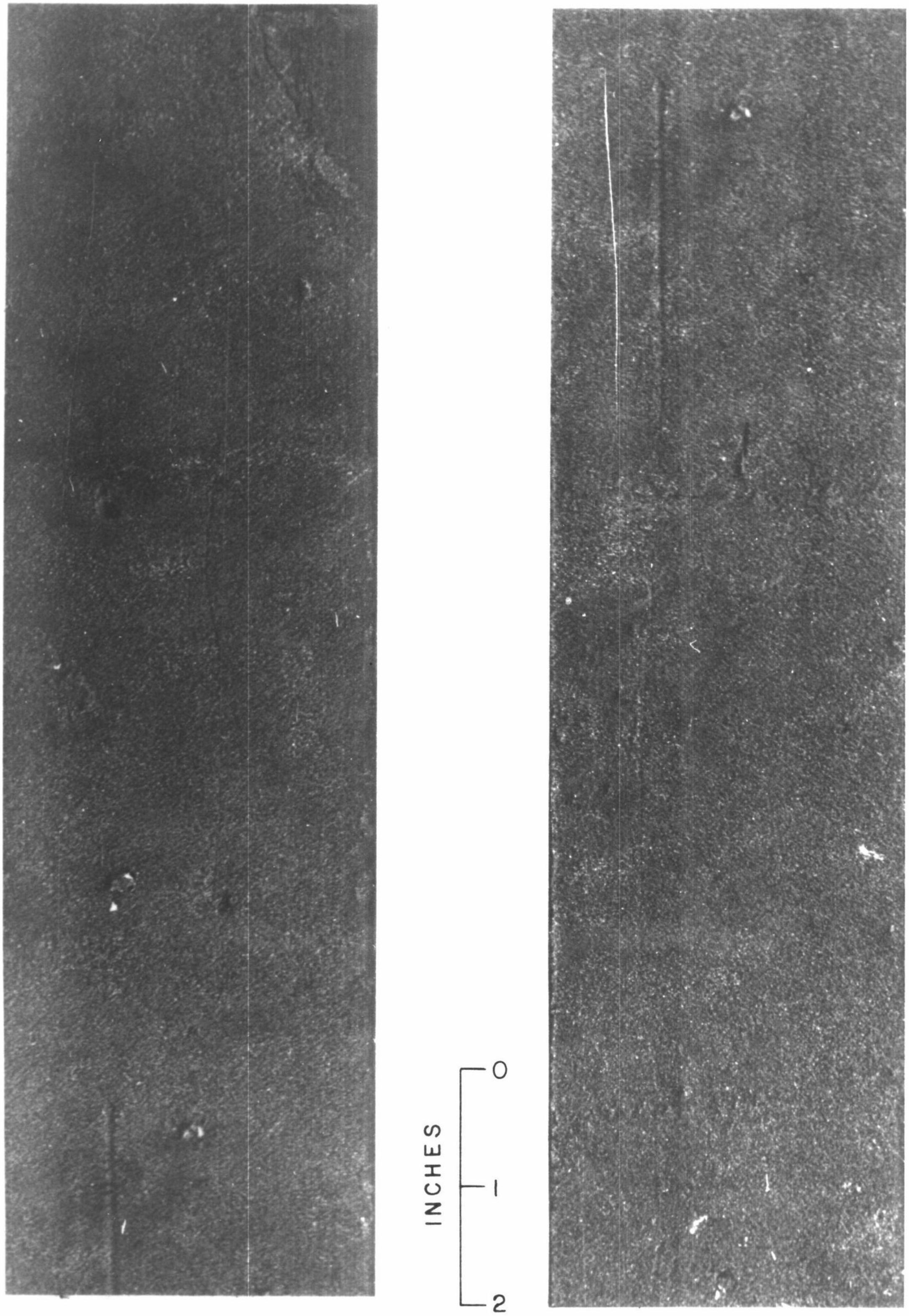

Figure 30. Core YB-90, Southbeach Tidal Flat. Top, upper left; middle, right. Total core length 2.5 feet. Vertical striae due to sectioning.

the lense of sand. This abundant accumulation of carbonate shells may have been the result of high animal productivity at this time or merely a concentration of detrital shells in an intertidal channel as shown previously on the surface. The small amount of carbonate material in core YB-90 is largely detrital as shown by the few small particles scattered throughout the length of the core.

In order to account for the marked difference in calcium carbonate in the two cores, the present-day areas of carbonate productivity and detrital accumulation must be considered. Marriage (28, p. 26-28) has described the areas of major clam producing beds in Yaquina Bay (Figure 31). Core YB-89, which has the highest shell content, is located in the only known clam bed (area 4) on Southbeach Tidal Flat. The following clams inhabit the region where this core was taken: the Littleneck Clam, Protothaca staminea (Conrad), the Cockle Clam, Clinocardium nuttalli (Conrad), and the Gaper Clam, Schizothaerus nuttalli (Conrad). They are found living at the surface, beneath the surface of the tidal flat from 1 to 3 inches, and from 14 to 16 inches respectively. Optimum sediment types include mixtures of mud and sand, or sand. The detrital bivalve shells found in core YB-89 apparently occur at the maximum depth of burrowing normally attained by the forementioned living clams. The core taken at station YB-90 is outside the clam bed described, which probably explains its

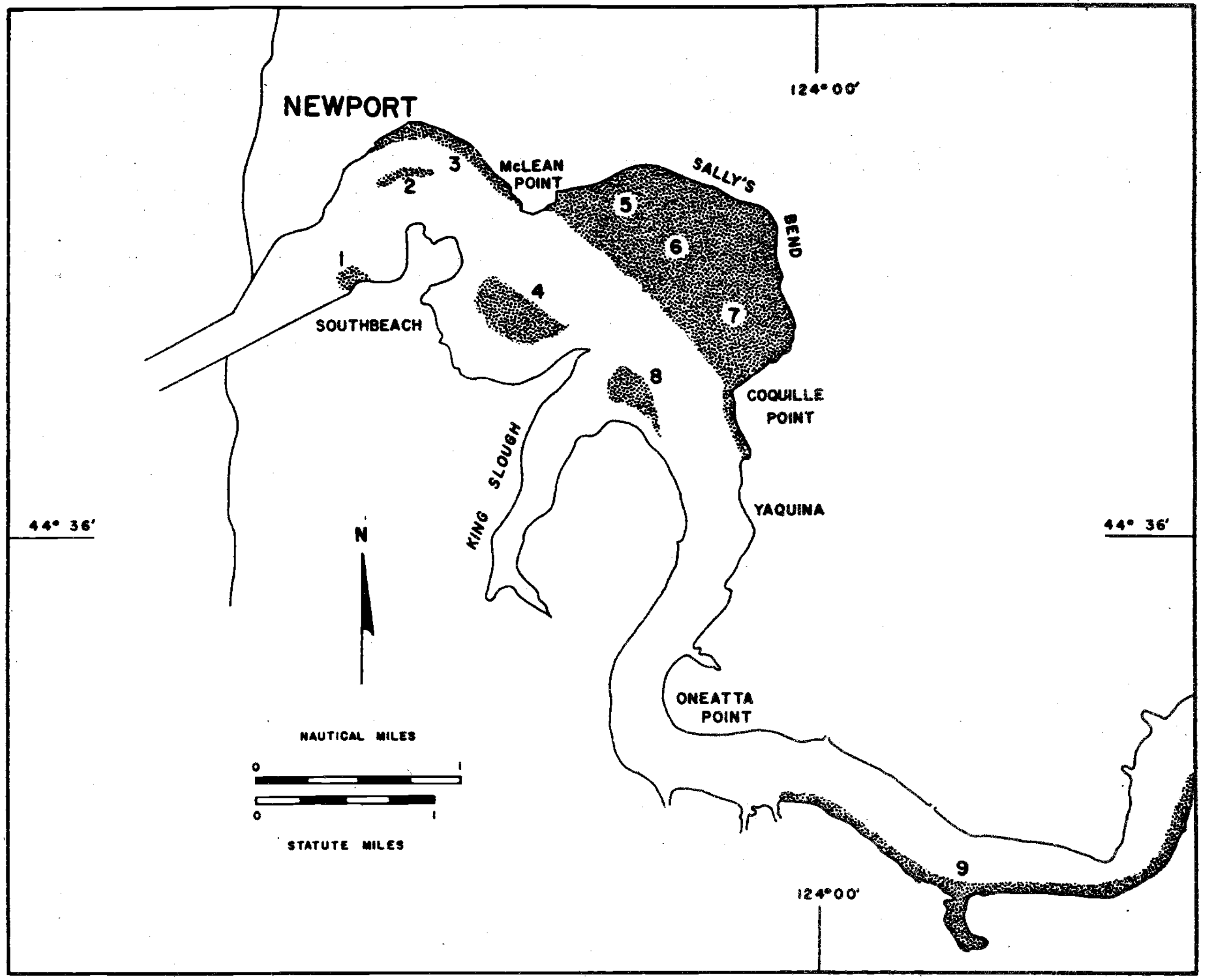

Figure 31. Location of clam beds in Yaquina Bay. (Modified from Marriage, 28, Figure 17, p. 26)

low shell content.

Molluscan productivity on Southbeach Tidal Flat may be related in part to the organic content of the sediments. The organic content in the top few centimeters of core YB-89 is about average (0. 98 percent) for both tidal flats whereas that in YB-90 is neglibible.

Sediments at various levels in the two cores collected from Southbeach Tidal Flat were examined with a binocular microscope to determine whether there were any significant changes in mineral composition. As a rule, these sediments are similar in composition and texture to those at the surface. In particular, the absence of "yellow grains" was noted throughout the cores.

Several criteria have been presented heretofore that favor the reworking of sediments of Southbeach Tidal Flat. At present, the surface sediments of the tidal flat are being reworked by burrowing organisms. This process produces a featureless, homogeneous sediment. The present depth of reworking is probably limited to the depth of penetration of the burrowing organism. The homogeneous character of sediment in the cores indicates that burrowing processes have been active through the interval of time represented by the core; however, the length of time is not known.

Sallys Tidal Flat

The present and post depositional environments of Sallys Tidal Flat are somewhat different than those of Southbeach Tidal Flat. The sediment composition and structures are more variable from one area to the next, and reworking is not as prominent.

Core YB-87 (Figure 32), which is about 2 feet in length, is fairly homogeneous and structureless from top to bottom, but it has a larger percentage of fine-grained components, silt and clay, than cores from the other tidal flat. In addition, abundant whole and broken shell material, and numerous woody fragments are dispersed throughout the core.

The core taken at YB-85 (Figure 33) is in marked contrast to the one just described. Minute fragments of calcium carbonate are barely perceptible, but large fragments of wood are pronounced. Its grain size varies from medium sand in the top six inches to clay and silt with interbedded pebbles in the lower levels of the core. Common to both cores are what appear to be dark olive green (when moist) clay nodules or balls. Some individual nodules are more than an inch in diameter. An excellent example is seen in core YB-85 in the lower half of the core. Neither the origin nor the composition of these clay nodules are known. Cores collected at localities on the flat other than in the area of YB-85, are similar to YB-87.

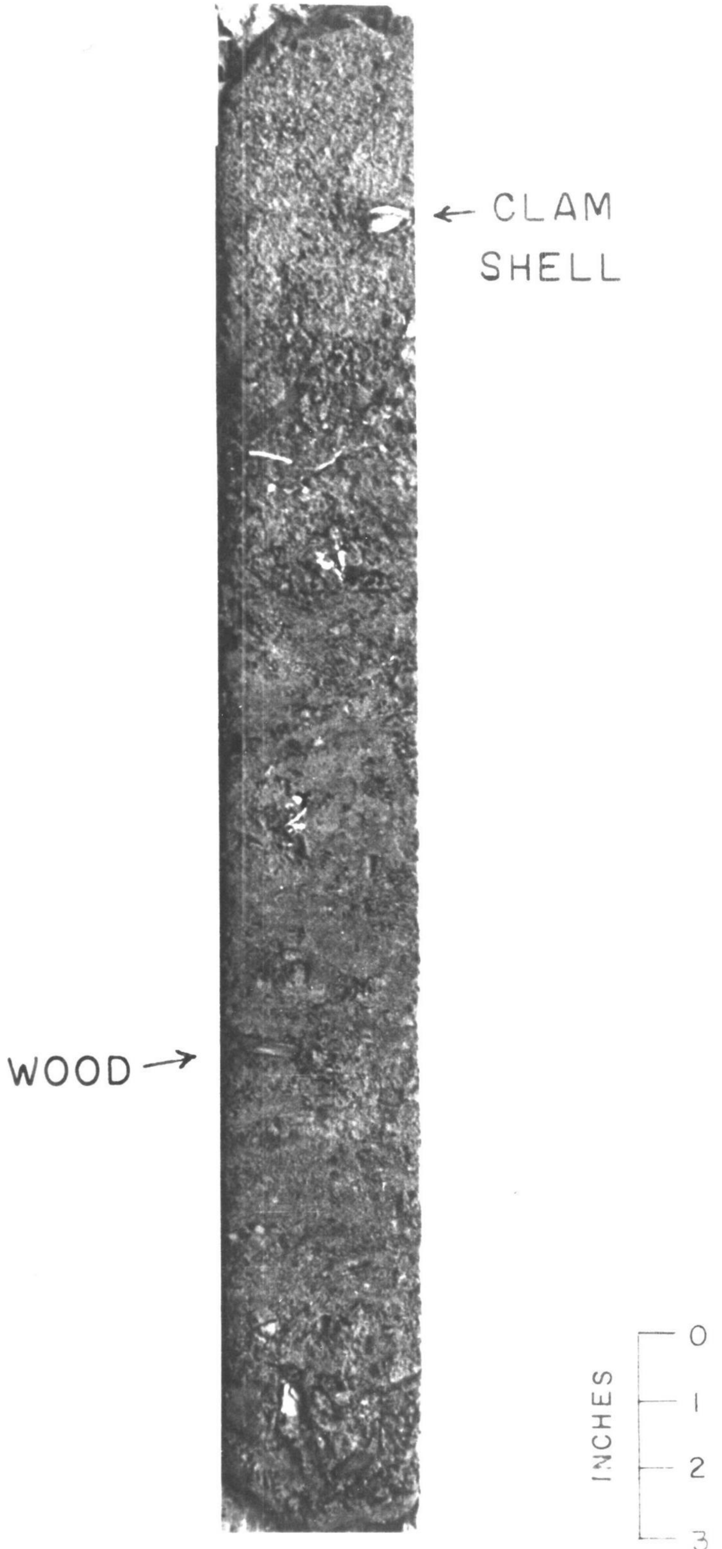

Figure 32. Core YB-87, Sallys Tidal Flat. Note the whole molluscan shell and wood fragment. Total core length 2 feet.

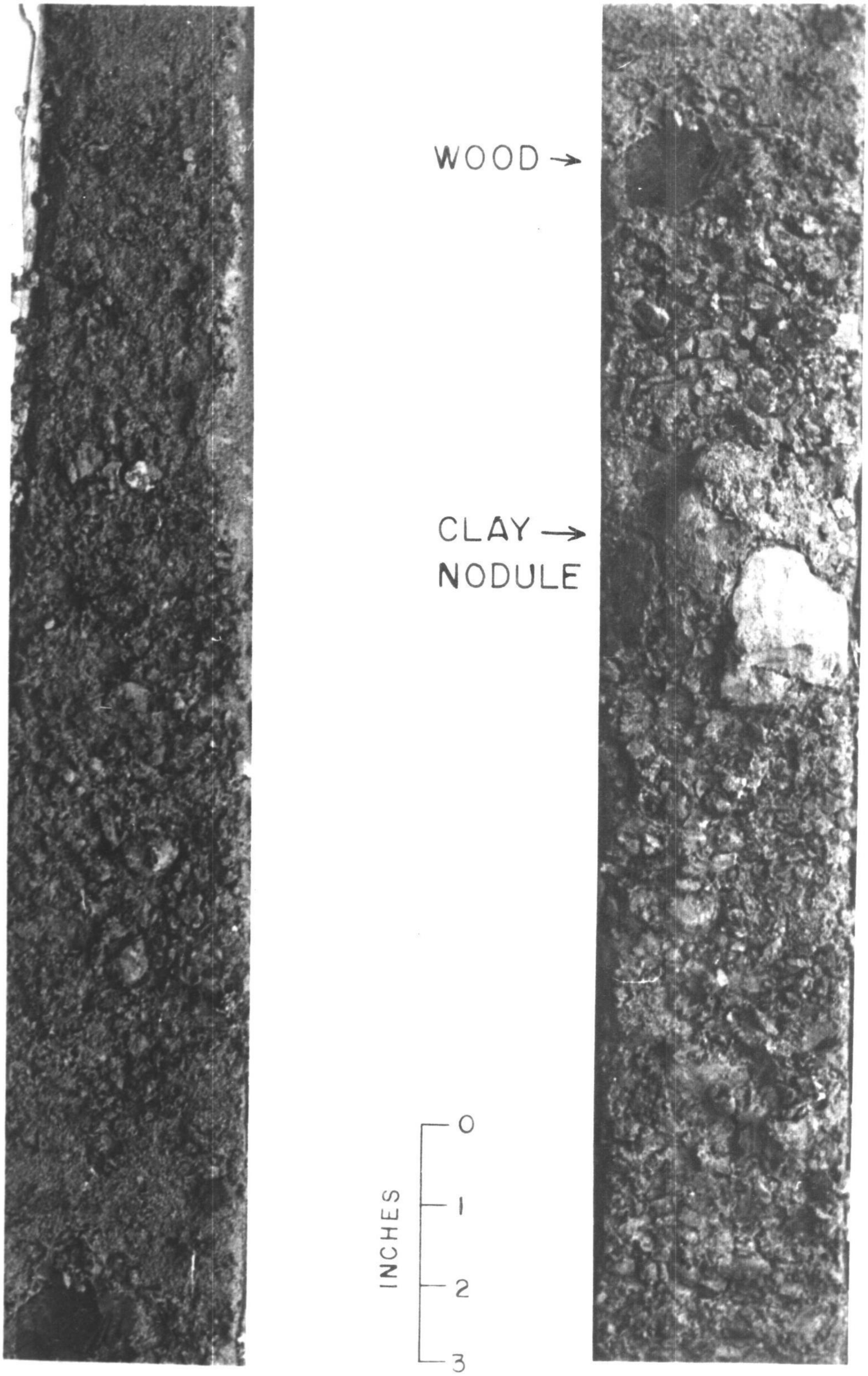

Figure 33. Core YB-85, Sallys Tidal Flat. Top, upper left; bottom, lower right. Note wood fragment and clay nodule. Total core length 2.6 feet.

The abundance of shell fragments in the cores correlates well with the areas of molluscan productivity. According to Marriage (28, p. 26-28), the largest single clam flat in the bay occurs on Sallys Tidal Flat and is approximately 500 acres in extent (Figure 31; areas 5, 6, and 7). Conditions for the growth of bivalves appear to be optimum on this tidal flat. The four dominant species of clams that inhabit Sallys Tidal Flat include: the Gaper Clam, Schizothaerus nuttalli (Conrad), the Cockle Clam, Clinocardium nuttalli (Conrad), the Butter Clam, Saxidomus giganteus (Deshayes), and the Littleneck Clam, Protothaca staminea (Conrad). The Butter Clam is the only addition to Sallys Tidal Flat that is not found on Southbeach Tidal Flat. It usually lives from 6 to 12 inches beneath the surface of the beds and prefers an environment of gravel and mud.

The abundance of bivalves in the vicinity of core YB-87 probably explains the concentration of shells in the various levels of this core. Since core YB-85 is on the extreme northwestern margin of the clam beds, it seems likely that this would be an area of low productivity as evidenced by the lack of shells throughout the core.

The lithology and structures of the cores taken on Sallys Tidal Flat indicate that its depositional history is different from that of Southbeach Tidal Flat. The sources of sediment, for the most part, appear to be quite dissimilar. In general reworking by organisms is not as prominent on Sallys Tidal Flat and has been largely confined to the upper few centimeters.

Summary of Depositional Environments

The following environments of deposition occur in the Yaquina Bay area: beach, dune, and estuary. Each environment is subdivided into physiographic zones which are generally characterized by a distinctive sediment texture and mineral assemblage.

BEACH

The beach environment which lies 1.7 miles north and 2 miles south on either side of the bay entrance, is divided into two zones, the lower foreshore and the upper foreshore. Sediments of the lower foreshore are subjected to seasonal longshore drift and generally consist of well-sorted, subangular to subrounded, fine sand (average Mdϕ, 2.20 ϕ). The recently migrating dune sands of the upper foreshore are being derived locally from the lower foreshore sediments as a result of strong onshore winds. They are also composed of fine sand; however, the average median diameter (2.34 ϕ) of the upper foreshore dune sands is smaller than that of its source. There are no other significant differences in the texture of the sediments in these two zones. The arkosic beach sands of the upper foreshore and the lower foreshore in the Yaquina Bay area contain an average of 3.5 percent heavy minerals. Heavy minerals characteristic of this environment include opaque minerals (magnetite-ilmenite-chromite and leucoxene), pyroxenes (augite, diopside, and hypersthene), garnet, and such distinctive metamorphic minerals as kyanite, sillimanite, staurolite, tourmaline, and epidote.

DUNE

Coastal dunes in the Yaquina Bay area consist of recently migrating dunes and a few scattered semi-stable dune masses. All coastal dunes south of the bay entrance are composed of excellently sorted, subrounded, fine sand. Textural characteristics of the two types of dunes are similar with the exception that the semi-stabilized dunes are generally finer-grained (2.47 ϕ, average) than the transitory dunes (2.36 ϕ, average). The light and heavy mineral assemblages of the coastal dunes are identical to those of the nearby beaches. The percentage of heavy minerals in the dune sands is exceptionally high, ranging between 22 and 62 percent of the total sand fraction.

ESTUARY

In Yaquina Bay, three realms of deposition, Marine, Fluviatile, and Marine-Fluviatile are recognized on the basis of sediment texture and mineralogy (Figure 34). The Marine Realm extends 1.5 miles into the entrance of the estuary and is typified by normal marine salinity and vigorous tidal action. Sediments of this realm are similar to those of the adjacent beach and coastal dune sands and consist of well-sorted, subangular to subrounded, fine to medium sand. The immature arkosic sands in this realm are distinguished by the marine suite of heavy minerals which include abundant pyroxenes, primarily hypersthene and diopside, and such metamorphic minerals as kyanite, sillimanite, and staurolite. Especially diagnostic of the Marine Realm are the "yellow grains," which invariably constitute about 10 percent of the light mineral fraction.

The Fluviatile Realm occurs between the fresh-water head of the estuary in the vicinity of Elk City and reaches to Oneatta Point, 6 miles from the entrance, where brackish water conditions prevail. The poorly sorted, angular to subangular sediments of this realm range in grain size from silt to coarse sand. They are somewhat more arkosic than the sands of the Marine Realm and are represented by the fluviatile suite of heavy minerals. This assemblage

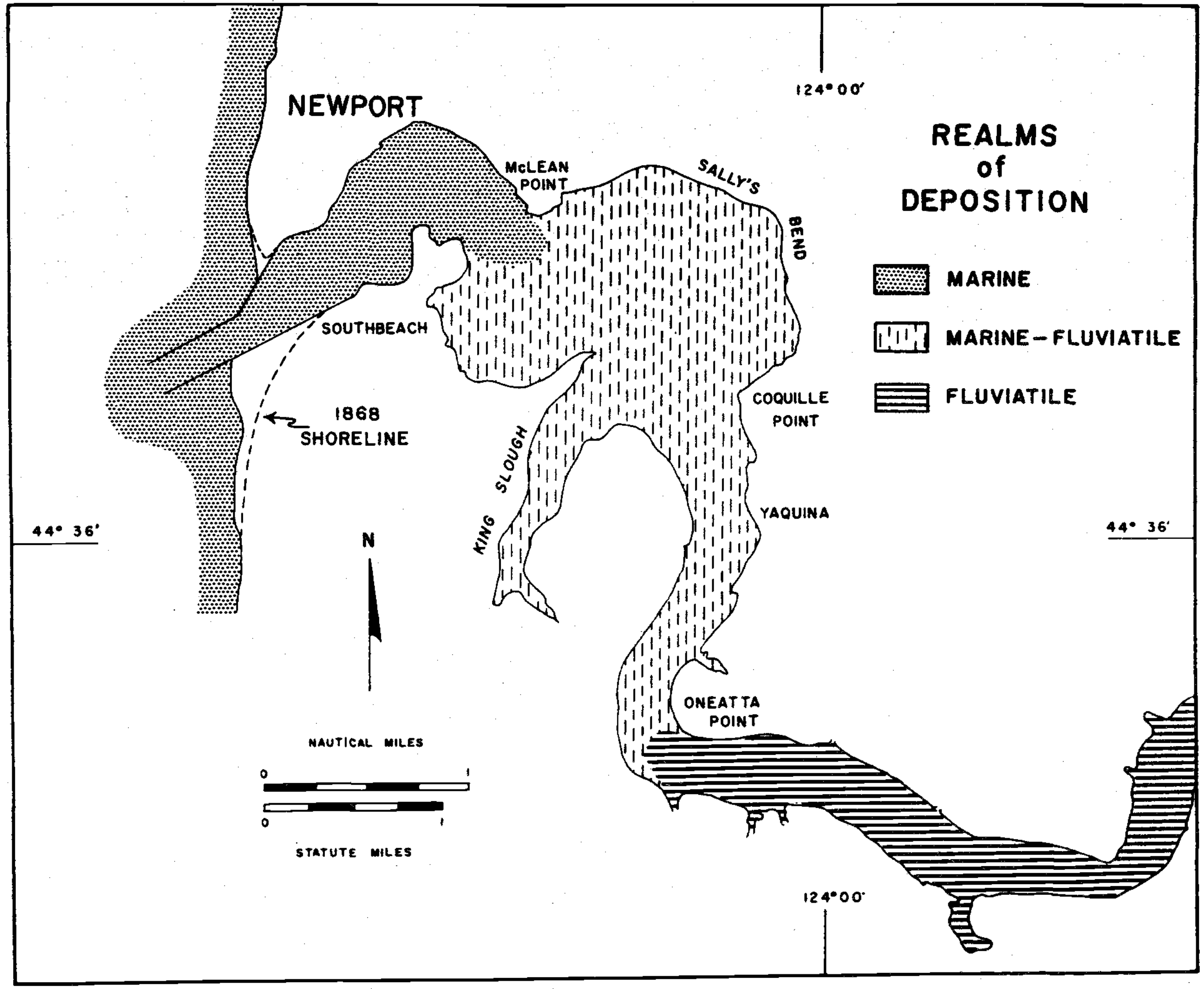

Figure 34. Realms of deposition in Yaquina Bay.

includes such diagnostic minerals as biotite and muscovite, and hematite and limonite. Diopside is absent and minor amounts of hypersthene occur in only a few samples. There is marked decrease in the abundance of garnet and the number of metamorphic species, compared with the Marine Realm.

The Marine-Fluviatile Realm, which consists of the river channel and the two marginal tidal flats, lies between the Fluviatile and Marine Realms. Normal marine to brackish water conditions are characteristic of this zone. A wide range of sediment texture and mineralogy occur in this realm. The well- to poorly sorted, angular to subrounded particles vary in grain size from silt to medium sand. Wide variations in mineralogy result because of admixtures of sediments from the adjoining Marine and Fluviatile Realms. The diminishing marine influence upstream from the bay entrance to Oneatta Point is demonstrated by the progressive landward decrease in the percent of "yellow grains" and of certain heavy minerals such as hypersthene, diopside, kyanite, sillimanite, and staurolite. In the vicinity of Oneatta Point most of these minerals terminate, thus marking the maximum landward intrusion of marine sedimentation. The two tidal flats are quite dissimilar in sediment texture and mineralogy. Sediments on Southbeach Tidal Flat are weighted as much towards the marine sands as those of Sallys Tidal Flat are towards the fluviatile sediments.

Source of Sediments

FLUVIATILE

The present drainage basin of the Yaquina River is the result of erosion following the Late Pliocene uplift of the Oregon Coast Range. Most sediments which are available to the drainage basin come from the weathering and erosion of the Tertiary sedimentary and igneous rocks on the western flank of the central Oregon Coast Range. Along the coast, a narrow belt of unconsolidated Quaternary estuarine, dune, and terrace deposits provide a local source of sediment to the Yaquina Bay area.

Although the composition of the Recent sediments in Yaquina estuary reflects the general character of the rocks in the Yaquina River drainage basin, it is difficult to evaluate the precise contribution of the many lithologic units. A detailed analysis of the light and heavy minerals of each formation would be necessary to make a comparison with the Recent sediments. It is not feasible in this study to make such a comparison; however, the general lithology can be ascertained from the description of the type section of each of the formations in the drainage basin. In the following discussion the author has attempted to correlate, wherever possible, the lithology of the rocks with similar characteristics of the Recent sediments of Yaquina Bay.

The textural and mineralogic character of the sediments near the head of the estuary reflect the composition of the widespread Middle Eocene Tyee Sandstone. The Tyee Formation, formerly known as the Burpee Formation (36, p. 455) and later correlated with the Tyee Formation named by Diller (12), has been recently estimated to be more than 10,000 feet thick along the Yaquina River. Baldwin states (4, p. 12),

> The Tyee Formation is a bluish-gray to gray, rhymically bedded, micaceous and arkosic sandstone and siltstone. The sandstone is firmly compacted and characterized by an abundance of mica (muscovite and bleached biotite) flakes.

Most of the Yaquina River drainage cuts through the Tyee Formation; therefore, it is probably the largest source of sediment in the drainage basin. The Recent sediments in the drainage system are arkosic and frequently contain high percentages of micas. Muscovite is generally more abundant than biotite, and both minerals commonly occur as large particles several millimeters in diameter. Lithic grains characteristic of the Tyee Sandstone were found in most samples collected from the Yaquina River and Elk Creek.

In the vicinity of Toledo the Tyee Formation is unconformably overlain by the Toledo Formation (Late Eocene to Middle Oligocene). This formation has been subdivided into two members, the Moody Shale (lower member) and the Upper Sandy Member. According to Vokes, Norbisrath, and Snavely (43), the lower member consists of,

> ..... dark-gray to black, hard, tuffaceous mudstones, often intricately fractured, with occasional discontinuous, irregular, hard cemented limy bands a few inches in thickness. Interbedded fine- and medium-grained sandstone containing much coarse pumiceous material and abundant glauconite occur at several horizons..... The rock weathers easily to form slopes of soft light-gray to rust colored, crumbly fragments.

The rust-colored weathering products described were observed in the sediments of the river channel between Toledo and Oneatta Point.

The Upper Sandy Member is Middle Oligocene in age and is composed of,

> .....fine-grained argillaceous and micaceous, tuffaceous sandstones, tuffaceous siltstones and shales with thin glauconitic beds.

(43). The Upper Sandy Member is most likely the source of the few scattered grains of glauconite found in the river channel seaward of Toledo.

The Yaquina Sandstone, which rest disconformably upon the Toledo Formation, has its type section at the town of Yaquina (17, p. 6-7). Vokes, Norbisrath, and Snavely (43) describe the Yaquina

Formation as follows:

> ..... Along the banks of the Yaquina River in the Type area, the lower part of the section consists mainly of relatively coarse-grained, massive, micaceous sandstones that contain an abundance of tuffaceous material. ..... The upper two-thirds of the formation in this area consists of fine- to medium-grained, grayish to brown, massive, micaceous and tuffaceous sandstone.

Faunal investigation by Vokes, Norbisrath, and Snavely (43) indicate this formation is Upper Oligocene.

In the vicinity of the tidal flats of Yaquina Bay, the Nye Mudstone disconformably overlies the Yaquina Formation. Schenck (36, p. 456) named the formation, and its type section is along the margin of Sallys Tidal Flat at the eastern edge of Newport and eastward toward Yaquina station. Vokes, Norbisrath, and Snavely(43) describe the formation as follows:

> ..... a monotonous series of dark-gray to black smooth-fracturing mudstones with occasional siltstone layers and, rarely, thin beds or aligned lenses of hard, calcareous material..... Exposures of the formation are readily and deeply weathered, so that the bedrock is usually covered with a layer of small, angular chips of iron-stained rubble and soft, grayish-brown clay.

Fauna and stratigraphic position indicate the Nye Formation is Early Miocene in age.

Along the north shore of Sallys Tidal Flat deposits similar to the Nye Mudstone, especially the weathered residue, were noted in the tidal flat sediments. The core taken at YB-85 is composed, among other things, of iron-stained detrital material and claystone. Small tributaries in the cliffed Nye Formation along the north side of the bay formerly drained onto the tidal flat before the road that rims the flat was constructed.

The Astoria Formation has the smallest river drainage because of its seaward position and relatively small areal extent. It is Middle Miocene in age and occurs mainly north of the bay entrance and north of Newport. According to Vokes, Norbisrath, and Snavely (43), the Astoria Formation has the following characteristics:

> ..... The predominant rock types consist of gray to blue-gray, fairly soft, fine- to medium-grained sandstone that is often feldspathic and in places tuffaceous. Dark greenish-gray pebblestones and conglomerates are locally present, as are a few beds of white to light-gray, firm and fairly hard, fine-textured tuff.....

Herron (19, p. 16-18) investigated these deposits and prefers to call them the Agate Beach Formation since they cannot be correlated with reasonable certainty with the type section of the Astoria Formation. The affect of the Astoria Formation on the sediments of Yaquina Bay is not known.

The Quaternary deposits in the coastal portion of the drainage basin overlie the older Tertiary rocks. They consist locally of Upper Pleistocene estuarine deposits overlain by marine terrace sands and gravels (3). The estuarine deposits have been correlated by Baldwin (3) with the Coquille Formation, which are local estuarine deposits at the mouth of the Coquille River in southern Oregon. Baldwin (3) describes the Coquille Formation in the vicinity of Newport as follows:

> ..... predominantly claystone and muddy sandstone with intercalated fragments of wood, some being quite large stumps and logs, and conglomerate..... The conglomerates contain pebbles of rocks common in Yaquina River drainage and a few whose source is not readily recognized.

Large fragments of wood, pebbles, and claystone constitute a fairly large percentage of the sediments in core YB-85. Fragments of wood were also noted in core YB-87. Some of these sediments appear to be similar to those described in the Coquille Formation. According to Heacock (18, p. 10), the Coquille Formation occurs in scattered patches along this portion of the shoreline.

Unconformably overlying the Coquille Formation are the marine terrace sands and gravels whose base is a wave-cut platform in the Nye and Astoria Formations on Nye Beach (3). The terrace deposits were originally named the Elk River beds by Diller (13, p. 30-31). However, they were later restricted by Baldwin (2, p. 37-39 and p. 42-43). The section restricted as the Elk River beds is described by Diller (11, Figure 14, p. 482) for a portion of the cliff near Newport Point one-half mile southwest of Newport. The uppermost segment of the section contains wind blown sand, underlain by a thick mass of partly indurated stratified yellow sand. This yellowish sand deposit resembles a similar deposit in the cliff at Nye Beach. Along the south shore of Yaquina Bay in the vicinity of Hinton Point, the upper three-fourths of the bluff is covered by stratified sandy deposits underlain by horizontal argillaceous strata. These sands were noted by the author along a good portion of the shore near the entrance of the estuary. Pleistocene deposits appear to have their greatest thickness close to the mouth of the bay.

The mineralogy and texture of the Recent sediments of Southbeach Tidal Flat, the estuary entrance channel to McLean Point, the adjacent ocean beaches, and the nearby coastal dunes are similar to those of the Elk River beds. Estuarine Coquille River sediments appear to be present on Sallys Tidal Flat in the vicinity of station YB-85. The present-day sediments in the lower reaches of the estuary were probably derived locally, in part, from the older Pleistocene deposits and from the Tertiary sediments in the Yaquina River drainage basin.

MARINE

Since sediments are made available to the present beaches in the Yaquina Bay area through agencies of transport from different directions and unrelated geologic areas, it is difficult to trace the sediments to their sources. There is generally no well defined drainage system to which the source can be traced, as in the Yaquina River drainage basin.

Local sources for the beach sands are found in the immediate area of the northern ocean beach. The cliffed coastline here consists of the Astoria Formation overlain by poorly consolidated terrace deposits. Both source deposits are being actively eroded and the detrital material is being incorporated into the present beach sands. The mineralogy and texture of the terrace deposits and of the beach sands is quite similar. At the northern end of the beach, Yaquina Head, which is composed of coarse basaltic agglomerates and flows intruded by dikes of basalt, is contributing basalt pebbles and cobbles to the beach around the headland.

Some of the sediments carried by the Yaquina River undoubtedly reach the beaches and nearshore areas, but the relative amount of this material is believed to be very small, since the transport of marine sands into Yaquina Bay is so prominent.

Beach sands, other than those derived from obvious local sources, are the most difficult to trace to their parent rock. Because of longshore currents, the latitude of source areas is expanded considerably; therefore, the source rocks and source areas must be inferred from the mineralogy of the beach sands. The immature mineral assemblage indicates that these sediments were derived from a tectonically active source area of moderate to high relief in which erosion was rapid. The Oregon Coast Range and the Klamath-Siskiyou mountains of southwestern Oregon and northern California are the closest sources which have coastal drainage with these characteristics. To the north the Columbia River drainage basin also has large areas with similar properties.

All three rock types, sedimentary, igneous, and metamorphic, are represented in the mineralogy of the marine sands. The rock sources, as shown by the large percentages of intermediate to calcic plagioclase feldspar, augite, hypersthene, ilmenite, leucoxene, magnetite, and chromite, are for the most part basic igneous rocks (31, p. 513). However, there are a number of metamorphic mineral species such as kyanite, sillimanite, garnet, epidote, staurolite, hornblende (blue-green variety), and quartz (metamorphic) which together constitute a large portion of the mineral assemblage; these minerals suggest a rather extensive metamorphic source. Minor second cycle components such as chert, zircon (well-rounded), well-rounded quartz grains, and leucoxene are indicative of sedimentary source rocks.

Basic igneous and sedimentary rocks are widespread throughout the Oregon Coast Range and are, in part, sources of sediment for the Recent beach deposits along the Oregon coast. To the south, along the Oregon-California border, the Klamath-Siskiyou Mountains consist of a complex of igneous, sedimentary, and metamorphic rocks. Source rocks in the Columbia River drainage basin are numerous and widespread. This drainage basin has an area of roughly 260,000 square miles and contains approximately 50 percent volcanic, 18 percent sedimentary, 17 percent metamorphic, and 15 percent intrusive rocks. Sediments from the Columbia River drainage basin are more likely to be the source of metamorphic and many other mineral constituents than the sediments from the Klamath-Siskiyou drainage basin because longshore drift appears to have a predominate southward component along the central Oregon coast.

PROCESSES OF TRANSPORTATION AND DEPOSITION

Sites of Deposition

SHORELINE

Southern Ocean Beach

Comparison of old bathymetric survey charts with the more recent ones of the Yaquina Bay area show that the most pronounced area of deposition is adjacent to the south jetty on the southern ocean beach. Three stages of the prograding shoreline south of the jetty are seen for the years 1868, 1899, and 1953 (Figure 35). In 1868, before the jetties were constructed, the shoreline was probably in equilibrium, however considerable deposition resulted after the construction of the sea walls in 1885.

The predominate direction of littoral drift is from north to south during the spring, summer, and early fall and from south to north during late fall and winter (see section on littoral drift). Sediments are generally transported along the beaches without interruption according to the predominate direction of longshore drift providing there are no obstructions to the drift such as jetties or promontories.

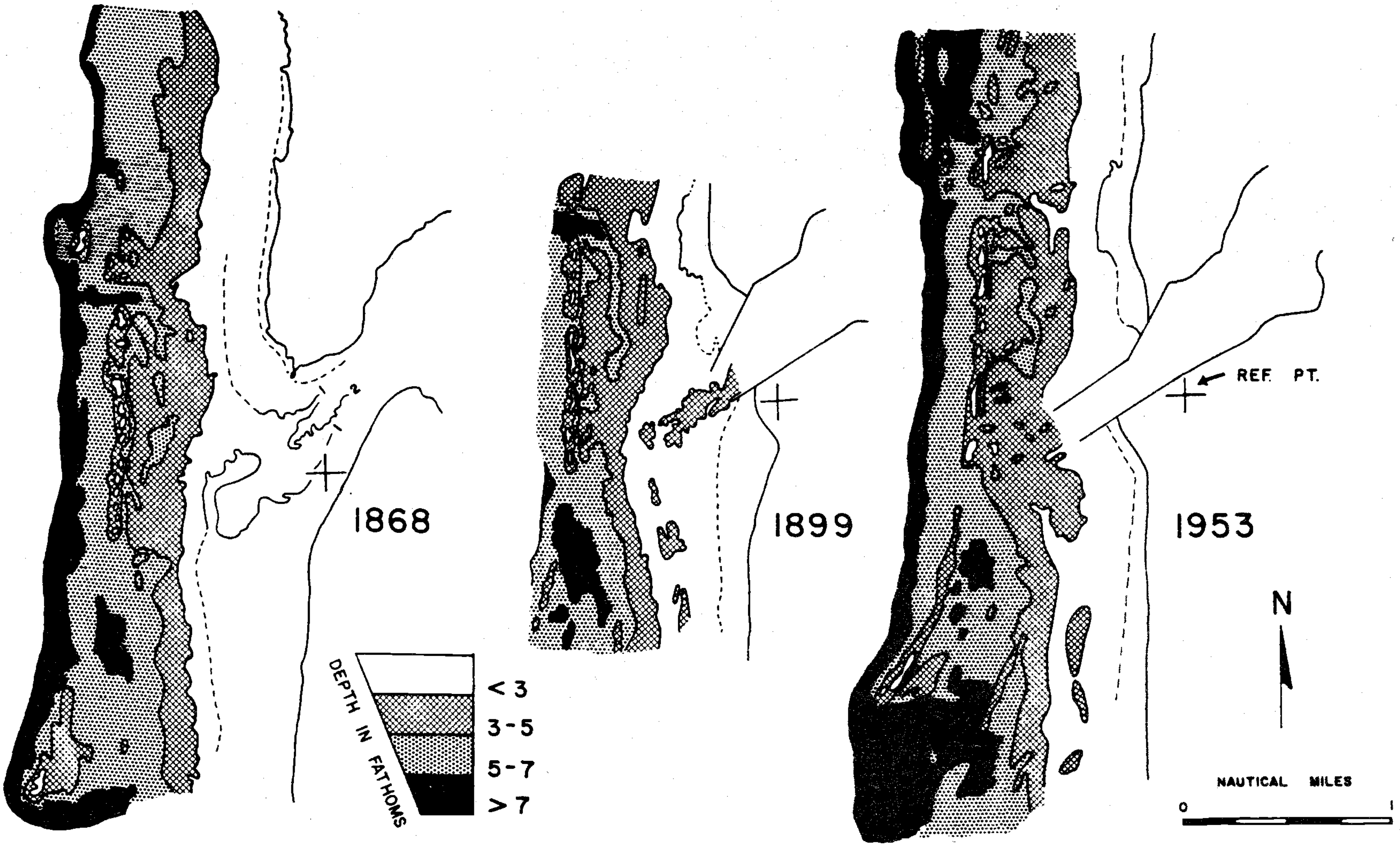

Figure 35. Nearshore and shoreline development in the vicinity of Yaquina Bay from 1868 to 1953.

Deposition occurs south of the south jetty when sediments are being supplied from the southern beaches by northward longshore drift. The accumulation of sediment has been negligible, however, north of the north jetty because of the lack of supply of sediment from the northern beaches. Several factors probably affect the supply of sediment from the beach north of Yaquina Head to the beach between the north jetty of Yaquina Bay and Yaquina Head. The general structural strike of the topographic highs offshore, Yaquina Reef and South Reef, is in a southwest-northeast direction. This series of offshore reefs terminates abruptly on the northern end against Yaquina Head. The lack of accumulation of sand behind the north jetty indicates the southward longshore drift is probably impeded between the headland and the jetty. The beach surrounding the headland is composed of gravels and evidence of only slight movement of sand in the surf zone around the headland has been noted. Whether the headland or the reef structure or both disrupt the southward drift is not known, but the transport of fine sand into this area from the north is restricted. In contrast, the transport of fine sand from the south is uninterrupted for approximately 8.2 miles until it reaches the southern jetty, where it accumulates, or is carried into the estuary by strong tidal currents.

Rate of Deposition

A rough approximation of the rate of sedimentation along the southern shoreline can be ascertained from the amount of material deposited since the construction of the south jetty in 1888. By comparing the positions of the 1888 and 1961 shorelines, Rosenberg (35) estimated that about 20,000 cubic yards of sediment had been deposited over a period of 73 years. This represents an average annual supply of 274 cubic yards of material.

YAQUINA BAY

Basin-Channel-Bar

Recent deposition in estuaries is not only of geologic interest, but of primary concern to mariners because of the inevitable shoaling of the shipping channels. Shoaling in Yaquina Bay is a perennial problem faced by the U. S. Corps of Engineers who have the job of keeping the channel open. The turning basin opposite McLean Point, the channel seaward of the turning basin, and the channel across the bar are dredged annually to depths of 22, 20, and 26 feet respectively. Before each dredging, a predredge survey consisting of many soundings is carried out to determine the shoal areas. Annual predredge survey charts of Yaquina Bay from 1950 to 1961* were kindly supplied

*1957 charts were not available.

to the author by the U. S. Corps of Engineers for this study.

When the survey charts are compared over the eleven-year period from 1950 to 1961, a striking similarity is seen between the areas of shoaling. Since there is no average year in terms of shoaling, three survey charts have been selected to show the pattern of deposition during the years mentioned.

The pattern of deposition in 1951 (Figure 36) is typical for the years 1950 to 1953. In the turning basin, deposition occurred in areas 1 and 2; however, area 1 was apparently not considered a part of the basin until 1953. In the channel, segments 3, 4, and 5 were shoaled randomly with about 1 to 2 feet of sediment. Little or no deposition, however, occurred in segment 6, which represents nearly 40 percent of the channel surface area. Between the jetties, in segment 7, the north side of the channel was invariably the site of a great deal of deposition. No sedimentation took place in segment 8, which lies between 7 and the end of the jetties. The bar, situated beyond the mouth of the jetties, was the site of the thickest accumulation of sediment in the channel. Nearly 6 feet of sand was deposited in several places between the end of the jetty and the offshore reefs (segment 9).

In 1954 the same segments (4, 5, and 7) of the channel shoaled as in 1951, but in 1954 deposition was prominent over most of the

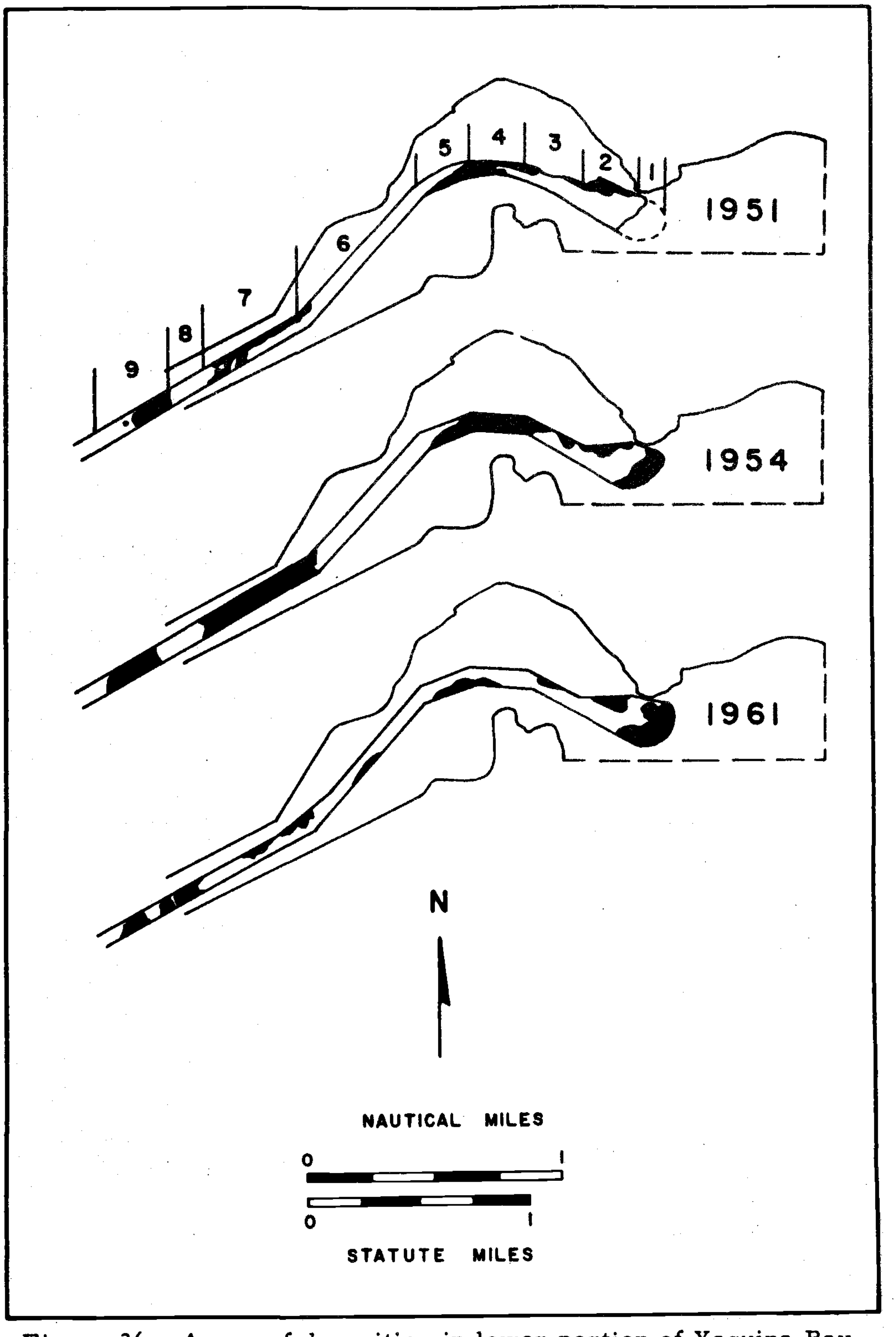

Figure 36. Areas of deposition in lower portion of Yaquina Bay from 1950 to 1961. Channel is divided into numbered segments for discussion in text.

surface area of the channel. Also, a much larger area of the turning basin (segment 1) was covered by sediment than in the previous year. Shoaling on the bar was extensive in 1954, and deposits 8 feet thick occurred in numerous places. The year 1954 was abnormal in comparison to the other years investigated because of the extensive area shoaled and the thicker accumulations of sediment.

The year 1961 is representative of the period from 1955 to 1961. From 1955 to the present, the pattern of deposition has changed in segments 4, 5, and 6. Shoaling occurred for the first time only along the south side of the channel in segments 4 and 5, and at the western end of segment 6. For the first time, segment 8 accumulated a slight amount of sediment over a large area. As in the past, most of the bar was shoaled, but this time with only about 2 feet of sediment.

In all years studied, deposition was slight or non-existent in segments 6 and 8. The absence of shoals near the seaward extremities of the jetties (except 1961) is probably due to the increase in current velocity which is associated with the abrupt decrease in cross-sectional area at the mouth of the jetties. Although the amount of material deposited on the bar was variable from 1950 to 1961, more than two-thirds of the surface area of the bar has been consistently shoaled by at least 2 feet of sediment.

When longshore drift is from south to north in winter, sediment should be transported inside the trough-like structure between the southern beach and the offshore reefs. This drifting beach sand may be the predominant source of sediment supplied to the bar and carried into the bay by flood tidal currents in the winter.

In order to transport the drifting beach sands into the entrance of the estuary, the bottom flood tidal currents must be of sufficient magnitude. A maximum average velocity of 109 cm/s was computed from the tidal prism at the jetty entrance where the cross-sectional area is at a minimum. Current velocities in excess of 50 cm/s were found to exist on the bottom flood tide as far upstream as the turning basin opposite McLean Point. According to Hjulstrom (21, p. 9-11) a velocity of 20 cm/s is sufficient to erode and transport fine sands. As the cross-sectional area increase upstream into the lower reaches of the estuary, current velocities will dissipate to a minimum value at which transport of sediment is no longer possible either by suspension or by traction. Because no marine sands are found above Oneatta Point, it is assumed that the current velocity falls below the minimum value needed for the transport of fine sand at this position. Marine sands seaward of Oneatta Point decrease in abundance upstream from the estuary mouth with decreasing flood current velocities.

The coastal dunes south of the bay entrance are also a source of shoaling material in the bay. When the wind is from the southwest, dune sand is blown over the jetty wall into the tidal channel and onto the tidal flat, at least as far inland as the sand spit projecting into the estuary from Southbeach.

Rate of Deposition

The rate of deposition of sediment in the estuarine channel, between the entrance of the jetties and the upstream end of the turning basin, can be computed by use of the dredging records of the U. S. Army Corps of Engineers, Portland District. An average of 245, 417 cubic yards of sediment has been dredged annually from this area over the 6-year period from 1956-1961. The square area of the region is approximately 619, 588 square yards. If the total volume of sediment removed is divided by the area of the region, the average rate of accumulation is estimated to be 9.1 inches per year. Marine sand is the principal shoaling material in these areas.

Seasonal Fluctuations in Transportation and Deposition

Four factors, type of estuarine system, river runoff, direction of littoral drift, and wind direction, influence the rate, magnitude, and extent of sedimentation in the estuary. All four factors are related to meteorological conditions; consequently, they change with the seasonal climatic fluctuations.

The sediment load that is carried in the Yaquina River drainage to the estuary reaches a maximum following periods of high rainfall in the winter and spring (Figure 37). Since littoral drift is generally from south to north at this time of the year, the marine influx of sediment into the lower reaches of the estuary should also be at a maximum. As the estuarine system tends to approach a two-layered system at this time (due to increased precipitation) the bottom flood current velocities increase, thus enhancing the movement of marine sediments into the estuary and on up the channel. The point of maximum inland intrusion should occur at this time since the salt wedge, which is fairly well defined, penetrates upstream to its greatest extent.

During the summer and fall, the estuarine system is well-mixed because of the negligible precipitation, which results in a net non-tidal flow outward at all levels; therefore, the marine intrusion of sediments should be inhibited. Also at this time of the year the littoral drift is from north to south, but because of the irregular physiography of the northern coast it is not an effective agent for transporting sediments along the north beach to the mouth of the estuary. From these observations it is apparent that the rate of

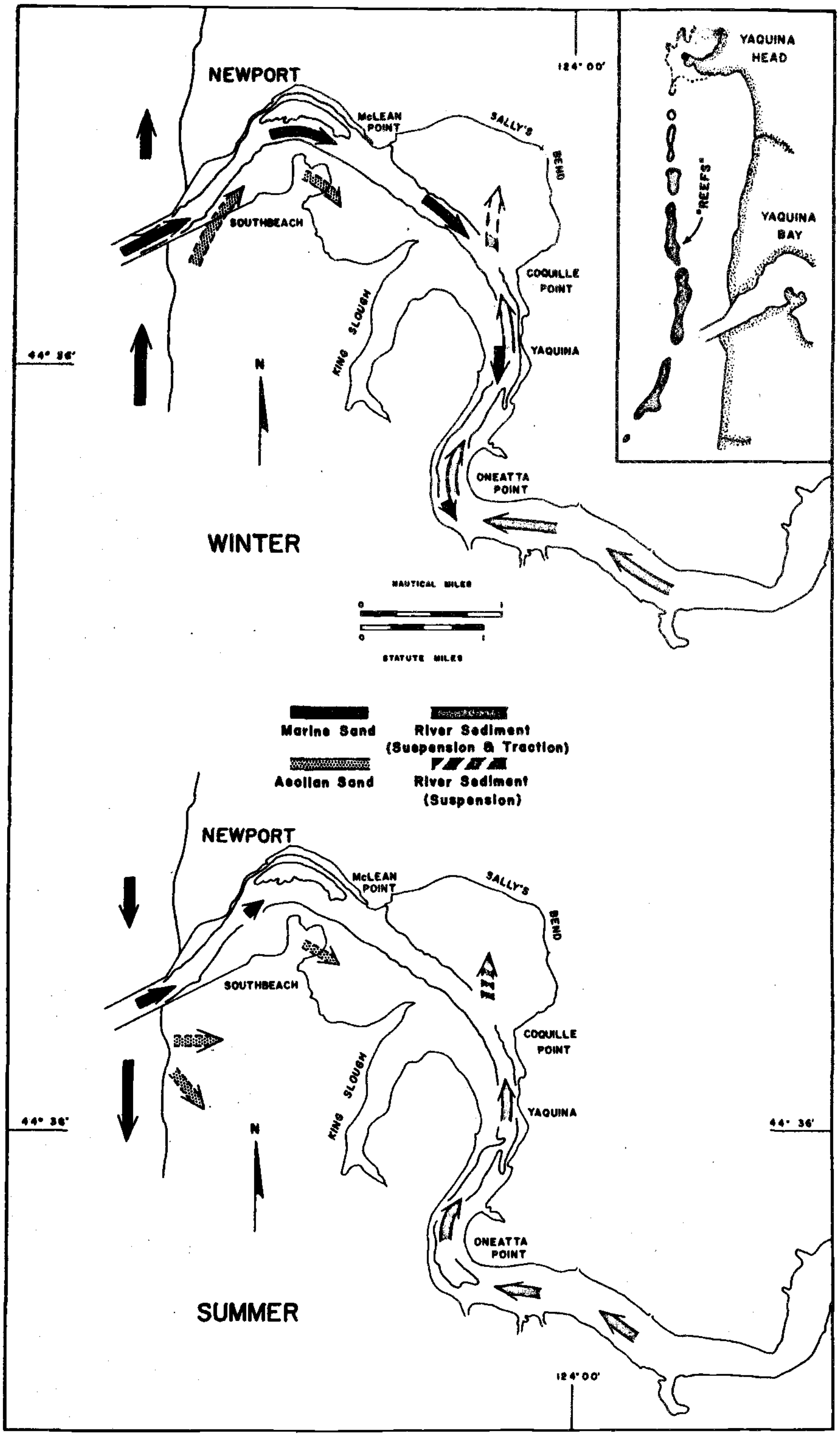

Figure 37. Inferred seasonal transportational and depositional patterns in Yaquina Bay. The lengths of the arrows indicate the relative magnitude of sediment transport and deposition by the various sedimentary processes.

sedimentation from both marine and fluviatile sources is at a minimum during the summer and fall.

Seasonal changes in the rate of aeolian deposition in the estuary are analogous to those just described. The maximum rate of sedimentation due to the transportation of dune sands into the lower reaches of the estuary generally occurs during the winter and spring when the high velocity winds are from the south and southwest. In contrast, in the summer and fall the prevailing winds are from the northwest, and there is little or no deposition in the estuary from the adjacent dune sands. However, it must be kept in mind that the wind direction changes frequently along the Oregon coast and deposition of aeolian sands could occur at any time.

CONCLUSIONS

1. Three sedimentary Realms, Marine, Fluviatile, and Marine-Fluviatile, can be defined in Yaquina Bay on the basis of sediment texture and mineralogy. The Marine Realm extends 1.5 miles into the entrance of the estuary and is characterized by normal marine waters and vigorous tidal action. Sediments of this realm are texturally and mineralogically related to the fine sands of the adjacent beaches and nearby coastal dunes. The Fluviatile Realm occurs between the fresh-water head of the estuary and reaches to a point 6 miles from the entrance at Oneatta Point. Brackish water conditions prevail. Sediments of this realm originate from the Yaquina River drainage basin. The Marine-Fluviatile Realm is physiographically represented by the river channel and the two marginal tidal flats and lies between the Marine and the Fluviatile Realms. Marine to brackish water conditions are indicative of this region. The sediments deposited here contain varying percentages of sediment particles derived from the adjoining Marine and Fluviatile Realms.

2. The sources of the Recent sediments in the Yaquina Bay area are quite diverse and widespread. The chief sources of the sediment carried by the Yaquina River drainage to Yaquina Bay are the Tertiary sandstones, siltstones, and mudstones, and basic

igneous intrusives of the central Oregon Coast Range. Near the bay mouth, Pleistocene marine terrace sands and estuarine deposits have been reworked by the wind and tidal currents. These sediments have been incorporated into the Recent beach, dune, and estuarine deposits. Since the beach sands are transported along the coast by seasonal littoral drift, other distant sediment sources may include the Klamath-Siskiyou Mountain complex in southern Oregon and northern California, and the numerous geologic provinces in the Columbia River drainage basin.

3. Marine sands from the adjacent ocean beaches are transported into the estuary by strong tidal currents and to Oneatta Point 6 miles from the entrance. Also, nearby coastal dune sands are blown into the tidal channel near the mouth of the estuary and onto the southwestern shore of Southbeach Tidal Flat by strong onshore winds. The amount of marine sand transported into the estuarine channel decreases upstream according to the decreasing bottom flood current velocities.

4. In Yaquina Bay, known areas of shoaling occur on the bar, in the main channel, and in the turning basin. The shoaled areas have maintained a farly constant position with only minor changes in the depositional pattern from 1950 to 1961. On the basis of material removed by dredging, the average rate of sedimentation in the

channel and turning basin is estimated to be 9.1 inches per unit area per year. Marine sand is the principal shoaling material in these areas. Extensive deposition has occurred on the southern ocean beach behind the south jetty since it was constructed in 1888. This barrier to northward longshore drift has caused the shoreline to prograde seaward with each new addition of the sea wall. An estimated 274 cubic yards of material have accumulated annually during the past 73 years. Very little sediment has accumulated behind the north jetty on the northern ocean beach because of the lack of supply of material from the northern beaches. Physiographic barriers along the coast, Yaquina Head and several shallow offshore reefs, apparently divert or disrupt the southward drift of beach sands between Yaquina Head and the entrance of Yaquina Bay, thus inhibiting the supply of sediment to the northern ocean beach.

5. Sedimentation in Yaquina Bay appears to be largely seasonal. Maximum deposition should occur in the bay during the winter and spring. At this time river runoff is highest, the longshore drift is from south to north, and the highest velocity winds originate from the southwest. During periods of high runoff, the tidal circulation pattern of the partly-mixed estuarine system is especially effective in transporting drifting beach sands into the entrance of the estuary. Strong southwest winter winds also enhance the movement of coastal

dune sands into the tidal entrance and onto the southwestern shore of Southbeach Tidal Flat. Conversely, during the summer and early fall little deposition occurs because precipitation is negligible, littoral drift is from north to south, and the relatively low velocity winds are predominantly from the northwest. In summer the well-mixed estuarine system inhibits the transport of marine sands into the estuary since there is a net non-tidal flow outward at all depths. The physiography of the coast and nearshore areas impede the supply of sediment from the north, thus little marine sand is available for deposition onshore or in the estuary. The predominant northwest winds also divert the coastal dune sands away from the southwest shore of the bay entrance.

6. The type of estuarine system present at any given time in Yaquina Bay is dependent upon seasonal climatic conditions. Complete annual salinity data collected during the years 1940-1941, 1960-1961, and 1961-1962 show that, although seasonal variations in estuarine types are usually similar from one year to the next, marked changes in mixing patterns can occur during all seasons with the exception of summer which consistently exhibits a well-mixed estuarine system. In general, the estuary is partly-mixed in winter, well-mixed in summer, and can alternate between these two types during the spring and fall. These data confirm the results of a

similar but more general study made by Burt and McAlister (8, Table 1, p. 22). The chief factor effecting the type of estuarine system present at any given time is the river runoff, which is largely a function of the amount and rate of seasonal precipitation in the bay area. Since the drainage basin is small, the number of inches of rainfall recorded at Newport are generally proportional to the average monthly change in salinity between the top and bottom of the channel in the lower reaches of the estuary. In this manner the precipitation at Newport reflects the type of estuarine system present during each month of the year for any given year.

7. The estuarine waters of Yaquina Bay strongly reflect the nature and origin of their sources. In summer, the high salinities, low temperatures, and dissolved oxygen values of the homogeneous waters of the lower reaches of the estuary are characteristic of upwelled bottom waters off the Oregon coast at Newport. In winter, physical-chemical properties of the bottom waters in the estuary correlate remarkably well with those at the surface 5 miles offshore. On the other hand, the surface waters of the bay reflect more closely the character of the out flowing fluviatile waters.

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APPENDICES

Appendix 1. Textural Data

Sample number	Md (mm)	Mdϕ	σ_ϕ	$\alpha_{1\phi}$	$\alpha_{2\phi}$	β	Percent Sand	Percent Silt	Percent Clay	Environment*
YB-1	.121	3.05	1.97	0.63	---	---	67	22	11	RC
YB-2	.044	4.49	3.39	0.57	---	---	40	36	24	RC
YB-3	.127	2.97	0.73	0.26	0.63	0.82	87	13	---	RC
YB-4	.093	3.43	3.06	0.70	---	---	60	29	11	RC
YB-5	.102	3.29	0.69	-0.06	-0.12	0.60	89	11	---	RC
YB-6	.190	2.40	0.31	-0.03	-1.22	1.38	40	35	25	RC
YB-7	.110	3.17	1.37	0.70	1.56	1.08	75	18	7	RC
YB-8	.218	2.20	2.64	0.65	1.08	0.36	75	17	8	RC
YB-9	.230	2.12	0.37	-0.06	-0.38	1.00	100	---	---	RC
YB-10	.010	6.64	2.94	0.03	---	---	20	43	37	RB
YB-12	.043	4.54	2.60	0.60	---	---	31	48	21	SL
YB-13	.076	3.72	2.58	0.64	---	---	59	25	16	RB
YB-14	.019	5.70	2.97	0.26	---	---	25	48	27	RB
YB-15	.082	3.61	1.58	0.39	---	---	64	24	12	RB
YB-15A	.071	3.82	2.46	0.45	---	---	58	27	15	RB
YB-16	.140	2.84	1.42	0.23	---	---	77	15	8	TF
YB-17	.165	2.60	0.65	0.12	0.58	1.63	91	9	---	TF

*BLF, Beach, Lower Foreshore; BMD, Beach, Upper Foreshore Migrating Dune; BUF, Beach, Upper Foreshore; MCD, Migrating Coastal Dune; SCD, Stable Coastal Dune; SF, Sand Flat; SL, Slough; SS, Sand Spit; TF, Tidal Flat; TS, Terrace Sand; RB, River Bank; RC, River Channel.

Appendix 1. Textural Data (Continued)

Sample number	Md (mm)	Mdϕ	$\sigma\phi$	$\alpha 1\phi$	$\alpha 2\phi$	β	Percent Sand	Percent Silt	Percent Clay	Environment*
YB-18	.202	2.31	0.34	0.03	-0.26	0.70	100	---	---	RC
YB-18A	.226	2.15	0.25	-0.12	-0.28	0.76	100	---	---	SF
YB-19	.231	2.12	0.23	-0.22	-0.44	1.00	100	---	---	RC
YB-20	.268	1.90	0.39	-0.05	-0.16	0.47	100	---	---	RC
YB-21	.225	2.15	0.40	-0.43	-0.75	0.50	100	---	---	RC
YB-22	.198	2.33	0.40	-0.15	-0.40	0.60	100	---	---	RC
YB-23	.200	2.32	0.29	-0.10	-0.69	0.93	100	---	---	RC
YB-24	.218	2.20	0.35	-0.34	-0.72	0.77	100	---	---	RC
YB-25	.236	2.09	0.43	-0.16	-0.30	0.63	100	---	---	RC
YB-26	.186	2.43	0.32	0.00	-0.38	0.69	100	---	---	RC
YB-27	.215	2.22	0.32	-0.22	-0.60	0.59	100	---	---	RC
YB-28	.228	2.14	0.46	-0.26	-0.31	0.81	100	---	---	RC
YB-29	.291	1.78	0.31	-0.10	-0.16	0.62	100	---	---	RC
YB-30	.150	2.74	0.88	0.58	---	---	83	11	6	RC
YB-31	.390	1.36	0.33	0.36	0.94	1.73	100	---	---	RC
YB-32	.315	1.67	0.36	0.28	-0.08	0.67	100	---	---	RC
YB-33	.330	1.60	0.36	-0.14	-0.11	0.48	100	---	---	RC
YB-34	.220	2.18	0.87	0.58	3.21	2.90	87	8	5	RC
YB-35	.168	2.57	0.58	0.21	0.40	0.88	97	3	---	RC
YB-36	.171	2.55	1.03	0.68	1.22	1.22	84	16	---	RC
YB-37	.235	2.09	0.37	-0.16	-0.22	0.68	100	---	---	RC
YB-38	.256	1.97	0.40	-0.10	0.00	0.85	100	---	---	RC

Appendix 1. Textural Data (Continued)

Sample number	Md (mm)	Mdϕ	$\sigma\phi$	$\alpha 1\phi$	$\alpha 2\phi$	β	Percent			Environment*
							Sand	Silt	Clay	
YB-39	.238	2.07	0.39	0.31	0.80	1.05	98	2	---	RC
YB-40	.305	1.71	0.52	-0.42	-0.84	1.03	100	---	---	RC
YB-41	.366	1.45	0.39	-0.08	-0.90	1.79	100	---	---	RC
YB-42	.321	1.64	0.42	0.00	-0.05	0.48	100	---	---	RC
YB-43	.329	1.60	0.44	-0.09	-0.35	0.82	100	---	---	RC
YB-45	.042	4.57	3.10	0.57	---	---	39	37	24	SL
YB-46	.059	4.08	2.32	0.64	---	---	48	36	16	TF
YB-47	.024	5.38	2.96	0.37	---	---	26	48	26	TF
YB-48	.055	4.17	2.31	0.50	---	---	45	40	15	TF
YB-49	.063	4.00	2.52	0.53	---	---	50	34	16	TF
YB-50	.040	4.64	2.20	0.37	0.66	0.52	34	52	14	SL
YB-51	.080	3.64	2.20	0.44	---	---	56	33	11	TF
YB-52	.180	2.47	0.98	0.63	1.41	2.46	84	10	6	TF
YB-53	.094	3.41	1.71	0.61	1.51	1.02	70	20	10	RB
YB-54	.171	2.55	0.35	-0.09	-0.60	1.48	97	3	---	RC
YB-55	.255	1.97	0.40	-0.18	-0.25	0.62	100	---	---	RC
YB-56	.321	1.64	0.52	-0.18	0.60	0.51	100	---	---	RC
YB-57	.473	1.08	0.40	-0.03	0.00	0.80	100	---	---	RC
YB-58	.529	0.92	0.83	0.05	---	---	98	2	---	RC
YB-59	2.20	-1.13	---	---	---	---	---	---	---	RC
YB-60	.068	3.88	3.54	0.70	---	---	44	36	20	RB
YB-61	.076	3.72	3.28	0.66	---	---	56	27	17	RB

Appendix 1. Textural Data (Continued)

Sample number	Md (mm)	Mdϕ	σ_ϕ	$\alpha_{1\phi}$	$\alpha_{2\phi}$	β	Percent Sand	Silt	Clay	Environment*
YB-62	.046	4.44	---	---	---	---	43	31	26	RB
YB-63	.160	2.64	1.40	0.74	---	---	80	10	10	RC
YB-64	.220	2.18	0.52	-0.10	0.75	1.77	95	5	---	RC
YB-65	.210	2.25	0.27	-0.15	-0.26	0.56	100	---	---	RC
YB-66	.260	1.94	0.40	-0.17	-0.52	0.98	100	---	---	RC
YB-67	.158	2.66	2.30	0.62	---	---	73	17	10	RC
YB-69	.052	4.27	2.91	0.60	---	---	42	40	18	TF
YB-70	.126	2.99	0.90	0.25	2.75	2.86	83	12	5	TF
YB-71	.168	2.57	0.43	0.02	0.61	1.37	96	4	---	TF
YB-72	.190	2.40	0.30	-0.13	-0.40	0.57	100	---	---	RC
YB-73	.132	2.92	1.21	0.52	1.04	0.78	76	24	---	TF
YB-74	.200	2.32	0.84	0.37	1.67	1.69	87	13	---	TF
YB-75	.221	2.18	0.47	0.30	2.36	2.57	92	8	---	TF
YB-76	.020	5.68	---	---	---	---	22	45	33	RB
YB-77	.066	3.92	3.00	0.59	---	---	52	29	19	RC
YB-78	.084	3.57	3.02	0.61	---	---	57	25	18	RC
YB-79	.140	2.84	2.66	0.35	---	---	69	17	14	RC
YB-80	.115	3.12	2.09	0.69	---	---	70	18	12	RC
YB-81	.050	4.32	3.05	0.57	---	---	44	34	22	RB
YB-85	.130	2.94	4.02	0.73	---	---	59	18	23	TF
YB-87	.080	3.64	3.29	0.35	---	---	60	22	18	TF
YB-88	.155	2.69	1.13	0.44	2.30	2.25	78	15	7	TF
YB-89	.146	2.78	0.74	0.12	2.41	2.81	89	7	4	TF

Appendix 1. Textural Data (Continued)

Sample number	Md (mm)	Mdϕ	$\sigma\phi$	$\alpha 1\phi$	$\alpha 2\phi$	β	Percent Sand	Silt	Clay	Environment*
YB-90	.200	2.32	0.64	0.41	4.47	4.38	86	8	6	TF
YB-B1	.185	2.43	0.24	-0.17	-0.37	0.58	100	---	---	BLF
YB-B2	.183	2.45	0.28	0.04	-0.10	0.80	100	---	---	BMD
YB-B3	.192	2.38	0.28	-0.15	-0.58	0.73	100	---	---	BLF
YB-B4	.210	2.25	0.26	-0.23	-0.46	0.85	100	---	---	BLF
YB-B5	.181	2.47	0.16	-0.23	-0.42	1.06	100	---	---	MCD
YB-B6	.176	2.51	0.22	-0.19	-0.36	0.55	100	---	---	SCD
YB-B7	.205	2.28	0.26	-0.08	-0.61	1.15	100	---	---	BLF
YB-B8	.194	2.36	0.27	0.00	-0.04	0.56	100	---	---	BMD
YB-B9	.209	2.26	0.24	0.00	-0.42	0.87	100	---	---	BLF
YB-B10	.225	2.15	0.26	-0.15	-0.42	0.69	100	---	---	BLF
YB-B11	.218	2.20	0.30	-0.07	-0.57	0.87	100	---	---	BUF
YB-B12	.214	2.22	0.25	0.00	-0.44	0.90	100	---	---	TS
YB-B13	.212	2.24	0.26	0.04	-0.23	0.50	100	---	---	BLF
YB-B14	.242	2.05	0.48	0.36	-0.79	0.94	100	---	---	BLF
YB-B15	.183	2.45	0.22	-0.09	-0.23	0.50	100	---	---	SCD
YB-B16	.223	2.18	0.22	-0.27	-0.59	0.64	100	---	---	SF
YB-B17	.178	2.49	0.39	-0.26	-0.69	1.31	100	---	---	SF
YB-B18	.206	2.28	0.37	-0.09	-0.08	0.48	100	---	---	SF
YB-B19	.264	1.92	0.31	-0.15	-0.08	0.52	100	---	---	SF
YB-B20	.199	2.33	0.25	-0.04	-0.44	0.64	100	---	---	MCD
YB-B21	.193	2.37	0.26	-0.04	-0.44	0.71	100	---	---	SF

Appendix 1. Textural Data (Continued)

Sample number	Md (mm)	Mdϕ	$\sigma \phi$	$\alpha_1 \phi$	$\alpha_2 \phi$	β	Percent Sand	Percent Silt	Percent Clay	Environment*
YB-B22	.203	2.30	0.25	-0.20	-0.48	0.68	100	---	---	MCD
YB-B23	.207	2.27	0.21	-0.09	-0.33	0.62	100	---	---	MCD
YB-B24	.210	2.25	0.28	-0.09	-0.29	0.50	100	---	---	BLF
YB-B25	.216	2.21	0.23	0.02	-0.13	0.62	100	---	---	BMD
YB-B26	.254	1.98	0.35	-0.35	-0.42	0.69	100	---	---	BLF
YB-B27	.233	2.10	0.20	0.00	-0.08	0.73	100	---	---	BLF
YB-B28	.200	2.32	0.27	0.06	-0.28	0.53	100	---	---	BMD
YB-B29	.183	2.45	0.22	-0.14	-0.36	0.59	100	---	---	SCD
YB-B30	.217	2.20	0.21	-0.05	-0.09	0.62	100	---	---	BLF
YB-B31	.190	2.40	0.26	-0.15	-0.31	0.54	100	---	---	MCD
YB-B32	.190	2.40	0.24	-0.04	-0.46	0.67	100	---	---	MCD
YB-B33	.197	2.36	0.26	-0.08	-0.31	0.62	100	---	---	MCD
YB-B34	.214	2.22	0.24	-0.08	-0.21	0.58	100	---	---	BLF
YB-B35	.225	2.15	0.23	-0.18	-0.27	0.44	100	---	---	BLF
YB-B36	.199	2.33	0.24	0.00	-0.52	0.77	100	---	---	BMD
YB-B37	.190	2.40	0.27	-0.15	-0.56	0.63	100	---	---	SS

Appendix 2. Heavy Mineral Counts of Selected Samples*
(Numbers are in percent.)

Sample No.:	YB-1	YB-2	YB-4	YB-16	YB-17	YB-19	YB-20
Actinolite	---	---	---	---	---	---	---
Andalusite	---	---	---	---	---	---	---
Apatite	2.8	1.0	2.6	---	---	---	1.1
Augite**	5.5	5.0	7.7	6.8	10.1	2.8	2.2
Basaltic Hornblende	---	---	---	0.4	0.3	2.0	1.6
Biotite	13.8	22.0	27.4	0.8	---	---	---
Chlorite	4.4	8.0	5.1	0.8	---	---	---
Diopside	---	---	---	3.4	3.3	12.0	15.9
Epidote	1.3	0.5	0.9	1.1	1.6	2.0	2.2
Garnet	4.1	1.0	1.7	6.4	9.1	7.6	8.3
Hematite	4.1	2.0	---	3.0	---	0.5	---
Hornblende	3.3	2.0	3.4	6.1	9.5	0.8	3.3
Hypersthene	2.2	---	---	4.5	7.2	5.2	4.4
Chromite-Ilmenite-Magnetite	17.7	1.0	20.5	33.7	36.9	12.0	8.8
Ilmenite-Leucoxene Alteration	5.2	4.0	6.8	3.0	0.6	2.8	3.8
Kyanite	1.3	---	---	---	---	0.5	---
Leucoxene	7.2	3.0	5.1	13.6	12.3	35.2	37.3
Limonite	2.1	4.0	---	---	---	---	---
Monazite	---	---	---	0.8	0.3	0.8	0.6
Muscovite	7.2	41.0	9.4	3.8	---	---	---
Olivine	---	---	---	---	---	0.5	---
Rutile	2.1	---	---	1.1	1.3	0.8	2.2
Sillimanite	---	---	---	---	---	0.2	---
Spinel	---	---	---	1.5	---	---	---
Sphene	1.1	---	---	1.5	1.0	0.5	1.7
Staurolite	---	---	---	0.4	0.3	0.8	---
Tourmaline	2.1	2.0	---	---	0.3	---	1.1
Zircon	1.1	2.0	2.6	2.7	1.7	1.6	3.3
Unidentified and weathered minerals	8.3	---	4.3	4.2	3.2	6.8	1.1
Rock fragments	2.1	2.0	1.5	1.9	1.7	0.8	0.6
Total grains counted	97	100	117	264	303	250	182

* Also identified, but not included with the mineral counts are: Clinozoisite, Enstatite, Glaucophane, Topaz, Tremolite, Zoisite.
**Titanaugite is included with augite.

Appendix 2. Heavy Mineral Counts of Selected Samples (Cont.)*
(Numbers are in percent.)

Sample No. :	YB-21	YB-23	YB-24	YB-25	YB-26	YB-27	YB-28
Actinolite	---	---	---	---	0.7	0.5	---
Andalusite	---	---	---	---	---	---	---
Apatite	---	0.5	0.3	---	---	0.5	---
Augite**	2.8	2.4	6.4	3.9	4.7	1.8	7.2
Basaltic Hornblende	2.3	1.4	1.3	1.7	2.0	1.4	0.5
Biotite	---	---	---	---	0.7	0.5	---
Chlorite	---	---	---	---	0.7	---	---
Diopside	11.2	6.7	11.2	5.5	4.0	4.1	2.1
Epidote	2.8	3.4	1.6	1.7	4.0	2.3	2.7
Garnet	13.5	16.7	11.9	11.0	8.0	15.8	8.2
Hematite	---	---	0.6	0.6	---	---	1.5
Hornblende	5.6	3.8	7.1	11.0	9.7	5.4	9.3
Hypersthene	3.3	5.3	7.4	5.0	6.7	5.0	4.1
Chromite-Ilmenite-Magnesite	10.7	22.1	13.2	21.1	8.7	41.7	26.2
Ilmenite-Leucoxene Alteration	2.8	3.4	3.9	3.3	2.7	0.5	3.6
Kyanite	0.5	0.5	0.3	0.6	0.7	---	---
Leucoxene	31.2	20.7	25.4	25.3	28.7	11.3	21.5
Limonite	---	---	---	---	---	---	---
Monazite	0.5	1.4	0.6	1.1	2.0	---	1.1
Muscovite	---	---	---	---	---	---	1.7
Olivine	---	---	---	0.6	0.7	---	---
Rutile	1.4	0.5	0.6	---	0.7	0.9	---
Sillimanite	---	0.5	---	---	---	---	---
Spinel	---	0.5	---	0.6	0.7	---	0.5
Sphene	1.0	1.0	1.0	0.6	2.0	1.4	0.5
Staurolite	1.4	1.4	0.3	0.6	1.3	0.9	1.1
Tourmaline	1.4	1.0	0.3	1.7	1.3	0.5	1.1
Zircon	3.7	3.8	3.1	1.7	2.7	1.4	2.1
Unidentified and weathered minerals	2.8	2.4	3.5	2.2	4.7	2.3	4.1
Rock fragments	1.4	---	0.3	1.1	1.3	2.0	1.1
Total grains counted	215	208	311	181	150	221	195

Appendix 2. Heavy Mineral Counts of Selected Samples (Cont.)*
(Numbers are in percent.)

Sample No.:	YB-30	YB-31	YB-32	YB-34	YB-36	YB-40	YB-43
Actinolite	---	---	---	---	---	---	---
Andalusite	---	---	---	---	---	---	---
Apatite	1.7	1.0	---	2.1	3.3	---	---
Augite**	4.9	19.0	8.9	15.1	9.1	18.8	8.3
Basaltic Hornblende	1.7	---	---	---	0.8	---	---
Biotite	1.7	4.2	---	1.1	6.8	---	2.8
Chlorite	---	---	2.2	---	1.7	3.1	---
Diopside	1.7	---	---	---	---	---	---
Epidote	1.1	1.0	---	0.5	0.8	---	2.8
Garnet	3.3	3.1	6.7	3.8	4.1	12.5	5.6
Hematite	4.9	7.3	4.5	2.7	---	3.1	2.8
Hornblende	9.3	15.6	4.5	9.7	8.3	6.2	2.8
Hypersthene	2.7	---	6.7	---	---	3.1	---
Chromite-Ilmenite-Magnesite	32.4	17.7	22.2	32.8	36.0	18.7	25.0
Ilmenite-Leucoxene Alteration	5.5	4.2	2.2	5.9	5.0	6.3	14.0
Kyanite	---	---	---	---	---	---	---
Leucoxene	13.2	9.4	2.2	7.5	3.3	9.4	8.4
Limonite	---	---	6.7	---	1.7	---	---
Monazite	---	---	---	---	2.5	---	---
Muscovite	2.8	---	---	1.0	5.8	---	---
Olivine	---	---	---	---	---	---	---
Rutile	0.5	1.0	---	---	---	---	---
Sillimanite	---	---	---	---	---	---	---
Spinel	---	---	---	---	---	---	---
Sphene	---	1.0	---	0.5	3.3	---	---
Staurolite	---	---	---	---	---	---	---
Tourmaline	--	1.0	---	0.5	---	---	---
Zircon	2.2	1.0	---	2.1	3.3	3.1	---
Unidentified and weathered minerals	6.6	6.3	8.9	4.8	2.5	---	14.0
Rock fragments	3.3	7.2	24.3	8.6	2.5	15.7	14.0
Total grains counted	182	96	45	186	121	32	36

Appendix 2. Heavy Mineral Counts of Selected Samples (Cont.)*
(Numbers are in percent.)

Sample No.:	YB-46	YB-47	YB-48	YB-51	YB-52	YB-69	YB-70
Actinolite	---	---	---	---	---	---	---
Andalusite	---	---	---	---	---	---	---
Apatite	0.3	---	0.6	0.7	1.6	---	0.4
Augite**	16.5	13.7	15.2	2.8	2.4	12.2	7.8
Basaltic Hornblende	0.7	0.3	0.3	1.4	0.8	0.8	0.4
Biotite	7.6	7.2	1.6	---	---	---	1.1
Chlorite	---	---	0.3	---	---	---	0.4
Diopside	1.4	0.7	1.0	4.3	4.8	3.4	4.1
Epidote	0.3	1.0	0.6	3.6	2.4	1.7	1.5
Garnet	1.0	1.0	2.5	10.7	13.5	6.3	6.7
Hematite	3.4	4.2	2.2	0.7	---	2.9	1.1
Hornblende	17.2	19.2	19.7	7.1	6.4	16.8	9.2
Hypersthene	1.4	0.7	3.5	7.1	8.7	6.7	6.7
Chromite-Ilmenite-Magnetite	11.7	8.1	16.9	24.8	8.0	21.8	28.6
Ilmenite-Leucoxene Alteration	1.4	3.3	1.6	2.1	8.7	2.1	3.3
Kyanite	---	---	0.3	1.4	0.8	0.5	0.4
Leucoxene	14.1	17.2	17.2	17.7	25.4	13.9	16.7
Limonite	0.3	---	---	---	---	0.8	---
Monazite	---	---	---	1.4	1.6	---	0.8
Muscovite	15.2	17.2	9.2	0.7	---	2.5	0.6
Olivine	---	---	---	---	---	---	---
Rutile	0.3	0.3	0.6	3.5	0.8	0.8	1.1
Sillimanite	---	---	---	---	---	---	---
Spinel	---	---	---	---	---	---	0.4
Sphene	0.3	---	0.3	2.1	0.8	0.5	1.5
Staurolite	---	---	---	---	1.6	---	0.4
Tourmaline	---	---	0.3	1.4	0.8	---	---
Zircon	0.7	1.0	1.0	2.1	3.2	2.1	2.6
Unidentified and weathered minerals	4.1	3.6	3.2	3.5	7.1	2.9	2.6
Rock fragments	2.0	1.3	1.3	1.4	---	1.3	2.2
Total grains counted	291	307	314	141	126	238	270

Appendix 2. Heavy Mineral Counts of Selected Samples (Cont.)*
(Numbers are in percent.)

Sample No.:	YB-71	YB-72	YB-73	YB-74	YB-75	YB-85	YB-90
Actinolite	0.5	0.5	---	---	---	---	---
Andalusite	---	---	---	---	---	---	---
Apatite	0.5	1.5	0.9	0.6	0.9	0.3	0.8
Augite**	4.1	3.4	3.7	5.8	3.1	5.7	2.0
Basaltic Hornblende	0.9	2.9	3.7	0.6	0.4	---	1.2
Biotite	---	1.5	---	---	---	---	---
Chlorite	---	---	0.5	---	---	---	0.4
Diopside	2.4	2.9	5.0	4.1	6.2	1.6	5.2
Epidote	2.4	2.9	1.8	2.5	1.8	0.6	2.8
Garnet	9.2	3.4	7.7	8.7	13.3	9.7	14.1
Hematite	1.4	3.9	1.4	---	0.4	1.3	0.8
Hornblende	6.4	12.7	6.9	15.6	7.2	1.3	8.1
Hypersthene	5.5	9.3	7.8	6.4	7.0	2.2	7.2
Chromite-Ilmenite-Magnetite	40.4	4.9	18.8	17.9	24.1	56.4	25.7
Ilmenite-Leucoxene Alteration	2.7	2.9	1.4	8.7	1.3	1.0	2.8
Kyanite	---	---	0.5	1.1	0.9	---	1.2
Leucoxene	13.7	25.8	23.8	15.6	14.1	6.0	12.9
Limonite	---	---	---	---	---	3.8	---
Monazite	0.5	0.5	0.5	1.1	0.9	0.3	0.8
Muscovite	0.9	6.3	1.8	---	---	---	---
Olivine	---	---	---	0.6	---	---	0.4
Rutile	0.9	1.5	2.3	0.6	1.8	---	2.0
Sillimanite	---	---	---	0.6	0.4	---	0.4
Spinel	---	---	---	---	---	---	0.4
Sphene	0.9	2.9	2.3	2.9	2.3	0.6	1.6
Staurolite	0.5	---	0.5	1.1	0.9	0.6	0.4
Tourmaline	0.5	1.0	0.9	1.1	2.2	0.3	2.0
Zircon	2.8	1.0	2.8	1.7	5.7	3.8	4.0
Unidentified and weathered minerals	2.3	4.3	3.2	2.3	2.6	3.5	1.2
Rock fragments	0.5	3.4	1.4	---	3.1	1.6	2.4
Total grains counted	218	205	218	173	228	319	249

Appendix 2. Heavy Mineral Counts of Selected Samples (Cont.)*
(Numbers are in percent.)

Sample No. :	YB-B7	YB-B12	YB-B13	YB-B15	YB-B24	YB-B32	YB-B34
Actinolite	1. 1	---	---	---	1. 0	---	0. 5
Andalusite	---	---	---	---	---	0. 5	---
Apatite	0. 6	0. 4	0. 4	0. 5	0. 5	0. 3	1. 0
Augite**	6. 1	2. 7	2. 2	7. 2	3. 3	4. 0	5. 9
Basaltic Hornblende	1. 1	1. 0	0. 7	0. 5	1. 9	0. 6	2. 5
Biotite	---	---	---	---	---	---	---
Chlorite	---	---	---	---	---	---	---
Diopside	2. 8	5. 8	6. 2	10. 1	4. 7	6. 7	6. 9
Epidote	2. 8	0. 7	1. 8	1. 8	1. 9	0. 8	2. 5
Garnet	7. 8	10. 7	15. 7	11. 5	1. 9	11. 6	5. 4
Hematite	1. 1	1. 4	0. 4	1. 0	0. 5	---	1. 0
Hornblende	10. 0	3. 8	6. 9	7. 6	15. 1	7. 6	7. 9
Hypersthene	5. 6	7. 2	8. 1	10. 2	7. 7	9. 7	9. 8
Chromite-Ilmenite-Magnetite	14. 6	47. 0	32. 1	6. 2	1. 9	32. 4	5. 9
Ilmenite-Leucoxene Alternate	3. 9	0. 4	1. 5	0. 5	6. 6	0. 8	3. 4
Kyanite	1. 1	0. 4	0. 7	1. 0	1. 0	0. 3	1. 0
Leucoxene	30. 8	9. 3	11. 7	30. 4	34. 0	13. 1	33. 9
Limonite	---	---	---	---	---	---	---
Monazite	---	0. 7	0. 7	0. 5	0. 5	0. 8	0. 5
Muscovite	---	---	---	---	---	---	---
Olivine	1. 1	---	0. 4	---	1. 0	0. 3	0. 5
Rutile	1. 1	0. 4	1. 5	1. 0	1. 4	1. 0	1. 0
Sillimanite	0. 5	0. 7	---	---	0. 5	---	---
Spinel	---	---	---	---	---	---	---
Sphene	1. 7	1. 2	0. 7	1. 0	1. 4	0. 8	1. 5
Staurolite	0. 5	0. 7	1. 0	1. 3	0. 5	1. 0	1. 0
Tourmaline	0. 5	0. 4	0. 7	1. 3	1. 0	0. 8	1. 0
Zircon	1. 7	3. 1	3. 3	3. 1	1. 9	4. 0	2. 5
Unidentified and weathered minerals	2. 8	1. 4	2. 6	2. 4	5. 2	3. 4	2. 9
Rockfragments	1. 1	0. 7	0. 4	1. 3	4. 7	0. 3	1. 5
Total grains counted	179	292	274	227	212	328	204

Appendix 3. Descriptive Mineralogy

Several methods of identifying the various heavy mineral species were used in this investigation. In addition to heavy liquids as a means of separating heavy minerals, electromagnetic fractionation of the concentrated "heavies" proved useful in differentiating and identifying several heavy mineral species. The Frantz isodynamic separator was adjusted with a forward slope of 25° and a side tilt of 15°. But before separations were made, ferro-magnetic material was removed with a hand magnet. Separations were made on unsized samples at current intervals of one-tenth ampere.

The U. S. Bureau of Mines, Albany, Oregon, was most helpful in aiding in the confirmation of the author's identification of several heavy mineral species.

A detailed description of most of the abundant or most significant non-opaque heavy mineral species is given. The opaque mineral leucoxene is the only exception listed, because of its unique genesis involving both opaque and non-opaque species. Each of the heavy minerals given in the Appendix is described as it occurs in the marine or fluviatile environments. When differences in the physical characteristics of the same mineral species do occur, they probably originate from the parent rock sources, weathering, or transportational history. These characteristics are frequently helpful in tracing the same mineral species to different source areas.

The many references used in the identification and description of the heavy mineral suite include Tickell (40, p. 106-141), Milner (29, p. 15-207), Krumbein and Pettijohn (27, p. 412-464), Winchell and Winchell (46), Winchell (45), Kerr (25), and Hutton (22).

APATITE

(Marine)

HABIT: Oval or nearly circular grains to rounded elongated prismatic crystals.

COLOR: Colorless, white.

RELIEF: Low to moderate.

MAGNETIC PROP.: Non-magnetic; current 1.6 plus amps.

OPTICAL PROP.:
Birefringence: Weak.
Extinction: Straight.
Elongation: Length-fast.

INCLUSIONS: When present, commonly containing heavy minerals which are rectangular or rod-like in shape. Also present are clear needle-like inclusions of indeterminable composition. The inclusions are commonly oriented parallel to the principal axis.

ROUNDNESS: Subrounded to well-rounded.

ETCHING: Grain surface etching is variable; euhedral to anhedral grains usually exhibit some etching. Well-rounded oval or circular grains generally are not etched, probably as a result of surface polishing due to grain agitation in the surf zone.

APATITE

(Fluviatile)

HABIT: Usually euhedral to anhedral elongate prismatic grains, occasionally rectangular in outline.

COLOR: Colorless.

RELIEF: Low to moderate.

MAGNETIC PROP. : Non-magnetic; current 1. 6 plus amps.

OPTICAL PROP. : Same**

INCLUSIONS: Same**

ROUNDNESS: Subangular to subrounded.

ETCHING: Commonly exhibiting an irregular etched pattern on grain surfaces. Terminal ends of prisms commonly etched in an irregular or "saw-tooth" pattern.

AUGITE

(Marine)

HABIT: Commonly prismatic to oval grains, or infrequent cleavage fragments.

COLOR: Light to medium green, yellow-green; mauve to purplish-brown (titanaugite?).

MAGNETIC PROP. : Weakly magnetic

OPTICAL PROP. : Birefringence: Moderate to strong.
Extinction: Oblique, $Z \wedge c = 45\text{-}51^{\circ}$.
Pleochroism: None.

INCLUSIONS: Few.

ROUNDNESS: Subangular.

**Same properties that are found in the marine environment also apply to the fluviatile environment.

ETCHING: "Saw-tooth" etching occurs on the terminal ends of the prisms in varying degrees.

COMMENTS: The mauve colored grains appear to be titanaugite. These grains are invariably rounded to well-rounded.

AUGITE

(Fluviatile)

HABIT: Commonly irregular cleavage fragments or occasionally prismatic grains.

COLOR: Light to dark green.

MAGNETIC PROP. : Same**

OPTICAL PROP. : Birefringence: Same**
Extinction: Same**
Pleochroism: Generally none; a few grains exhibit colorless to light green pleochroism.

INCLUSIONS: Dusty iron inclusions occur in some grains.

ROUNDNESS: Very angular to angular.

ETCHING: "Saw-tooth" etching on terminal ends of the grains is very common.

DIOPSIDE

(Marine only)

HABIT: Commonly elongate prisms, but occasionally oval when occurring in the form of stumpy grains, or as irregular broken fragments that are somewhat rounded.

COLOR: Pale green to grayish-green, or white to grayish.

**Same properties that are found in the marine environment also apply to the fluviatile environment.

MAGNETIC PROP. : Weakly magnetic; current 0. 7 amps.

OPTICAL PROP. : Birefringence: Strong.
Extinction: Oblique, $Z \wedge c = 38\text{-}45^{o}$.
Pleochroism: Non-pleochroic.

INCLUSIONS: Generally inclusionless. When present, occurring in the form of dusty iron oxide.

ROUNDNESS: Subangular to well-rounded; on the average subrounded.

SURFACE TEXTURE: Grain surfaces commonly "pock-marked", which appears to be the result of solutional effects. A few grains exhibit etched terminal ends of the prism (common to the terrace sands).

COMMENTS: Microscopic differentiation between diopside and augite is generally quite difficult; however, the following properties are helpful in identifying the two minerals in the sediments studied: (1) Diopside has a lower extinction angle ($Z \wedge c = 38\text{-}45^{o}$) than augite ($Z \wedge c = 45\text{-}51^{o}$). (2) Diopside has a lower index of refraction ($\alpha = 1.664$) than augite ($\alpha = 1.699$). The refractive index was measured in non-oriented grains with index oils. The lowest index was found to be 1. 664-1. 666, which is generally less than the lowest indices of refraction of augite. (3) Diopside is usually marked by its light color and particularly by its seemingly greater resistance to weathering. (4) Its moderately rounded to well-rounded form is also distinctive.

GARNET

(Marine)

HABIT: Most commonly angular, sharp-cornered, irregular grains bounded by concoidal fracture surfaces. A few grains are equidimensional and appear to be dodecahedral in form.

COLOR: Colorless, pale pink, salmon pink, and red to reddish-brown.

FRACTURE: Concoidal; fracture controls grain shape in most cases.

MAGNETIC PROP. : Weak to moderate.

OPTICAL PROP. : Birefringence: Isotropic; however, a few grains exhibit weakly birefringent halos.

INCLUSIONS: Opaque heavy minerals are common.

ROUNDNESS: Angular to rounded, generally subangular.

ETCHING: Grains often etched into a "mosaic" pattern consisting of facets or pits.

COMMENTS: Two varieties of garnet appear to be present in the marine sediments. The colors of garnet described seem to be weakly to moderately magnetic. On the basis of magnetism and color it seems probable that at least Almandite and Spessarite are present.

GARNET

(Fluviatile)

HABIT: Angular, sharp-cornered irregular grains bounded by concoidal fracture surfaces.

COLOR: Colorless, pale pink.

FRACTURE: Same**

MAGNETIC PROP. : Same**

OPTICAL PROP. : Same**

**Same properties that are found in the marine environment also apply to the fluviatile environment.

INCLUSIONS: Opaque heavy minerals for the most part.

ROUNDNESS: Angular to subrounded, generally angular.

ETCHING: Same**

HORNBLENDE (BLUE-GREEN)

(Marine only)

HABIT: Elongate prisms.

COLOR: Greenish-yellow to bluish-green.

MAGNETIC PROP.: Moderately magnetic; current 0.4-0.5 amps.

OPTICAL PROP.: Birefringence: Moderate.
Extinction: Oblique, $Z \wedge c = 15\text{-}25^{\circ}$.
Elongation: Length-slow.
Pleochroism: Strongly pleochroic from blue-green to green.

INCLUSIONS: None.

ROUNDNESS: Subrounded to rounded.

BASALTIC HORNBLENDE

(Marine only)

HABIT: Commonly prismatic or stumpy grains.

COLOR: Brown to black.

MAGNETIC PROP.: Moderately magnetic; current 0.4-0.5 amps.

OPTICAL PROP.: Birefringence: Moderate to high.
Extinction: $Z \wedge c = <10^{\circ}$.
Elongation: Length-slow
Pleochroism: X = yellow or reddish-brown, Y = dark brown, Z = dark green or brown.

**Same properties that are found in the marine environment also apply to the fluviatile environment.

INCLUSIONS: Generally inclusionless, occasionally a few opaque heavy minerals.

ROUNDNESS: Angular to well-rounded; on the average subrounded.

HORNBLENDE (BROWN)

(Marine)

HABIT: Prismatic.

COLOR: Dark brown.

MAGNETIC PROP. : Moderately magnetic; current 0.4 amps.

OPTICAL PROP. : Birefringence: Moderate.
Extinction: $Z \wedge c = 15\text{-}25^{\circ}$.
Elongation: Length-slow.
Pleochroism: Weak to moderate, light to dark brown, often deeply colored.

INCLUSIONS: None

ROUNDNESS: Subrounded.

HORNBLENDE (BROWN)

(Fluviatile)

HABIT: Same**

COLOR: Brown to black and dark brown.

MAGNETIC PROP. : Same**

OPTICAL PROP. : Same**

INCLUSIONS: Occasionally heavy minerals, generally opaque.

**Same properties that are found in the marine environment also apply to the fluviatile environment.

ROUNDNESS: Very angular to angular.

ETCHING: Terminal ends of the prisms are frequently etched in irregular patterns.

HORNBLENDE (COMMON)

(Marine)

HABIT: Prismatic, elongate ll c. Occasionally irregularly shaped or oval grains.

COLOR: Greenish-brown to brownish-green. Also dark green to black.

MAGNETIC PROP. : Moderately magnetic; current 0. 4 amps.

OPTICAL PROP. : Birefringence: Moderate.
Extinction: $Z \wedge c = 15\text{-}25^{o}$.
Elongation: Length-slow.
Pleochroism: Moderate to weak. Green and brown to brownish-green.

INCLUSIONS: Few, some anhedral opaque heavy minerals.

ROUNDNESS: Subangular to rounded; on the average subrounded.

HORNBLENDE (COMMON)

(Fluviatile)

HABIT: Prismatic.

COLOR: Dark green to black.

MAGNETIC PROP. : Same**

OPTICAL PROP. : Same**

**Same properties that are found in the marine environment also apply to the fluviatile environment.

INCLUSIONS: Same**

ROUNDNESS: Angular to subangular; on the average angular.

ETCHING: Occasionally prisms are etched into irregular shapes. Notches are frequently etched from the faces of the prisms.

HYPERSTHENE

(Marine)

HABIT: Two forms are common, stubby prismatic grains or long slender prisms.

COLOR: Light grayish-green to grayish-green with brownish tints.

MAGNETIC PROP.: Weakly magnetic; moderately magnetic when containing opaque inclusions.

OPTICAL PROP.: Birefringence: Moderate.
Extinction: Straight.
Elongation: Length-slow.
Pleochroism: X = light reddish pink to red, Y = straw-yellow to golden yellow, Z = light grayish-green to dark green.

INCLUSIONS: Opaque heavy mineral inclusions very common, generally randomly oriented. Some grains have clear inclusions consisting of needle-like anhedral crystals, and probably bubbles. The clear inclusions generally do not occur with the opaque ones.

ROUNDNESS: Subangular to rounded, generally subrounded.

ETCHING: Little or no etching to strongly etched grains. Terminal ends of the prisms exhibit "saw-tooth" edges.

**Same properties that are found in the marine environment also apply to the fluviatile environment.

COMMENTS: Grains with strongly etched terminal ends occur in the marine terrace deposits. It seems likely that the infrequent etched grains of this nature, found in the beach sands, were derived from the terrace deposits. They apparently become polished, losing their jagged edges through abrasion.

HYPERSTHENE

(Fluviatile)***

HABIT: Short stubby or long prismatic grains.

COLOR: Light grayish-green.

MAGNETIC PROP. : Weakly magnetic.

OPTICAL PROP. : Birefringence: Moderate.
Extinction: Straight.
Elongation: Length-slow.
Pleochroism: X = light reddish-pink to red, Y = straw-yellow, Z = light grayish-green.

ROUNDNESS: Angular to rounded.

ETCHING: Grains upstream from Toledo are invariably strongly etched, especially the terminal ends of the grains, in in the form of "saw-tooth" edges. Also, strong surfacial etching was noted.

COMMENTS: Upstream from Toledo, hypersthene is rarely found, but when it does occur it is invariably strongly etched. Hypersthene occuring between Oneatta Point and Toledo is very similar to the marine type.

***Description based on 6 grains.

KYANITE

(Marine only)

HABIT: Commonly elongate prismatic (bladed) grains with distinctive cleavage controlled rectangular outline. Frequently grains are stubby, moderately rounded or elliptical in form. Anhedral crystals are common.

CLEAVAGE: Generally two directions of cleavage are visible, (100) and (010), and frequently three (001). Cleavage traces are approximately at 90 degrees to one another. Kyanite is distinguished by its cleavage controlled rectangular detrital form and the numerous obvious cleavage lines.

COLOR: Colorless.

MAGNETIC PROP.: Non-magnetic; current 1.6 plus amps.

OPTICAL PROP.: Birefringence: Moderate.
Extinction: Oblique on (100), $Z \wedge c = 27\text{-}32^{\circ}$.
Elongation: Generally length-slow.

INCLUSIONS: For the most part inclusionless or exhibiting opaque looking material (carbonaceous ?).

ROUNDNESS: Subangular to rounded, generally subrounded. Some of the rounded grains are broken and exhibit sharp corners.

REENTRANTS: Fairly common.

LEUCOXENE

(Marine)

HABIT: Irregular to equidimensional rounded detrital grains.

COLOR: Commonly "snow white" to yellowish-white, or less frequently porcellaneous.

MAGNETIC PROP. : Non-magnetic; however, if an ilmenite "core" is present, very weakly magnetic.

OPTICAL PROP. : Birefringence: Usually opaque. If the host mineral is anisotropic, the grain may exhibit some birefringence depending upon the stage of alteration to leuxocene.

ROUNDNESS: Variable, depending chiefly upon the initial roundness of the host mineral.

SURFACE TEXTURE: Pitting prominent on "snow white" grains.

COMMENTS: Leucoxene in the marine sands appears to be derived from the alteration of at least two minerals: (1) Sphene (very common) (2) Ilmenite (common). In alteration from sphene, leucoxene occurs as streaks or patches of white in a yellow background, or as nearly completely altered white grains with streaks or "cores" of yellow. The degree of opaqueness of leucoxene increases with increasing alteration. In the grain counts partly altered grains exhibiting opaqueness and a yellowish white or "snow white" color were considered to be leucoxene. Leucoxene is also derived from the alteration of ilmenite. Ilmenite "cores" or scattered specks of ilmenite set in a background of "snow white" were noted in many grains. Various states of ilmenite alteration were noted and grains obviously derived from the alteration of ilmenite were separated in the grain counts.

LEUCOXENE

(Fluviatile)

HABIT: Same**

COLOR: Dull white to yellowish-white.

**Same properties that are found in the marine environment also apply to the fluviatile environment.

OPTICAL PROP. : Same**

ROUNDNESS: Same**

SURFACE TEXTURE: Pitted, irregular surfaces common.

COMMENTS: Same**

SILLIMANITE

(Marine only)

HABIT: Commonly short or slightly elongate prisms, occasionally somewhat rectangular; usually fibrous, generally || c. Some grains are striated || c.

COLOR: Colorless to pale yellow.

MAGNETIC PROP. : Non-magnetic; current 1. 6 plus amps.

OPTICAL PROP. : Birefringence: Moderate
Extinction: Straight, parallel to the prism edge.
Elongation: Length-slow.
Pleochroism: None.

ROUNDNESS: Subrounded to well-rounded.

STAUROLITE

(Marine only)

HABIT: Irregularly shaped grains, somewhat platy, haphazard boundaries.

COLOR: Straw-yellow to brownish-yellow.

FRACTURE: Marked by hackly to subconchoidal fracture.

MAGNETIC PROP. : Weak to moderate; current 0. 4 amps.

**Same properties that are found in the marine environment also apply to the fluviatile environment.

OPTICAL PROP. : Birefringence: Moderate to strong.
Pleochroism: Moderate; X = colorless, Y = pale yellow, Z = golden yellow.

INCLUSIONS: Numerous, including opaque heavy minerals, also clear rod-like or irregularly shaped inclusions of random orientation. Inclusions impart a porous (Swiss Cheese) appearance to the detrital grains.

ROUNDNESS: Very angular to rounded.

ZIRCON

(Marine)

HABIT: Grains range from euhedral short prisms with pyramids to slightly rounded large elongate crystals. Elliptical to globular well worn grains are also common. The smaller sized grains are invariably euhedral.

COLOR: Commonly colorless; however, a few grains are light pink or yellow.

RELIEF: High.

MAGNETIC PROP. : Non-magnetic; current 1.6 plus amps.

OPTICAL PROP. : Birefringence: Strong.
Extinction: Straight.
Elongation: Length-slow.
Pleochroism: Pink colored grains are pleochroic (colorless to pink). Thick grains are also invariably pleochroic.

INCLUSIONS: Inclusions are varied: (1) Opaque stumpy, square, or rounded inclusions (heavy minerals) oblique to the principal axis. (2) Clear needle-like inclusions that appear to be liquid or gaseous. (3) Rod-like inclusions are common. They vary in length, are clear, and generally are not associated with other type inclusions.

ROUNDNESS: Angular to well-rounded, generally subrounded to rounded.

ZIRCON

(Fluviatile)

HABIT: Commonly short euhedral prismatic grains; a few are anhedral.

COLOR: Colorless.

RELIEF: High.

MAGNETIC PROP. : Same**

OPTICAL PROP. : Same**

INCLUSIONS: Commonly clear rods of variable length and random orientation. Also opaque heavy mineral inclusions.

ROUNDNESS: Very angular to subrounded.

**Same properties that are found in the marine environment also apply to the fluviatile environment.