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ROBERT CORNELIUS ROUSH for the M. S.
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Title: SEDIMENT TEXTURES AND INTERNAL STRUCTURES: A COMPARISON BETWEEN CENTRAL OREGON CONTINENTAL SHELF SEDIMENTS AND ADJACENT COASTAL SEDIMENTS

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LaVerne Duane Kulm

A study of sedimentary structures and sediment texture of beach and continental shelf sediments provides a basis for the interpretation of the recent history of sedimentation on the Oregon continental shelf. The texture of various sediment types suggests that coastal rivers supply a considerable quantity of very fine sand in addition to modern mud to the continental shelf. Relict sediments remain uncovered on areas of the shelf not under the influence of major river runoff and are mixed or covered by modern mud and very fine sand where rivers influence shelf sedimentation.

Primary sedimentary structures show that sands ranging from very fine to medium in mean grain size are capable of being

moved at shelf water depths from at least 38 to 88 meters. No net transport of sand, however, can be determined from these structures. Organic structures apparently are controlled by water depth and/or grain size and sediment type which determine faunal composition and concentration. At mid-shelf depths fine sand cores are characterized by shell fragments, worm tubes, and worm trails. Beyond 100 meters water depth worm tubes were not found, but worm trails become abundant, and large burrows appear in the sediment.

Sediment Textures and Internal Structures: A Comparison Between Central Oregon Continental Shelf Sediments and Adjacent Coastal Sediments

by

Robert Cornelius Roush

A THESIS

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APPROVED:

Signature redacted for privacy.

Associate Professor of Oceanography
in charge of major

Signature redacted for privacy.

Chairman of Department of Oceanography

Signature redacted for privacy.

Dean of Graduate School

Date thesis is presented September 24, 1969

Typed by Sammy McMurphey for Robert Cornelius Roush

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INTRODUCTION

Purpose of Study

A study of sediments is undertaken to obtain knowledge of environmental factors responsible for the origin, transportation, deposition, and post-depositional changes of a sedimentary deposit. Sedimentary structures and sediment textures are studied in an attempt to define past and present sources of Oregon continental shelf sediments and to understand the processes responsible for their distribution and deposition. The methods of investigation allow a look back in history only as far as the last rise of sea level following the late Quaternary glaciations and sea level fluctuations.

Area of Investigation

Three profiles of box cores, A, B, and C (see Figure 1) were chosen to provide the widest range of environmental conditions affecting sediment transport and deposition on the central Oregon continental shelf. Profile A extends across the shelf at approximately 45° 00'N latitude. At this location the shelf narrows to 26 kilometers, and the slope of the shelf is uniform (i.e. not interrupted by banks or other topographic features). Profile A is located off a major headland, Cascade Head, where no significant river drainage should affect shelf sedimentation in the immediate area.

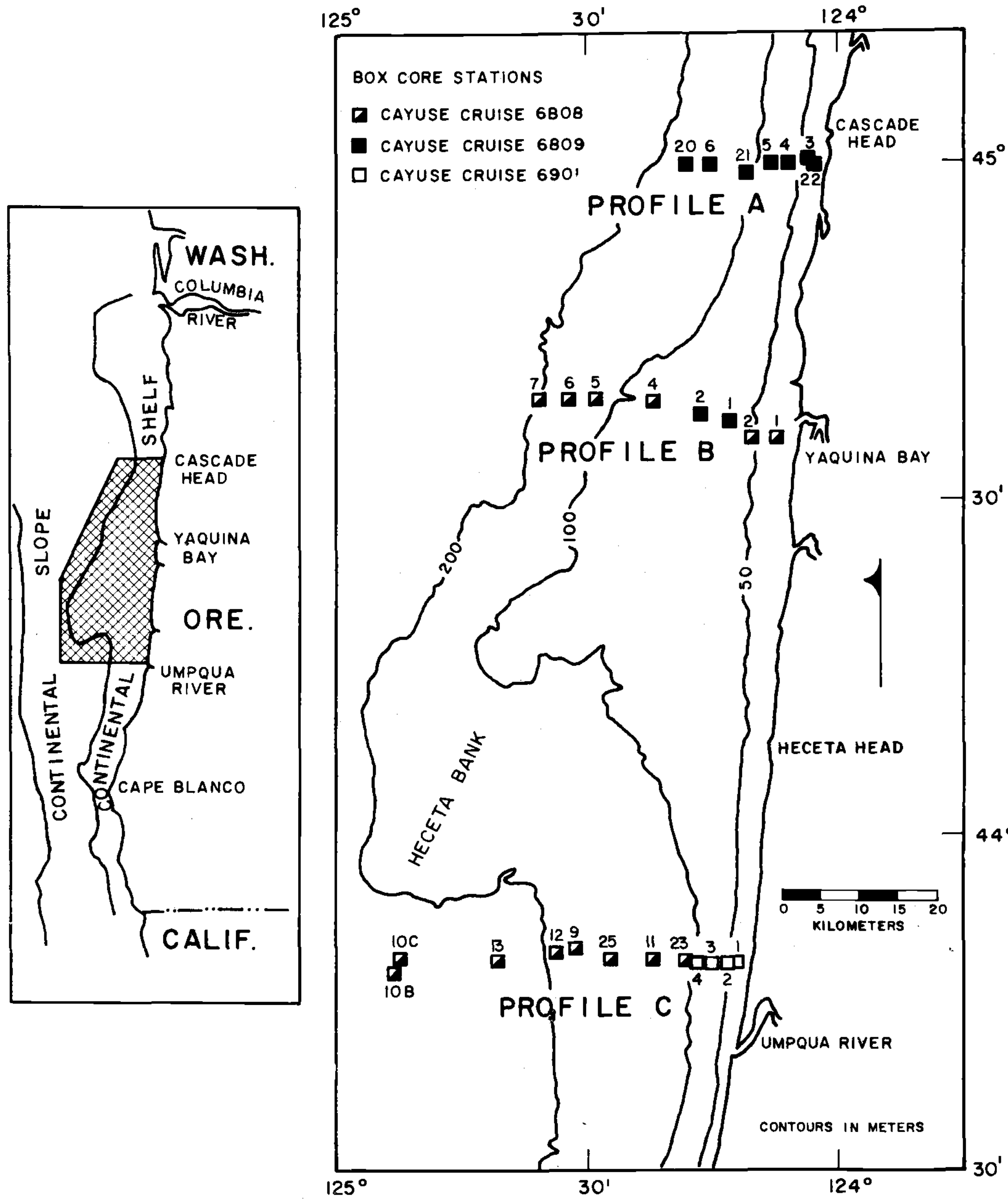

Figure 1. Map of the central Oregon continental shelf showing area of investigation and locations of box cores.

Profile B extends across the continental shelf at latitudes between 44°35'N and 44°39'N. The shelf is wider here (40 kilometers) than along Profile A to the north or Profile C to the south. The seaward extent of Profile B crosses the northern flank of Stonewall Bank, and the landward end of the profile is located off the mouth of the Yaquina River which has an average annual runoff of 1.38 million acre feet, typical of most smaller Oregon rivers (U. S. Geological Survey Water Resources Division, 1966).

Profile C extends across the continental shelf at approximately 43°49'N latitude. Here the width of the shelf is about 29 kilometers. The Umpqua River which has the second highest average annual runoff in Oregon (6.80 million acre feet compared with 180 million acre feet of the Columbia River and 5.52 million acre feet for the Rogue River) is located about 16 kilometers to the south of Profile C (U. S. Geological Survey Water Resources Division, 1966). Heceta Bank is located about 14 kilometers to the north of Profile C on the outer continental shelf.

Previous Studies

The study of Oregon coastal features predates extensive offshore investigations. Coastal landforms including beaches, dunes, and terraces have been discussed by Twenhofel (1943 and 1946), Dicken (1955), Cooper (1958), McKay (1962), Baldwin (1964), and

North and Byrne (1965). Ballard (1964) studied the distribution of beach sediment near the Columbia River. Kulm, Scheidegger, and Spigai (1968) report on a preliminary investigation of the heavy mineral suites of Oregon and northern California coastal rivers and beaches. Kulm and Byrne (1966) have described the sedimentology of Yaquina estuary. Byrne (1962, 1963a, and 1963b) has described the bathymetry of the Oregon continental shelf. Bushnell (1964), Maloney (1965), and Runge (1966) collected over 550 surface samples on a three-mile grid between the Columbia River and Cape Blanco for their studies of Oregon continental shelf geology. Chambers (1968) investigated potential placer deposits on the Oregon shelf off the Rogue River. He used box cores and piston cores as well as surface samples for studying the sedimentary history that included possible stillstands of sea level during the Holocene transgression.

In this study, Holocene is defined as the time since the glaciers began retreating and sea level began rising for the last time following the late Wisconsin glaciation. A problem in Pleistocene-Holocene stratigraphic nomenclature is discussed adequately by Curray (1965). The main problem concerns the evidence that should be used to define absolute time breaks between the Pleistocene, Holocene, and Recent. Regardless of the absolute date of the beginning of the Holocene Epoch (between 14, 000 and 20, 000 years before present) it can be said that the Holocene transgression was rapid, with a eustatic sea level rise of 100 meters in less than 20,000 years (Curray, 1965).

BATHYMETRY AND GEOLOGY

Byrne (1962, 1963a, and 1963b) has described the geomorphology of the continental terrace off Oregon. The Oregon continental shelf is narrower, deeper, and steeper than the average shelf as defined by Shepard (1963). The outer edge of the shelf is sinuous, being 59 kilometers wide at 46°N latitude, 24.5 kilometers wide at 45°N latitude, 66 kilometers wide at 44°10'N latitude, and 14.5 kilometers wide at 43°20'N latitude. The continental shelf-slope boundary occurs at depths ranging from 140 meters to 200 meters with the latter depth being closer to the average depth. The shelf break may occur outside of the range given depending upon personal interpretation in a few cases. Narrower shelf profiles tend to be steeper than wider shelf profiles since the shelf break generally occurs at a similar average depth for all profiles.

The inner shelf extends from the shoreline to a depth of 50 meters on the average, but ranges from the shoreline to 20 to 70 meters in depth. It dips seaward at an average slope of 0°45.8' and is usually the steepest part of the shelf profile. A change in slope occurs at the outer boundary of the inner shelf, and the seaward declivity of the shelf decreases by one-half, averaging 0°20.7'. This mid-shelf segment may terminate at the shelf break or in other cases give way to another change in slope and an outer shelf region. The outer shelf segment dips seaward at an average slope of 0°15.5' and terminates at the shelf break or steepens in some cases to form yet another shelf segment which then terminates at the shelf break.

Several elongate banks exist on the mid- and outer-shelf regions. Outcropping rocks have been described as clayey siltstones and glauconitic clayey siltstones, and the foraminiferal faunas indicate a Pliocene and younger age for most of them (Fowler, 1966, and Byrne, Fowler, and Maloney, 1966).

The Oregon coastal plain is narrow due to the presence of the Coast Range in northern and central Oregon and the Klamath Mountains in southern Oregon. A variety of landforms are present along the coast. These shoreline features include dunes, beaches, surf-cut terraces, resistant cliffs and headlands, estuaries and bays. Tertiary marine sediments consisting of micaceous and tuffaceous sandstones, siltstones, and mudstones are overlain unconformably by Pleistocene silts, sands, and gravels (Wells and Peck, 1961, and Baldwin, 1964). The igneous rocks which form resistant headlands are composed of basalt flows, pillow lavas, flow breccias, agglomerates and tuffs (Wells and Peck, 1961, and Baldwin, 1964). Between Heceta Head and the Columbia River, North and Byrne (1965) found 79.60 miles of beaches and dunes, 36.76 miles of igneous rock, and 33.38 miles of sedimentary rock exposed along the coast. In southern Oregon the Klamath Mountains are composed of sedimentary, metasedimentary, and volcanic rocks and also silicic and ultrabasic igneous rocks. Formations that crop out on the southern Oregon coast consist of sandstones and siltstones, both of which are well-indurated at times and in places contain volcanic rocks, conglomerates, and chert (Wells and Peck, 1961, and Baldwin, 1964).

CONTINENTAL SHELF SEDIMENTATION MODELS

Neritic detrital sedimentation has been discussed by Dietz and Menard (1951), Bradley (1958), Dietz (1963), and Curray (1965). In neritic or nearshore sedimentation models, sand is transported as a linear body consisting of nearshore sands, beaches, and dunes. The nearshore sands are transported parallel to shore and rarely are carried into water deeper than ten meters (Bradley, 1958, and Dietz, 1963). This limiting depth might be somewhat deeper for the Oregon continental shelf due to higher energy oceanographic conditions. According to these models, therefore, continental shelf sand deposits seaward of ten to twenty meters are products of lower stands of sea level during the Holocene transgression and cannot be regarded as recent sediments.

An example of the above mentioned model is reported by Pilkey and Frankenberg (1964), who indicate that off the coast of Georgia, movement of recent sands is confined to a surf zone lens of sand within the 11 meter contour. The boundary between the recent and relict sands is sharp and is marked by a change in grain size. The recent detrital sediments are fine-grained sands with some silts and very fine sands, whereas the Pleistocene or relict sediment is coarse to medium-grained sand. An intermediate sediment type due to mixing is not apparent. Emery (1968) states that relict sediments, such as those mentioned above off the coast of Georgia, cover 70 percent of the world's continental shelf area. Apparently the only modern detrital sediments being deposited on the continental shelf deeper than ten to twenty meters are muds entering the ocean via rivers and transported in suspension to their place of deposition.

Some evidence exists for the movement of sand seaward of the surf zone. By conducting a few tests using tracer sands, Ingle (1966) and Vernon (1966) have demonstrated that finer sand sizes are dispersed in a seaward direction as well as onshore and alongshore. These studies are limited to within 30 meters water depth. The writer, however, is not aware of any quantitative or sand budget models for continental shelf sedimentation seaward of the breaker zone.

Some photographic evidence has been obtained showing the presence of currents and sediment movement on the Oregon continental shelf. The following observations were made by Neudeck (1969) and also compiled into a report by Kulm (1969). Ripple marks occur across the entire width of the continental shelf although the fresher (better preserved) and most frequently observed ripples occur nearer shore. The orientation of such ripples suggests that east-west currents are responsible for their creation despite the fact that mass water transport on the shelf is to the north in winter and to the south in summer. Normal waves and storm waves account for part of the rippling on the inner shelf while tidal currents probably are of importance in moving sediment on all parts of the shelf. Despite the fact that continental shelf sediments are capable of being moved at least periodically during the year, proof of net sediment transport is scarce. According to Curray (1960) little net movement of sediment results from the oscillatory motion due to waves, although such motion is responsible for modifying physiographic features such as ridge flattening. In summary, various investigators have shown that mechanisms are available for transporting sand seaward through the breaker zone, and that mechanisms are available for reworking continental shelf sediments periodically.

METHODS

Sample Collection

Twenty-seven box cores were collected from the central Oregon continental shelf along three profiles (A, B, and C in Figure 1). The locations of the cores are listed in Appendix I. The box coring device is similar to that described by Bouma and Marshall (1964). Maximum possible penetration is 46 centimeters, and the dimensions in plan view are 20 by 30 centimeters. The primary function of the box corer is to obtain an undisturbed sediment sample which permits study of sedimentary structures as well as textural, mineralogical, and biological aspects of the samples.

Sample Processing

In order to free boxes for additional samples, some of the sandier samples with relatively low mud content were processed partially aboard ship. The finer-grained sediment samples were kept intact for later processing and analysis in the laboratory. Most cores were sliced in two vertical planes at right angles, yielding slabs two to five centimeters thick.

In the laboratory the sediment slabs were photographed and x-rayed. X-radiographs were obtained with a Faxitron 804 x-ray unit built by Field Emissions Corporation, McMinnville, Oregon.

With the aid of the photograph and the x-radiograph, a descriptive log was made of each core. Finally, relief peels of the core slabs were obtained by epoxy resin impregnation using methods outlined in Appendix V.

Sediment Textural Analysis

Sample preparation is discussed in Appendix V. Textural data were obtained primarily by particle settling techniques. The coarse fraction (sand) analysis was done by settling tube (Emery, 1938, and Poole, 1957), and the fine fraction (silt and clay) analysis was done by pipette (Krumbein and Pettijohn, 1938). A few samples were too coarse for the settling tube so that sieving at quarter phi intervals was necessary. Data obtained by particle settling techniques were processed by a CDC 3300 computer. The computer program output provides size class percentages, cumulative percentages, sand, silt, and clay percentages and ratios, and various textural parameters according to Folk (1966). For comparing textural characteristics of continental shelf sand with present-day beach sand, an additional program is used that considers the coarse fraction (sand) only. In effect, the silts and clays are removed from the sediment sample by considering the sand fraction as 100 percent of the sample. Appendices II-IV contain a listing of various textural parameter values for the samples.

SEDIMENTOLOGY

Analysis of the Total Sediment

Variations of mean grain size and percentages of sand, silt, and clay with depth in the core and with varying water depths along the continental shelf profiles A, B, and C are shown in Figures 2 and 3. Mean grain size decreases with increasing water depth except along Profiles A and B between 38 and 64 meters where sediments are coarser grained than those both seaward and shoreward (see Figure 2). Many surface sediments from Runge (1966) show a similar coarsening of grain sizes between 36 and 72 meters. A question still to be answered is whether this band of relatively coarser sediments that parallels the coast at a depth between 36 and 72 meters is a relict deposit reflecting a lower stillstand of sea level or is instead a product of modern processes.

In Figure 3 the textural classification of Shepard (1954) is used to show variation in the sand, silt, and clay content of the cores. The sand-silt-clay ratios of most inner shelf cores are observed to remain fairly uniform with depth in the cores. Mid-shelf and outer-shelf cores, however, show more textural variation within the core than do the ones on the inner shelf. A few cores exhibit slight "textural reversals." (See for example 6809-6, 6809-20, 6901-2, 6901-1, and 6808-23 in Figure 3.) These textural reversals

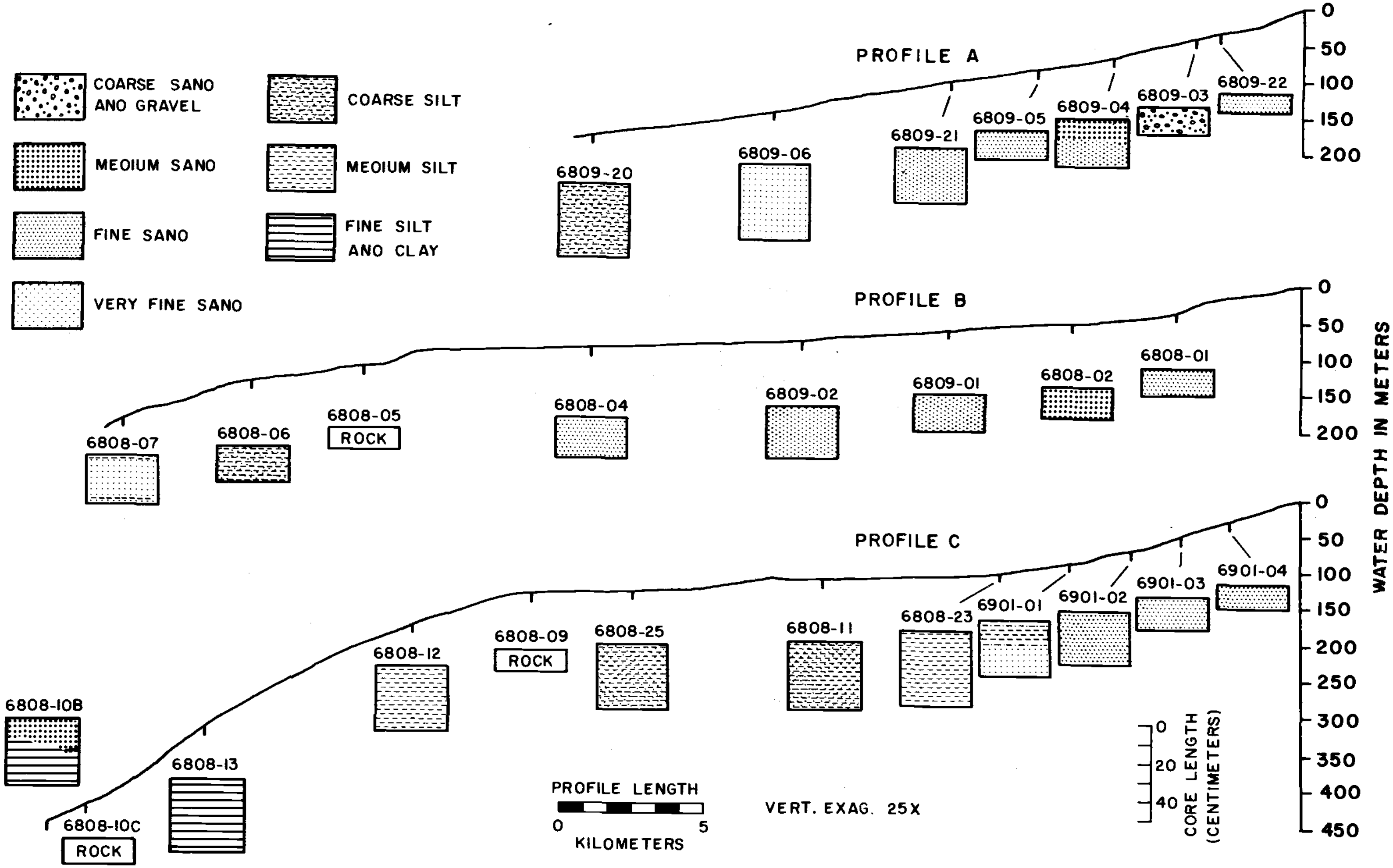

Figure 2. Variations of mean grain size with core length along three continental shelf profiles. Refer to Figure 1 for core locations.

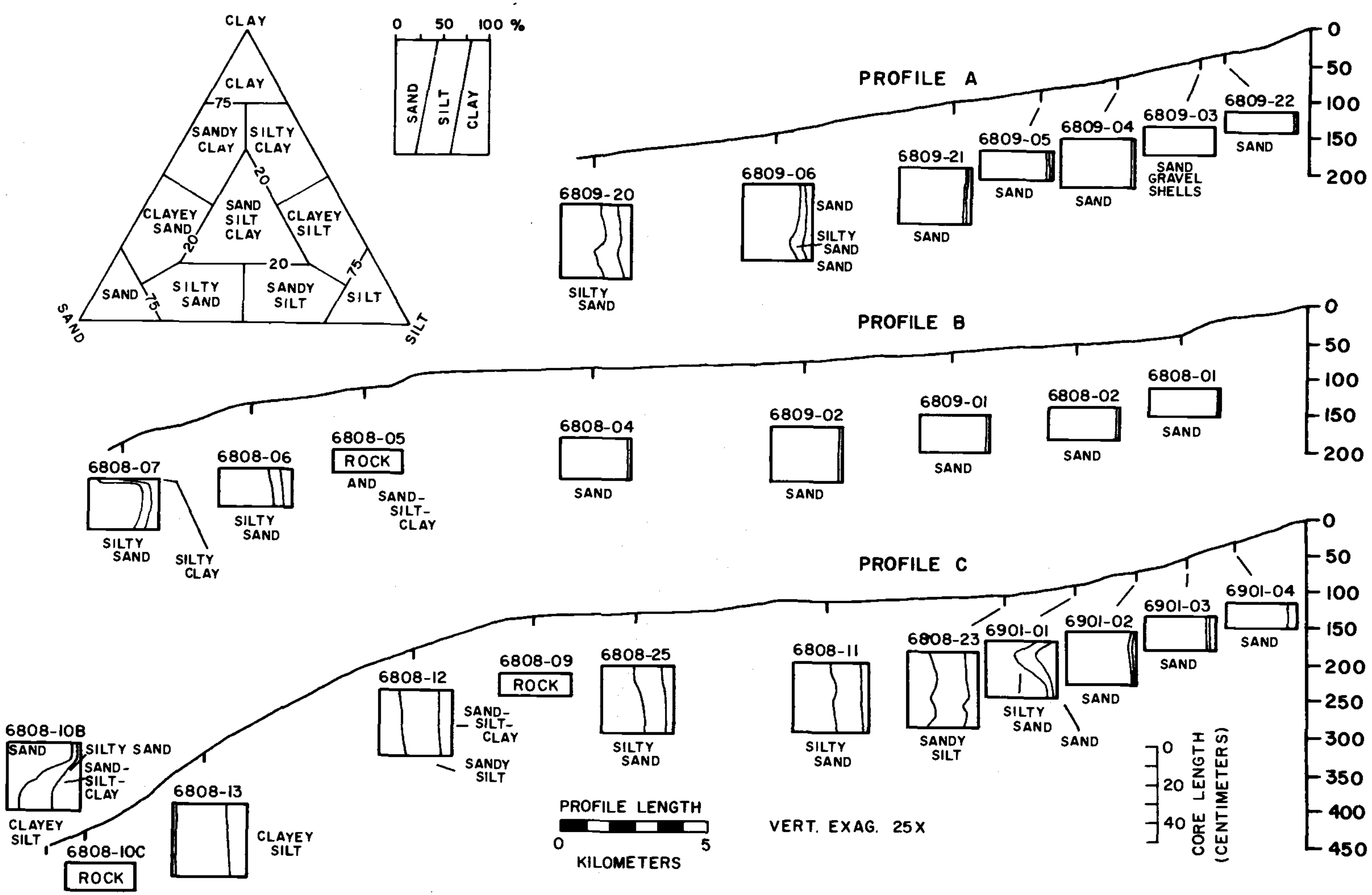

Figure 3. Sediment classification according to Shepard (1954) noting variations in sand, silt, and clay percentages within three continental shelf profiles. Refer to Figure 1 for core locations.

are gradual such that no visible boundaries separate one lithology from another.

For some time sedimentologists have been devising and working with various textural parameters in an attempt to relate environment of deposition to a sedimentary deposit. (For example see Doeglas, 1946; Folk and Ward, 1957; Passega, 1957; Mason and Folk, 1958; Friedman, 1961; Shepard and Young, 1961; Friedman, 1962; Folk, 1966; Friedman, 1967; Moiola and Weiser, 1968; and Hails and Hoyt, 1969). These studies have investigated the possibility of using textural parameters to differentiate between modern beach, coastal dune, and river sands as well as these same features from paleoenvironments. Moiola and Weiser (1968) have concluded from these previous studies that few investigators have been able to agree on the sensitivity or value of textural parameters.

Runge (1966) used bivariant plots of textural parameters to infer the energy conditions of the environment of deposition for sediments on the Oregon continental shelf. He assigned fine-grained, poorly-sorted, and generally positively-skewed sediments to a lower energy environment, and coarser-grained, better-sorted, and more negatively-skewed sediments to a higher energy environment. Chambers (1968) also used bivariant plots of textural parameters to determine modern and paleoenvironments of deposition on the southern Oregon continental shelf. On the basis of these plots, he was able to distinguish a basal transgressive sand facies, a recent fine-grained mud facies, and a mixed facies. Both Runge (1966) and Chambers (1968) point out that a considerable portion of continental shelf sand deposits is characteristic of a higher energy environment than is found at corresponding continental shelf depths today. Since these sediments are not in equilibrium with the present-day environment, they are termed relict according to a classification proposed by Emery (1952).

The writer has constructed the following bivariant plots of textural parameters: skewness versus standard deviation, skewness versus mean grain diameter, and standard deviation versus mean diameter for sediments of the central Oregon continental shelf. These plots are presented along with similar data from the southern Oregon continental shelf (data from Chambers, 1968) in Figures 4 and 5. An obvious difference exists between the southern and central Oregon continental shelf sediments. The southern shelf displays a mid-shelf mud facies that consists of recent silts and clays in equilibrium with the environment at mid-shelf depths. The central shelf lacks a well-defined mid-shelf mud facies. Along Profile C at mid-shelf depths (>101 meters) the mud content is high, ranging from 40 to 65 percent (see Figures 2 and 3). This sediment, however, contains from 35 to 60 percent admixed sand and perhaps is more characteristic of a mixed facies, similar to that defined by Chambers (1968) on the

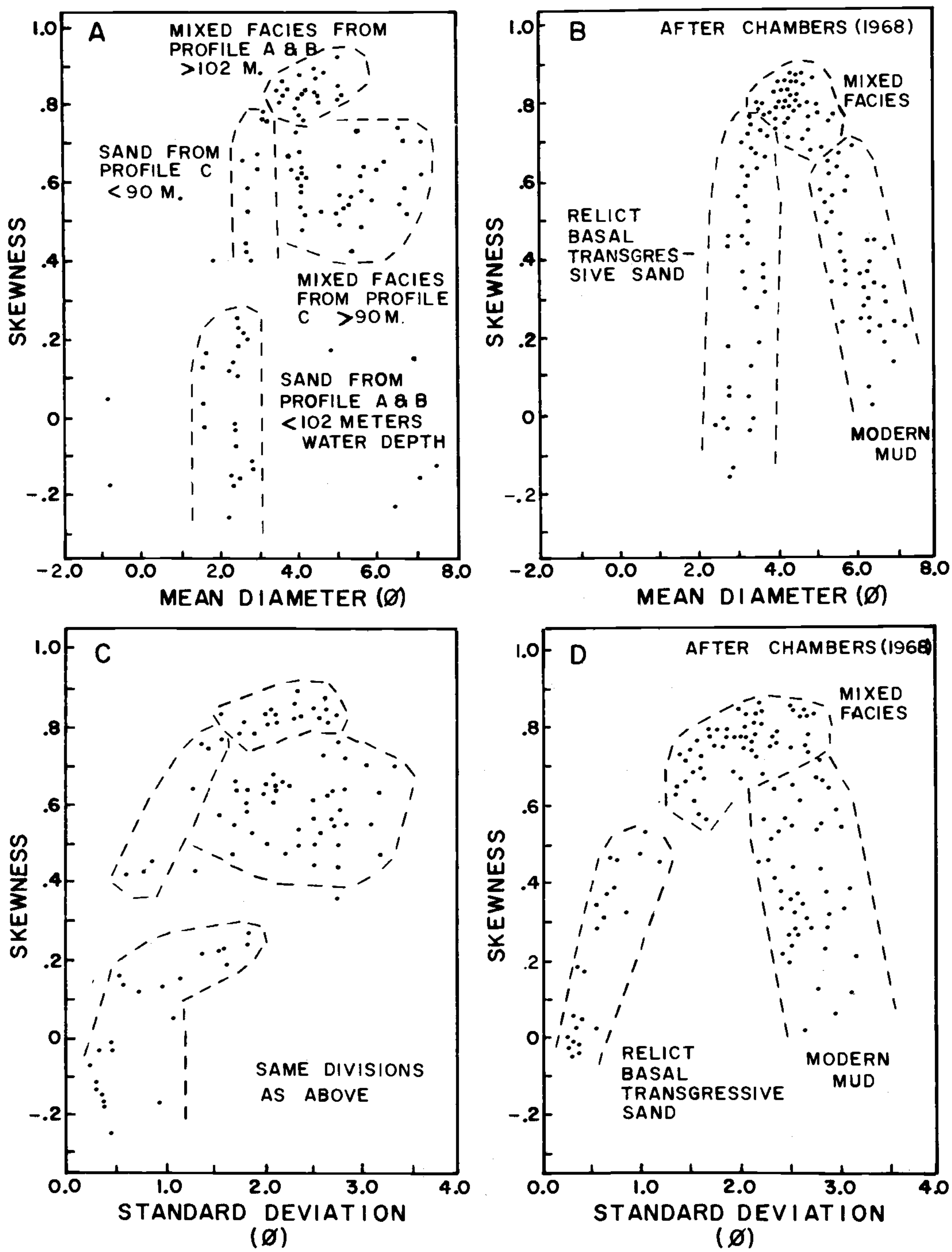

Figure 4. Top: Skewness versus mean diameter.
Bottom: Skewness versus standard deviation.
A and C: Central Oregon continental shelf.
B and D: Southern Oregon continental shelf after Chambers (1968).

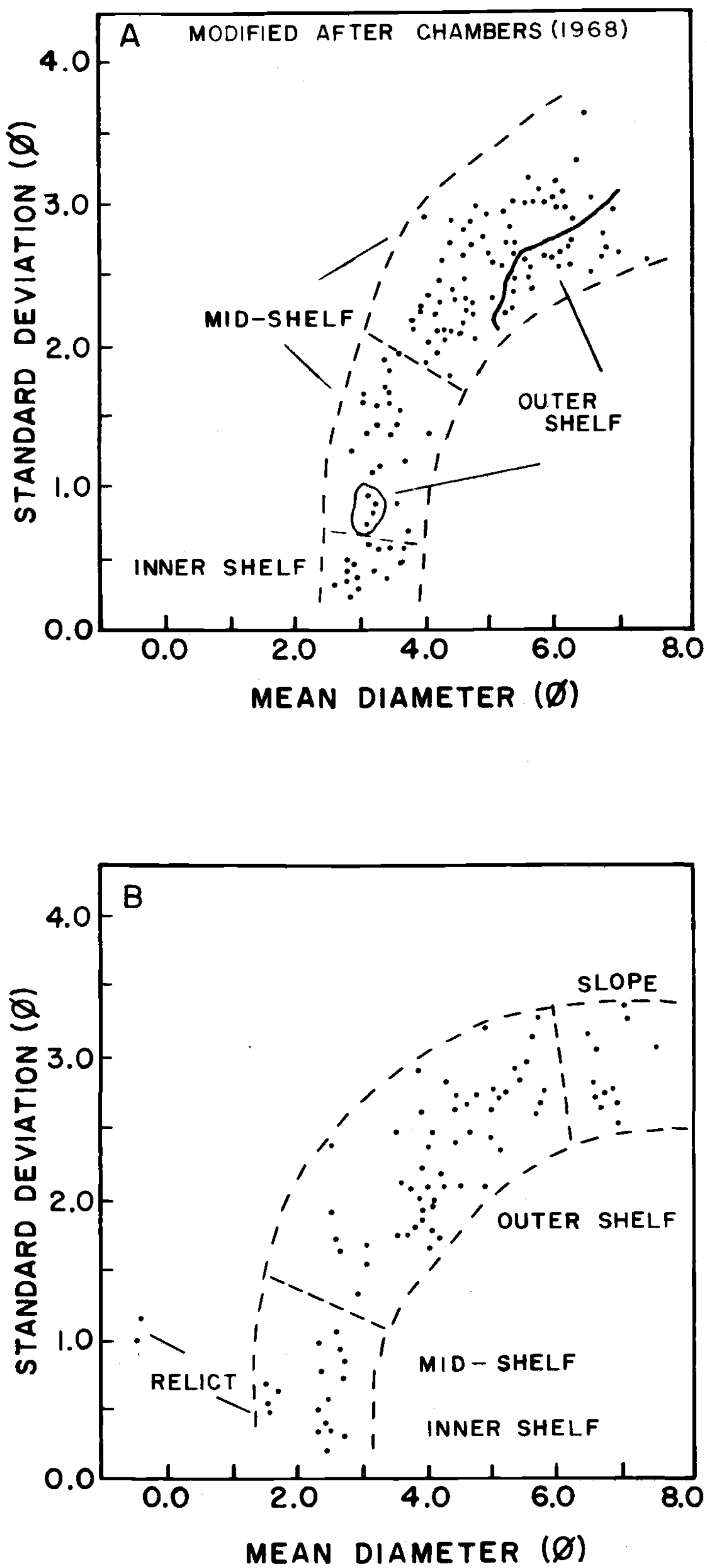

Figure 5. Standard deviation versus mean diameter.
A: Southern Oregon continental shelf after Chambers (1968).
B: Central Oregon continental shelf.

southern Oregon shelf. As interpreted by Chambers (1968), the mixed facies is the result of recent muds being reworked into the underlying basal transgressive sand by benthic animals. Animal sediment relationships are discussed further in a later section on organic structures.

Referring again to Figure 4A and C, note that the basal transgressive sand (probably containing both relict and modern sand) is well defined in Profiles A and B. Here the transgressive sands occur at depths shoaler than 102 meters, while the mixed facies (sand plus mud) occurs at greater depths. The transgressive sands from Profile C are distinguished less easily in the bivariant plots than are sands from the other profiles due to the masking of sands along it by the present-day influx of fine-grained sediment from the Umpqua River. The basal transgressive sands along Profile C are strongly fine-skewed due to the influx of silt, clay, and very fine sand from the Umpqua River, whereas the basal sands from Profiles A and B display a fine to coarse skew.

Also note in Figure 4A and C that mixed facies samples from Profiles A and B cluster together in a group that is more positively or finely skewed than samples from Profile C. This pattern seems odd in light of the fact that Profile C is located on the fringes of an area affected by the relatively high discharge of sediment from the Umpqua River. The addition of silt and clay to the underlying sands by mixing should affect the environmentally sensitive tails of the grain size distribution such that skewness should become increasingly positive or more finely skewed.

Evidently sand-sized sediment which affects the central part of the grain size distribution has as much control on the skewness values as do the finer sediments which influence the tails of the distribution. The origin of the sand is questionable. One possibility is that the sand is relict, related to the Holocene rise of sea level. An alternative but yet to be proved explanation is that very fine sand is being deposited in addition to silt and clay along Profile C, in which case these shelf sediments cannot be called relict. As mentioned previously, photographs taken near the mouth of the Umpqua River suggest that finer material is stirred up periodically and may undergo net transport seaward in a turbid bottom layer (Neudeck, 1969).

The plot of mean diameter versus standard deviation for the central Oregon shelf yields a pattern similar to that obtained by Chambers (1968) for the southern shelf (Figure 5). The similarity of the two plots is due to the apparent relationship between standard deviation (sorting) and the degree of mixing of recent muds into the underlying basal transgressive sand. On the central shelf a correspondence of these textural parameters with water depth also exists as shown in Figure 5B; mean grain size decreases and sorting worsens progressively offshore with increasing water depth. Finer material is allowed to settle to the bottom in deeper waters where the winnowing action due to the horizontal orbital velocities of waves is less than in shallower water (Neudeck, 1969).

Despite the similarity in the plots of central and southern Oregon continental shelf textural data (Figure 5A and B) the correspondence of the mean grain size and standard deviation with water depth does not hold as well for the southern shelf sediments. In Figure 5A (data from Chambers, 1968) the bivariant plot has been modified somewhat to show the position of sample points with regard to water depth. The coarsest-grained and best-sorted sediments are found both on the inner and outer shelf, whereas outer-shelf sediments from the central Oregon shelf are finer grained and more poorly sorted than inner-shelf sediments as shown in Figure 5B. Chambers (1968) considered the coarser-grained and better-sorted sediments from the southern Oregon shelf to be relict.

An alternative suggestion is that the coarser-grained and better-sorted sediments on the outer part of the southern Oregon continental shelf are winnowed modern deposits. In other words, very fine sand, silt, and clay may be transported across the entire shelf with deposition beginning at mid-shelf depths to form a mid-shelf mud layer. The sediment that is deposited on the outer shelf is subject to the winnowing action of wave-induced bottom currents resulting in a coarser-grained and better-sorted deposit. Admittedly this model is supported mainly by circumstantial evidence.

Sand Fraction Textural Analysis

A grain-size analysis of the sand fraction of the shelf sediments was done for comparisons between different areas of the shelf and also between shelf sand and modern beach sand. Ranges of mean grain size, standard deviation (sorting), and skewness values for shelf and beach sands are presented in Figure 6. Both the present-day beach sands and the sand fraction of the continental shelf sediments are well sorted except for some of the beaches which are moderately well sorted south of the Umpqua River. This good sorting probably reflects the following factors: 1) the size range of the source material has remained constant during the Holocene and Recent; 2) the source material is well sorted due to the fact that it is derived from multicycle sedimentary terrace deposits; and 3) waves in the surf zone are able to sort in short time the quantity of sediment supplied to the beaches and ocean. Considerable overlap in the ranges of skewness values for shelf and beach sands as shown in Figure 6 further indicates the similarity in grain size distribution of these sands.

Further examination of Figure 6 shows that the sand fraction of continental shelf sediments is approximately one phi unit finer

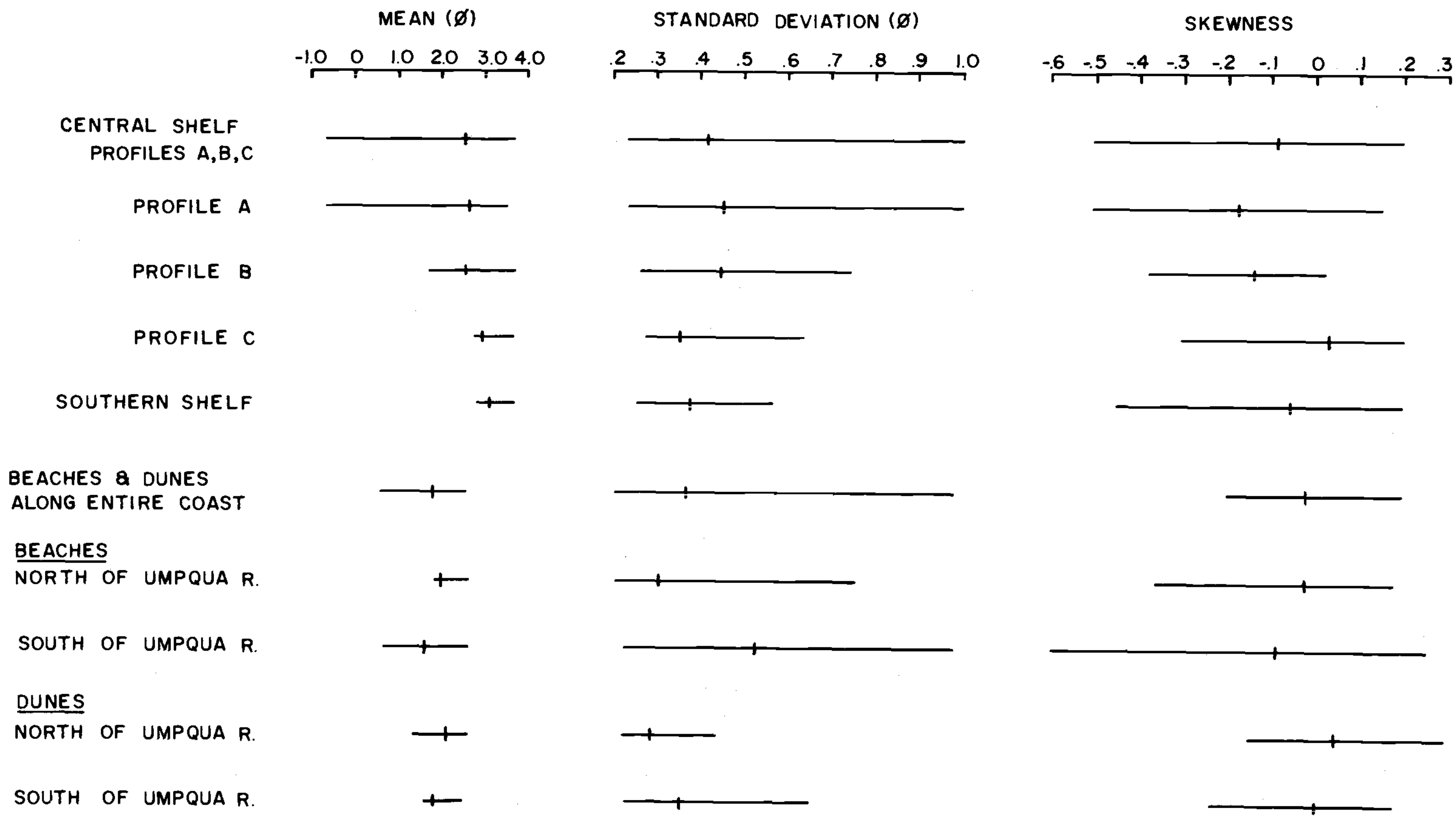

Figure 6. Ranges of mean diameter, standard deviation, and skewness values for the sand fraction of Oregon continental shelf sediments and coastal beach and dune sands. Southern Oregon shelf data is from Chambers (1968).

grained than present-day beach sands. Ranges of mean grain size for the beaches and shelf sand fraction overlap only for samples obtained along Profiles A and B, whereas the shelf sand fraction along Profile C and those farther south off the Rogue River (data from Chambers, 1968) always possess finer mean grain sizes than beach sands along the entire coast. Very fine sand (finer than 3 ϕ) accounts for less than five and quite often less than two percent of the coastal beach and dune sediment. Sand finer than 3 ϕ evidently is unstable on the beaches and either is transported seaward through the surf zone or is blown inland beyond the dunes (since it accounts for less than five percent of the dune sand). Rivers, therefore, appear to be a likely source for the very fine sand which occurs on the shelf but not on the beaches or dunes.

The question arises as to why very fine sand is the predominant mean grain size of the sand fraction from southern Oregon continental shelf sediments, whereas along Profiles A and B on the central shelf the mean grain size may range from medium to very fine sand, and, in a few cases, coarse sand. Two possible explanations are that 1) much of the sand on the central Oregon continental shelf is relict or 2) that river drainages along the central Oregon coast have sufficiently low runoffs so that their loads of very fine sand do not blanket the shelf. In the first case one might assume from energy considerations that coarse sand and gravel occurring on the continental shelf are relict and have not been transported from shore to their present position on the shelf during the present stand of sea level. The quantity of medium sand on the shelf that is relict is difficult to determine. Primary sedimentary structures have been found in medium sands from the central Oregon shelf and show that grain movement is possible but shed little light on net transport of this sand seaward across the shelf.

In the second case one might assume that coastal rivers are the primary source of very fine sand and that nearshore processes are responsible for transporting this sand seaward of the breaker zone. Larger sediment discharges of the Umpqua and Rogue Rivers may be responsible for covering coarser sediments related to the Holocene rise of sea level with modern mud and very fine sand. Central Oregon rivers have a much lower discharge than the Umpqua or the Rogue River to the south, and, therefore, probably carry less sediment. On the central Oregon continental shelf coarser-grained relict sediments are not masked entirely by mud and very fine sand, and the sand fraction of the sediments along Profiles A and B as a result has a wider range of mean grain sizes.

Grain Size Modes

Textural parameters (mean, standard deviation, and skewness) were used in the preceding sections to help distinguish environments of deposition and to suggest possible sources and transport of shelf sediments. Modal grain sizes can be used for tracing "discrete sediment masses on the shelf even where mixed with other masses" (Curray, 1960 and 1961). Curray (1960) discusses modal size analysis as being a valuable, although rarely used tool in grain size analysis as applied to geological problems.

The mode is the most frequently occurring particle diameter and corresponds to a point of inflection on the cumulative curve (Folk, 1968). A sample may be bimodal or multimodal (two or more peaks occurring on the frequency curve or two or more inflections on the cumulative curve) in which case two or more sources may be contributing sediment. The mode, therefore, is a useful tool for studying sediment source and transport.

Runge (1966) and others have provided a rather complete textural analysis of the Oregon continental shelf surface sediments; parameters such as mean grain size and sorting were contoured in map form for most of the continental shelf. The writer, using these data, has studied the occurrence of modes of the shelf, beach, and dune sediments of Oregon and believes that they merit further brief discussion as an addition to the exhaustive textural analyses of previous workers. The modes were determined to the nearest $1/4\phi$ unit but were plotted subjectively in either $1/4$ or $1/2\phi$ groups in Figures 7 and 8. Two figures (Figures 7 and 8) were used instead of one to

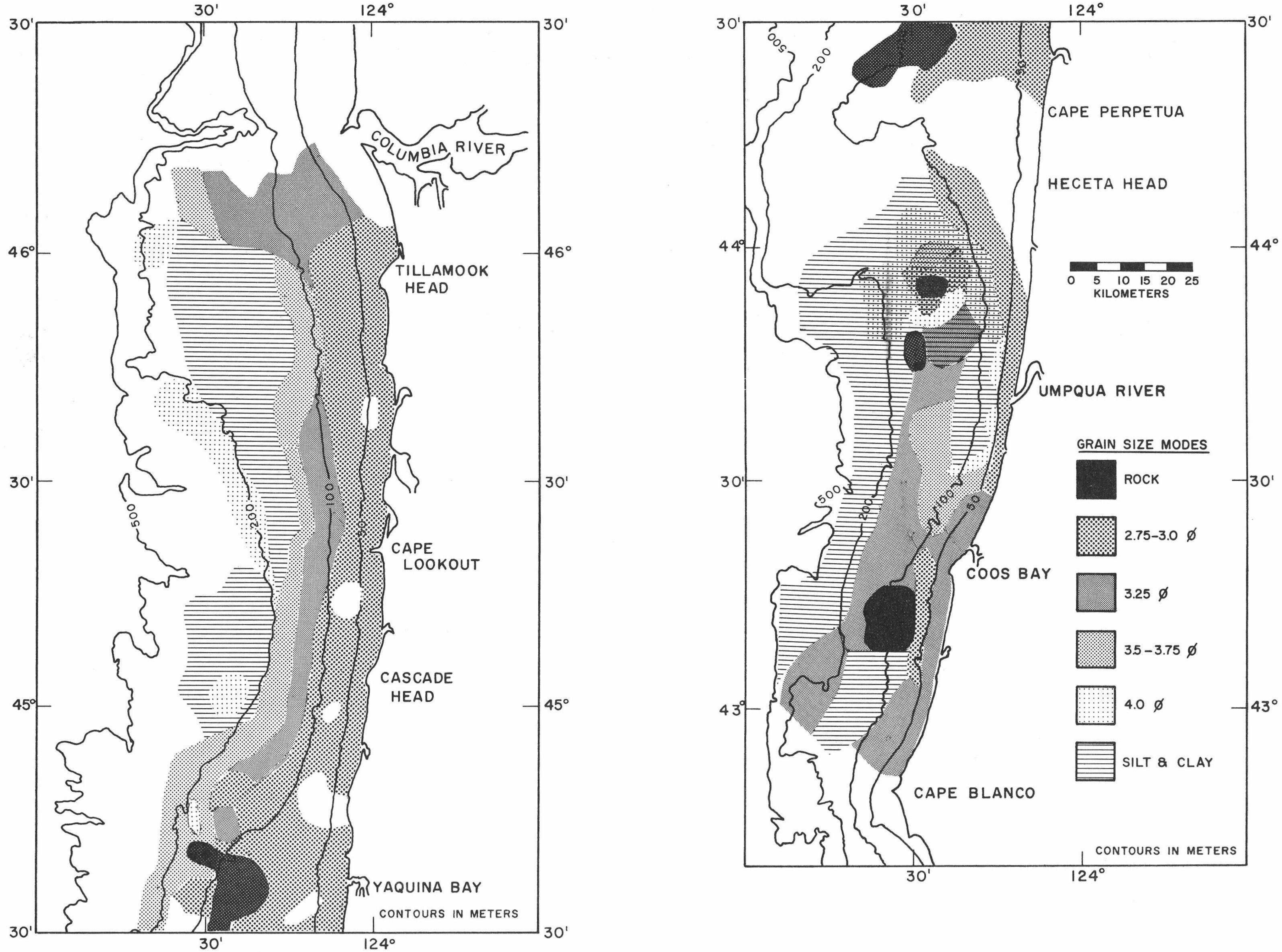

Figure 7. Occurrence of grain size modes finer than 2.75 ϕ in Oregon continental shelf sediments.

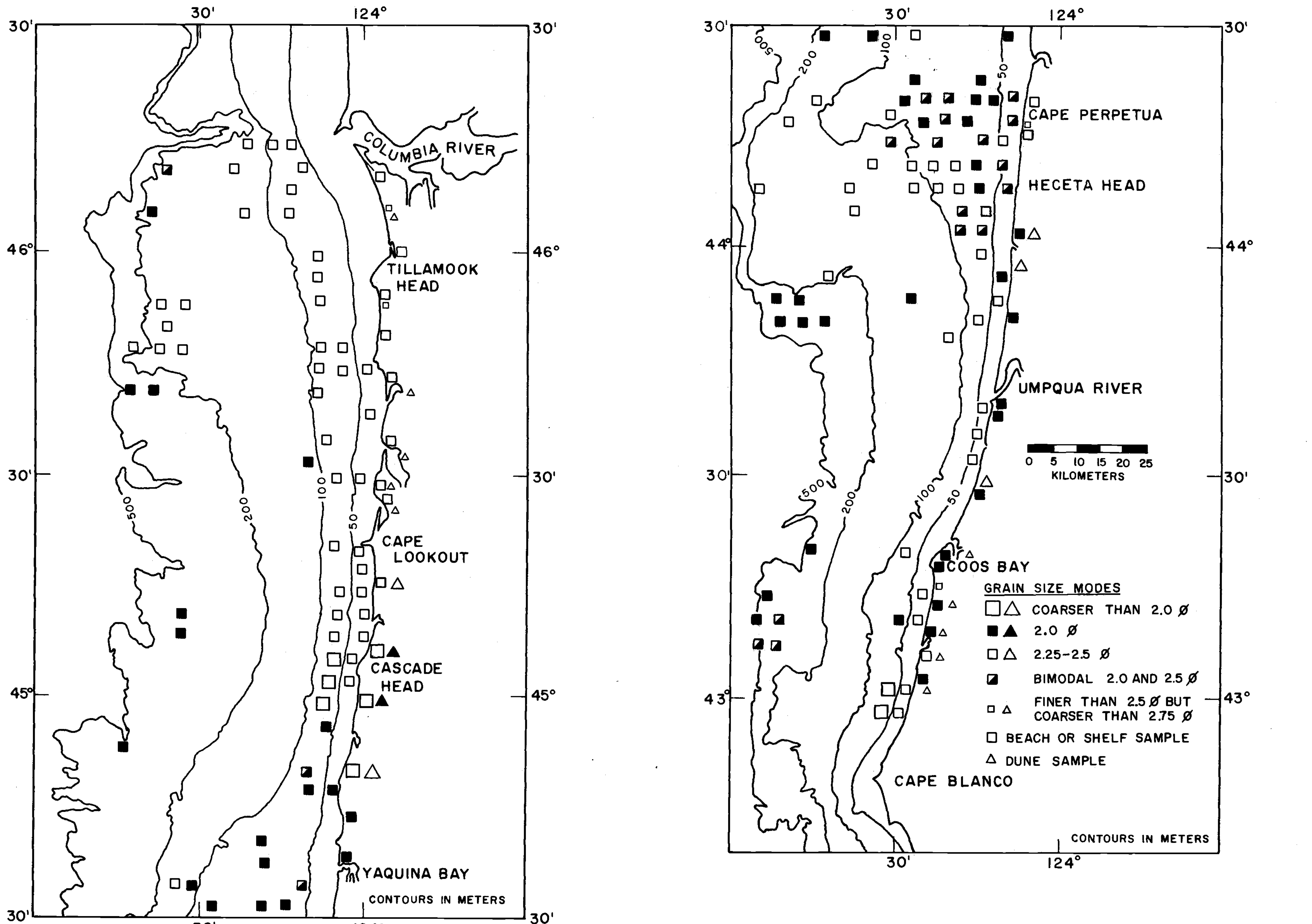

Figure 8. Occurrence of grain size modes coarser than 2.75 ϕ in continental shelf and coastal beach and dune sediments.

simplify the handling of a large amount of information. The occurrence of modes finer and coarser than 2.75 ϕ is illustrated in Figures 7 and 8 respectively. In Figure 8, each symbol overlies a sample point, whereas in Figure 7 a pattern is used to envelop a large number of sample stations each possessing the same mode or modes. Modes finer than sand are not distinguished and instead are referred to as a silt plus clay mode.

In general, over most of the northern and central shelf the modal sizes finer than 2.75 ϕ decrease with increasing water depth and distance offshore (Figure 7). In other words the modal grain sizes roughly parallel the bathymetric contours. This graded appearance of the sediments may be due to the decreasing intensity of physical agents such as the oscillatory motion due to waves with depth on the shelf. The graded pattern actually is broken on the northern shelf by the accumulation of a silt and clay mode on the mid- and outer portions of the shelf. Neudeck (1969) points out from physical oceanographic considerations that the northern shelf is a favorable area for the accumulation of fine-grained material; the zone of maximum rippling due to the effects of sea and swell should occur at depths shallower than the zone of silt and clay accumulation as shown in Figure 7.

This fine sediment is derived mostly from the Columbia River, and its movements have been traced by associated radionuclides released into the Columbia River at Hanford, Washington. The decrease in activities of the nuclides suggests that sediment from the Columbia River moves northward 12 to 30 kilometers per year along the shelf and 2.5 to 10 kilometers per year westward and southward (Gross and Nelson, 1966).

The silt and clay mode on the northern continental shelf is flanked to the seaward by very fine sand having a mode at 4ϕ. The existence of this band of sediment on the outer shelf may be explained in three ways. First the very fine sand may be a relict deposit (deposited during a lower stand of sea level) now being covered by modern silts and clays. Secondly, an alternative suggestion is that the very fine sand as well as the silt and clay may be modern. In this case, silt and clay are prevented from covering the sand by the increased winnowing of finer sediment on the outer shelf. A third possible explanation is that the mode is due to the five to twenty percent glauconite which occurs in the sediment on parts of the outer and mid-shelf.

The modal size groups on the southern Oregon continental shelf lack the simplicity of design of a graded shelf (Figure 7). It is important to remember, however, that 1/4ϕ intervals are being used between some of the modal size groups and that a simpler design can be obtained by increasing the interval. On the other hand, one might try to explain the distributional pattern of grain size modes as a function of the submarine topography. For example, note in Figure 7 that rocks cropping out on the sea floor southwest of Coos Bay are related to a submarine topographic high area extending seaward from land. Sediments surrounding such outcrops often possess multimodal grain size distributions, suggesting that these sediments are derived from more than one source. Possibly these sediments are a mixture of recent, relict, and residual sediments.

Rivers also affect the sediment distribution on the inner continental shelf. In Figure 7 some of the modal size groups do not parallel the bathymetry. Such an area is near the mouth of the Columbia River where the 3.25 ϕ modal size group cuts across the shelf bathymetric contours, reflecting the influence of the river on shelf sedimentation. Other rivers that appear to serve as major sediment sources influencing the grain size modes of shelf sediments are the Umpqua and Coos Rivers.

Interesting observations also can be made from Figure 8 which shows the distribution of modes coarser than 2.75 ϕ both in continental shelf and coastal beach and dune sediments. Grain size modes coarser than 2.75 ϕ occur in both inner and outer shelf sediments. The presence of these modes in outer shelf sediments correlates with high percentages of glauconite (greater than 90 percent) found in these samples collected and analyzed by Runge (1966).

The source of the coarser modes on the inner shelf is more difficult to determine than those in outer shelf sediments. A relationship seems to exist between the occurrence of these modes in the inner shelf sediment and those in coastal beach and dune sand. A large portion of the inner northern and central shelf sediment is characterized by a grain size mode between 2.75 and 3.0ϕ as shown in Figure 7. South of Coos Bay, however, the nearshore sediments are characterized by a mode at 3.25ϕ. Other parts of the inner shelf are covered by sediment having one or more grain size modes between 2.0 and 2.5ϕ as shown in Figure 8. Modes finer than 2.75ϕ (Figure 7) and those coarser than 2.75ϕ (Figure 8) in some cases exist together in the shelf sediment, creating a bimodal grain size distribution, but often the modes shown in Figure 8 occur to the exclusion of those shown in Figure 7. One such area is between Cape Perpetua and Heceta Head where modes coarser than 2.75ϕ occur in the sediment. By comparison with the inner shelf sediments, the coastal beach and dune sediments possess modes between 2.0 and 2.5ϕ as shown in Figure 8. Beach and dune sediments, however, do not possess any of the nearshore sediment grain size modes finer than 2.75ϕ.

On the inner shelf a textural boundary exists at 45°00'N latitude (Cascade Head). North of this boundary a mode between 2.25 and 2.5ϕ occurs in the sediment. South of this boundary both the 2.0ϕ mode and the mode between 2.25 and 2.5ϕ are present in the sediments. On the beaches a similar boundary exists. North of 45°06'N latitude (just north of Cascade Head) the beaches and dunes exhibit modes between 2.25 and 2.5ϕ. South of this boundary the beaches and dunes exhibit grain size modes of 2.0 or 2.25ϕ. In the vicinity of Cascade Head it is interesting to note that both beach and inner shelf sediments possess grain size modes coarser than 2.0ϕ.

The comparisons between modes occurring in inner shelf, beach, and dune sediments are interpreted as follows. A considerable portion of the inner continental shelf sediment is characterized by grain size modes between 2.75 and 3.0ϕ as shown in Figure 7. This sediment may be modern. These grain sizes (between 2.75 and 3.0ϕ and finer) rarely account for more than five percent of the grain sizes in beach and dune sands as discussed previously in the section on sand fraction analysis. Rivers have been suggested as the source of this sediment. Other areas of the inner shelf, on the other hand, possess sediment having grain size modes coarser than 2.75ϕ (Figure 8). These grain size modes also occur in beach and dune sands. Where these modes occur in shelf sediments, the deposits may be relict (for example the inner shelf sediments between Cape Perpetua and Heceta Head as shown in Figure 8).

The sediments (relict ?) between Cape Perpetua and Heceta Head remain uncovered by sediments (modern ?) having grain size modes of 2.75 and finer because of the lack of rivers along this stretch of coast. Between Cape Perpetua and Heceta Head the longest basalt outcrop on the central Oregon coast forms sheer cliffs, and unconsolidated terrace sands that overlie the basalt are protected from wave erosion (North and Byrne, 1965). The modal grain sizes occurring in sediment located on the inner shelf west of the basalt cliffs are not masked by the unconsolidated terrace sands which are not exposed to direct wave attack or carried to the sea via river run-off.

The model discussed above is quite significant in that a considerable portion of the Oregon continental shelf appears to be covered by modern sediments that include very fine sand as well as mud. Some of the inner- and mid-shelf deposits appear to be mixtures of modern and relict sediments. Other areas of the inner shelf seem to consist predominantly of relict sediments. Such deposits are located off major headlands and stretches of the coast where sediment supply by rivers is of limited influence on shelf sedimentation.

Concrete evidence for establishing what is relict and what is modern on the Oregon continental shelf is unfortunately scarce. Until a good method to distinguish between relict and recent sands on the Oregon shelf is found, more than one sedimentation model should be kept in mind. Physical agents such as semipermanent currents, normal wind waves, storm waves, tidal currents, and storm tidal currents affect the modal grain size distribution of sediment (Curray, 1960). Future quantitative measurements of bottom currents on the Oregon continental shelf should be quite useful in showing the significant influence of the physical agents listed above on the distribution of sediments.

Sedimentary Structures

Previous investigations of the Oregon continental shelf have been concerned mainly with the physical, mineralogical, and biological aspects of the sediments. Only recently have sedimentary structures been investigated. The following discussion concerns sedimentary structures found in box cores from the central Oregon continental shelf.

Primary sedimentary structures are inorganic in origin and are dependent mainly on current velocity and rate of sedimentation (Pettijohn, 1957). Graded bedding and ripple laminations are two examples of primary structures. Organic structures result from organic activity which leaves evidence in the form of borings, burrows, trails, casts, molds, and fecal pellets.

As previously mentioned, box core Profiles A, B, and C were chosen to include the widest possible range of environmental conditions affecting shelf sediment transport and deposition. As described in the methods section and also in Appendix V, the box cores were sliced in vertical planes, photographed, x-rayed, and then impregnated with epoxy resin in order to investigate sedimentary structures. An illustrative summary of the internal sedimentary structures is presented in Figure 9.

Primary Sedimentary Structures

Sediments cored in water depths from 32 to 64 meters along Profiles A and B consist predominantly of horizontally laminated fine sand, medium sand, and in one case coarse sand and gravel (see Figure 10). A core at 88 meters from Profile B also is laminated. The laminations appear to be a function of texture with the lighter laminae being coarsest and the darker laminae being finest. More opaque minerals are contained in the finer grain sizes and may add to the darkness of the finer lamina. In deeper shelf waters (deeper than 88 meters) the only primary structures observed are thinly laminated surface mud layers. These thin surface mud layers, which are found only along Profiles B and C, range in thickness from less than one centimeter to three centimeters, with most of the layers averaging less than one centimeter in thickness. It is conceivable that some of these laminated mud layers were created during the shipboard handling of the samples.

Neudeck (1969) has calculated the percentage of total time during a period of one year that conditions will exist for the formation

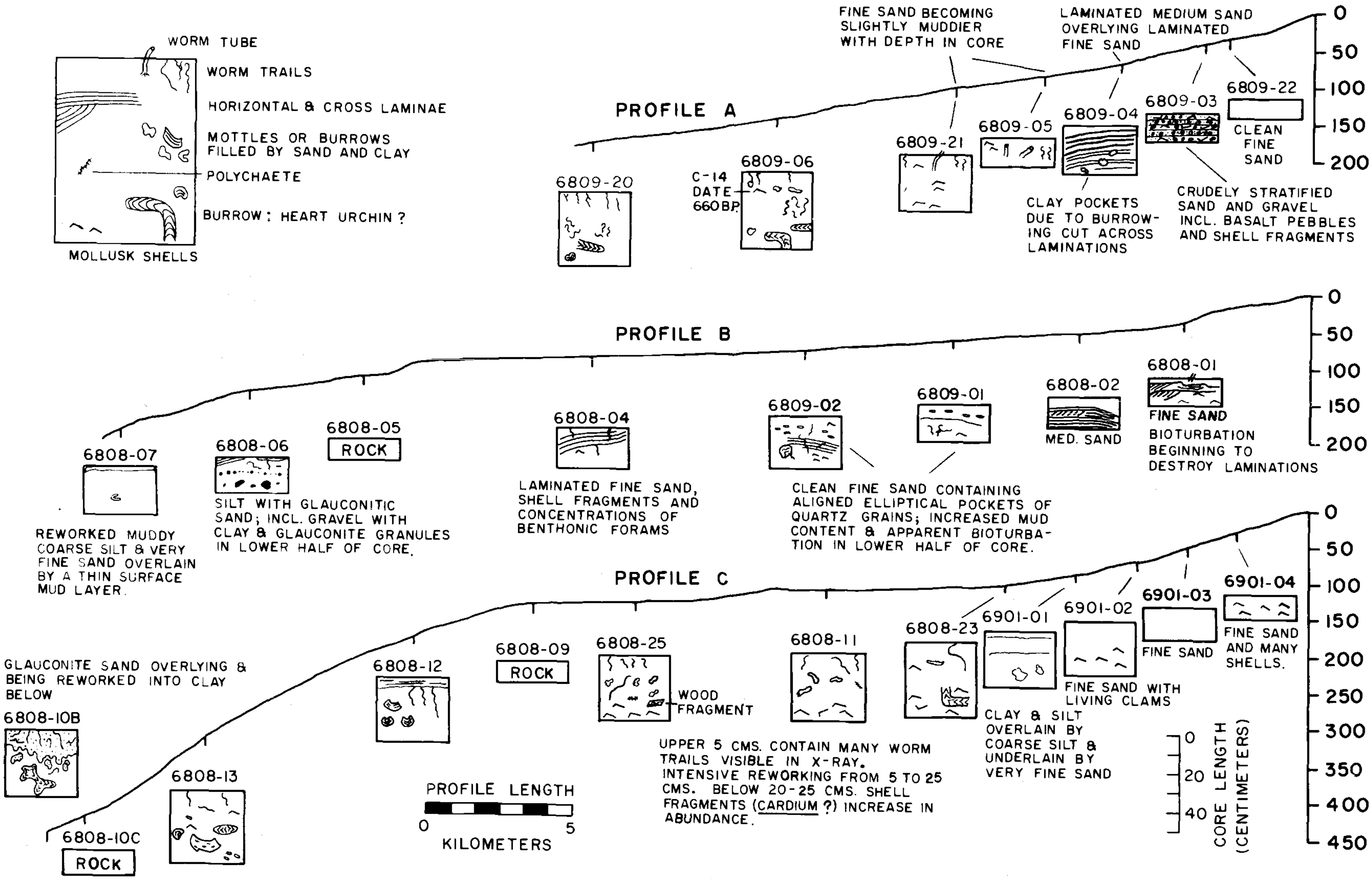

Figure 9. Sedimentary structures in box cores from three continental shelf profiles.

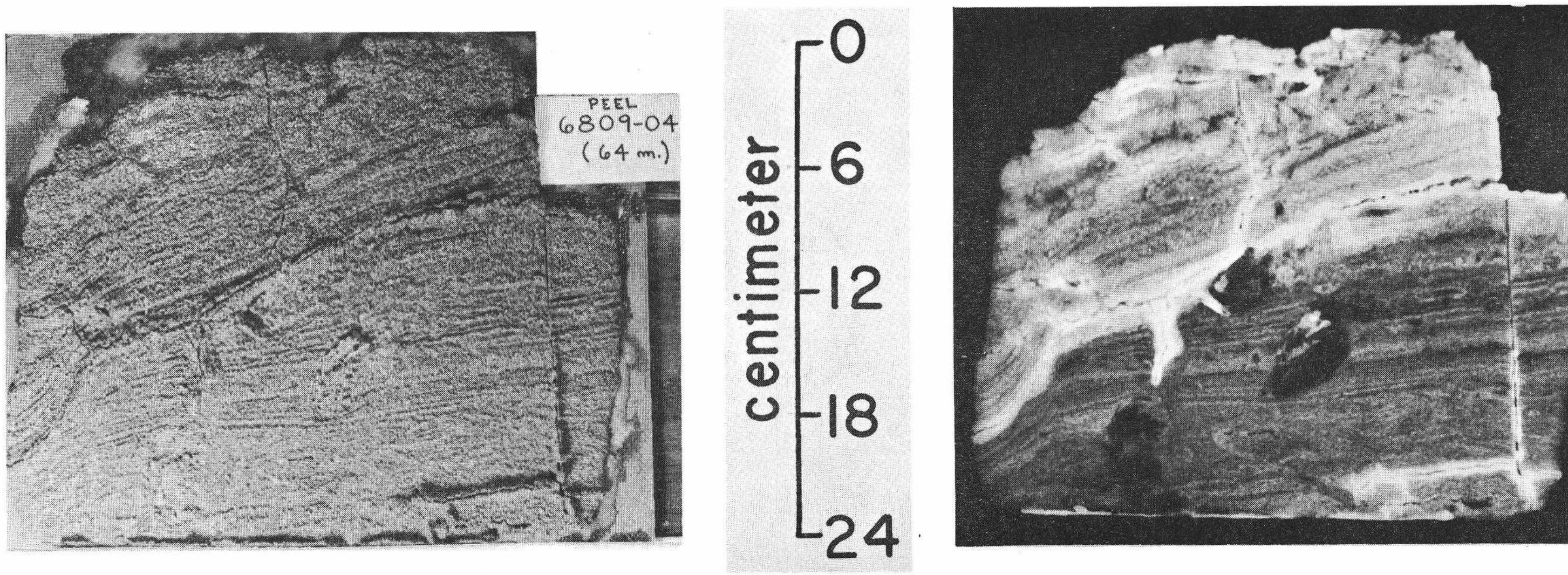

Figure 10. Epoxy resin peel and x-radiograph of core 6809-4 (64 meters). Horizontal lamina are typical primary structures found in inner shelf sediments along Profiles A and B. The core consists of medium and fine sand and the upper 11 centimeters are coarser grained than the lower 13 centimeters. Bioturbation in the lower half of the core is beginning to destroy the primary structures as shown by clay filled burrows which cut across the lamina.

of ripple marks in medium to very fine sand at a given water depth due to the effects of sea and swell. These calculations show that rippling is expected the entire year out to 40 meters, 50 percent of the year for depths extending to 60 meters, and about 25 percent of the year for depths extending to 80 meters. Since bottom photographs indicate that rippling can occur across the entire width of the shelf to depths of 200 meters, more evidence of cross lamination was expected in the cores than was found. McKee (1965) points out, however, that ripple lamination does not accompany the surface formation of ripples in all cases.

Simons, Richardson, and Nordin (1965) and Harms and Fahnestock (1965) discuss classifications of flow regime and bed form. Horizontal or plane stratification develops in an upper flow regime where water velocities are high. Although shelf box cores exhibit horizontal stratification, the bottom water velocities probably are not characteristic of the upper flow regime. Ripples form in the lowest flow regime, just above the threshold of grain movement. Bottom water velocities on the shelf probably are characteristic of this lower flow regime.

Perhaps the best explanation for the coexistence of ripple bed forms and horizontally laminated internal structures is that offered by McKee (1965), who states that "the development of ripple lamination from ripple marks requires that abundant sediment continually be supplied to a current or wave so that the ripple marks are built upward in overlapping series rather than merely migrate in a forward direction." Laboratory studies (McKee, 1965) show that ripples will migrate continuously without building permanent internal structures unless sediment is added in abundance. Field evidence (McKee, 1965) showed that no subsurface ripple lamination structures were formed on a particular tidal flat which developed an extensive ripple-marked surface. Instead, horizontal lamina were developed apparently by the redistribution of sediment by the changing tides.

On the Oregon continental shelf sea and swell set up horizontal orbital movements that flatten with depth and cause a to-and-fro redistribution of the sediment. A rippled bed is formed by these oscillations, and apparently since no new material is being added to the bed load, horizontal lamina are preserved internally rather than cross laminations or other ripple lamination types. One can further assume, therefore, that sedimentation rates on the inner and mid-shelf along Profiles A and B are low.

Preservation of ripple laminations on the shelf might be more likely in an area receiving a large suspended load from a major river (such as the Columbia, Umpqua, or Rogue Rivers). If a storm produced sufficient horizontal orbital velocities to ripple the bed load, then perhaps some of the sediment from the suspended load could be added to the bed load to increase the chances for ripple lamination formation. Cores from the vicinity of the Umpqua River mouth have been examined for such structures, but they were found absent despite previously obtained camera evidence of ripple bed forms in this area.

Organic Sedimentary Structures

One possible reason that cores taken north of the mouth of the Umpqua River (Profile C) lack primary structures is that benthic activity destroys them soon after they develop. Carey (1965) states that the abundance of shelf fauna correlates with the organic content of the sediment, which correlates in part with sediment size. Clay-sized sediments contain considerably more organic matter than sands. This association partly is due to the fact that clays and organic matter are influenced similarly by water movements (Trask, 1939). Compared to the entire sea, of course, the organic content of the Umpqua River is minor, but it may be of local importance. Dapples (1942) states that worms prefer mud bottoms with much admixed sand. Such is the case for the inner shelf cores taken along Profile C near the Umpqua River, but it is not the case for the inner shelf along Profiles A and B. The benthic activity, therefore, may be higher off the Umpqua River so that primary structures are destroyed soon after formation and replaced by organic structures.

Different degrees of bioturbation exist in the box cores. In deeper water, where wave energy affects the movement of bottom sediment less than in shallower water and where the sediments become finer grained, organic structures become more apparent. The silt and clay content increases at the expense of sand offshore, and burrowing activities are easier to detect in cores where the organic structures are emphasized by textural contrasts. In other words, the shape or design of the structure is the result of a sand-silt-clay mixture. In addition, animal populations may differ in composition and density so that different burrowing habits and degrees of reworking result in different organic structures.

From box core Profiles A, B, and C, two groups of cores can be distinguished that contain organic structures but little or no traces of primary structures. The shallower group of cores as shown in Figure 11 consists of fine sand (mean diameter of about 2.5 ϕ) with a mud content that ranges from 2 to 13 percent. The mud content increases gradually with depth in the cores, although higher concentrations of mud occur in patches. (See core 6809-2 in Figure 11 which contains a high concentration of worm trails in an isolated mud patch.) Characteristic cores are 6809-5 and 6809-21 from Profile A at 82.3 and 102.4 meters respectively (see Figure 11), 6809-1 and 6809-2 from Profile B at 64 and 80.5 meters respectively, and possibly 6901-2 from Profile C at 70 meters. Gastropod and pelecypod shells, worm tubes, and some worm trails are less than moderately abundant in these cores. Large burrows are absent.

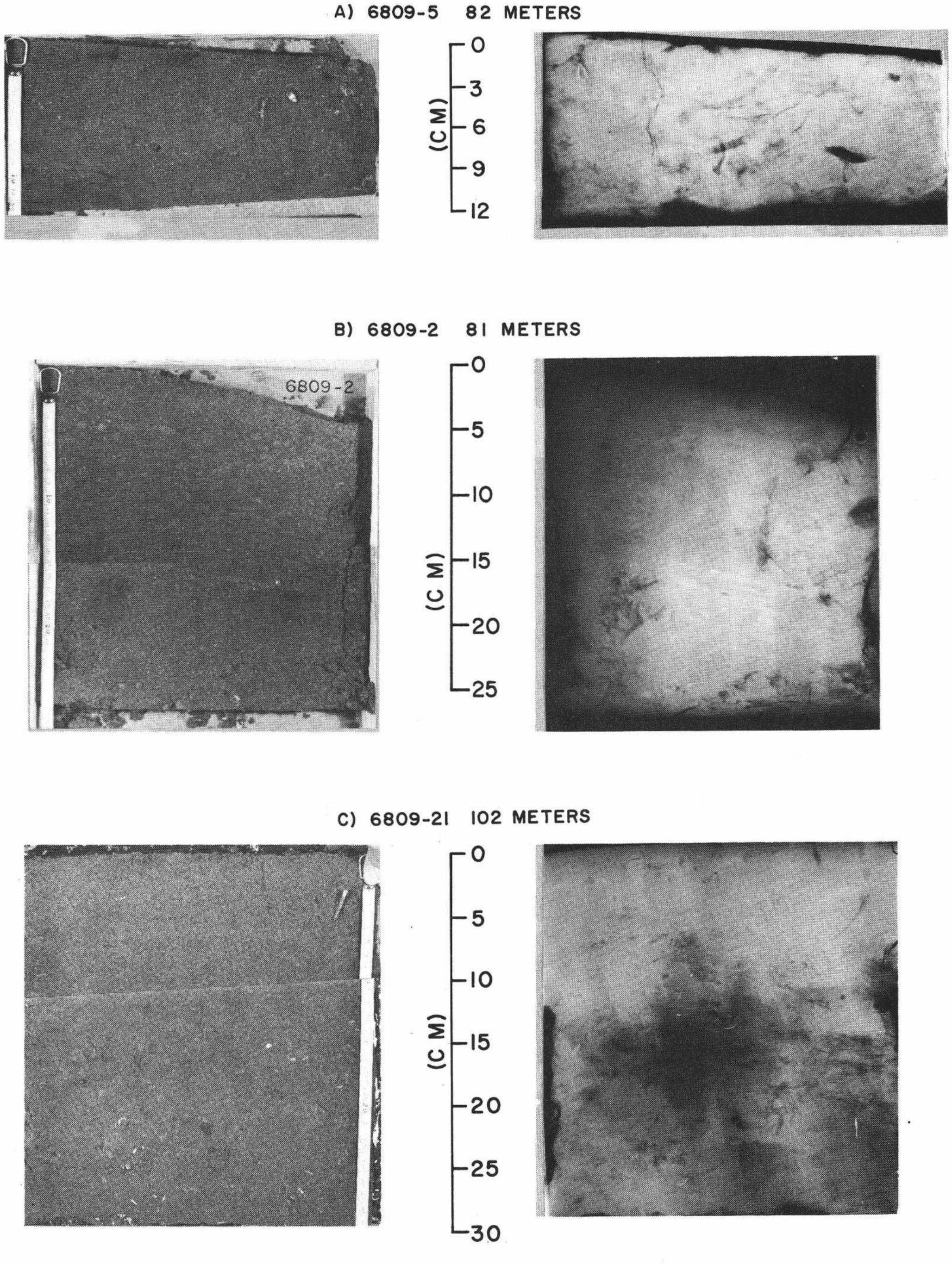

Figure 11. Three box core photographs and x-radiographs typical of mid-shelf sediments. Shells, worm tubes, and worm trails are present in fine sand.

The cores seaward of 102 meters along Profile A, seaward of 88 meters along Profile B, and seaward of 70 to 80 meters along Profile C exhibit bioturbation to a greater degree than do the shallower cores. (See for example core 6809-20 in Figure 12.) The average grain size for these cores is 4.6 ϕ with the mud content ranging from 20 to 70 percent. The burrowing habits of polychaetes, mollusks, and possibly echinoderms are distinctive in these cores as detected visually and by x-radiography. Worm trails are very abundant, especially in the muddier sections of the core and also in the top ten centimeters of the cores. Other types of trails and burrows (especially those of larger animals) are generally found below the top ten centimeters.

Pelecypod shells are particularly abundant below 25 centimeters depth in some of the cores as indicated in mid- and outer-shelf cores from Profile C (see Figure 9). The explanation of the common occurrence of pelecypod shells (whole and fragmental) below 20 to 25 centimeters in mid- and outer-shelf cores from Profiles A and especially C remains unexplained. The shells are in poor physical condition as even whole valves are soft and crumble easily. The concentration of shells is not high enough so that a discrete shell layer can be recognized.

Rhoads (1967) has studied the biogenic reworking of sediments and shows how polychaetes are able to size grade the sediment

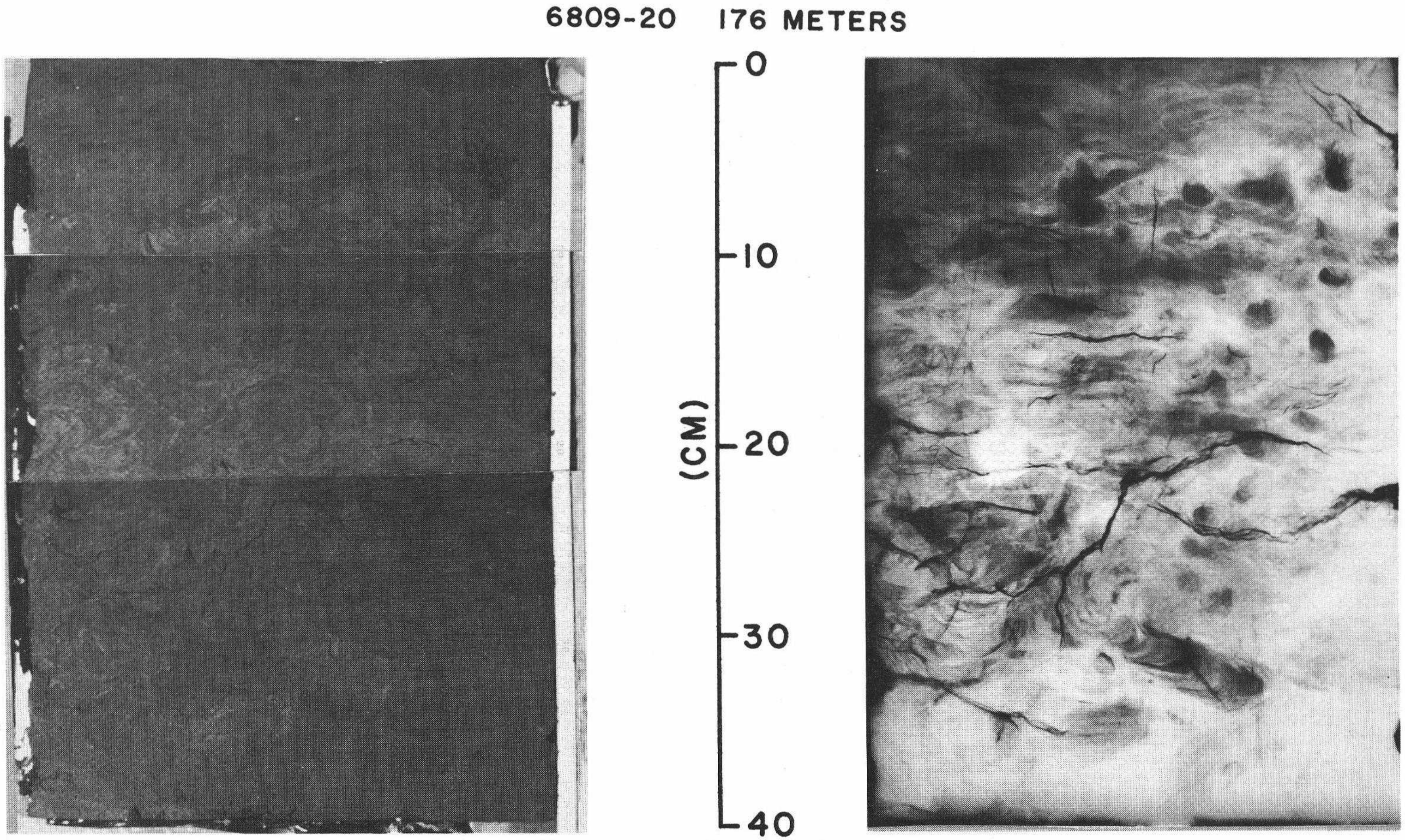

Figure 12. Box core 6809-20 and accompanying x-radiograph showing organic structures typical of the outer shelf.

vertically. In one example he illustrates how sediment one millimeter or less in size is ingested at the anterior end of an agglutinated sand tube located 20 to 30 centimeters below the sediment surface and is egested at the sediment surface. Sand, gravel, and shell fragments greater than one millimeter in diameter remain and become concentrated at depths 20 to 30 centimeters below the surface. The accumulation of pelecypod shells below 20 to 25 centimeters in the box cores may be due to similar biogenic reworking and sediment size grading.

Finally, Figure 13 is included to show the transition from continental shelf to slope. Besides the striking lithology (glauconite sand overlying clay) the burrows appear to be larger than those in outer shelf cores.

6808-10B 466 METERS (UPPER SLOPE)

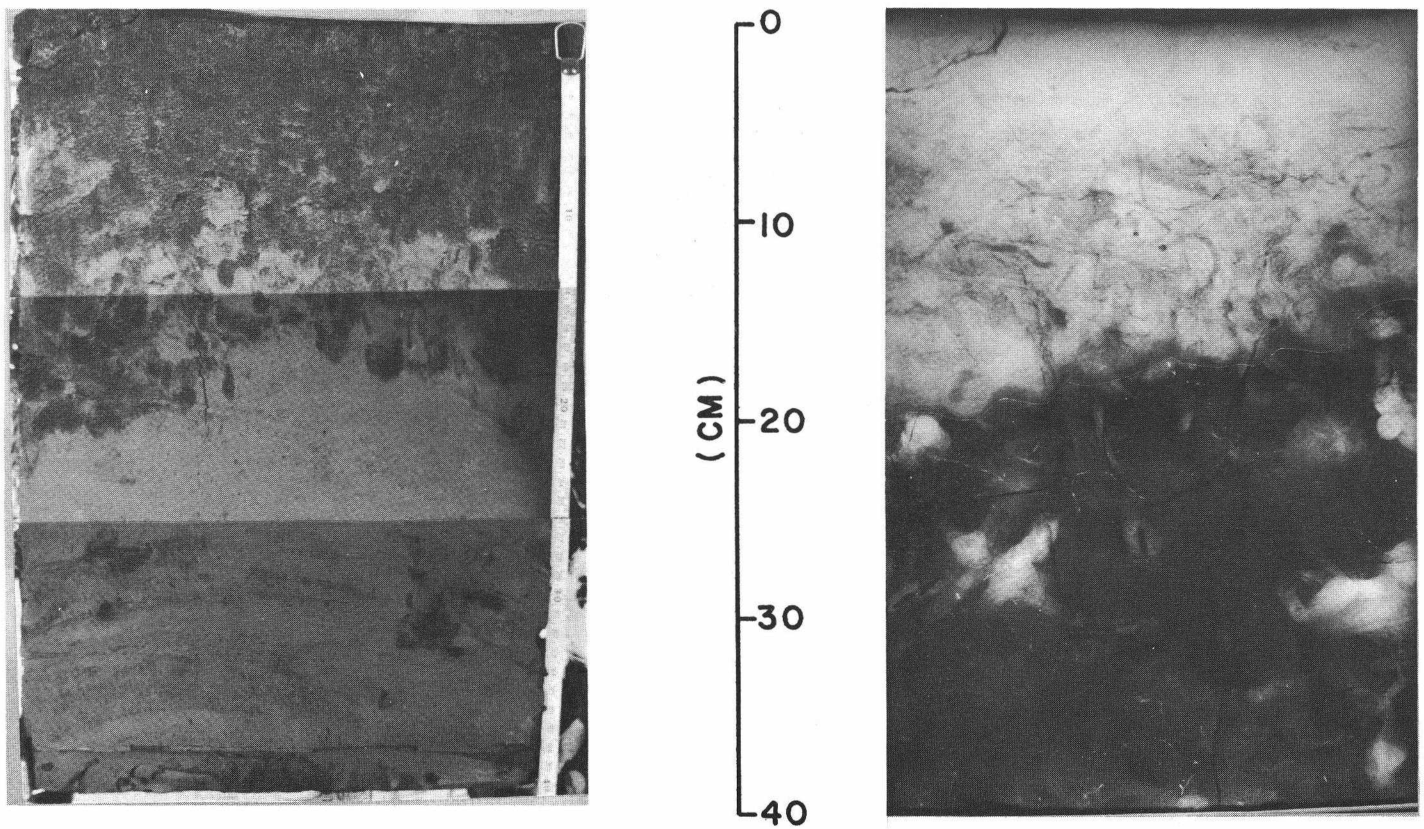

Figure 13. Box core 6808-10B from the upper continental slope. Glauconite sand overlies olive-gray clay. The x-radiograph reveals burrowing and mixing of the glauconite sand into the underlying clay.

SUMMARY:

SEDIMENTATION ON THE OREGON CONTINENTAL SHELF

To a limited extent the study of sediment textures and structures help determine the recent history of sedimentation on the Oregon continental shelf. Box cores from the central Oregon continental shelf show little variation in grain size with depth in the core. Sediments generally become finer grained with increasing water depth except for cores taken at 38 and 55 meters water depth along Profiles A and B respectively. These cores are coarser grained than those taken in shallower or deeper water. Runge (1966) also noted that sediments from depths between 35 and 70 meters often were coarser grained than those occurring in deeper or shallower water. This band of sediment paralleling the coast may be related to a lower stand of sea level, and is, therefore, a relict nearshore deposit. Any alternative explanation would seem to require that a higher energy environment of deposition exist between 35 and 70 meters water depth than depths shallower or deeper.

Bivariant plots of textural parameters from continental shelf sediments along three shelf profiles indicate that grain size decreases, size sorting of the grains worsens, and the grain size distribution becomes more positively (finely) skewed as water depth increases, although this may not be the case for other areas of the shelf. Such a correspondence of these textural parameters with depth reflects the increased mixing of mud into sand, as physical agents influencing the transportation and deposition of shelf sediments decrease in intensity.

Photographic observations indicate that turbid zones develop periodically just above the bottom on the continental shelf near the mouth of the Umpqua River (Neudeck, 1969). Very fine sand and a high percentage of silt and clay travel beneath this zone or periodically in suspension within the turbid layer. An analysis of the grain size distribution also suggests that very fine sand is more abundant along Profile C (located near the Umpqua River) than Profiles A or B and may indicate that coastal rivers are a major source of modern very fine sand in addition to mud. This modern very fine sand probably is deposited on the inner shelf but substantial evidence is lacking for the transport of this very fine sand across the entire shelf, even though circumstantial evidence indicates such transport may be likely.

An analysis of the sand fraction of the continental shelf sediments and also the coastal beach and dune sands shows that sand from shelf Profiles A and B have grain size distributions somewhat similar to beach and dune sands. Sand from continental shelf sediments along Profiles A and B has a mean grain size range that partly overlaps that for beach and dune samples. The sand fraction for continental shelf sediments taken along Profile C and also southern Oregon in the vicinity of the Rogue River is approximately one phi unit finer grained than Oregon beach and dune sand.

Very fine sand from major coastal rivers is unstable in the nearshore zone (since sand finer than 3 ϕ accounts for only a few percent of the beach and dune grain size distribution) and is transported across the shelf to an undetermined depth. Along Profiles A and B, no rivers comparable to the Rogue or Umpqua Rivers influence shelf sedimentation. Influx of very fine sand is minor so that little if any of the relict sand from the Holocene rise of sea level becomes covered, although mixed sediments are likely.

An analysis of grain size modes reinforces the idea that relict sediments occur on areas of the central Oregon continental shelf not directly influenced by major rivers. This type of analysis also indicates that sand-sized particles occurring in shelf sediments are related texturally to the adjacent beach sands. A boundary at about 45°00'N latitude (Cascade Head) separates texturally similar shelf and beach sands to the north from those to the south (Figure 8). Shelf sand possessing the same textural characteristics as the beaches is thought to be relict. Very fine sand from coastal rivers appears to be mixing with the relict sand, covering it in a few places and surrounding patches of it in other places.

Finally, sedimentary structures were examined from box cores taken along the continental shelf Profiles A, B, and C. Primary sedimentary structures in the form of horizontally laminated sand occur between 38 and 88 meters water depth. These structures show that movement of sand is possible, but unfortunately shed little light on net transport of sand across the shelf.

Organic structures occur in the form of worm tubes, worm trails, shells, and burrows. The organic structures in shelf sediment from water depths shallower than 100 meters are characterized by shells, worm tubes, and some worm trails. Large burrows are absent. Cores seaward of 102 meters along Profile A, 88 meters along Profile B, and 70 to 80 meters along Profile C exhibit bioturbation to a greater degree than shallower cores. Larger burrows become noticeable and worm tubes are lacking. Worm trails are abundant. Increases in shell fragment content below 20 to 25 centimeters in some of the cores may be related to biogenic reworking and size grading of the sediment.

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APPENDICES

APPENDIX I

BOX CORE SAMPLE LOCATIONS

OSU Sample Number	Latitude	Longitude	Water Depth in Meters
6808-1	44°35.8'	124°07.3'	37
6808-2	44 35.8	124 10.0	55
6808-4	44 39.0	124 21.9	88
6808-5	44 39.1	124 28.8	115
6808-6	44 39.0	124 31.8	139
6808-7	44 39.0	124 35.9	190
6808-9	43 50.2	124 31.0	135
6808-10B	43 48.6	124 52.1	466
6808-10C	43 49.4	124 51.7	430
6808-11	43 49.0	124 22.0	110
6808-12	43 49.5	124 35.4	174
6808-13	43 49.2	124 40.1	338
6808-23	43 48.8	124 18.0	101
6808-25	43 49.1	124 27.0	124
6809-1	44 37.4	124 12.6	64
6809-2	44 38.0	124 16.1	79
6809-3	45 00.1	124 03.6	38
6809-4	45 00.0	124 05.8	64
6809-5	45 00.0	124 07.7	82
6809-6	45 00.1	124 14.6	146
6809-20	45 00.1	124 18.0	176
6809-21	44 59.3	124 09.9	102
6809-22	44 59.9	124 02.8	33
6901-1	43 48.9	124 15.6	89
6901-2	43 49.0	124 14.0	70
6901-3	43 49.0	124 12.9	50
6901-4	43 49.0	124 11.8	30

APPENDIX II

TEXTURAL ANALYSES OF THE TOTAL SEDIMENT CONTINENTAL SHELF BOX CORES

OSU Sample Number		Depth Interval in Cores (cm)	$M_z(\phi)$	$\sigma_I(\phi)$	Sk_I	Percent sand	Percent silt	Percent clay
6808-1		--------	2.55	.28	-0.07	98.3	1.7	0
6808-2	A	0 - 1	1.77	.46	.03	98.7	1.3	0
	B	0 - 16	1.72	.51	-0.03	98.7	1.3	0
6808-4		--------	2.55	.52	-0.37	97.2	2.8	0
6808-5		--------	6.99	4.15	.15	33.6	24.8	41.6
6808-6	A	0 - 9	4.40	2.78	.77	67.7	17.3	15.0
	B	9 - 18	4.07	2.51	.74	73.5	13.6	12.9
6808-7	A	0 - 1/3	7.62	2.97	-0.11	15.9	33.9	50.2
	B	1/3- 3	4.02	1.97	.80	74.5	14.6	10.9
	C	3 - 8	4.22	2.10	.81	72.1	15.7	12.2
	D	8 - 13	4.07	1.88	.79	72.7	16.2	11.0
	E	13 - 20	4.17	1.91	.81	70.5	18.5	11.1
	F	20 - 25	4.64	3.02	.84	63.3	21.4	15.3
6808-9		--------	5.52	2.86	.43	38.1	40.6	21.3
6808-10	B-A	0 - 5	2.01	1.40	.40	88.5	7.2	4.2
	B	5 - 10	2.77	2.28	.67	80.3	11.9	7.8
	C	10 - 15	4.00	2.89	.63	58.6	26.2	15.2
	D	15 - 20	5.04	3.18	.18	46.8	30.5	22.7
	L	20 - 30	7.12	2.46	-0.16	14.1	46.5	39.4
	M	30 - 40	6.61	2.81	-0.22	20.2	41.9	37.9

OSU Sample Number		Depth Interval in Cores (cm)	$M_z(\phi)$	$\sigma_I(\phi)$	Sk_I	Percent sand	Percent silt	Percent clay
6808-11	A	0 - 5	4.34	1.98	.52	49.1	40.5	10.4
	C	5 - 10	4.16	2.16	.67	57.3	32.7	10.0
	E	10 - 15	4.20	1.91	.62	54.5	35.7	9.8
	G	15 - 20	4.31	1.76	.48	49.7	41.2	9.1
	I	20 - 25	4.19	1.72	.55	53.4	37.7	8.8
	K	25 - 30	4.19	1.83	.62	55.3	35.7	9.0
	M	30 - 35	4.15	1.64	.58	54.1	37.5	8.4
6808-12	T	0 - 1/2	5.86	2.51	.62	27.1	52.1	20.7
	A	0 - 5	6.12	2.68	.63	21.8	54.4	23.8
	C	5 - 15	5.91	2.54	.58	29.1	48.6	22.3
	E	15 - 25	5.94	2.63	.63	29.9	47.9	22.2
	G	25 - 35	6.01	2.69	.56	37.6	39.7	22.7
	I	35 - 40	5.27	2.25	.65	38.1	46.6	15.3
6808-13	A	0 - 5	7.08	2.79	.51	1.7	69.3	29.1
	C	5 - 15	6.94	2.54	.51	1.3	70.4	28.3
	E	15 - 25	6.83	2.64	.55	1.8	72.0	26.2
	G	25 - 35	6.95	2.54	.43	1.7	70.1	28.2
	I	35 - 45	6.90	2.80	.59	2.3	71.8	25.9
6808-23	A	0 - 5	5.59	2.83	.56	35.7	44.5	19.8
	C	5 - 10	5.44	2.64	.54	40.7	39.8	19.5
	E	10 - 15	5.40	2.58	.52	40.7	40.6	18.7
	G	15 - 20	5.40	2.73	.56	38.1	44.0	17.9
	I	20 - 25	5.11	2.04	.51	34.5	51.6	13.9
	K	25 - 30	6.33	4.04	.64	39.0	37.6	23.3
	M	30 - 35	5.17	2.35	.50	39.4	44.8	15.8
	O	35 - 40	5.86	3.08	.55	30.5	47.9	21.7

OSU Sample Number		Depth Interval in Cores (cm)	$M_z(\phi)$	$\sigma_I(\phi)$	Sk_I	Percent sand	Percent silt	Percent clay
6808-25	A	0 - 5	4.90	2.43	.54	44.9	40.5	14.6
	B	5 - 10	4.49	2.09	.60	53.6	34.9	11.5
	C	10 - 15	4.39	2.10	.64	55.5	32.9	11.6
	D	15 - 20	4.28	2.02	.61	55.2	34.4	10.4
	E	20 - 25	4.20	2.01	.64	58.2	31.6	10.2
	F	25 - 30	4.18	1.89	.60	57.0	33.9	9.1
	G	30 - 35	4.05	1.86	.60	58.0	32.5	9.5
6809-1	A	0 - 5	2.51	.38	-0.16	97.3	2.7	0.0
	B	5 - 13	2.51	.42	-0.04	95.6	4.4	0.0
6809-2	A	0 - 14	2.46	.38	-0.15	98.3	1.7	0.0
	B	14 - 26	2.46	.50	-0.01	95.6	4.4	0.0
6809-3	T	0 - 7	-0.65	1.12	.05	73.6	0.2	26.2 } gra-
	B	7 - 15	-0.79	1.01	-0.18	66.6	0.0	33.3 } vel
6809-4	A	0 - 10	1.80	0.57	.16	98.6	1.4	0.0
	B	10 - 13	1.62	0.61	.13	98.9	1.1	0.0
	C	13 - 24	2.29	0.48	-0.27	97.9	2.1	0.0
6809-5	A	0 - 4	2.51	0.75	.10	94.7	1.5	3.9
	B	4 - 13	2.47	0.99	.12	93.3	2.7	4.0
6809-6	A	0 - 5	3.73	2.48	.84	79.7	10.0	10.3
	B	5 - 10	3.83	1.71	.83	78.9	11.2	9.8
	C	10 - 15	3.85	2.05	.84	79.1	11.1	9.8
	D	15 - 20	3.94	2.01	.83	75.9	13.5	10.6
	E	20 - 25	4.20	2.38	.87	73.5	14.3	12.2
	F	25 - 30	4.79	2.58	.86	65.9	18.0	16.1
	G	30 - 35	4.63	2.41	.87	68.6	16.6	14.8
	H	35 - 38	3.78	1.71	.81	80.8	10.4	8.8

OSU Sample Number		Depth Interval in Cores (cm)	$M_z(\phi)$	$\sigma_I(\phi)$	Sk_I	Percent sant	Percent silt	Percent clay
6809-20	A	0 - 5	5.14	2.56	.84	56.8	25.9	17.3
	B	5 - 10	4.87	2.58	.87	63.3	21.4	15.3
	C	10 - 15	5.58	3.55	.91	61.5	20.3	18.2
	D	15 - 20	4.62	2.51	.84	61.7	24.4	13.9
	E	20 - 25	5.70	2.91	.72	44.7	34.2	21.1
	F	25 - 30	5.19	2.55	.82	54.4	28.1	17.6
	G	30 - 35	5.17	2.58	.81	53.7	29.4	16.9
	H	35 - 38	4.63	2.05	.82	63.4	23.8	12.8
6809-21	A	0 - 5	2.61	1.19	.15	93.0	1.9	5.1
	C	5 - 11	2.62	2.41	.25	90.5	1.2	8.3
	E	11 - 16	2.66	1.89	.26	87.2	3.5	9.3
	G	16 - 21	2.64	1.89	.22	88.1	2.8	9.1
	I	21 - 27	2.62	1.71	.20	87.2	4.0	8.7
	K	27 - 30	2.59	1.63	.21	86.7	3.9	9.4
6809-22	A	0 - 4	2.92	.34	-0.13	98.2	1.8	0.0
	B	4 - 9	2.92	.33	-0.11	98.2	1.8	0.0
6901-1	A	0 - 2	4.37	2.38	.83	64.2	22.0	13.8
	B	2 - 8	5.91	3.25	.49	41.0	32.0	27.0
	C	8 - 13	4.69	2.68	.83	61.1	22.4	16.5
	D	13 - 18	3.87	2.08	.84	75.4	14.6	9.9
	E	18 - 23	3.35	1.51	.76	81.4	11.7	6.8
	F	23 - 28	3.35	1.48	.76	81.5	11.8	6.7
	G	28 - 32	3.39	1.63	.78	80.9	11.8	7.3
6901-2	A	0 - 2	2.90	.69	.41	90.1	6.0	3.9
	B	0 - 8	3.05	1.31	.65	86.1	7.9	6.0
	C	8 - 20	2.88	.95	.45	90.2	5.2	4.6
	D	20 - 27	2.87	.85	.42	91.8	4.4	3.8

OSU Sample Number		Depth Interval in Cores (cm)	$M_z(\phi)$	$\sigma_I(\phi)$	Sk_I	Percent sand	Percent silt	Percent clay
6901-3	A	0 - 5	3.02	2.32	.66	85.1	2.1	12.8
	B	5 - 12	2.94	2.27	.57	87.6	1.4	11.0
6901-4		-------	2.87	2.27	.49	88.0	12.0	0.0

APPENDIX III

TEXTURAL ANALYSES OF THE SAND FRACTION ONLY CONTINENTAL SHELF BOX CORES

OSU Sample Number		$M_z(\phi)$	$\sigma_I(\phi)$	Sk_I
6808-1		2.54	.28	-0.09
6808-2		1.76	.44	.01
6808-4		2.54	.51	-0.38
6808-5		2.53	.74	.02
6808-6	A	2.86	.49	.02
	B	2.86	.51	.03
6808-7	A	3.65	.27	-0.28
	B	3.31	.29	-0.02
	C	3.32	.30	-0.01
	D	3.33	.30	.01
	E	3.31	.28	.01
	F	3.32	.30	.01
6808-9		2.98	.63	-0.07
6808-10B-A		1.82	.65	0.00
	B	1.73	.67	.03
	C	1.93	.67	.09
	D	1.96	.71	.14
	L	2.51	.72	-0.08
	M	2.64	.68	-0.18
6808-11	A	3.22	.36	.16
	C	3.22	.36	.14
	E	3.18	.37	.05
	G	3.20	.38	.11
	I	3.18	.38	.10
	K	3.20	.37	.07
	M	3.19	.35	.11
6808-12	T	3.66	.26	-0.23
	A	3.67	.25	-0.30
	C	3.65	.25	-0.19
	E	3.65	.27	-0.26
	G	3.65	.25	-0.22
	I	3.64	.26	-0.21

OSU Sample Number	$M_z(\phi)$	$\sigma_I(\phi)$	Sk_I
6808-13 A	3.41	.85	-0.52
C	2.88	.80	.01
E	3.23	.64	-0.33
G	3.47	.55	-0.75
I	3.62	.39	-0.67
6808-23 A	3.30	.43	.18
C	3.28	.44	.14
E	3.28	.43	.18
G	3.27	.42	.15
I	3.32	.44	.11
K	3.22	.45	.11
M	3.27	.44	.15
O	3.24	.43	.20
6808-25 A	3.15	.44	.08
B	3.14	.43	.11
C	3.09	.43	.06
D	3.09	.44	.06
E	3.09	.44	.07
F	3.09	.45	.08
G	3.06	.45	.03
6809-1 A	2.49	.36	-0.21
B	2.48	.36	-0.21
6809-2 A	2.45	.37	-0.16
B	2.43	.39	-0.24
6809-3 T	-0.66	1.07	.02
B	-0.78	1.01	-0.18
6809-4 A	1.79	.56	.15
B	1.60	.60	.12
C	2.27	.47	-0.28
6809-5 A	2.48	.42	-0.35
B	2.42	.47	-0.42
6809-6 A	3.14	.24	-0.01
B	3.16	.24	0.00
C	3.17	.23	-0.04
D	3.17	.24	.01
E	3.16	.25	.02
F	3.17	.24	.03
G	3.17	.24	-0.01
H	3.16	.25	-0.01

OSU Sample Number		$M_z(\phi)$	$\sigma_I(\phi)$	Sk_I
6809-20	A	3.46	.25	-0.04
	B	3.46	.25	-0.03
	C	3.45	.26	-0.02
	D	3.49	.25	-0.04
	E	3.49	.26	-0.11
	F	3.47	.26	-0.08
	G	3.49	.25	-0.07
	H	3.49	.25	-0.05
6809-21	A	2.56	.43	-0.44
	C	2.55	.46	-0.46
	E	2.54	.45	-0.48
	G	2.53	.48	-0.50
	I	2.50	.50	-0.52
	K	2.46	.52	-0.47
6809-22	A	2.91	.34	-0.15
	B	2.91	.32	-0.14
6901-1	A	2.90	.34	.19
	B	2.93	.37	.17
	C	2.91	.38	.08
	D	2.91	.34	.13
	E	2.89	.35	.18
	F	2.91	.32	.17
	G	2.87	.32	.13
6901-2	A	2.85	.29	.02
	B	2.83	.30	.03
	C	2.82	.28	-0.04
	D	2.82	.28	-0.06
6901-3	A	2.83	.29	.01
	B	2.83	.29	-0.01
6901-4		2.80	.30	-0.11

APPENDIX IV

TEXTURAL ANALYSES OF BEACH AND DUNE SAND

OSU Sample Number	Latitude on the Coast	$M_z(\phi)$	$\sigma_I(\phi)$	Sk_I
BEACHES				
8- 3	43°19'	2.15	1.58	-0.62
4	43 18	1.13	.40	.05
5	43 18	1.70	.45	.10
6	43 20	1.94	.39	.05
7	43 16	2.40	.27	-0.14
8	43 16	2.97	.36	-0.06
9	43 14	1.66	.58	.17
11	43 07	1.28	.39	.07
14	43 06	2.15	.60	-0.53
16	43 05	1.75	.35	.08
18	42 50	2.41	.36	.06
20	42 51	1.41	1.11	-0.46
22	42 49	2.30	.36	-0.07
23	42 44	.83	.71	-0.02
24	42 44	1.01	.47	-0.13
25	42 44	1.55	.97	-0.29
26	42 44	2.15	.42	-0.14
27	42 41	1.17	.63	-0.13
28	42 37	1.32	.35	.12
31	42 27	1.86	.48	.04
32	42 26	1.99	.39	.07
33	42 25	1.61	.61	0.00
34	42 23	1.95	.37	-0.02
36	42 11	.85	.69	-0.39
37	42 11	1.75	.38	.14
39	42 01	.70	.33	-0.14
40	42 01	-1.11	1.09	-0.30
41	42 01	1.07	.84	-0.18
43	41 57	2.42	.32	-0.15
44	41 52	1.69	.99	-0.54
47	41 45	2.77	.25	-0.04
48	41 36	1.95	.33	0.00
55	42 19	2.24	.39	-0.12
65	43 52	1.94	.39	-0.03
71	46 10	2.65	.33	.01

OSU Sample Number	Latitude on the Coast	$M_z(\phi)$	$\sigma_I(\phi)$	Sk_I
72	45°54'	2.25	.23	.11
74	45 36	2.14	.22	-0.03
77	45 15	2.00	.22	-0.08
79	45 48	2.20	.20	.14
80	45 54	2.25	.25	.09
81	42 33	1.45	.43	-0.06
82	45 28	2.22	.24	.18
84	45 54	2.25	.22	.03
86	45 43	2.22	.20	-0.05
87	45 06	1.62	.32	-0.03
88	45 54	2.24	.22	-0.09
90	46 05	2.23	.31	.08
93	45 33	2.25	.25	.18
96	45 54	2.23	.22	-0.12
97	45 06	1.62	.28	.05
98	45 54	2.22	.23	-0.04
102	44 16	2.25	.27	-0.07
104	45 54	2.26	.22	-0.16
105	46 00	2.36	.30	-0.03
106	44 18	1.98	.39	-0.01
108	43 29	1.24	.30	.14
110	44 02	2.04	.26	0.00
111	43 40	1.98	.28	.11
113	45 26	2.26	.25	-0.05
114	44 59	1.35	.40	-0.03
116	46 12	2.24	.33	.06
120	44 19	-1.02	.74	-0.21
125	44 38	1.99	.32	.01
126	44 44	1.99	.39	.11
127	44 50	.62	.75	-0.23
DUNES				
12	43 07	1.99	.40	-0.15
13	43 06	1.76	.63	-0.25
15	43 05	2.31	.35	.14
17	43 05	2.48	.23	.10
21	42 51	1.86	.22	.03
29	42 33	1.75	.43	0.00
35	42 15	1.56	.29	-0.02
45	41 52	1.83	.58	-0.06
59	42 54	1.77	.38	-0.05
68	45 41	2.29	.22	-0.03
69	45 15	2.36	.40	.29

OSU Sample Number	Latitude on the Coast	$M_z(\phi)$	$\sigma_I(\phi)$	Sk_I
70	46°05'	2.39	.32	.02
73	44 02	2.25	.25	.23
75	46 05	2.54	.30	-0.12
76	43 57	2.28	.28	.19
78	43 29	2.14	.31	.02
83	46 05	2.40	.31	.03
85	43 29	1.76	.26	.05
89	46 05	2.58	.32	.10
94	46 05	2.35	.29	.01
95	46 05	2.51	.24	.09
99	46 05	2.56	.27	.15
100	45 26	2.24	.26	0.00
101	45 28	2.31	.29	0.00
103	44 50	1.33	.42	-0.11
107	44 59	1.85	.25	.03
109	44 50	1.29	.41	-0.03
115	43 29	1.77	.35	.11
117	45 06	2.00	.27	.07
118	43 05	2.48	.34	.18
119	43 29	2.05	.31	-0.04
121	46 12	2.12	.31	.10
122	45 32	2.24	.25	-0.15

APPENDIX V

Sediment Textural Analysis

Textural data was obtained primarily by particle settling techniques. The procedure used for this analysis is outlined as follows in order of execution.

1. An approximate 20 gram split was taken from each sample in original moist condition.

2. This 20 gram subsample was oxidized in 50 milliliters of dilute (10%) hydrogen peroxide, H_2O_2, for removal of organic material. If the reaction was not complete after 24 hours, 25 milliliters of 30 percent H_2O_2 was added periodically until the reaction ceased.

3. Distilled water was added to the sample and then drawn off through micropore candle filters.

4. A solution of Calgon (sodium hexametaphosphate) and water was then added to the sample and drawn off by micropore candle filters. This step was repeated three or four times. The Calgon concentration is two grams per liter.

5. The sample was wet sieved through a 62 micron screen, thus separating a coarse fraction and a fine fraction. The coarse fraction was weighed.

6. The fine fraction analysis was done by pipette (Krumbein

and Pettijohn, 1938).

7. The coarse fraction analysis was done by settling tube (Emery, 1938, and Poole, 1957).

8. A few samples were too coarse for the settling tube so that sieving at quarter phi intervals was necessary (Folk, 1968).

9. Input data obtained from the last three steps were handled by a CDC 3300 computer. The textural parameters used in this study are those of Folk and Ward (1957).

Analysis of Sedimentary Structures

Epoxy resins are used to preserve sedimentary structures and fabrics in wet, unconsolidated materials. The use of the resins at OSU at the time of this writing is relatively new, and future improvements in technique are expected.

Preservation of sedimentary structures and fabric requires the differential penetration of the resins into the sediment sample. Grain size, sorting, water content of the sample, and the immiscibility and difference in specific gravities between water and the resins are factors that control the rate of penetration. The technique described here has been used successfully for sediment sizes ranging from muddy, very fine sand to gravels. Rather poor results have been obtained from silt and clay samples resulting from the failure of the resin to penetrate more than a millimeter or two into the sample. Heezen and Johnson (1962) report that "Elmer's Glue-All" is suited ideally for making peels of lutite cores. Maarse and Terwindt (1964) describe a method of making lacquer peel sections from core samples of clayey sediments.

The following recipe was recommended to me by Dr. Jim Howard (personal communication). (See Burger, Klein, and Sanders, 1969, for information related to similar recipes.)

Materials

CIBA Products: Epoxy 6005 and Epoxy 6010; Hardener 850 and Hardener 830.

Procedure

1. Mix the two epoxy resins at 1 part 6005 to 1 part 6010. Mix the two hardeners at 1 part 830 to 4 parts 850.

2. When ready for use, the combined hardeners and the combined epoxy resins are mixed as follows: 4 parts epoxy to 1 part hardener.

3. Spread the mixture on a 3/8 inch tempered masonite board cut to size slightly larger than the sediment slice.

4. Place the resined surface of the masonite board on top of the sediment slice, the surface of which has been cleaned and smoothed carefully so as not to destroy or distort any existing internal structure.

5. Let dry until hard (24 hours, with setting time taking place between 1/2 and 1 hour).

6. Optional: Overturn the sediment slice so that the sediment slice now rests on top of the resined masonite board. This procedure is easier for finer-grained and moist samples, and also for samples which have bound sides, such as by plaster. This overturned sample tends to yield a more even epoxy job and more satisfactory peel, although the overturning process risks disturbance and cracking of the sample.

7. Remove the sediment slice with a gentle stream of water or air, leaving a delicate peel about 1/8 inch thick.

In addition to the references cited in this Appendix, the following articles may be helpful for future work with preserving internal structures: Bouma (1964) and McMullen and Allen (1964).