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KAREN E. CLEMENS for the degree of Master of Science in Oceanography presented on January 6, 1987

Title: Along-Coast Variations of Oregon Beach-Sand Compositions Produced by the Mixing of Sediments From Multiple Sources Under a Transgressing Sea

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Heavy mineral compositions of sands from Oregon beaches, rivers and sea cliffs have been determined in order to examine the causes of marked along-coast variations in the beach-sand mineralogy. The study area extends southward from the Columbia River to the Coquille River in southern Oregon. The heavy-mineral compositions were determined by standard microscopic identification with additional verification by X-ray diffraction analyses. Initially the beach-sand samples were collected as single grab samples from the mid-beachface, but significant selective sorting of the important heavy minerals prevented reasonable interpretations of the results. Factor analysis of multiple samples from the same beach yielded distinct factors which correspond with known mineral sorting patterns. The effects of local sorting were reduced by the subsequent use of large composite samples,

permitting interpretations of along-coast variations in sand compositions. Four principal beach-sand sources are identified by factor analysis: the Columbia River on the north, a Coastal Range volcanic source, sands from the Umpqua River on the south-Oregon coast, and a metamorphic source from the Klamath Mountains of southern Oregon and northern California. The end members identified by factor analysis of the beach sands correspond closely to river-source compositions, the proportions in a specific beach-sand sample depending on its north to south location with respect to those sources. During lowered sea levels of the Late Pleistocene, the Columbia River supplied sand which was dispersed both to the north and south, its content decreasing southward as it mixed with sands from other sources. The distributions of minerals originating in the Klamath Mountains indicate that the net littoral drift was to the north during lowered sea levels. With a rise in sea level the longshore movement of sand was interrupted by headlands such that the Columbia River presently supplies beach sand southward only to the first headland, Tillamook Head. At that headland there is a marked change in mineralogy and in grain rounding with angular, recently-supplied sands to the north and rounded sands to the south. The results of this study indicate that the present-day central Oregon coast consists of a series of beaches separated by headlands, the beach-sand compositions in part being relict, reflecting the along-coast mixing at lower sea levels and subsequent isolation by onshore migration of the beaches under the Holocene sea-level transgression. This pattern of relict compositions has been modified during the past several thousand years by some addition of sand to the beaches by sea-cliff erosion and contributions from the rivers draining the nearby Coastal Range.

Along-Coast Variations of Oregon Beach-Sand Compositions Produced by the Mixing of Sediments From Multiple Sources Under a Transgressing Sea

By

Karen E. Clemens

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ALONG-COAST VARIATIONS OF OREGON BEACH-SAND COMPOSITIONS PRODUCED BY THE MIXING OF SEDIMENTS FROM MULTIPLE SOURCES UNDER A TRANSGRESSING SEA

INTRODUCTION

The coast of north and central Oregon consists of a series of beaches separated by stretches of rocky shoreline and pronounced headlands (Figure 1). There are multiple potential sand sources for Oregon-coast beaches. The most obvious possible contributor is the Columbia River, forming the state's northern boundary with Washington (Figure 1). Numerous rivers drain the nearby Coastal Range, but many of these are separated from the beaches by estuaries which may trap the river sands. In addition, the beach sands have a clearly defined metamorphic source which has been identified as the Klamath Mountains of southern Oregon and northern California, this source being a major compositional component well to the north of the rivers which actually drain the Klamaths (Kulm et al., 1968; Scheidegger et al., 1971). Another potential sand source is from sea-cliff erosion, particularly the cliffs containing Plio-Pleistocene marine terrace deposits as these are rich in uplifted beach and dune sands.

It is probable that the large headlands on the Oregon coast

Figure 1. Map of the study area on the Oregon coast, showing the distributions of the major headlands and stretches of beach, the principal rivers, and the locations of the beach-sand samples.

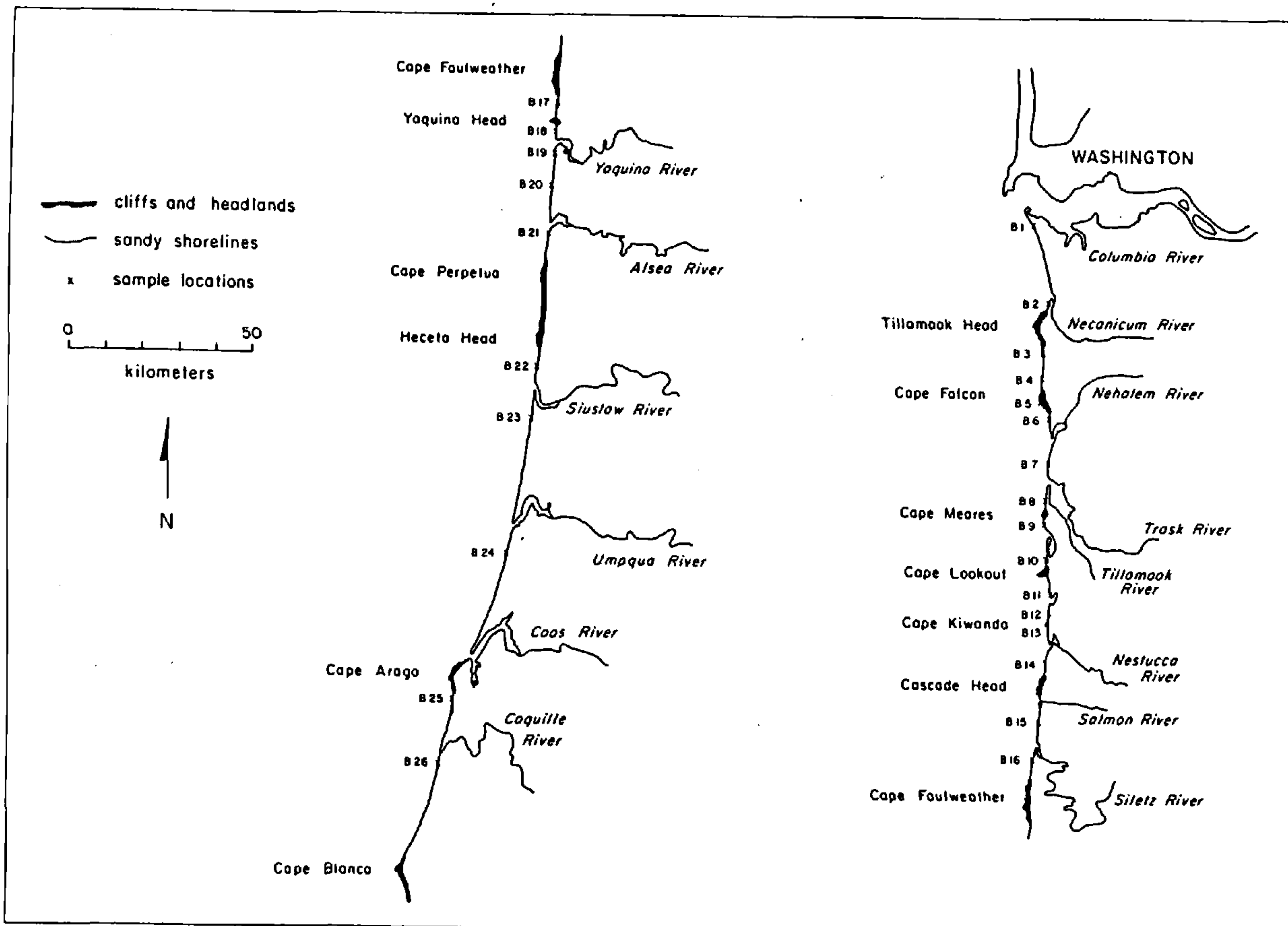
cliffs and headlands
sandy shorelines
x sample locations
0
50
kilometers
N
Cape Foulweather
B17
Yaquina Head
B18
B19
Yaquina River
B20
B21
Alsea River
Cape Perpetua
Heceta Head
B22
Siuslaw River
B23
Umpqua River
B24
Coos River
Cape Arago
B25
Coquille River
B26
Cape Blanco
WASHINGTON
B1
Columbia River
B2
Tillamook Head
Necanicum River
B3
B4
Cape Falcon
B5
Nehalem River
B6
B7
B8
Cape Meares
Trask River
B9
B10
Cape Lookout
Tillamook River
B11
B12
Cape Kiwanda
B13
B14
Nestucca River
Cascade Head
B15
Salmon River
B16
Cape Foulweather
Siletz River

Figure 1

prevent any along-coast dispersal on the modern beach of sands from these multiple sources. This study examines the hypothesis that the beach sands are in part relict, their compositions having been determined by the longshore mixing of sand from the several sources during Late Pleistocene lower stands of sea level. These relict sands subsequently would have been isolated between headlands within the last few thousands years of the Holocene transgression, during which time the overall beach compositions could be modified by more local sources. In order to test this model, a detailed study has been undertaken of the heavy-mineral compositions of Oregon beach sands and of the potental river and sea-cliff sources. The results of this study have importance to a general understanding of onshore beach-sand migrations during a marine transgression, to the longshore exchange of beach sands around headlands, and to how such processes control littoral-sand mineralogies. In addition, selective sorting of the minerals on the beaches by their differing grain densities and sizes greatly affected the mineral compositions of our initial samples, and this hampered interpretations of the results but at the same time provided an excellent example of such problems in the use of heavy-mineral compositions to determine sediment sources.

THE PHYSICAL ENVIRONMENT OF THE STUDY AREA

The present-day configuration of the Oregon coast is controlled for the most part by the distribution of resistant volcanic rocks versus the more-easily eroded sedimentary rocks. All of the major headlands in the study area, the blackened areas of Figure 1, are composed of Tertiary volcanic or related intrusive rocks. These headlands plunge directly into the sea, and have offshore depths on the order of 10 meters or more. These depths together with the considerable along-coast lengths of many of these rocky headlands likely act to limit or totally prevent any bypassing of beach sands. Pocket beaches directly associated with the headlands are composed of locally-derived gravels and boulders. The one exception to this in the study area is Short Sand Beach nestled within Cape Falcon, a normal quartz-rich sand beach having an alongshore length of 800 meters; this pocket beach has no obvious local sand source, and so will be of particular interest in this study.

The principal beaches in the study area are backed by more-easily eroded rocks or by topographically low-lying regions. The rocks are mainly mudstones and siltstones of various Tertiary formations, and in some areas these are part of uplifted marine terraces. The long stretch of coast from Cape Perpetua south to Cape Arago is low-lying and the beach is backed by the large Oregon Dunes (Cooper, 1958); these dunes represent a loss of beach sands, there being no erosion which presently cycles this sand back onto the beaches. The lengths of the beach segments vary considerably, Figure 1, and it is apparent that these lengths are determined by the distributions of the volcanic rocks which form the rocky headlands.

Although some of these beaches are many kilometers in length, they can still be viewed as effectively a series of pocket beaches separated by headlands. Within each pocket there is a seasonally-reversing direction of sand transport on the beaches, but with no long-term net sand transport along the coast. This is most-readily apparent in the effects of jetty construction on the beach configuration, investigated in the study area by Komar et al. (1976). Jetty construction tended to produce sand accumulation both to their immediate north and south, with erosion at greater distances. This symmetrical pattern of coastline changes immediately following jetty construction leads to the conclusion that there cannot be any net longshore sand movements along the beaches. This in turn supports the impression that the beach segments are isolated pockets and that significant quantities of sand cannot bypass the headlands. The one exception to this condition of zero net longshore sand transport is the beach to the south of the Columbia River, the large quantities of sand derived from that river causing sand transport to the south and coastal accretion down to Tillamook Head. However, it is clear that at present most of the sand derived from the Columbia River is transported northward along the Washington coast (Scheidegger et al., 1971).

A number of rivers of various sizes reach the coast from the nearby Coastal Range which extends southward from the Columbia River to approximately the Coquille River (Figure 1). This range crests at an average elevation of about 450 m but locally exceeds 1,000 m. The southern half, up to approximately the latitude of Cape Foulweather, mainly contains turbidites and mudstones of the Eocene Tyee Formation, with the crests of the mountains often consisting of the more resistant Siletz River volcanics. The geology of the northern half of the Coast Range is complex, containing Tertiary volcanic rocks of marine origin, accreted to the continent during subduction, as well as intrusives directly emplaced. To the south of approximately Cape Blanco, the Coast Range gives way to the Klamath Mountains which achieve their maximum development in northern California. The Klamaths consist of complexly folded and faulted pre-Tertiary sedimentary rocks, a wide range of metamorphic rocks, and intrusions of serpentinized ultrabasic and granitic rocks.

There have been a number of previous studies of the mineralogy of Oregon beach sands, largely induced by the economic potential of the placers that are found on many of these beaches (Hornor, 1918; Pardee, 1934; Twenhofel, 1946; Griggs, 1945; Kulm et al., 1968; Scheidegger et al., 1971; Luepke, 1980; Komar and Wang, 1984; Peterson et al., 1986). In order to locate the sources of the minerals, several of these studies also investigated the mineralogies of the coastal rivers. In brief summary, these investigations have demonstrated that sands on Oregon beaches must have multiple sources, the metamorphic minerals from the Klamath Mountains being traceable northward along nearly the full length of the Oregon coast, while the extent of southward movement of Columbia River sands is less well defined. Also uncertain is the contributions by the rivers draining the Coastal Range. These river sands mainly contain volcanic augite, and so cannot account for the full spectrum of minerals found on the beaches. Kulm and Byrne (1966) and Peterson, et al. (1982, 1984a) have investigated the mineralogies of estuaries separating these rivers from the ocean beaches, and have demonstrated that to varying degrees they presently trap much of the river sand, also being sinks of beach sand transported by tidal currents through the inlets. By coring through the Holocene fill of Alsea Bay, Peterson et al. (1984b) has documented the evolution of that bay under rising sea levels and how its trapping efficiency changed through the last 10,000 years. The findings of these previous studies of Oregon-coast sand mineralogies will be discussed at greater length later, after the findings of the present analyses of sand compositions from Oregon beaches, rivers and sea-cliffs have been presented.

METHODS OF SAMPLING AND ANALYSIS

The beach-sand samples analyzed in this study were collected from the locations indentified in Figure 1, extending from Fort Stevens immediately south of the Columbia River to Bandon Beach near the Coquille River. This represents a total along-coast distance of some 360 km. Initially, sampling involved the traditional approach of obtaining a single grab sample from the middle of the beach face. However, analyses of those samples demonstrated that they were strongly affected by local selective sorting of the heavy minerals, precluding interpretations of along-coast sand dispersal patterns (this problem of selective sorting will be analyzed in the next section). As a result, a second set of samples was collected, involving composite samples from each beach site. These were obtained by sampling with a shovel along a complete beach profile, thoroughly mixing this large volume of sand on a plastic sheet, and then taking a subsample of this mixture for the analyses. Much of the mineral sorting on these beaches occurs in the cross-shore direction, at many locations leading to placer formation at the back of the beach (Komar and Wang, 1984). In obtaining composite samples along profiles, our objective was to eliminate most of this local cross-shore sorting which greatly affects the heavy-mineral compositions.

Sand samples also have been obtained from rivers and sea cliffs that are potential sources of sand to the beaches. Nearly all of the major rivers shown in Figure 1 were sampled, the sand samples usually having been obtained from exposed bars. Collecting satisfactory samples of the potential sea-cliff sources offered more of a problem due to their extreme variability. Cliff erosion from the Columbia River south to Cascade Head (Figure 1) is limited and in large part involves Tertiary formations consisting of deep-sea mudstones and siltstones, contributing little sand-size material to the beaches. In some areas, landslide deposits from the nearby Coastal Range are being eroded within the sea cliffs. These are again mainly mud, and it is likely that any sand-size material contributed by this cliff erosion is identical to that being transported in the rivers draining those areas. Because of this, our sea-cliff sampling program concentrated on the area from Cascade Head south to Cape Perpetua. This stretch of coast is experiencing greater cliff erosion, and most of this occurs in marine terraces that contain uplifted beach and dune sands. When available, we sampled tallus material that had accumulated at the base of the cliff, this representing something of a composite sample of the cliff section and thus being comparable to the composite samples obtained on the beaches.

All sand samples were first washed and dried. A subsample was then obtained using a splitter, and this was sieved to obtain a 62 to 250 micron fraction, the objective being to eliminate any potential grain-size controls on the determined mineralogy. In our early analyses the heavy minerals were separated from the light fraction utilizing tetrabromoethane (specific gravity 2.96). However, due to the potential health hazards in using that heavy liquid, in most of the study the mineral separations were accomplished using sodium polytungstate (specific gravity 3.00) (see Appendix I). The heavy-mineral separates were mounted on slides in Canada Balsum, and 300 non-opaque heavy minerals were identified and counted under a microscope using standard petrographic techniques (see Appendix II). Further confirmations of the mineral identifications were made by using immersed oils rather than Canada Balsum, and with X-ray diffraction analyses of select samples. In spite of such measures, some of the mineral identifications remain a problem and can account for differences in analysis results between the present study and those undertaken by earlier investigators. This is particularly true for the river sands, many of which contained significant portions of highly-altered grains. The heavy-mineral counts have been converted into percentages of the total non-opaque heavy content, and the results are given in the tables of Appendix III, Table III-1 for the beach samples, Table III-2 for the rivers, and Table III-3 for the sea-cliff samples.

COMPOSITIONAL CONTROLS DUE TO SELECTIVE SORTING

In analyzing the set of grab samples from the beach face, it soon became apparent that selective sorting greatly affected their heavy-mineral compositions. The along-coast variations in mineral percentages were highly erratic, and duplicate samples from the same beach often yielded markedly different compositions. These results are not surprising in light of the considerable degree of sorting on these beaches leading to the formation of placers (Luepke, 1980; Komar and Wang, 1984; Peterson et al., 1986).

This caused us to abandon our use of grab samples in favor of composite samples, and also induced us to investigate how local sorting might affect studies of mineral compositions, perhaps introducing end members into factor analyses. In order to determine this, twelve grab samples were taken randomly from the beach at Otter Rock to the south of Cape Foulweather (Figure 1), the same beach involved in the studies of Komar and Wang (1984) and Peterson et al. (1986). These were analyzed for their mineral contents as described in the preceeding section. The results are given in Table III-4 of Appendix III where it is apparent that there are major compositional differences. Factor analysis was performed on these samples and the results are given in Figure 2. Ninety-eight percent of the variation was accounted for by two factors, one dominated by augite, green hornblende, and hypersthene with a second factor of

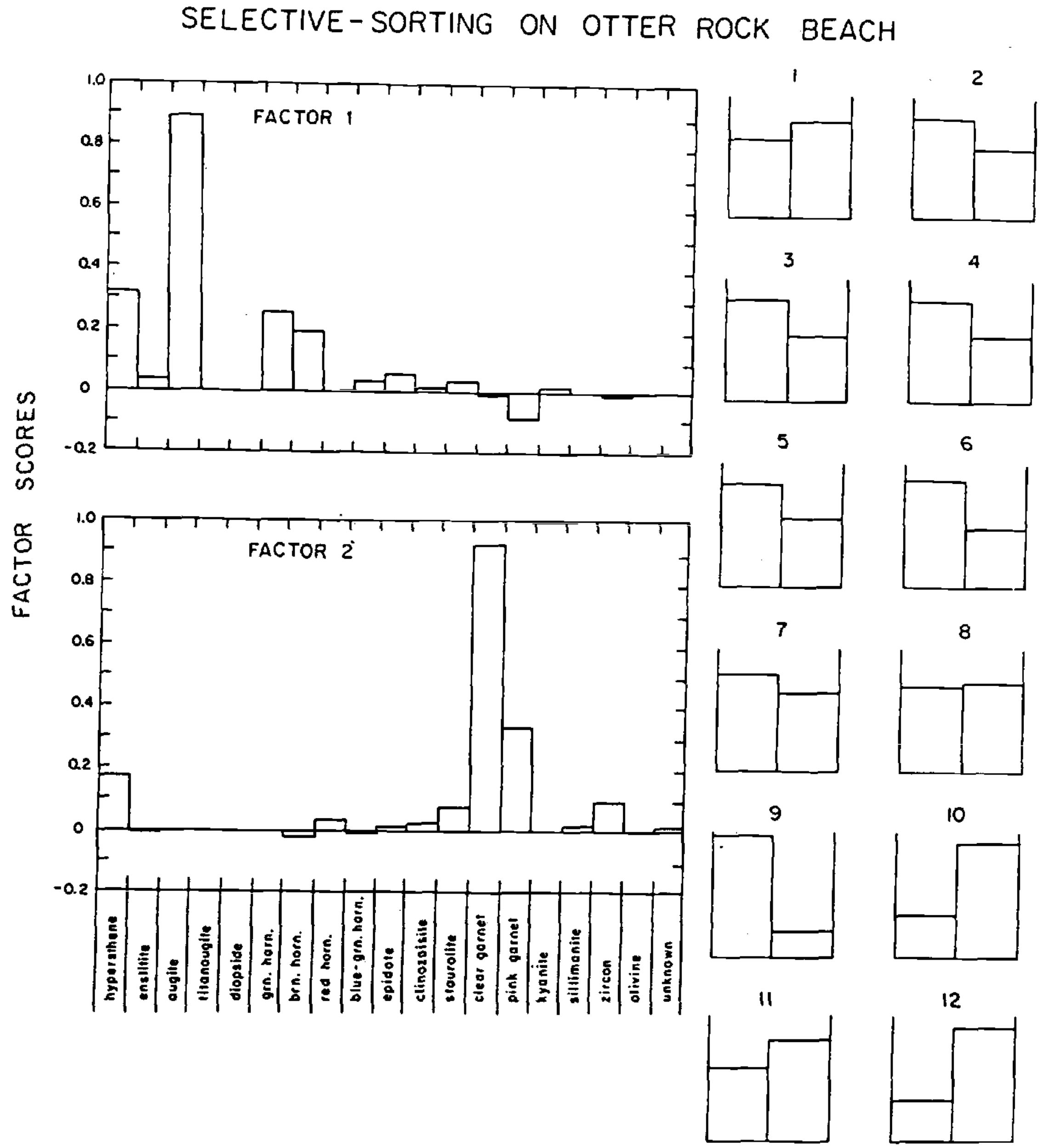

Figure 2. Compositions of the two factors obtained in the analysis of selective sorting in multiple samples from the beach at Otter Rock to the south of Cape Foulweather. The loadings in the twelve beach-sand samples are illustrated on the right in the diagram.

pink and clear garnet together with some zircon.

The two factors obtained in this analysis correspond closely to the selective-sorting patterns on this beach. In a series of samples across the beach width obtained at a time of beach erosion and heavy-mineral concentration at the top of the beach, Komar and Wang (1984) found that nearly all of the garnet and zircon remains with the opaques (ilmenite and chromite) in the placer while augite, hornblende and hypersthene are not as efficiently separated from the quartz and feldspar, a higher portion tending to move offshore during an erosion period. Therefore, it would appear that factor analysis of the present sample series is revealing the same sorting patterns. This sorting need not only be on a large scale, involving the complete cross-shore profile as studied by Komar and Wang. The same sorting can readily be seen from the patterns of sand coloration on the beach produced by the different minerals, making it apparent that marked sorting occurs on smaller scales between the crests and troughs of backwash ripples and within rill marks.

As will be seen in the next section, the garnet-zircon factor obtained by selective sorting is similar to that derived from the Klamath Mountains metamorphic source. Because of this similarity, local sorting can lead to an over representation of that Klamath source in the beach sands, masking the true dispersal patterns. This accounts for the confused patterns of beach mineralogies as measured in the series of grab samples. Therefore, this analysis of selective sorting has reaffirmed the need for composite samples in order to remove most of the local sorting, yielding compositions that are more representative of the beach as a whole.

RESULTS OF ANALYSES OF COMPOSITE BEACH SAMPLES

Beach Versus River-Sand Compositions

Our interpretations of the along-coast dispersal of sands on Oregon beaches are based mainly on the results in Table III-1 for the composite samples. It is seen that eighteen different minerals were identified in these samples, but the major constituents are augite, green and brown hornblende, hypersthene and the garnets. The along-coast percentages of these principal heavy-mineral components are shown plotted in Figure 3, revealing how they vary with along-coast distance south of the Columbia River. The most noticeable variation is the percentage of augite which dominates beach-sand compositions between Tillamook Head and Cape Foulweather. North of Tillamook Head the percent of augite abruptly drops as the beach there is richer in hornblende and hypersthene. The augite content also decreases significantly to the south of Cape Foulweather, the beaches there containing higher quantities of hornblende, hypersthene and garnet. Of particular interest is the increase in garnet content toward the south even though it never dominates the heavy-mineral composition. This southward increase in garnet was expected in view of its source in southern Oregon and the Klamath Mountains, but it is noteworthy that this metamorphic mineral is found in beach sands all the way north to Tillamook Head. Garnet thereby serves as one tracer of the northward dispersal of sands entering the study area from southerly sources.

The compositions of the beach sands in large part reflect the heavy-mineral contents of the rivers, given in Table III-2 and graphed in Figure 3. It is seen that the mid-coast rivers which drain the Coastal Range, the Trask River south to the Siletz River, are particularly rich in augite which comprises 60 to 80 percent of the heavy minerals, the remainder being hornblende. Thus, the high augite contents of the beaches between Tillamook Head and Cape Foulweather clearly must reflect a major contribution by these rivers, perhaps together with some sea-cliff erosion of the same source materials.

The abrupt compositional change at Tillamook Head, Figure 3, similarly reflects contributions by the Columbia River whose principal heavy-mineral component is hypersthene (45%) with lesser amounts of hornblende (22%) and augite (19%), and only a trace of garnet (1%). It is seen that the beach north of Tillamook Head has just about the same mineral proportions. This stretch of beach from Tillamook Head to the Columbia River forms a part of the Clatsop Plains whose depositional history is clearly dominated by the Columbia River. Therefore, the correspondence found here between the beach and river compositions was to be expected. However, of interest is the abrupt compositional change at Tillamook Head, indicating that at present beach sand is unable to bypass this major headland.

Figure 3. Along-coast variations in the percent abundances of the principal heavy minerals found in the beach-sand samples. Also graphed on the diagram are the compositions of the river sands, and the positions of Tillamook Head, Cascade Head and Cape Foulweather, the major headlands which apparently have some control on the beach mineralogies.

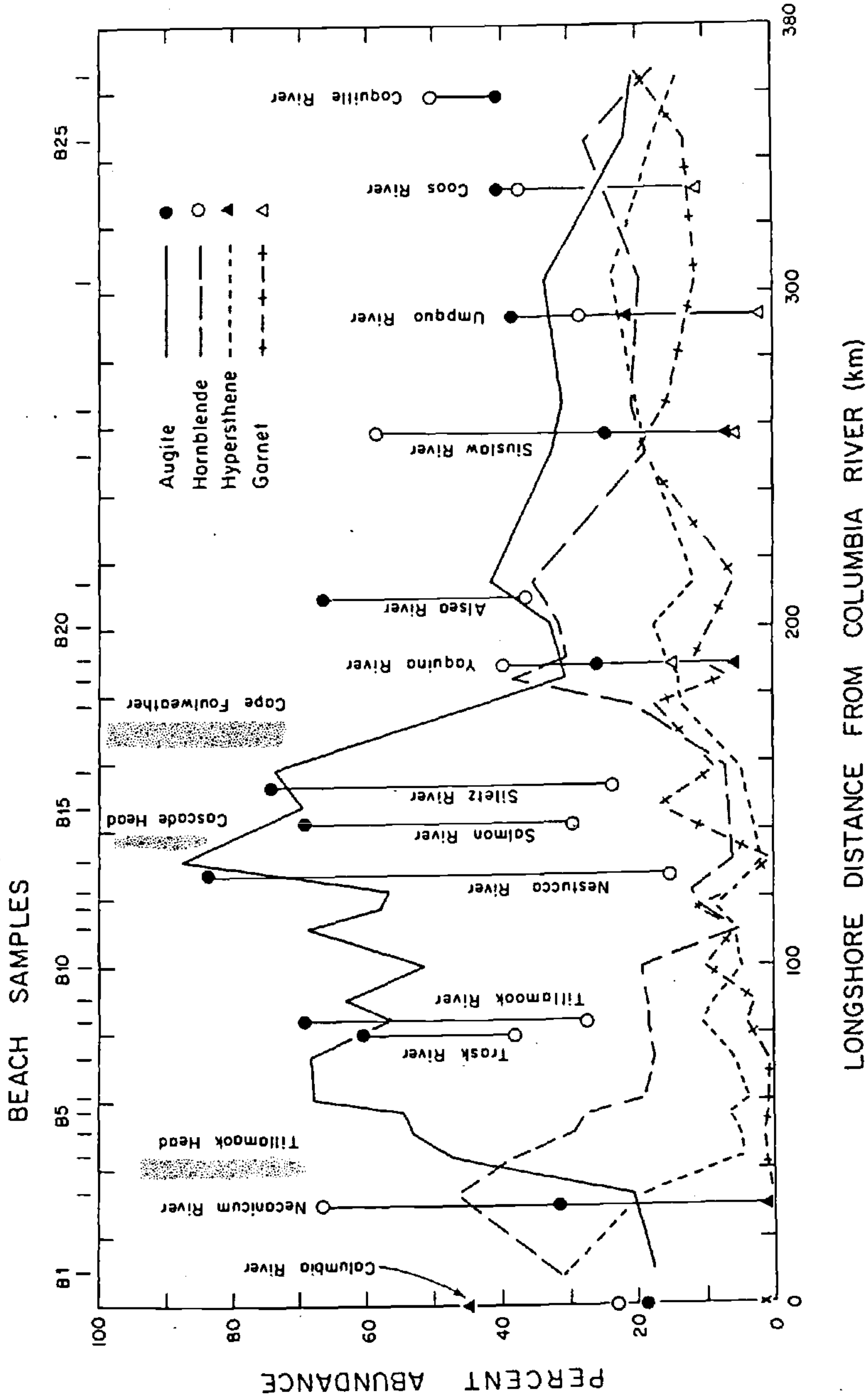
BEACH SAMPLES
B1
B5
B10
B15
B20
B25
LONGSHORE DISTANCE FROM COLUMBIA RIVER (km)
0
100
200
300
380
PERCENT ABUNDANCE
100
80
60
40
20
0
Augite
Hornblende
Hypersthene
Garnet
Columbia River
Necanicum River
Tillamook Head
Trask River
Tillamook River
Nestucca River
Salmon River
Cascade Head
Siletz River
Cape Foulweather
Yaquina River
Alsea River
Siuslaw River
Umpqua River
Coos River
Coquille River

Figure 3

The rivers south of Cape Foulweather are more erratic in their compositions (Figure 3). Augite is still the dominant mineral in the Alsea, Umpqua and Coos Rivers, but hornblende is the most abundant mineral in the Yaquina, Siuslaw and Coquille Rivers (much of it being highly altered, however). The Yaquina, Siuslaw and Umpqua Rivers also contain significant percentages of hypersthene and garnet. These latter three rivers do not have primary sources of hornblende, hypersthene and garnet, and it is likely that these minerals are recycled from the Tyee Formation which is important in the Coastal Range south of Cape Foulweather. Heller et al. (1985) have demonstrated that most of the Tyee light minerals and micas likely are derived from the Idaho Batholith. Some sediments apparently were contributed to the Tyee from the Klamaths, introducing the heavy minerals of intermediate rank metamorphic origin. Peterson et al. (1982) found these minerals in tributaries of the Alsea River which drain areas of Tyee Formation, even though the total heavy-mineral content of the Alsea was dominated by augite derived from erosion of the Siletz River volcanics.

Factor Analysis of Beach-Sand Compositions

The above interpretations were based on individual heavy minerals within the sands. Since the mineral assemblages of the Oregon coast sands form a complex data set, factor analysis can be used to find simple patterns among the samples (Imbrie and van Andel, 1964). There are two types of factor analysis, R-mode and Q-mode. In R-mode each variable is represented by a vector and these vectors are compared. In Q-mode each sample is represented by a vector, thereby comparing the compositions of all samples. In heavy mineral analyses Q-mode is used to produce factors which may be interpreted as source compositions, each individual sample being represented as a mixture of these sources.

Q-mode factor analysis was performed on the 26 beach samples with the heavy minerals as variables. In one analysis the mineral compositions were transformed to the mean to enhance the contributions of trace minerals, but this approach did not yield results identifiable with known sources and so was abandoned. It is not surprising that such a transformation of the data was unsuccessful in reflecting potential sources since this approach tends to accentuate errors in the data (Imbrie and van Andel, 1964).

In contrast, the Q-mode analysis using the raw percent compositions of the samples did produce three factors accounting for 89 percent of the variance, Figure 4, factors which have compositions that are similar to probable sources. Factor 1 in Figure 4 consists almost entirely of augite, and it is seen in Figure 5 that this factor dominates the beach-sand compositions between Tillamook Head and Cape Foulweather, just as seen in Figure 3 for augite alone. As discussed above, this factor is clearly associated with a Coastal

Figure 4. Compositions of the three factors obtained in analyses of the heavy-mineral contents of the composite beach-sand samples, accounting for 89 percent of their variability.

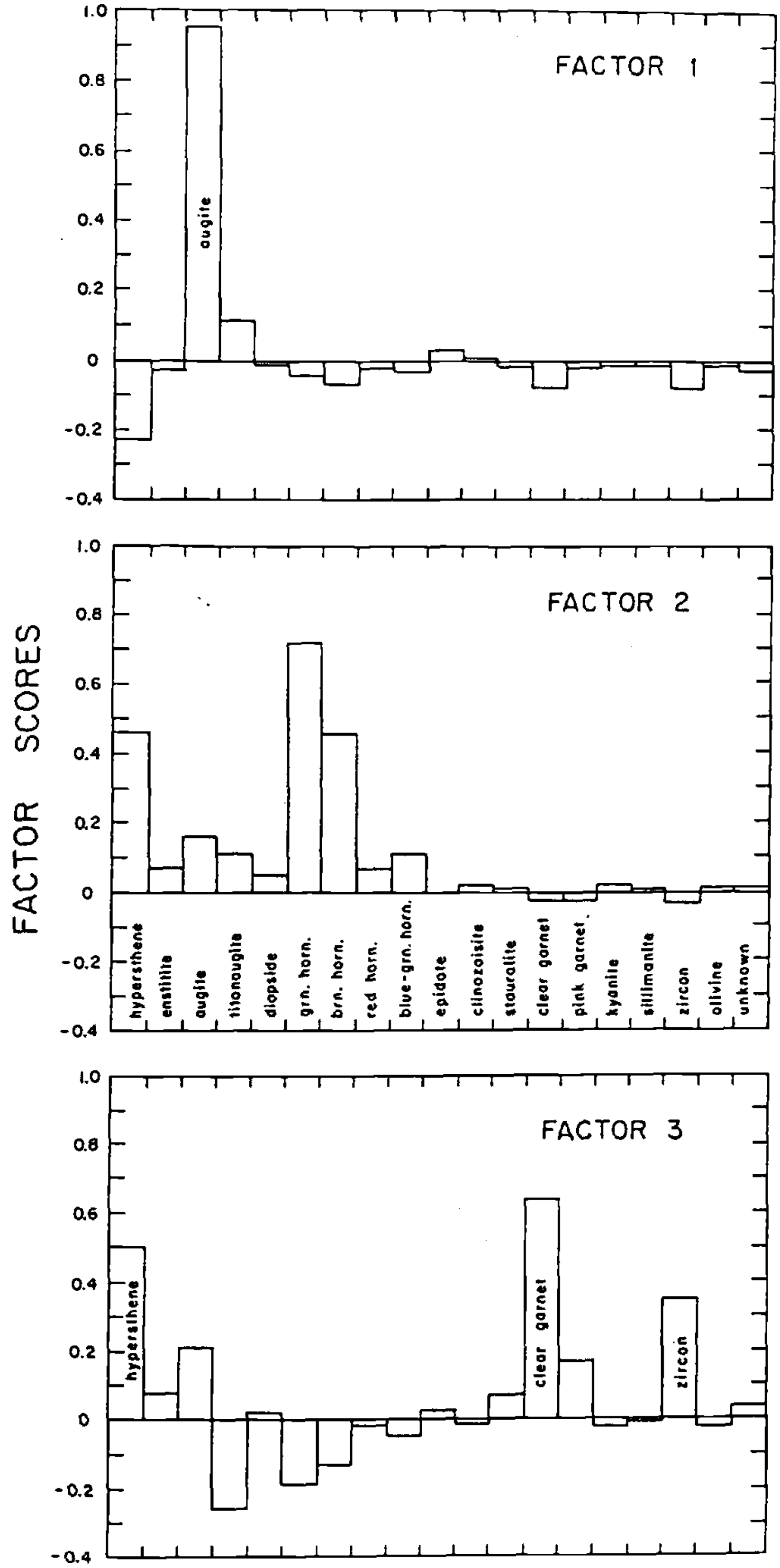
FACTOR 1
augite
FACTOR 2
FACTOR SCORES
hypersthene
enstitite
augite
titanaugite
diopside
grn. horn.
brn. horn.
red horn.
blue-grn. horn.
epidote
clinozoisite
staurolite
clear garnet
pink garnet
kyanite
sillimanite
zircon
olivine
unknown
FACTOR 3
hypersthene
clear garnet
zircon
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4

Figure 4

Figure 5. Along-coast distributions of the loadings for the three factors (fig. 4) obtained in the analyses of the beach-sand heavy-mineral compositions.

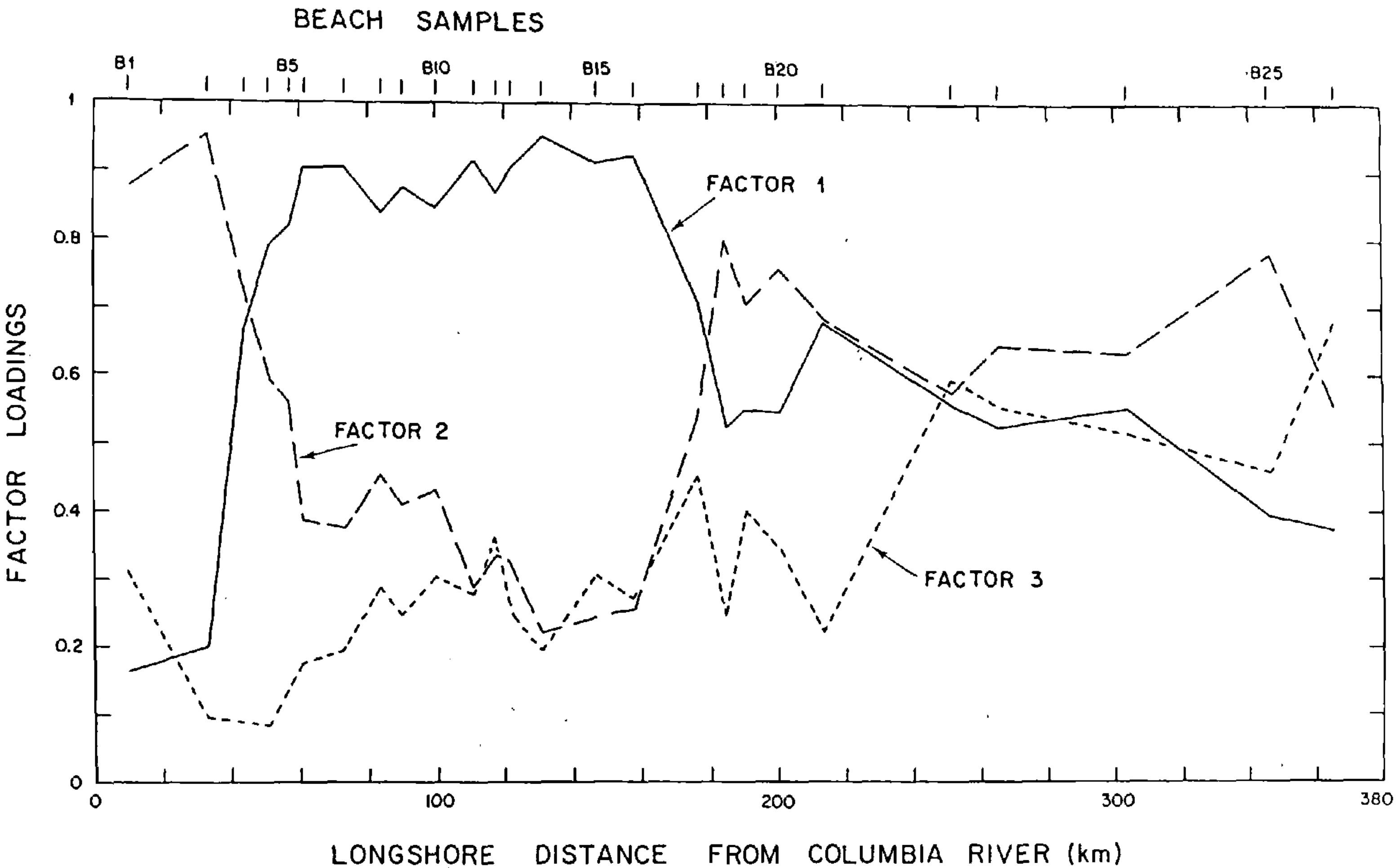
BEACH SAMPLES
B1
B5
B10
B15
B20
B25
FACTOR 1
FACTOR 2
FACTOR 3
FACTOR LOADINGS
0
0.2
0.4
0.6
0.8
1
0
100
200
300
380
LONGSHORE DISTANCE FROM COLUMBIA RIVER (km)

Figure 5

Range volcanic source, either contributed by the mid-coast rivers or by sea-cliff erosion. However, the factor analysis did not associate any of the hornblende with Factor 1 even though this mineral is found in the Coastal Range rivers. This may result from much of the river hornblene being highly weathered and its nonsurvival in the beach environment. The green and brown hornblende in the beach sands is instead found in Factor 2 which is also rich in hypersthene (Figure 4). As seen in Figure 5, this factor has a bimodal distribution along the coast. Its main loading, approaching 1, occurs on the beach to the north of Tillamook Head and is clearly associated with the Columbia River source which is rich in hypersthene and hornblende. The broad increase in Factor 2 extending from 190 km south of the Columbia to the end of our sample range at 365 km south might be from sands contributed by the Umpqua River. Sand from this river has a high content of both hornblende and hypersthene, in addition to augite, and with its large drainage basin could have been a major source. Therefore, Factor 2 appears to be associated with two major sources which are similar in compositions, the Columbia and Umpqua Rivers. This interpretation is supported by factor analyses which include sands from these rivers as well as from the beaches. When the Columbia River sand is included, it is identified as being composed of nearly 100 percent Factor 2. The Umpqua River assemblage consists of nearly equal portions of Factors 1 and 2, this being a reasonable result in that this river drains the augite-rich Coastal Range as well as extending further inland into the Cascades.

Factor 3 in Figure 4 is rich in garnet and zircon, and also includes the metamorphic minerals staurolite and epidote. This composition together with its northward along-coast decrease seen in Figure 5 clearly point to a southern source in the Klamath Mountains. Being based on samples distant from its actual sources, Factor 3 likely involves a composite of sources. This may account for its high content of hypersthene, that mineral not being supplied in appreciable quantities by the major rivers which drain the Klamaths (Scheidegger et al., 1971). As discussed above, the Yaquina, Siuslaw, Umpqua and Coos Rivers in the present study area do supply some recycled metamorphic minerals, likely derived from the Klamaths, and so contribute to Factor 3 as well.

The factors determined in the present analysis are similar in some respects to those obtained by Scheidegger et al. (1971) in their study of the heavy-mineral compositions of sands from the rivers and the continental shelf, together with a few beach samples. One factor found by Scheidegger et al. out to mid-shelf depths consisted mainly of augite, showing a similar distribution to that of Factor 1 obtained here in the beach sands. A second factor consisting of hypersthene, augite and hornblende is similar to our Factor 2, and is associated with the Columbia and Umpqua Rivers just as found here. Another factor obtained by Scheidegger et al. had a clear Klamath Mountain source, being traceable in the offshore as a tongue extending northward from northern California to just south of the Columbia River. That factor consisted mainly of hornblende, some augite and hypersthene, and trace amounts of epidote, olivine and garnet. Much of the garnet went into a fourth factor found by Scheidegger et al., a factor which also contained significant quantities of hornblende, epidote and pyroxenes, as well and a number of other minerals. This factor had multiple sources, the Yaquina, Siuslaw, Coos and Coquille Rivers. It would appear from this that our Factor 3 attributed to southerly sources in part combines two of the factors (1 and 4) obtained by Scheidegger et al (1971), their study having extended further southward to the Klamaths so as to make this factor distinction possible. However, it is unclear why hornblende is absent in our Factor 3 but present in the factor of Scheidegger et al. which has a Klamath Mountain source.

Another potentially useful analysis approach is linear programming, a technique wherein one defines the end members of a mixing model. This approach was employed to analyze the beach sands, using as end members the measured composition of Columbia River sand, that of the Trask River as representative of the Coastal Range, the Umpqua River composition, and the assemblage from Bandon Beach, the southern-most beach sample of our study area (used as an approximation of the sand transported from the south). This analysis yielded satisfactory results for identifying the presence of Coastal Range (Trask River) and south coast (Bandon

Beach) sources in the beach compositions, but tended to confuse the Columbia and Umpqua River sources. Some beach samples on the north Oregon coast were mistakenly identified as Umpqua while some to the south were declared to be primarily from the Columbia River. This result is no doubt due to the fact that the Columbia and Umpqua River sands are compositionally similar, and that the Umpqua can be modeled as a mixture of Columbia and Coast Range sources. As a result there were no well-defined north to south variations in the proportions specific to these four sources so that linear programming provided little help in our interpretations of the along-coast compositional changes.

The factor analyses have helped to affirm the interpretations made earlier based on the distributions of individual minerals graphed in Figure 3. Being based on natural groupings of minerals rather than individual minerals, the factor analyses have more clearly defined how the mineralogy of the beach sands is a product of the mixing of sands from the several sources.

Sea-Cliff Erosion as a Beach-Sand Source

As discussed earlier, sea cliff erosion is potentially an important source of sand to the modern beaches, especially between Cascade Head on the north and Cape Perpetua to the south. Further north cliff erosion is not as extensive and involves Tertiary mudstones and Coastal Range landslide debris, while south of Cape Perpetua to Cape

Arago the beach is backed by sand dunes. However, in this mid-coast region between Cascade Head and Cape Perpetua, extensive sea-cliff erosion has occurred and involves Pleistocene marine terrace deposits consisting of uplifted beach, dune and shallow-water offshore deposits. Erosion of this material thereby supplies second-cycle coastal-zone sands to the modern beaches.

Study of these terrace deposits in their own right is of interest as they record an along-coast dispersal of sand that must have been similar to that found on the modern beaches. However, such a study is more complex than that undertaken here of the modern beach sands, caused by the variety of environments represented in these terraces. In some of the cliff sampling areas the deposits clearly were ancient dunes, while others were various subenvironments of the beach and shallow offshore. This must introduce significant problems with selective-sorting processes which affect the measured mineralogical compositions. This likely accounts for the considerable along-coast variability in heavy-mineral compositions found in our sample series (Table III-4). It is seen that some samples are very rich in garnet, indicating a northward dispersal of Klamath Mountain minerals during the emplacement of these Pleistocene terrace sands, much as found on the modern beach. Factor analysis was undertaken on this series of samples from the terrace sands (Figure 6), but the results are difficult to interpret. Two factors were identified accounting for 95% of the total variance. These two factors are similar to those

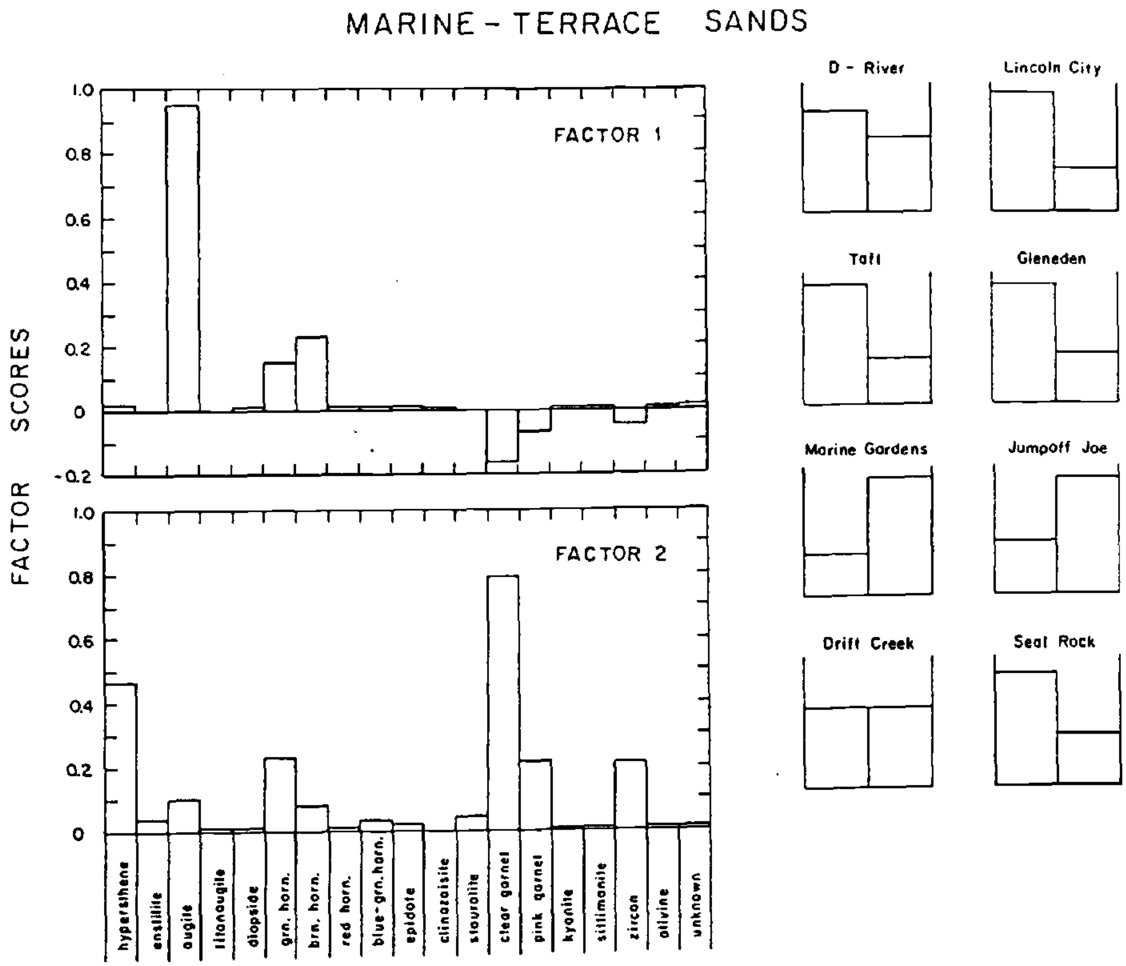

Figure 6. Compositions of the factors obtained in the analysis of the marine-terrace sands (left), together with the loadings of these factors in the individual samples (right).

found in the selective-sorting analysis (compare Figures 2 and 6), indicating that our terrace samples have been affected by sorting. However, some less-dense minerals such as hypersthene and green hornblende were included in the factor with the placer minerals garnet and zircon. This difference in the factors may be caused by the variety of environments represented in the terraces, environments having somewhat different selective-sorting patterns from that found on the beach alone.

The present observation that the terrace sands are rich in garnet and other metamorphic minerals raises the possibility that the presence of these minerals on the modern beach is due in part to sea-cliff erosion. Accordingly, the northward transport of these Klamath Mountain minerals would have occurred during a Pleistocene high stand of sea level when the terrace environments were active. However, this hypothesis cannot explain the presence of these metamorphic minerals on the modern beach all the way north to Tillamook Head since the terrace sands exist northward only to Cascade Head. Sands derived from cliff erosion of these terrace deposits might account for the mineralogical changes between Cascade Head and Cape Foulweather, seen in Figures 2 and 4, this source dominating over the augite-rich source of the Coastal Range which is important north of Cascade Head.

SAND-SOURCE DIFFERENCES IN GRAIN ROUNDNESS

While determining the heavy-mineral compositions of the beach and river sands, noticeable differences in grain rounding were noted. This was particularly the case for the beach sands on opposite sides of Tillamook Head. To its north at Seaside, the heavy-mineral grains are highly angular, including some delicate hypersthene crystal clusters. In contrast, to the south of Tillamook Head at Cannon Beach the heavy mineral grains are noticeably more rounded.

Such observations induced us to undertake measurements of rounding of some of the principal beach and river minerals. The photo-comparison illustrations of Shepard and Young (1961) were used for this purpose, a series of photographs of grains ranging from very angular to well rounded. Comparisons between these photographs and individual grains permit one to categorize the degree of rounding. In our analyses such comparisons were made for about 50 grains of each mineral in a sample, yielding a distribution of roundness values for a mineral. Such analyses were primarily performed on augite, but some evaluations were also made for hypersthene, hornblende and quartz. The approach of Shepard and Young can be viewed as only semi-quantitative, but it still proved to be satisfactory in the present study to examine gross variations in grain rounding. This was also demonstrated in the study of Peterson et al. (1982) who applied the same techniques to examine the mixing of river and beach sands in Alsea Bay.

The samples from the Columbia and Nestucca Rivers and from the beaches extending southward from the Columbia to Manzanita Beach south of Cape Falcon were all analyzed for grain rounding. This stretch of coast, Figure 7, includes Tillamook Head where we first qualitatively observed marked roundness changes, and Short Sand Beach which is isolated within a pocket of Cape Falcon. The results for the roundness of augite in the samples are presented in Figure 7 as histograms. It is seen that the most noteworthy change occurs at Tillamook Head, the beach sand to the immediate north being significantly more angular than that to the south. The augite in the Columbia and Necanicum Rivers appears to have approximately the same angularity as that on the adjacent beaches north of Tillamook Head. The beaches futher to the south of Tillamook Head, including Short Sand Beach, show an essentially uniform degree of augite rounding, although there is some suggestion for a slight increase southward. The change in augite rounding at Tillamook Head is seen in the other minerals as well, including quartz whose histograms are given in Figure 7.

As with the contrasting mineralogies north and south of Tillamook Head, the differences in grain rounding can be explained by the respective sand sources. The angular grains to the north are derived directly from the Columbia River, a sand source characterized by highly angular grains as observed in our samples. The rounder

Figure 7. Histograms of the rounding of augite grains in the Columbia and Necanicum Rivers and in the beach-sand samples from the Columbia south to Manzanita Beach south of Cape Falcon. Also included are roundness histograms from quartz in the beach sands immediately north and south of Tillamook Head. (VA - very angular, A - angular, SA - subangular, SR - subrounded, R - rounded, WR - well rounded).

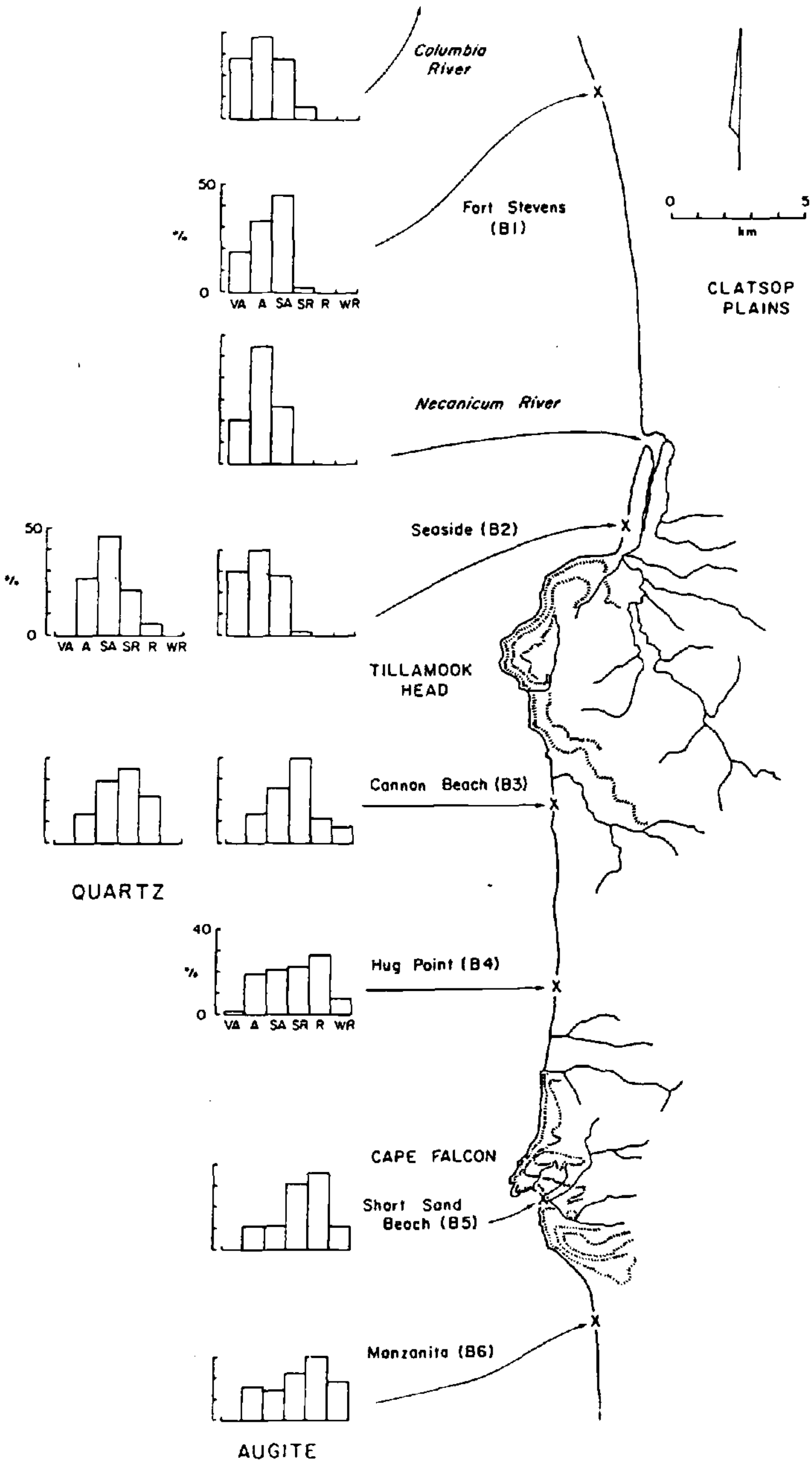
Columbia River
Fort Stevens (B1)
Necanicum River
Seaside (B2)
TILLAMOOK HEAD
Cannon Beach (B3)
Hug Point (B4)
CAPE FALCON
Short Sand Beach (B5)
Manzanita (B6)
CLATSOP PLAINS
0 5 km
50
%
0
VA A SA SR R WR
40
QUARTZ
AUGITE

Figure 7

grains on the beaches to the south of Tillamook Head must be the product of their long residence time in the beach environment. All of the sands derived from rivers draining the Coastal Range are highly angular, similar to those in the Columbia (Peterson et al., 1982, 1984a), so that the roundness differences cannot be attributed to contrasting sources.

Many researchers have addressed the question of how much time or distance of transport is necessary to round sand grains. These studies include both field investigations (MacCarthy, 1933; Pettyjohn and Lundahl, 1943; Balazs, et al., 1972; Rottmann, 1973) and laboratory mechanical abrasion studies (Kuenen, 1959, 1960, 1964). In an early review of the literature, Twenhofel (1945) found that transport in streams and rivers does not appear to affect grain rounding, and this was reaffirmed by the later investigations, particularly those of Kuenen. Twenhofel also found, and later studies have confirmed, that rounding by traction transport on beaches does occur. This was shown by Rottmann on the Oregon coast, sand grains in a pocket beach of Cape Arago being rounder than the source grains in the adjacent sea cliff. Although it is difficult to evaluate the time periods required for rounding sand-sized grains on beaches, it is qualitatively assessed by most investigators as involving thousands of years.

This suggests a marked difference in residence times of the beach sands to the north and south of Tillamook Head. To the north the sand must be derived directly from the Columbia River with a mean residence time sufficiently short that the beach processes have not been able to significantly round the sand grains, even those that are fragile and sharply angular. In marked contrast, the beach sands to the south of Tillamook Head must have had a very long residence time, likely involving thousands of years.

These observations also indicate that the rivers draining the Coastal Range to the south of Tillamook Head cannot at present be major sources of beach sand, for otherwise the minerals supplied by these rivers would yield a significant angular component on the beaches. This does not rule out there being any contributions from these rivers, only that it must involve small quantities over time periods sufficient for the beach environment to round the augite grains as they are contributed to the beach. To further examine this, roundness measurements were made for the augite in the Nestucca River and adjacent beach at Neskowin (Sample B14). As seen in Figure 3, augite comprises 85% of the heavy minerals in the Nestucca, the highest of the river sands analyzed, and the adjacent beach similarly shows a maximum in augite content for the beaches of the study area. The roundness measurements are shown as histograms in Figure 8 where it seen that there is something of a bimodal distribution in the beach sand, the more-angular mode of which might be from the Nestucca River. As will be discussed in the next section, the estuary of the Nestucca is likely bypassing some river sands to the beach due to its small tidal prism in comparison with the river's discharge.

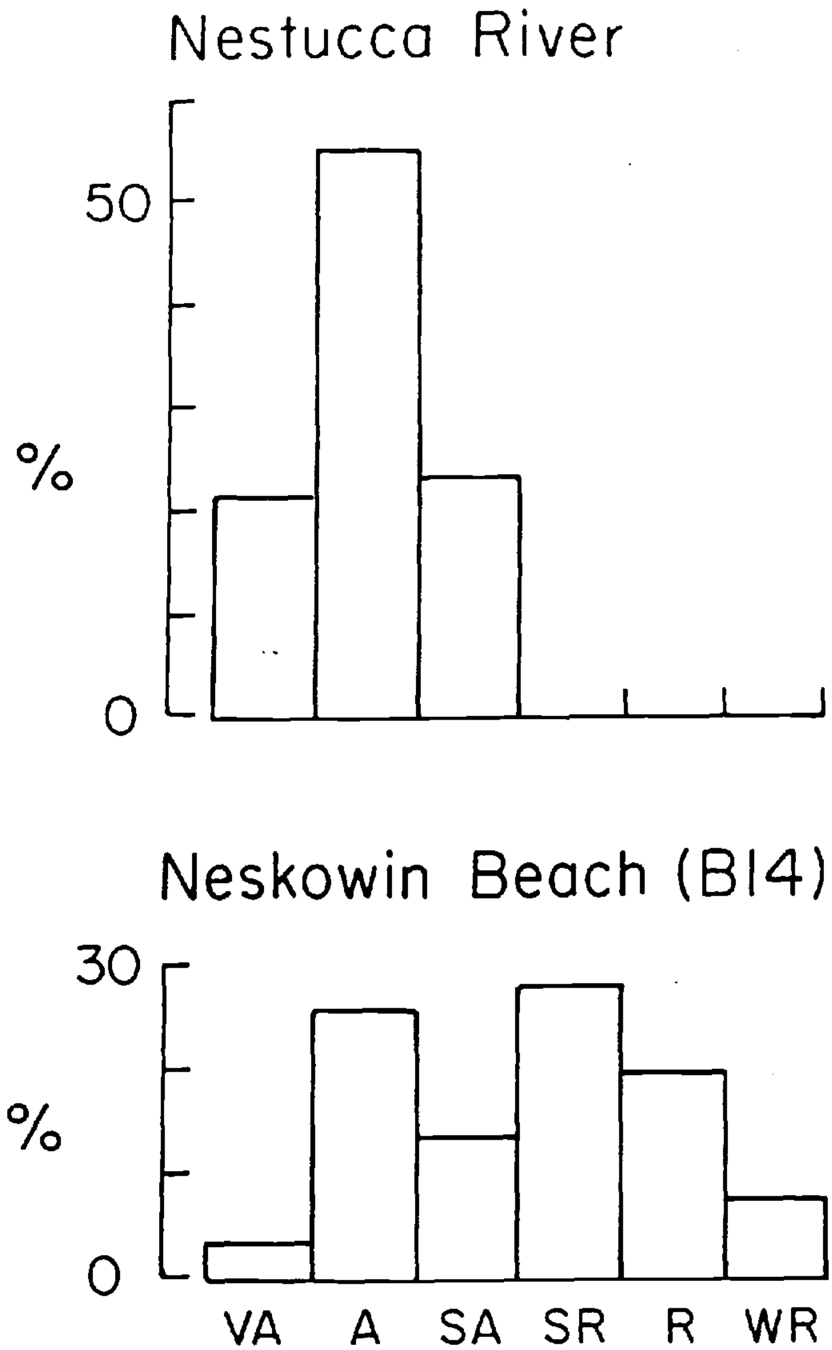

Figure 8. Histograms of the angularity of augite grains in the Nestucca River and Neskowin Beach. (VA - very angular, A - angular, SA - subangular, SR - subrounded, R - rounded, WR - well rounded).

DISCUSSION OF RESULTS AND MODEL OF COASTAL EVOLUTION

The distributions of individual minerals, Figure 3, and of factors from the factor analysis, Figure 5, both indicate that the mineralogy of Oregon beaches is derived by the mixing of sands from multiple sources. All beaches, excepting those immediately south of the Columbia, are found to contain significant quantities of minerals derived from southern Oregon and northern California, primarily the Klamath Mountains. This indicates a northward transport of sand along the coast, but this transport must have occurred during lower stands of sea level when headlands did not interrupt such sand movements. With a rise in sea level the beaches must have migrated landward, much as envisioned for many of the barrier islands of the east and Gulf coasts of the United States. Such a northward transport during lowered sea level is supported by the analyses of Scheidegger et al. (1971) of continental-shelf sands, their factor analysis having defined an offshore tongue of sand originating in the Klamaths and extending as far north as Tillamook Head.

Such a model also explains the distribution of Columbia River sands along the coast. We have seen that this source dominates the beach southward to Tillamook Head, but the marked changes in sand mineralogy and grain rounding at that headland demonstrate that at present Columbia sand cannot move further south. But the distribution of Factor 2 in Figure 5, having in part a Columbia origin, indicates that sand from this source is found on the beaches much further to the south. Again, this southward movement must have occurred during lowered sea levels, the sand subsequently moving onshore to the modern beach. Therefore, although the beaches north and south of Tillamook Head both have contributions from the Columbia, that to the south is relict and its higher degree of rounding indicates that it has been in the littoral zone for thousands of years, while the angular sand to the north of Tillamook Head likely has a residence time of only a hundred years or less.

This southward dispersal of Columbia River sand during lowered sea levels does not conflict with the observation of a northward transport of sand from the Klamaths. When waves reach the coast from various directions, sand from a specific source can be dispersed to the south even though the predominant transport is northward. Stated another way, even though the net sand advection is to the north, there will be a diffusion or dispersal of sand southward from a source. This southward diffusion from the Columbia River is especially apparent due to the large volumes of sand contributed from that source.

The exact pattern of the southward dispersal of Columbia River sand is complicated by the Umpqua River which has a similar mineralogy. As a result, the southward movement of Columbia sand mixes with the northward transport of sand from the Umpqua, yielding the distribution of Factor 2 in Figure 5. A further complication is dilution from the Coastal Range, Factor 1 of Figure 5. Such a dilution would act to decrease the portions attributed to Factor 2 between Tillamook Head and Cape Foulweather where the Coast Range input is important.

Sand from the Coast Range would have been contributed to the beach during lower stands of sea level, participating in the along-coast mixing with the other sources. Therefore, some of the sand on the modern beach from the Coast Range must also be relict, perhaps that portion represented by the grains that have achieved the greatest rounding. However, it appears that sand from this source has reached the beach since its isolation between headlands. This is indicated by the rather abrupt decreases of augite in Figure 3 and of Factor 1 in Figure 5 at Tillamook Head and between Cascade Head and Cape Foulweather. These transitions of course are greatly affected by the contributions from the other sources and so may not indicate a large Coastal Range sand supply. At Tillamook Head the abrupt change in the portion of Coastal Range sands in the beach is caused mainly by the complete dominance of Columbia River sands to the north, not necessarily a significant contribution from the Coastal Range to the south. The decrease in Coastal Range content to the south of Cascade Head is in part a response to the growing importance on these beaches of sources from southern Oregon and the Klamaths, and likely from the Yaquina and Siuslaw Rivers whose mineralogy differs from the Coastal Range rivers further to the north.

Another cause of the change of beach mineralogy between Cascade Head and Cape Foulweather might be contributions from sea-cliff erosion, the marine terrace sands first playing a role south of Cascade Head. As found here, erosion of the terraces would supply sand whose original sources are the Klamaths, the Columbia, Umpqua, etc. , making it impossible to distinguish this secondary source from those primary sources. However, the input from cliff erosion presumably became most important as the sea approached its present level and the beaches were isolated between headlands. This could account for the marked change in beach compositions south of Cascade Head where this sea-cliff source is introduced. Such late-stage additions of sand from cliff erosion south of Cascade Head and Coastal Range sands to the north would yield the observed gradient in beach-sand compositions between Cascade Head and Cape Foulweather.

An attempt was made to evaluate present-day contributions of sand to beaches from the rivers and from sea-cliff erosion. The resulting assessments of bedload sand transport rates for the rivers in the study area, and those to the south draining the Klamath Mountains, are given in Table 1. The values for the drainage areas and

Table 1: River Sand Sources

River	Drainage Area (km^2)	Discharge (km^3/yr)	Bedload Transport (10^3 m^3/yr)	Tidal prism (10^6 m^3)	H_F
Columbia	661,211	216.21	13,784	818	5.53
Necanicum	225	0.27	4.5	2.09	11.34
Nehalem	1730	2.49	25.4	17.87	10.49
Tillamook	607	0.76	10.4		
Trask	376	0.86	6.9	66.34	35.66
Wilson	417	1.10	7.6		
Nestucca	466	1.05	8.3	7.66	10.66
Salmon	194	0.56	4.0	1.28	3.33
Siletz	523	1.42	9.2	8.14	8.38
Yaquina	655	0.96	11.1	31.69	48.26
Alsea	865	1.40	14.1	16.02	16.73
Siuslaw	1523	2.17	22.8	10.92	7.35
Umpqua	9,534	6.77	234.6	50.52	10.91
Coos	1567	2.71	23.3	2.16	44.32
Coquille	1960	2.21	32.9	6.12	4.05
Sixes	334	0.54	6.3	2.48	6.71
Elk	243	0.4	4.8	2.16	7.91
Rogue	13,394	10.10	293.9	4.31	0.62
Pistol	272	0.44	5.3	1.72	5.72
Chetco	702	2.28	11.8	1.05	0.68
Smith	1577	3.46	23.5	3.65	1.54
Klamath	29,362	12.21	929.6	4.04	0.48
Eel	8,623	7.35	165.7	12.77	2.54

discharges are those compiled by Karlin (1980) from a variety of sources. Our estimates here of the bedload transport were derived from the approach of Langbein and Schumm (1958) which is based on the quantities of sediment trapped in river reservoirs, relating those quantities to the drainage-basin area and to the effective mean annual precipitation. This effective precipitation is that which results in the river runoff, and so the calculations here are based on the gauged discharges rather than rainfall measurements. This approach yields the total average sediment transport, bedload plus suspension, so it was necessary to assume what portion is bedload since it is likely that the suspended load is too fine grained to remain on the ocean beaches. In the present calculations the bedload was assumed to be 15% of the total. Langbein and Schumm based their empirical curves on reservoirs throughout the entire United States so as to provide representative results for a wide range of climates, topography, vegetation cover, etc. However, the approach is necessarily very approximate, and the values given in Table 1 should be viewed as little better than order-of-magnitude estimates.

The rivers in Table 1 are listed in order from north to south. It is seen that the potential supply of bedload from the Columbia dwarfs all others. This is due mainly to its large discharge and drainage basin, but also because, according to the curves of Langbein and Schumm (1958), the sediment yield per unit basin area is higher than for rivers draining the Coastal Range where the vegetation cover is dense. The other primary sources are seen to be the Umpqua, the Rogue, the Klamath and the Eel Rivers. Of significance, with the exception of the Umpqua, none of the rivers draining the Coastal Range within our study area are potentially large contributors of bedload sediments.

An accompanying question is how much of this bedload in a river actually reaches the ocean beaches since many of these rivers have extensive estuaries which could trap this sand. This trapping of the river sands by estuaries on the Oregon coast has been investigated by the studies of Kulm and Byrne (1966), Boggs (1969), Boggs and Jones (1976), and Peterson et al. (1982, 1984a, 1984b). These studies have shown that not only can an estuary trap the river sand, but they can also represent a sink of beach sand which is carried inward through the inlet by tidal currents or by salt-wedge intrusion. Peterson et al. (1984a) analyzed estuarine sediment fills as to the proportions of river versus beach sands, comparing this proportion to a hydraulic factor H_F defined as the ratio of the tidal prism of the estuary to the river-water input during six hours of a half-tidal cycle. This H_F dimensionless ratio provides a reasonable measure of the tidal flow tending to carry beach sand into the bay versus the river flow which prevents its entry and tends to transport river sands through the estuary. Based on measurements in several estuaries in Oregon and

Washington, Peterson et al. obtained a statistically significant regression between the portions of beach versus river sediments in an estuary and the H_F hydraulic factor.

Although Peterson et al. (1984a) used H_F in an attempt to assess the two sources of sediment fill in the estuaries, beach and river, it is apparent that one might expect that H_F relates directly to the ability of the river-derived sands to bypass the estuary and reach the ocean beaches. As H_F decreases in magnitude, the river discharge increasingly dominates over the tidal prisim and it is more likely that sand can bypass the estuary. Accordingly, H_F values have been calculated for the rivers in the study area and are given in Table 1. Perhaps of greatest significance are the high H_F values for the Tillamook Bay system (the combined Tillamook, Trask and Wilson Rivers which enter that bay), for the Yaquina River and the Coos River. In view of these high H_F factors, it is doubtful whether any of these rivers presently supply sand to the ocean beaches. Unfortunately, we cannot define an H_F value where bypassing does become significant. Low values such as those of the Columbia, Salmon, and all of the rivers south of and including the Rogue would suggest significant bypassing. Uncertain are rivers in the range $H_F \approx$ 10 to 20, which unfortunately are the majority of those on the mid-Oregon coast within the immediate study area.

Figure 9 provides a summary of the potential river sand sources to the present-day beaches, combining the estimated bedload transports and H_F values. The most significant potential contributors should fall in the upper left portion of the diagram, rivers having both high sediment transport rates and low H_F values which indicate that the sand can reach the beach. It is seen that only the Klamath, Rogue and Eel Rivers to the south of our study area fit this pattern. For the most part, the bedload quantities from the rivers draining the Coastal Range are not very large and it remains uncertain what portion of that sand is actually reaching the ocean beaches.

Of course, the H_F hydraulic factor of a particular river system will vary through time, especially during the thousands of years of the Holocene sea-level transgression. It can be expected that at low stands of sea level there would have been minimal estuarine traps (very low H_F values) and so effectively all of the river sand would have reached the beaches. Later there must have been a stage where the newly-formed estuaries were deep and served as highly effective traps, perhaps preventing any bypassing. Within the last five to seven thousand years, the rate of sea-level rise has decreased, and during this period the estuaries have been filling such that their H_F values are decreasing with time and they are progressively approaching conditions where they can once more supply sand to the ocean

Figure 9. Estimated bedload transport rates for the rivers and the H_F hydraulic factors for their estuaries as an indication of their bypassing of sand to the adjacent ocean beaches. The x symbol represents rivers from the Columbia south to Tillamook Head, the triangles are rivers between Tillamook Head and Cascade Head, the closed circles represents rivers from Cascade Head to the southern extent of the study area, and the + symbols are for rivers south of the study area.

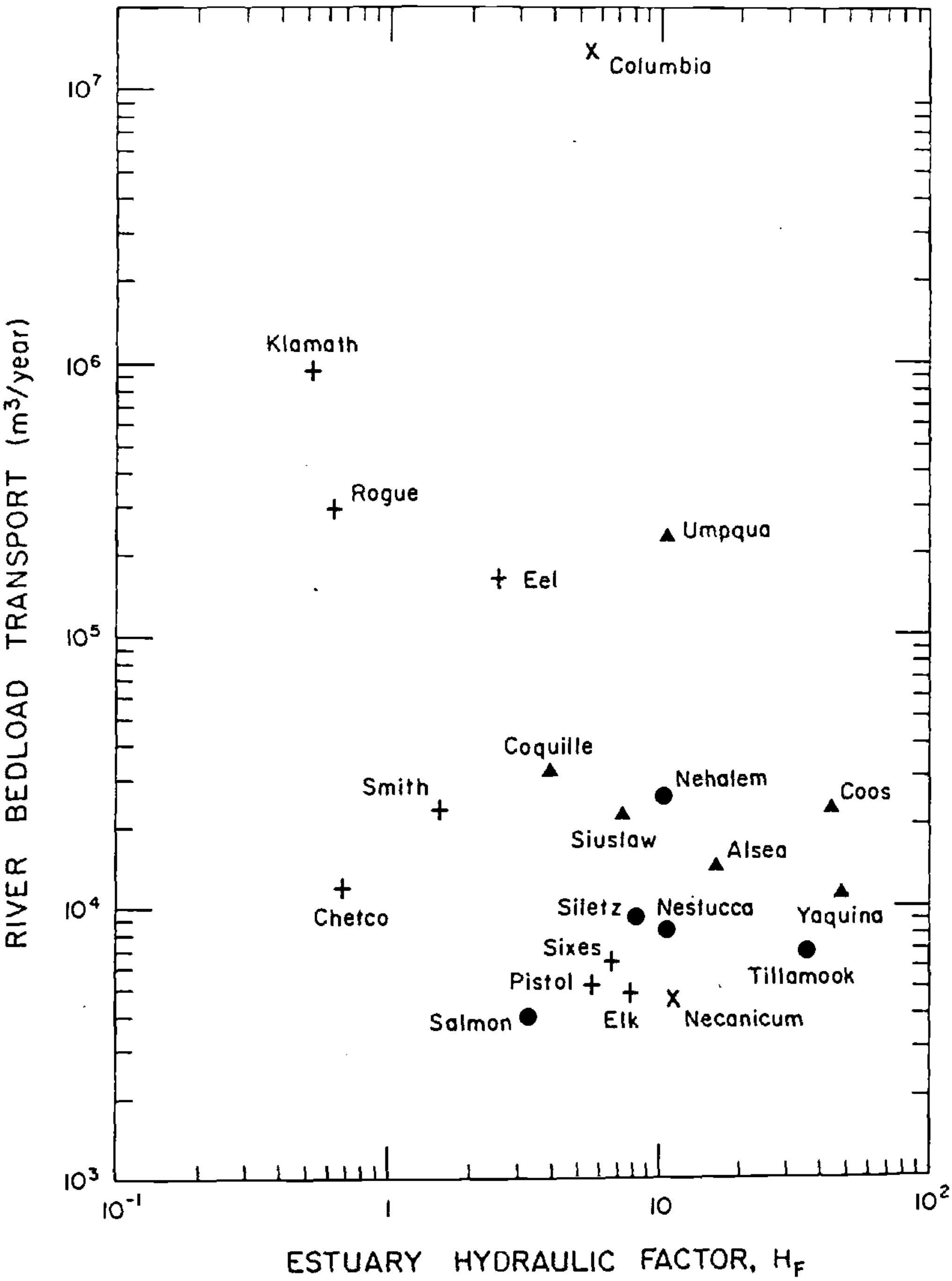
RIVER BEDLOAD TRANSPORT (m3/year)
10^7
10^6
10^5
10^4
10^3
10^-1
1
10
10^2
ESTUARY HYDRAULIC FACTOR, H_F
Columbia
Klamath
Rogue
Umpqua
Eel
Coquille
Nehalem
Coos
Smith
Siuslaw
Alsea
Chetco
Siletz
Nestucca
Yaquina
Sixes
Tillamook
Pistol
Elk
Necanicum
Salmon

Figure 9

beaches. Such a history of estuarine filling has been established in Alsea Bay by Peterson et al. (1984b), and it likely was similar in other Oregon-coast estuaries as well.

Evaluations of potential sand contributions from sea-cliff erosion are still more difficult, so much so that reasonable values cannot be deduced at present. This is because little information exists as to cliff-erosion rates. Smith (1978) used photogrametric techniques in such an attempt, concluding that in the past 34 years the average retreat rate in the marine terrace sections is about 23 cm/year. Observations during the present study suggest that this assessment is much too large, the long-term rates more likely being less than 10 cm/year. Until a more detailed study is undertaken of cliff erosion rates, it is not possible to make estimates of this sand contribution to the modern beach.

Although precise estimates of present-day sand inputs to the beaches are not possible, these analyses indicate that they must be small in the immediate study area, excepting north of Tillamook Head where sand is derived from the Columbia River. This conclusion supports those based on our analyses of the beach-sand compositions. Were these sources of major importance, their sand inputs would have thoroughly obscured the patterns of along-coast mixing of the more distant sources (Klamaths, etc.) at low stands of sea level, and all beach sands would be angular like those found to the north of Tillamook Head.

It might mistakenly be concluded from the beach compositions that Tillamook Head and Cape Foulweather are the only headlands that are effective in blocking longshore movements of sands on the modern beach. Only those two headlands demonstrate marked changes in mineral compositions on their two sides, and significant grain roundness changes are found only at Tillamook Head. However, these patterns have been seen to be the product of mixing of sand sources at lowered sea levels with subsequent modifications since the beaches were isolated. Certainly the most substantial headland on the Oregon coast is Cape Lookout which forms an abrupt ridge extending seaward 1.75 km into deep water. There can be no question that this Cape is effective in preventing longshore movements of beach sands, yet there are no significant compositional or rounding differences between its north and south beaches. This results from those beaches having had the same sand sources and Holocene histories, in contrast to Tillamook Head and Cascade Head where there are different sands sources to their north and south sides.

To the north of Cape Lookout is a 10-km long pocket beach having no immediately obvious sources of sand. Most of this coastal segment consists of Netarts Spit. This spit is backed by an extensive bay that has only a few small streams flowing into it, there being no river and hence little sand contribution. There is some cliff erosion to the north of the spit, but this source would be totally inadequate to account for the extensive volume of sand in Netarts Spit and its dune cover. This sand can only have been derived during lowered stands of sea level and subsequent onshore migration, a source also indicated by its mineralogy and rounding as documented here. An even more marked example of this is Short Sands Beach which is an isolated pocket beach within Cape Falcon (Figure 7). In spite of its isolation and being surrounded by volcanic sources, its mineralogical composition is much the same as the larger beaches in the area and contains a substantial portion of sand from distant sources such as the Klamaths. This can only be accounted for by an onshore migration of the beach during the Holocene rise in sea level.

There are other lines of evidence indicating the onshore migration of Oregon-coast beaches. Bore holes up to 16 meters length were obtained by the Corps of Engineers, Portland District, into Bayocean Spit sometime during the 1940s or 50s, and these demonstrate that this spit has migrated landward such that it overlies estuarine silts and clays. This can also be seen on Netarts Spit where erosion of the spit during the past few years has exposed estuarine and marsh deposits on the seaward side of the spit. Cooper (1958) had noted that just to the north of Netarts Spit, Holocene dunes are found atop sea cliffs, cut off from their former beach source by the onshore transgression which initiated cliff erosion. The beach at Neskowin has migrated over a forest, the stumps of which are exposed during periods of unusual erosion which cut back the level of the beachface.

SUMMARY OF CONCLUSIONS

The heavy-mineral compositions of beach sands on the Oregon coast have been produced by the along-coast mixing of sands from four primary sources. From north to south these include the Columbia River, rivers draining the Coastal Range, the Umpqua River whose drainage extends inland beyond the Coastal Range, and a metamorphic source from the Klamath Mountains of southern Oregon and northern California. The series of headlands presently prevent the along-coast dispersal and mixing of sands from these sources, so the observed mineral distributions must have been acquired during lower stages of sea level with a subsequent onshore migration of the sands during the latest transgression. This implies that much of the sand found on Oregon's beaches is relict and that it has been in the littoral environment for thousands of years. This is also indicated by the high degree of rounding of the beach sands in comparison with the river sources where the grains are very angular.

There have been additions of sand to the present-day beach subsequent to the onshore migration. This addition has been most significant north of Tillamook Head where the Columbia River is the major source. The beach sand there still retains most of the angularity of its river source, indicating a comparatively short residence time, contrasting with the rounded sand to the south of Tillamook Head. The beaches from Tillamook Head to about Cascade

Head show a significant contribution from the Coastal Range, but it is uncertain whether most of this contribution came during lower stages of sea level or following isolation of the beaches between the headlands. The grains are rounded, suggesting that much of the contributed sand is relict or that the present-day input from coastal streams and cliff erosion represent comparatively small volumes. This is also indicated by assessments of the quantities of bedload in these rivers and its likelihood of passing through the estuaries, and that sea-cliff erosion has not been significant in this region. To the south of Cascade Head, cliff erosion appears to have been an important source of beach sand, cliff erosion there cutting into marine terraces which contain uplifted beach and dune sands. Those terrace sands have had the same primary sources as the modern beaches, so that terrace erosion contributions cannot be distinguished.

The beaches on the Oregon coast provide an interesting example of how mineral compositions are controlled by an interplay of sea-level changes and the geomorphic configuration of the coast. At low stands of sea level there must have been long stretches of shoreline which permitted the along-coast mixing of sands from the several sources, a mixing that is now prevented during the present high stand of sea level because headlands segment the coast into isolated beaches. The time of transition between these two conditions depends on the changes in sea level compared with variations in the land level (the

Oregon coast has been rising throughout this period), and on the offshore extents of the headlands. Also of importance during this transition were the drowning of the major river valleys to form estuaries, the formation of which cut off a number of the river sources of beach sand. The present study of beach-sand compositions points to the need for a full analysis of such changes during the late Pleistocene and Holocene, changes which have had major effects in sediment-transport processes and patterns on the Oregon coast.

REFERENCES

BALAZS, R.J., AND KLEIN, G.D., 1972, Roundness - mineralogical relations of some intertidal sands: Jour. Sedimentary Petrology, v. 42, p. 425-433.

BOGGS, S., 1969, Distribution of heavy minerals in the Sixes River, Curry County, Oregon: The Ore Bin, v. 31, p. 133-150.

BOGGS, W.S. AND JONES, C.A., 1976, Seasonal reversal of flood-tide dominated sediment transport in a small Oregon estuary: Geol. Soc. Amer. Bull., v. 87, p. 419-426.

CALLAHAN, J., in press, A nontoxic heavy liquid and cheaper filters for separation of mineral grains: Jour. Sedimentary Petrology.

COOPER, W.S., 1958, Coastal Sand Dunes of Oregon and Washington: Memoir of the Geol. Soc. America, v. 72, 169 p.

GRIGGS, A.B., 1945, Chromite bearing sands of the southern part of the coast of Oregon: U.S. Geological Survey Bulletin 945-3, p. 113-150.

HELLER, P.L., PETERMAN, Z.E., O'NEIL, J.R., AND SHAFIQULLAH, M., 1985, Isotopic provenance of sandstones from the Eocene Tyee Formation, Oregon Coast Range: Geol. Soc. Amer. Bull., v. 96, p. 770-780.

HORNOR, R.R., 1918, Notes on the black sand deposits of southern Oregon and northern California: U.S. Bureau of Mines Technical Paper 196, 32 p.

IMBRIE, J, AND VAN ANDEL, Tj. H., 1964, Vector analysis of heavy mineral data: Bull. Geol. Soc. America, v. 75, p. 1131-1156.

KARLIN, R., 1980, Sediment sources and clay mineral distributions off the Oregon coast: Jour. Sedimentary Petrology, v. 50, p. 543-560.

KOMAR, P.D., LIZARRAGA-ARCINIEGA, J.R., AND TERICH, T.A., 1976, Oregon coast shoreline changes due to jetties: Jour. Waterways, Harbors and Coastal Engineering Div., Amer. Soc. Civil Engrs., v. 102, No. WW1, p. 13-30.

KOMAR, P.D., AND WANG, C., 1984, processes of selective grain transport and the formation of placers on beaches: Jour. of Geology, v. 92, p. 637-655.

KUENEN, Ph.H., 1959, Experimental abrasion 3. Fluviatile action on sand: Amer. Jour. of Science, v. 257, p. 172-190.

KUENEN, Ph.H., 1960, Experimental abrasion 4: Eolian action: The Jour. of Geology, v. 68, p. 427-449.

KUENEN, Ph.H., 1964, Experimental abrasion 6: Surf action: Sedimentology, v. 3, p. 29-43.

KULM, L.D., AND BYRNE, J.B., 1966, Sedimentary response to hydrography in an Oregon estuary: Marine Geology, v. 4, p. 85-118.

KULM, L.D., SCHEIDEGGER, K.F., BYRNE, J.V., AND SPIGAI, J.J., 1968, A preliminary investigation of the heavy mineral suites of the coastal rivers and beaches of Oregon and Nothern California: The Ore Bin, v. 30, p. 165-180.

LANGBEIN, W.B., AND SCHUMM, S.A., 1958, Yield of sediment in relation to mean annual precipitation: Trans. Amer. Geophysical Union, v. 39, p. 1076-1084.

LUEPKE, G., 1980, Opaque minerals as aids in distinguishing between source and sorting effects on beach-sand mineralogy in southwestern Oregon: Jour. Sedimentary Petrology, v. 50, p. 489-496.

MacCARTHY, 1933, The rounding of beach sands: Amer. Jour. Science, v. 25, p. 205-224.

PARDEE, J.T., 1934, Beach placers on the Oregon coast: U.S. Geological Survey Circular 8, 41 p.

PETERSON, C., SCHEIDEGGER, K.F., AND KOMAR, P.D., 1982, Sand-dispersal patterns in an active-margin estuary of the northwestern United States as indicated by sand composition, texture and bedforms: Marine Geology, v. 50, p. 77-96.

PETERSON, C., SCHEIDEGGER, ., KOMAR, P.D., AND NIEM, W., 1984, Sediment composition and hydrography in six high-gradient estuaries of the northwestern United States: Jour. Sedimentary Petrology, v. 54, p. 86-97.

PETERSON, C.D., SCHEIDEGGER, K.F., AND SCHRADER, H.J., 1984, Holocene depositional evolution of a small active-margin estuary of the nothwestern United States: Marine Geology, v. 59, p. 51-83.

PETERSON, C.D., KOMAR, P.D., AND SCHEIDEGGER, K.F., 1986, Distribution, geometry and origin of heavy mineral placer deposits on Oregon beaches: Jour. Sedimentary Petrology, v. 56, p. 67-77.

PETTYJOHN, F.J. AND LUNDAHL, A.C., 1943, Shape and roundness of Lake Erie beach sands: Jour. Sedimentary Petrology, v. 13, p. 69-78.

PLEWINSKY, B., AND KAMPS, R., 1985, Sodium polytungstate, a new medium for binary and ternary density gradient cnetrifugation: Makromol. Chem., v. 185, p. 1429-1439.

ROTTMANN, C.J., 1973, Surf zone shape changes in quartz grains on pocket beaches, Cape Arago, Oregon: Jour. Sedimentary Petrology, v. 43, p. 188-199.

SCHEIDEGGER, K.F., KULM, L.D., AND RUNGE, E.J., 1971, Sediment sources and dispersal patterns of Oregon Continental Shelf Sands: Jour. Sedimentary Petrology, v. 41, p. 1112-1120.

SHEPARD, E.P., AND YOUNG, R., 1961, Distinguishing between beach and dune sands: Jour. Sedimentary Petrology, v. 31, p. 196-214.

SMITH, E.C., 1978, Determination of coastal changes in Lincoln County, Oregon, using aerial photographic interpretation: unpublished Masters research paper, Dept. of Geography, Oregon State Univ., 29 p.

TWENHOFEL, W.H., 1945, The rounding of sand grains: Jour. Sedimentary Petrology, v. 15, p. 59-71.

TWENHOFEL, W.H., 1946, Mineralogical and physical composition of the sands of the Oregon coast from Coos Bay to the mouth of the Columbia River: Oregon State Dept. of Geology and Mineral Industries Bulletin No. 30, 64 p.

APPENDICES

APPENDIX I

HEAVY-MINERAL SEPARATION WITH SODIUM POLYTUNGSTATE

It is well known that there are major health hazards associated with the use of tetrabromoethane in heavy-mineral separations, and for this reason the new technique of using sodium polytungstate was primarily used in this study. The use of this substance for density separations was first established by Plewinsky and Kamps (1984), and its use in heavy-mineral separations in sediments has been demonstrated by Callahan (in press). The specific gravity of sodium polytungstate is 3.00 and so provides effectively the same mineral division as did tetrabromoethane (specific gravity = 2.96).

The procedures employed in the present study involved the following steps:

1. Wash and dry the sand sample so as to avoid contaminating the sodium polytungstate.
2. Use a splitter to obtain a subsample of about 9 ml of the 65 to 250 micron size fraction.
3. Mix the subsample in a 43 ml centrafuge tube with enough sodium polytungstate to fill the tube.
4. Centrifuge at 8,000 rpm's for five minutes.
5. Freeze the heavy-mineral portion in the bottom of the tube with liquid nitrogen.

6. Pour off the unfrozen light fraction together with the excess sodium polytungstate, filtering to reclaim the tungstate (standard coffee filters were used as suggested by Callahan).
7. Thaw the heavy fraction and pour through a filter, rinsing liberally with distilled water.
8. Dry the heavy fraction.

The sodium polytungstate mixed with distilled water from the washing process can be reclaimed by placing the mixture in an oven at about 70°C to drive off the water. The saturated solution of tungstate will have a specific gravity of 3.00.

APPENDIX II

HEAVY-MINERAL IDENTIFICATION

It is difficult to identify heavy minerals in grain mounts since they do not follow the exact rules given in standary mineralogy textbooks, there being variations in thickness from one grain to the next. In this Appendix I give some of the primary criteria I used to identify the minerals.

HYPERSTHENE: Pleochroic from green to orange, parallel extinction, low interference colors.

ENSITITE: A clear mineral with the same properties as hypersthene.

AUGITE: A green mineral with 45° extinction.

TITANAUGITE: A brown mineral with 45° extinction and prismatic cleavage intersecting at 87° and 93°.

DIOPSIDE: A clear mineral with 45° extinction.

GREEN HORNBLENDE: Green mineral with varying degrees of pleochroism from dark to light green and from green to brown with 12° to 34° extinction, fairly low interference colors (first and low second order), and prismatic cleavage intersecting at 56° and 124°.

BROWN HORNBLENDE: Brown mineral with varying degrees of pleochroism from dark to light brown, 12° to 34° extinction, fairly low interference colors, and prismatic cleavage intersecting at 56° and 124°.

RED HORNBLENDE: A red mineral with varying degrees of pleochroism from dark to light red and 12° to 34° extinction.

BLUEGREEN HORNBLENDE: A distinctive bluegreen mineral which is pleochroic from bluegreen to green and has 12° to 34° extinction.

EPIDOTE: A green mineral that is slightly pleochroic and the birefringence is masked by strong dispersion.

CLINOZOISITE: The same properties as epidote but with much lower interference colors (first order grey, white or yellow).

STAUROLITE: An amber colored mineral that is slightly pleochroic with bright interference colors.

CLEAR GARNET: A clear isotropic mineral.

PINK GARNET: A pink to red isotropic mineral.

KYANITE: A clear mineral with high relief, bright interference colors, 45° extinction, and perfect cleavage producing elongated fragments with cross fractures dividing crystals into segments.

SILLIMANITE: A mineral with the same properties as kyanite but with parallel extinction.

OLIVINE: A green mineral with poor cleavage, coarse irregular fracture pattern, and bright interference colors.

ZIRCON: A clear mineral with high relief, high order white interference colors, and parallel extinction.

APPENDIX III

TABLE III-1: Beach-sand mineralogies

	B1 Fort Stevens	B2 Seaside	B3 Cannon Beach	B4 Hug Point	B5 Short Sand	B6 Manzanita	B7 Rockaway	B8 Cape Mears
Hypersthene	30.94	19.08	4.18	4.92	6.41	3.67	5.96	10.67
Enstitite	3.26	2.96	0.96	0.33	1.28	0.67	0.33	0.33
Augite	16.94	15.79	33.76	41.97	49.36	64.00	63.91	54.33
Titanaugite	0.65	4.61	13.50	11.15	5.45	4.00	4.30	2.00
Diopside	0.98	1.32	0.96	0.98	0.64	0.33	0.99	0.00
Green Horn.	18.57	23.03	24.44	17.38	21.47	15.67	10.93	14.00
Brown Horn.	12.70	23.68	13.50	12.46	6.09	3.33	6.29	4.67
Red Horn.	6.84	2.96	0.32	1.31	0.32	1.33	0.66	1.67
Bluegreen Horn.	7.49	4.93	2.25	2.95	3.21	0.00	1.99	1.00
Epidote	0.00	0.00	2.25	0.66	1.60	4.00	3.31	1.67
Clinozoisite	0.33	0.33	0.96	0.33	0.00	1.33	0.00	0.00
Staurolite	0.00	0.00	0.00	0.00	0.64	0.00	0.33	0.33
Clear Garnet	0.00	0.00	0.00	0.98	0.64	0.33	0.66	3.67
Pink Garnet	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.33
Kyanite	0.00	0.00	1.29	2.62	1.28	0.00	0.00	1.00
Sillimanite	0.00	0.00	0.32	0.00	0.32	0.00	0.33	0.00
Zircon	0.33	0.00	0.00	0.33	0.00	0.33	0.00	3.67
Olivene	0.00	0.66	0.64	1.31	1.28	1.00	0.00	0.00
Unknown	0.98	0.66	0.64	0.00	0.00	0.00	0.00	0.67

	B9 Oceanside	B10 Netarts Spit	B11 Sand Lake	B12 Tierra Del Mar	B13 Pacific City	B14 Neskowin	B15 Lincoln City	B16 Gleneden
Hyperstene	8.71	4.52	5.94	8.67	5.84	1.67	3.43	4.59
Enstitite	0.28	1.94	0.99	1.00	1.95	1.00	0.31	0.00
Augite	62.64	48.06	66.34	55.33	61.04	81.67	62.62	69.51
Titanaugite	0.56	3.23	2.64	2.67	5.84	6.00	6.85	3.93
Diopside	0.00	0.97	0.66	0.33	0.97	0.00	0.31	0.00
Green Horn.	14.89	12.58	6.27	5.67	6.17	2.33	2.49	3.93
Brown Horn.	3.65	6.77	2.31	4.67	5.84	3.67	4.36	2.95
Red Horn.	0.28	0.00	0.99	1.33	0.00	0.00	0.00	0.98
Bluegreen Horn.	1.12	1.61	0.99	0.67	0.00	0.00	0.00	0.33
Epidote	1.97	3.87	3.63	3.67	2.92	1.00	1.56	2.30
Clinozoisite	0.84	1.29	1.32	0.67	0.65	1.33	0.00	0.33
Staurolite	0.56	0.65	0.00	0.00	0.32	0.00	0.31	0.66
Clear Garnet	2.53	9.35	4.62	9.67	3.90	0.33	9.66	5.25
Pink Garnet	0.28	0.65	0.66	2.00	1.62	0.00	7.17	3.28
Kyanite	0.56	0.00	0.33	0.00	0.00	0.00	0.00	0.66
Sillimanite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zircon	0.56	2.90	1.32	1.67	0.97	0.00	0.62	0.66
Olivene	0.00	0.97	0.33	1.00	0.97	0.00	0.00	0.33
Unknown	0.56	0.65	0.66	1.00	0.97	1.00	0.31	0.33

	B17 Moolack	B18 Agate	B19 South	B20 Ona	B21 Patterson	B22 Heceta	B23 Siltcoos	B24 Umpqua
Hyperstene	13.91	13.81	15.71	17.30	11.11	18.54	19.74	23.93
Enstitite	1.53	1.20	2.42	3.14	0.98	0.33	1.29	3.21
Augite	40.18	30.33	31.42	31.76	41.18	32.78	30.10	33.93
Titanaugite	0.31	0.30	0.00	0.94	0.33	0.00	0.00	0.00
Diopside	0.61	1.80	0.91	0.94	0.33	0.66	1.62	1.07
Green Horn.	14.42	27.63	19.64	22.01	25.82	13.58	14.56	11.79
Brown Horn.	5.83	10.81	10.88	9.43	9.48	4.97	6.15	7.86
Red Horn.	0.61	0.30	0.60	0.00	0.33	0.33	0.65	0.36
Bluegreen Horn.	0.61	0.90	1.51	2.20	0.98	1.66	0.65	1.07
Epidote	1.23	0.90	0.00	0.31	1.96	1.32	0.65	0.71
Clinozoisite	0.31	1.80	0.30	0.63	0.00	0.00	0.00	0.00
Staurolite	0.31	0.30	1.21	0.94	0.00	0.33	1.29	0.00
Clear Garnet	13.80	6.01	10.27	7.86	4.58	16.89	11.65	8.93
Pink Garnet	3.68	0.90	1.21	0.94	1.31	2.32	3.88	2.14
Kyanite	0.31	0.90	0.00	0.31	0.33	0.00	0.97	0.36
Sillimanite	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00
Zircon	1.53	0.90	3.32	0.94	0.33	5.96	6.15	3.57
Olivene	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unknown	1.23	0.90	0.60	0.31	0.98	0.33	0.65	1.07

	B25 Whiskey Run	B26 Bandon
Hyperstene	17.42	13.71
Enstitite	4.84	3.68
Augite	21.94	20.40
Titanaugite	0.00	0.00
Diopside	4.19	0.67
Green Horn.	17.42	10.03
Brown Horn.	10.32	8.03
Red Horn.	0.65	0.33
Bluegreen Horn.	0.65	1.34
Epidote	2.90	2.34
Clinizoisite	0.97	0.00
Staurolite	2.58	2.68
Clear Garnet	10.65	14.72
Pink Garnet	2.26	5.02
Kyanite	0.00	0.33
Sillimanite	0.00	0.00
Zircon	1.61	14.72
Olivene	0.00	0.00
Unknown	0.97	2.01

Table III-2: River Sand Mineralogies

	Columbia	Necanicum	Trask	Tillamook	Nestucca	Salmon	Siletz	Yaquina
Hyperstene	44.58	1.00	0.33	0.00	0.00	0.00	0.00	5.26
Enstitite	4.02	0.00	0.00	0.00	1.56	0.00	0.00	9.65
Augite	18.89	7.31	50.82	58.80	73.80	24.46	54.28	22.81
Titanaugite	0.00	23.92	9.51	10.30	9.91	44.65	20.07	2.63
Diopside	1.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Green Horn.	14.24	6.98	17.38	17.61	0.00	4.89	12.83	19.30
Brown Horn.	8.67	59.80	20.66	9.63	16.22	24.77	10.86	20.18
Red Horn.	1.24	0.33	0.00	0.00	0.00	0.61	0.00	0.88
Bluegreen Horn.	1.24	0.33	0.00	0.33	0.00	0.00	0.33	0.00
Epidote	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Clinozoisite	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Staurolite	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.88
Clear Garnet	1.55	0.33	0.00	0.00	0.00	0.00	0.00	11.40
Pink Garnet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.63
Kyanite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sillimanite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zircon	2.17	0.00	0.00	0.00	0.00	0.00	0.33	2.63
Olivene	0.00	0.00	0.98	2.33	0.00	0.31	0.99	0.00
Unknown	0.93	0.00	0.33	0.66	0.00	0.31	0.33	3.51

	Alsea	Siuslaw	Umpqua	Coos	Coquille
Hyperstene	0.00	6.42	21.45	0.00	0.00
Enstitite	0.00	0.00	2.64	2.73	0.00
Augite	34.20	23.85	38.28	40.91	40.78
Titanaugite	32.57	0.92	0.00	0.00	0.00
Diopside	0.00	0.00	0.00	0.00	0.00
Green Horn.	8.14	29.36	22.77	20.91	23.30
Brown Horn.	22.48	29.36	5.61	16.36	27.18
Red Horn.	0.00	0.00	0.00	0.00	0.00
Bluegreen Horn.	1.95	1.83	2.64	0.91	0.00
Epidote	0.00	0.00	0.33	2.73	3.88
Clinozoisite	0.00	0.00	0.33	0.00	0.00
Staurolite	0.00	0.00	0.33	0.91	0.00
Clear Garnet	0.00	6.42	1.32	10.91	0.00
Pink Garnet	0.00	0.00	0.00	0.91	0.00
Kyanite	0.00	0.00	0.00	0.00	0.00
Sillimanite	0.00	0.00	1.32	0.00	0.00
Zircon	0.00	0.91	0.00	0.91	0.00
Olivene	0.00	0.00	0.00	0.00	0.00
Unknown	0.65	0.00	0.66	1.82	0.00

Table III-3: Marine-Terrace Sands

	D-River	Lincoln City	Taft	Gleneden	Marine Gardens	Jumpoff Joe	Drift Creek	Seal Rocks
Hyperstene	7.95	11.58	10.71	9.68	14.34	19.38	21.74	8.47
Enstitite	0.33	0.33	0.65	0.32	2.45	0.56	0.62	1.63
Augite	36.75	47.68	53.25	55.48	17.83	19.66	24.84	41.04
Titanaugite	0.00	0.00	0.00	0.32	0.00	0.28	0.00	0.00
Diopside	1.32	0.33	0.65	0.00	0.00	0.28	0.62	0.65
Green Horn.	8.28	14.57	8.44	5.81	3.85	11.80	26.71	11.07
Brown Horn.	12.91	11.59	9.09	8.71	6.29	5.90	7.45	21.17
Red Horn.	0.00	0.99	1.30	0.32	1.05	0.28	0.31	0.65
Bluegreen Horn.	0.99	0.99	0.32	1.61	1.05	1.12	0.62	0.98
Epidote	0.99	0.99	0.32	1.94	1.40	0.56	0.31	0.98
Clinozoisite	0.00	0.00	0.97	0.00	0.00	0.00	0.00	0.00
Staurolite	0.66	0.33	0.32	0.00	0.70	2.25	1.24	1.30
Clear Garnet	17.22	6.29	7.47	10.97	29.72	27.25	9.63	8.47
Pink Garnet	2.65	0.99	1.95	1.61	9.44	5.90	2.17	1.63
Kyanite	0.00	0.66	0.32	0.32	0.00	0.28	0.31	0.00
Sillimanite	0.33	0.00	1.62	0.00	0.00	0.56	0.62	0.00
Zircon	7.62	1.32	2.27	2.58	11.89	3.09	1.24	1.63
Olivene	0.33	0.00	0.00	0.00	0.00	0.00	0.31	0.00
Unknown	1.66	1.32	0.32	0.32	0.00	0.84	1.24	0.33

Table III-4: Selective-Sorting Samples at Otter Rock Beach

	OR1	OR2	OR3	OR4	OR5	OR6	OR7	OR8
Hyperstene	12.17	12.12	21.01	17.48	11.65	13.64	16.67	18.18
Enstitite	1.74	0.00	0.00	0.00	0.00	2.73	1.85	0.00
Augite	25.22	34.85	28.99	33.01	34.95	31.82	32.41	26.36
Titanaugite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diopside	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Green Horn.	6.09	9.85	9.42	5.83	12.62	10.91	6.48	7.27
Brown Horn.	4.35	3.79	5.80	9.71	5.83	7.27	3.70	7.27
Red Horn.	0.87	0.00	1.45	0.00	0.97	0.00	0.00	0.00
Bluegreen Horn.	0.00	0.00	0.72	0.00	1.94	0.91	0.00	0.00
Epidote	4.35	0.76	2.90	2.91	0.00	2.73	2.78	1.82
Clinozoisite	2.61	0.76	0.72	0.97	0.97	0.00	0.00	0.91
Staurolite	0.87	1.52	2.90	0.97	1.94	3.64	4.63	0.91
Clear Garnet	33.91	21.21	18.84	22.33	24.27	18.18	26.85	30.91
Pink Garnet	3.48	9.85	2.90	3.88	2.91	4.55	3.70	3.64
Kyanite	0.00	0.00	0.72	0.97	0.00	1.82	0.00	1.82
Sillimanite	0.00	0.00	1.45	0.00	0.00	0.00	0.00	0.00
Zircon	2.61	4.55	1.45	1.94	1.94	0.91	0.93	0.91
Olivene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unknown	0.87	0.76	0.72	0.00	0.00	0.91	0.00	0.00

	OR9	OR10	OR11	OR12
Hyperstene	17.36	12.84	11.21	14.29
Enstitite	1.65	0.00	0.00	0.00
Augite	41.32	13.76	24.30	12.38
Titanaugite	0.00	0.00	0.00	0.00
Diopside	0.83	0.00	0.00	0.00
Green Horn.	10.74	2.75	7.48	4.76
Brown Horn.	8.26	2.75	0.93	1.90
Red Horn.	0.83	2.75	1.87	0.00
Bluegreen Horn.	1.65	0.00	0.00	0.95
Epidote	1.65	0.00	0.93	0.95
Clinozoisite	0.83	0.92	0.00	0.95
Staurolite	4.13	5.50	4.67	3.81
Clear Garnet	6.61	40.37	32.71	36.19
Pink Garnet	1.65	11.93	12.15	18.10
Kyanite	0.00	0.00	0.00	0.00
Sillimanite	1.65	0.92	1.87	0.95
Zircon	0.00	5.50	0.93	3.81
Olivene	0.00	0.00	0.00	0.00
Unknown	0.83	0.00	0.93	0.95