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# Heavy-Mineral Variability in Beach and Dune Sands in the Vicinity of the Mouth of the Columbia River

by

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## INTRODUCTION

The present study is an outgrowth of a heavy-mineral study of modern and Pleistocene sediments in Willapa Bay, Washington (Luepke, 1982; Luepke and Clifton, in press). Preliminary examination of a series of beach sands collected on Long Beach Peninsula indicated a possiblity of a significant change in heavy mineral composition from north to south. A number of observations concerning the rarer species of heavy minerals are also worthy of report.

The sands in the vicinity of the mouth of the Columbia River have been studied for decades. Hodge (1934) made the first petrological study of these sands. Twenhofel (1946) included this area in his extensive reconnaissance study of beach sands from Coos Bay, Oregon to the mouth of the Columbia River. Runge (1966), White (1968), and Scheidegger, Kulm and Runge (1971) traced the distribution of Columbia River sediments onto the Oregon-Washington Continental Shelf. Kelley and Whetten (1969) and Whetten, Kelley and Hanson (1969) focused on Columbia River sediments in specific reservoirs along the river. Ballard (1964) made the most extensive study of Long Beach Peninsula sands to date; this was part of a study of beaches from Tillamook Head, Oregon to Copalis Head, Washington, a distance of about 70 km. Cooper (1958) presents the most comprehensive descriptions of the dunes in this area.

Long Beach Peninsula is a north-pointing barrier spit which stands between the Pacific Ocean and Willapa Bay, Washington (Fig. 1). Clatsop Beach[1] extends from Tillamook Head northward to Clatsop Spit at the mouth of the Columbia River. Both Clatsop Beach and the beach on Long Beach Peninsula are flanked on the landward side by a series of largely stabilized, vegetated, shore-parallel dune ridges.

## METHODS OF STUDY

A total of 39 samples were analyzed for this study. Beach samples, 21 from Washington and 8 from Oregon, were collected in the upper swash zone at relatively high tide by scraping the surface to a depth of 2 cm. Dune samples, 7 from Washington and 3 from Oregon, were collected at the top and edge of the dune lee-slope, away from vegetation, where the presence of wind ripples clearly indicated wind transport. Samples ranged in weight from 300 to 500 g. Sampling in Oregon extended from Gearhart, north of the mouth of the Necanicum River, to Clatsop Spit; in Washington, sampling on Long Beach

[1]Ballard's (1964) terminology; actually two beaches, Sunset and Columbia, according to U.S.G.S. Gearhart and Warrenton 7.5 min. quadrangles.

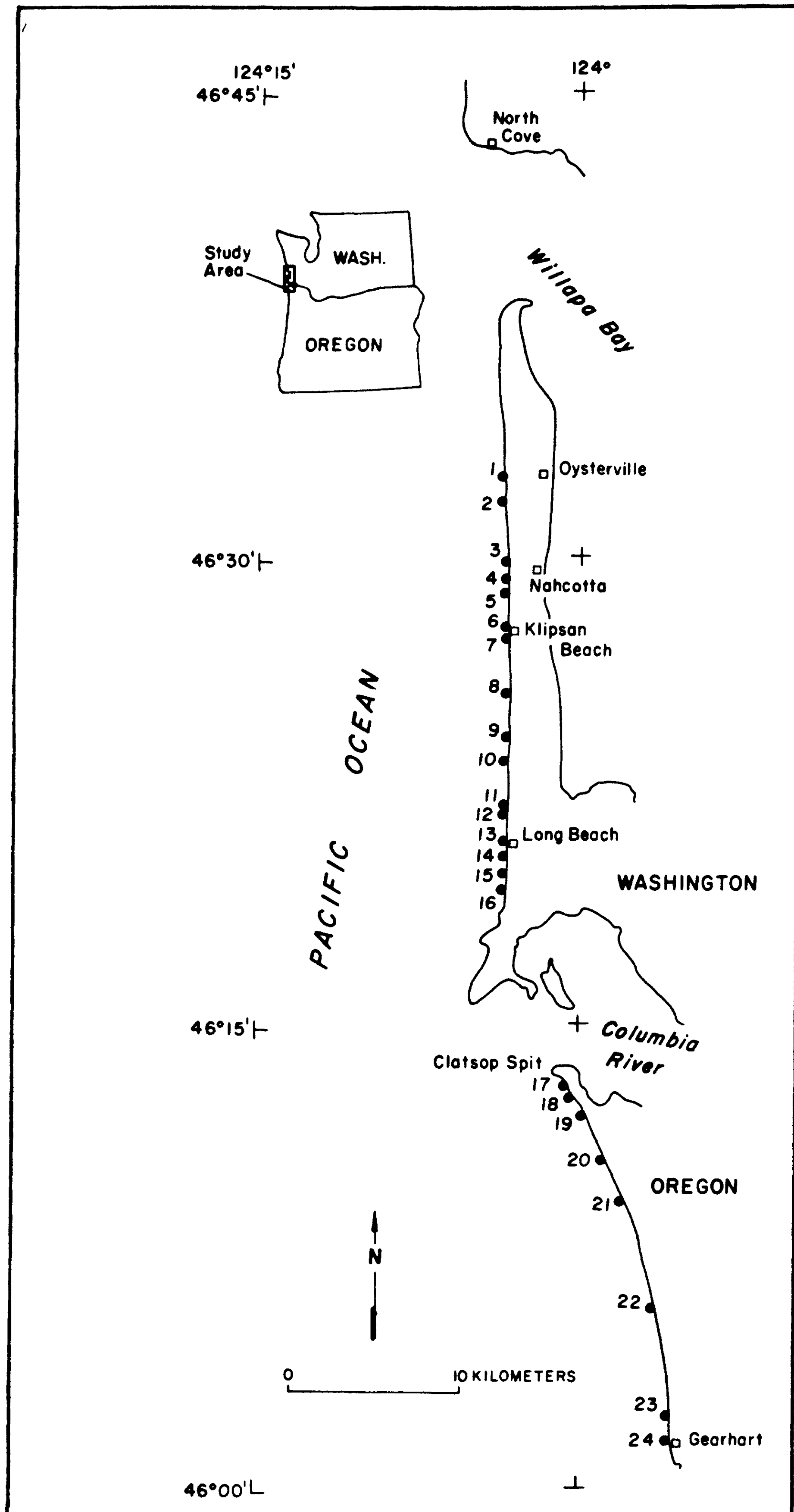


Figure 1. Sample location map with index map of study area. Key to sample locations on p. 3.

Key to Sample locations

1. 74WGL-52; 77WGL-56, 56a
2. 77WGL-57
3. 74WGL-53; 77WGL-58, 58a, 58b
4. 77WGL-59, 59a
5. 74WGL-54; 77WGL-60, 60a
6. 77WGL-61, 61a
7. 74WGL-55
8. 77WGL-62, 62a
9. 77WGL-63
10. 77WGL-64
11. 74WGL-56; 77WGL-65
12. 77WGL-66
13. 77WGL-67
14. 74WGL-57, 58
15. 77WGL-69
16. 77WGL-68
17. 77OGL-1, 1a
18. 77OGL-2, 2a
19. 77OGL-3
20. 77OGL-4
21. 77OGL-5
22. 77OGL-6
23. 77OGL-7
24. 77OGL-8, 8a

Peninsula extended from Seaview to the beach at the end of Oysterville Road (Fig. 1).

In addition, four samples from the Columbia River were scanned but not point-counted. Two of these samples were taken at a point aproximately 210 km above the mouth of the Columbia River. These samples were collected by Jerry L. Glenn, U.S. Geological Survey, Denver. The other two samples were supplied by Dr. Richard J. Stewart, University of Washington; one sample came from the Bonneville Reservoir, the other from the John Day River.

Samples were washed with demineralized water and air-dried. Each sample was split to a weight of 33-57 g. and separated in a 250-ml glass peparatory funnel with tetrabromoethane (S.G. = 2.96). The heavy-mineral fraction was then sieved and the 3-4Ø fraction (0.125 - 0.062 mm) split by microsplitter for grain mounts. Lakeside 70 (n = 1.54) was used as the mounting medium.

The number of grains counted on a slide depended on the abundance of grains and the number of opaque minerals and mineral aggregates (grains containing more than one mineral). The number of nonopaque, monomineralic grains counted ranged from 159 to 289, with an average of 244. Three hundred grains were usually sufficient to yield at least 150 nonopaque grains, but occasionally up to 700 grains needed to be counted. The lowest number counted was 200. However many grains were counted, the entire slide was examined to note mineral species seen but not encountered during the point-count.

The remaining heavy-mineral fractions of all but one sample were sieved at 1/4 Ø intervals from 0.21 to 0.062 mm on 3-inch screens; sieving took place for 7-8 min. on a mini-sieve shaker. Grain mounts were made of the fraction which contained the greatest percent by weight of heavy minerals, usually the 0.149-0.125 mm or the 0.125-0.105 mm fraction. Each fraction was weighed on an electronic balance to two decimal places. For samples containing greater than 1 g of heavy minerals, a fairly good idea of the grain-size distribution of the heavy minerals can be obtained. Where the sample contained less than 0.1 g, only a very rough idea of the grain-size distribution can be made. The one heavy-mineral sample that was not sieved weighed only 0.01 g.

## RESULTS

Grain size analysis. Fewer samples were collected on the Oregon side of the Columbia River than on the Washington side, but the following pattern seems evident: The heavy minerals in the beach sands become coarser in a southerly direction on both Clatsop and Long beaches. The mean grain size of heavy minerals in beach sands on Long Beach Peninsula ranges from 0.125-0.149 mm at the north end and increases to greater than 0.21 mm toward the south. In the dune sands the mean grain size ranges from 0.105-0.149 mm in the north to 0.149-0.177 mm in the south. This is in general agreement with increasing mean grain size in a southerly direction (Ballard, 1964).

On Clatsop Beach, over 50% of the heavy minerals in the beach sands are of a size greater than .21 mm, with no noticeable alongshore variation. Dunes in Oregon have a heavy-mineral mean grain size of 0.125-0.149 mm, which decreases to 0.105-0.125 mm in a southerly direction.

Heavy-mineral composition. Though the 0.125-0.062 mm fraction is a full phi interval as opposed to the more restricted 1/4 Ø interval used in the sieving analysis, this full phi interval is usually considered the best for mineralogical analysis. Three beach samples and one dune sample were examined in restricted size fractions to see if there were any significant differences in mineralogy atttributable to grain-size variations. In general, the amount of orthopyroxene decreases with increasing grain size, and hornblende increases with increasing grain size. Clinopyroxene shows a slight decrease with increasing grain size, and epidote shows little significant change.

The most common groups of minerals identified in the sands are orthopyroxene (mostly hypersthene with rare enstatite), clinopyroxene (mostly augite with rare diopsde), and hornblende (green, blue-green,brown and basaltic varieties). In the clinopyroxene group, aegerine-augite was sufficiently distinctive to permit positive identification.

Smaller percentages of garnet (colorless and pink, with rare yellow varieties) and epidote (including rare clinozoisite and zoisite) occur in all samples. Nearly all samples contain kyanite, sphene, apatite, zircon, and rutile. Other minerals identified are staurolite, tremolite/actinolite, sillimanite, chloritoid, glaucophane, tourmaline, and topaz(?).

Table 1 shows means and standard deviations of the major mineral groups. (For a comparison with mineral groups in Columbia River reservoirs, see Whetten et al., 1969). Tables 2 - 5 show a detailed mineralogical analysis of each sample. The number of samples examined in this study is comparable to the number examined in earlier studies. With some notable exceptions, all minerals identified by me have been identified in these sediments by other workers. These exceptions will be discussed in some detail.

The mineral groups in the four environments (Washington beaches, Washington dunes, Oregon beaches, Oregon dunes) were compared using a Student's t (sample means) statistical test. Only hornblende and epidote showed significant differences. Hornblende is significantly richer in beach sands on Long Beach Peninsula than in the dune sands; no such difference was noted in the beach and dune sands of Clatsop Beach. Epidote was significantly lower in beach sands overall than in dune sands.

A third difference was noted: on Long Beach Peninsula, the average percentage of opaque minerals significantly increases in beach and dune sands south of the Klipsan Beach-Ocean Park area (see Fig. 1). No such variability is apparent in the beach and dune sands of Clatsop Beach.

## DISCUSSION

There is little doubt that the sands of Long Beach Peninsula are derived from the Columbia River. The prevalent direction of longshore transport from the mouth of the Columbia is to the north (Ballard, 1964; Scheidegger et al., 1971). Also, Columbia River sediments are transported as far south of the mouth as 46° 10' (White, 1968, p. 61), a point north of Gearhart, Oregon (see

Fig. 1). Therefore, any variation in heavy-mineral composition on the beaches of this region cannot be due to major differences in source area.

Opaque minerals. The higher amounts of opaque minerals in sands south of Klipsan Beach may reflect density sorting. I examined the relationship in the percentages of garnet, zircon, and sphene in samples north and south of Klipsan Beach. These minerals, while of lower specific gravities than opaque minerals, nevertheless are among the "heavier heavy minerals" (Table 6). Also, these minerals tend to be of equant dimensions and are therefore more likely to behave similarly to opaque minerals than the elongated mineral grains such as kyanite.

There is no significant difference in the amount of garnet or zircon in north versus south samples, although for both minerals the percentages are slightly higher in the southern samples than in the northern samples. Samples south of Klipsan Beach, however, are significantly higher in sphene.

Rutile and chloritoid are "heavier heavy minerals" (Table 6) present only in trace amounts in the samples examined. However, chloritoid was seen in 3 samples south of Klipsan Beach, rutile seen in 4 samples. No samples north of Klipsan Beach showed either of these minerals. Though this information is not enough for a precise statistical analysis, it is interesting to speculate that these minor variations in the heavy mineral composition are a reflection of sorting effects, with the heavier heavy minerals tending to be concentrated toward the southern end of Long Beach Peninsula.

The rarer detrital minerals are not usually given as much weight in geologic interpretations as are the more common detritals. This is a mistake, for as Boswell (1927, p. 130) points out, "Insignificant as such rarely occurring grains may appear, they often provide more valuable clues to the history of the containing sediment than the more common heavy detrital minerals."

Certain minerals identified in this study may well have been overlooked by previous workers if they did not scan the entire slide after finishing the point-count. Indeed, it is often left unsaid whether this procedure was followed. Minerals identified for the first time include aegerine-augite, glaucophane, rutile, chloritoid, and topaz(?). White (1968, Table 4) identified glaucophane and rutile in Washington continental shelf sands but not in Columbia River estuary sands.

Topaz. Topaz(?) was identified on the basis of its parallel extinction, low birefringence, biaxial positive optic sign, and length-fast character. No other mineral seems to fit the grain characteristics, although it is not clear where the ultimate source in this region would be.

Glaucophane. Of all the minerals not previously identified in Columbia River sediments, the most significant by far is glaucophane. Kulm et al. (1968) state that no glaucophane is found in Columbia River sediments and cite several previous workers to support this. Based on this work, glaucophane in sediments on the Oregon continental shelf or beaches north of Coos Bay, Oregon, has been thought to originate in the Klamath Mountain drainage basins in northern California and southern Oregon and is cited as evidence for longshore transport in a northerly direction (Kulm et al., 1968; Scheidegger et al., 1971).

Three samples from Long Beach Peninsula each contain one grain of glaucophane (Table 1). Glenn (1978, Table 4, p. 22) identified glaucophane in one sample of oceanic sediments from the western margin of Tillamook Bay south of the study area of this report (on the oceanside beach of Bayocenn Spit). In addition, 15 of 175 samples from Pleistocene sediments in Willapa Bay contain one grain of glaucophane (Luepke, 1982). This one grain was often seen only after an examination of the entire heavy-mineral grain mount and was not commonly included within the point-count as an encountered grain.

The finding of glaucophane in Long Beach Peninsula and Willapa Bay sands does not preclude the possibility of its having been brought northward from the Klamath Mountain drainage. But this is a distance of over 560 km, and glaucophane, like most amphiboles, is not known for its great resistance to weathering. To date there have been no studies on the resistance of glaucophane to weathering (R.G. Coleman, pers. comm., 1981). However, glaucophane is considered to be as unstable as olivine (Krumbein and Pettijohn, 1938).

At the time of the work of Kulm et al. (1968), the presence of blueschists in the Columbia River drainage had not been documented. Since then, several workers have located blueschist bodies that could serve as source areas. The closest of these is the Myers Canyon-Tony Butte area near Mitchell, Oregon, on the John Day River (Hotz, Lanpere and Swanson, 1977; Swanson, 1969). Paterson and Harakal (1974) describe blueschists near Pinchi Lake in British Columbia; this area is also drained by the Columbia River. W. Porter Irwin (pers. comm., 1981) has noted the existence of blueschist bodies in the Blue Mountains of eastern Oregon and the Cache Creek area of British Columbia, both of which are drained by the Columbia River.

Examination of one sample taken from the John Day River did not show any glaucophane. Because the blueschist bodies documented within the Columbia River drainage are relatively small, any amount of glaucophane they might contribute would necessarily be limited. Only an extensive, systematic examination of many samples taken from rivers draining these blueschists would show if any glaucophane is in fact being supplied to the Columbia River.

Olivine. Only one mineral listed by several workers as present in Columbia River sands was not identified by this author. Twenhofel (1946), while listing olivine as present, did not differentiate between olivine and epidote, and actually seems to have assumed the presence of olivine because of known olivine-bearing rocks in the Columbia River drainage. White (1968, Table 6), while identifying olivine in amounts up to 10 percent in his continental shelf sands, curiously did not include olivine in his table of mineral descriptions. Whetten et al. (1969, p. 1161) identifies olivine in Bonneville Reservoir samples only. The only documented cases of olivine in beach sands are in areas where olivine-bearing basalt crop out directly adjacent to the beaches (Walker, 1932; Moberly et al., 1965). This is because of olivine's marked instability in sediments.

## CONCLUSIONS

For most of the heavy mineral groups identified in beach and dune sands north and south of the mouth of the Columbia River, there are no significant variations. Epidote is significantly lower in beach sands than in dune sands. Hornblende is significantly higher in beach sands; this may be because the more elongate grains are not as readily transported by the wind. On Long Beach Peninsula south of Klipsan Beach, a significantly higher percentage of opaque minerals are present than are present north of this area. This is probably a reflection of sorting effects, with the heavier heavy minerals tending to be more concentrated in the southern part of the peninsula. No similar distribution of opaque minerals in seen in Oregon on Clatsop Beach.

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| MINERAL | BEACH SANDS | | | | DUNE SANDS | | | |
|---|---|---|---|---|---|---|---|---|
| | Washington | | Oregon | | Washington | | Oregon | |
| | x | s | x | s | x | s | x | s |
| Orthopyroxene | 31.2 | 6.2 | 31.3 | 4.0 | 31.4 | 3.7 | 39.3 | 8.0 |
| Clinopyroxene | 18.5 | 4.1 | 19.6 | 3.2 | 22.0 | 1.7 | 21.0 | 2.7 |
| Hornblende | 37.8 | 10.0 | 32.9 | 6.5 | 29.3 | 4.2 | 20.2 | 11.0 |
| Epidote | 9.2 | 3.6 | 13.6 | 2.8 | 14.9 | 3.5 | 12.4 | 0.5 |
| Garnet | 1.2 | 1.2 | 1.3 | 0.7 | 0.8 | 0.6 | 5.2 | 3.8 |
| Sphene | 0.3 | 0.4 | 0.2 | 0.1 | 0.2 | 0.3 | 0.7 | 0.06 |
| Zircon | 0.12 | 0.2 | 0.1 | 0.13 | 0.09 | 0.11 | 0.4 | 0.6 |
| Apatite | 0.5 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.6 | 0.2 |

Table 1. Comparison of means and standard deviations of major mineral groups in the beach and dune sands in the studied area.

| SAMPLE No. | Opaque Minerals | Aggregates | Nonopaque Minerals | Orthopyroxene | Clinopyroxene | Hornblende | Tremolite/Actinolite | Epidote | Garnet | Sphene | Zircon | Kyanite | Staurolite | Apatite | Unknown | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 74WGL-52 | 10.2 | 15.8 | 74.0 | 36.9 | 16.4 | 40.0 | 0.4 | 2.7 | * | 0.4 | 0.4 | * | 0 | 0.3 | 1.8 | 0.4 tourmaline |
| 77WGL-56 | 6.0 | 7.7 | 86.3 | 30.9 | 18.1 | 35.2 | 0.4 | 12.0 | 1.2 | * | * | 0.8 | * | 0.4 | 0.4 | 0.4 tourmaline, 0.4 aegerine-augite |
| 77WGL-57 | 10.3 | 8.0 | 81.7 | 26.9 | 14.3 | 42.4 | 0 | 15.9 | 0.4 | * | 0 | * | 0 | * | 0 | *tourmaline, *glaucophane, *aegerine-augite |
| 74WGL-53 | 6.3 | 8.7 | 85.0 | 27.1 | 18.0 | 50.2 | 0 | 2.0 | 0.4 | * | 0.4 | 0.4 | 0 | 0.8 | 0.8 | |
| 77WGL-58 | 4.3 | 7.7 | 88.0 | 23.1 | 13.6 | 46.2 | 0 | 13.6 | 1.5 | 0 | 0 | 0.8 | 0 | 0.8 | 0 | 0.4 aegerine-augite |
| 77WGL-59 | 7.0 | 6.7 | 86.3 | 25.5 | 19.3 | 44.0 | 0 | 9.7 | 1.2 | 0 | 0 | * | 0 | 0.4 | 0 | |
| 74WGL-54 | 6.5 | 14.0 | 79.5 | 28.3 | 20.1 | 35.9 | 1.3 | 10.7 | * | 0 | 0 | 1.3 | 0 | * | 1.9 | 0.6 tourmaline |
| 77WGL-60 | 7.0 | 10.3 | 82.7 | 28.2 | 19.4 | 43.6 | * | 7.7 | 0 | * | 0 | 0.4 | 0 | 0.4 | 0 | 0.4 glaucophane |
| 77WGL-61 | 6.0 | 9.0 | 85.0 | 25.1 | 18.8 | 48.6 | 0.4 | 5.9 | 0.8 | * | 0 | * | 0 | 0.4 | 0 | |
| 74WGL-55 | 7.0 | 15.3 | 77.7 | 39.1 | 18.9 | 29.7 | 0 | 8.2 | 2.1 | * | * | * | * | 0.4 | 1.3 | 0.4 glaucophane |
| 77WGL-62 | 8.3 | 8.0 | 83.7 | 25.0 | 18.3 | 40.5 | 0 | 14.3 | 0.8 | 0 | 0 | 0.8 | 0.4 | * | 0 | *topaz |

Table 2. Samples collected from Long Beach Peninsula, north of Klipsan Beach, Washington (see Fig. 1). Samples are listed in order of position, north to south.

| SAMPLE No. | Opaque Minerals | Aggregates | Nonopaque Minerals | Orthopyroxene | Clinopyroxene | Hornblende | Tremolite/Actinolite | Epidote | Garnet | Sphene | Zircon | Kyanite | Staurolite | Apatite | Unknown | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 77WGL-63 | 10.7 | 6.8 | 82.5 | 26.2 | 11.5 | 52.7 | 0 | 9.0 | 0 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0.4 chloritoid |
| 77WGL-64 | 10.0 | 10.7 | 79.3 | 26.9 | 19.7 | 41.2 | 0 | 8.8 | 0.4 | 0.4 | 0 | 0.8 | 0 | * | 0.4 | 0.8 aegerine-augite, 0.4 topaz |
| 74WGL-56 | 19.7 | 8.3 | 71.8 | 45.8 | 22.2 | 20.4 | 0 | 5.1 | 3.2 | 0.9 | * | * | * | 0.9 | 0.5 | 0.5 tourmaline, 0.5 sillimanite |
| 77WGL-65 | 10.7 | 9.3 | 80.0 | 32.5 | 17.1 | 35.9 | 0.4 | 12.5 | 0.4 | 0.8 | 0 | 0 | 0 | 0.4 | 0 | *rutile |
| 77WGL-66 | 26.2 | 5.0 | 68.8 | 36.7 | 21.1 | 25.9 | 0 | 10.9 | 2.2 | * | 0.4 | 1.1 | 0 | 0.7 | 0 | 0.7 rutile, 0.4 chloritoid |
| 77WGL-67 | 20.7 | 10.2 | 69.1 | 33.0 | 13.0 | 38.4 | 0 | 12.0 | 1.8 | 0.4 | 0.4 | 0 | 0 | 1.1 | 0 | *aegerine-augite, *rutile |
| 74WGL-57 | 20.4 | 11.8 | 67.8 | 42.7 | 27.7 | 15.0 | 0 | 6.1 | 3.8 | 0.9 | 0.5 | 0.9 | 0 | 0.9 | 0.9 | 0.5 aegerine-augite, *rutile |
| 74WGL-58 | 34.4 | 9.3 | 56.3 | 35.1 | 28.0 | 22.7 | 0 | 7.6 | 3.3 | 1.4 | * | * | 0.5 | 0.5 | 0.5 | 0.5 rutile, *aegerine-augite |
| 77WGL-69 | 10.7 | 12.3 | 77.0 | 30.3 | 17.7 | 42.0 | 0 | 8.2 | 0.9 | 0.4 | 0 | 0 | 0 | 0.4 | 0 | |
| 77WGL-68 | 11.3 | 7.3 | 81.4 | 29.9 | 15.2 | 44.3 | 0 | 10.2 | * | * | 0 | 0.4 | 0 | * | 0 | *chloritoid, *topaz |

Table 3. Samples collected from Long Beach Peninsula, south of Klipsan Beach, Washington (see Fig. 1). Samples are listed in order of position, north to south.

| SAMPLE No. | Opaque Minerals | Aggregates | Nonopaque Minerals | Orthopyroxene | Clinopyroxene | Hornblende | Tremolite/Actinoli | Epidote | Garnet | Sphene | Zircon | Kyanite | Staurolite | Apatite | Unknown | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 770GL-1 | 5.8 | 11.3 | 82.9 | 29.5 | 18.1 | 35.7 | 0 | 13.3 | 0.7 | * | * | 0.4 | 0 | * | 0.7 | 0.4 aegerine-augite, 0.4 rutile 0.4 tourmaline, 0.4 chloritoid |
| 770GL-2 | 18.4 | 3.8 | 77.8 | 36.7 | 24.1 | 24.9 | 0 | 11.4 | 1.2 | 0.4 | * | * | 0 | 0.4 | 0 | 0.8 aegerine-augite |
| 770GL-3 | 15.6 | 7.8 | 76.6 | 33.5 | 18.4 | 29.0 | 0 | 16.3 | 1.6 | * | 0.4 | 0.4 | 0 | * | 0 | 0.4 aegerine-augite |
| 770GL-4 | 14.0 | 5.1 | 80.9 | 33.3 | 20.0 | 29.4 | 0 | 14.9 | 2.0 | * | * | * | 0 | 0.4 | 0 | *aegerine-augite |
| 770GL-5 | 8.0 | 14.0 | 78.0 | 28.6 | 14.1 | 36.4 | 0 | 18.4 | 1.7 | * | 0 | * | 0 | 0.9 | 0 | |
| 770GL-6 | 13.3 | 6.0 | 80.7 | 30.6 | 23.6 | 29.4 | 0 | 13.6 | 2.1 | * | * | * | 0 | 0.4 | 0 | 0.4 aegerine-augite |
| 770GL-7 | 11.5 | 11.1 | 77.4 | 23.9 | 18.9 | 46.1 | 0.4 | 9.9 | 0.4 | 0 | 0 | 0 | 0 | 0.4 | 0 | |
| 770GL-8 | 9.4 | 8.1 | 82.5 | 34.5 | 19.7 | 32.2 | 0 | 11.4 | 0.4 | 0.4 | 0 | 0.8 | 0 | 0 | 0 | 0.4 aegerine-augite, 0.4 topaz, *rutile |

Table 4. Samples collected on Clatsop Beach, Oregon (see Fig. 1).

| SAMPLE No. | Opaque Minerals | Aggregates | Nonopaque Minerals | Orthopyroxene | Clinopyroxene | Hornblende | Tremolite/Actinoli | Epidote | Garnet | Sphene | Zircon | Kyanite | Staurolite | Apatite | Unknown | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 77WGL-56a | 7.6 | 11.3 | 81.1 | 24.6 | 22.1 | 36.0 | 0.8 | 13.9 | 0.8 | 0 | 0 | * | 0.8 | 0.4 | 0.4 | |
| 77WGL-58b | 11.4 | 8.8 | 79.8 | 30.3 | 19.3 | 30.3 | 0.4 | 18.0 | 1.6 | 0 | * | 0 | 0 | 0 | 0 | |
| 77WGL-58a | 8.3 | 9.7 | 82.0 | 33.7 | 24.4 | 25.2 | 0 | 16.7 | * | * | 0 | * | * | * | 0 | |
| 77WGL-59a | 8.1 | 10.3 | 81.6 | 29.9 | 20.7 | 30.2 | 0 | 16.9 | 0.4 | 0.8 | * | 0.4 | 0 | 0.4 | 0.4 | |
| 77WGL-60a | 16.7 | 11.0 | 72.3 | 31.1 | 21.1 | 29.4 | 0 | 16.6 | 0.3 | 0.3 | 0.3 | * | 0 | * | 0 | 0.7 aegerine-augite, *topaz |
| 77WGL-61a | 17.2 | 7.9 | 74.9 | 35.8 | 23.0 | 23.0 | 0 | 15.0 | 0.9 | 0 | * | * | 0 | 0.9 | 0 | 0.4 aegerine-augite, 0.4 tourmaline, 0.4 rutile |
| 77WGL-62a | 17.2 | 8.9 | 73.9 | 34.2 | 23.3 | 30.8 | 0.4 | 7.5 | 1.7 | 0.4 | 0 | * | 0.4 | 0 | 0 | 1.2 aegerine-augite |
| 77OGL-1a | 59.9 | 3.3 | 36.8 | 42.2 | 19.4 | 16.6 | 0 | 12.8 | 7.4 | * | * | 0 | 0 | 0.8 | 0.8 | *aegerine-augite, *rutile |
| 77OGL-2a | 66.3 | 2.1 | 31.6 | 45.5 | 19.4 | 11.5 | 0 | 12.6 | 7.3 | * | 1.0 | 0 | * | 0.5 | 0.5 | 1.0 aegerine-augite, 0.5 tourmaline, *rutile |
| 77OGL-8a | 8.3 | 10.0 | 81.7 | 30.2 | 24.1 | 32.6 | 0 | 11.8 | 0.8 | 0 | 0 | * | 0 | 0.4 | 0 | |

Table 5. Dune samples collected on Long Beach Peninsula, Washington (77WGL series), and Clatsop Beach, Oregon (77OGL series). (See Fig. 1).

Table 6. Specific gravities of heavy minerals identified in beach and dune sands in the vicinity of the Columbia River.

| Mineral | Specific Gravity |
|---|---|
| Hypersthene | 3.4 - 3.5 |
| Augite | 3.2 - 3.4 |
| Hornblende | 3.0 - 3.4 |
| Tremolite/Actinolite | 3.0 - 3.3 |
| Sillimanite | 3.23 |
| Aegerine-augite | 3.4 - 3.5 |
| Epidote | 3.35 - 3.45 |
| Apatite | 3.15 - 3.2 |
| Glaucophane | 3.1 - 3.3 |
| Tourmaline | 3.0 - 3.25 |
| Topaz | 3.4 - 3.6 |
| Kyanite | 3.55 - 3.66 |
| Staurolite | 3.65 - 3.75 |
| Sphene | 3.4 - 3.55 |
| Chloritoid | 3.5 - 3.8 |
| Garnet | 3.5 - 4.3 |
| Rutile | 4.18 - 4.25 |
| Zircon | 4.68 |
| Opaque minerals | |
| Chrome spinel | 4.1 |
| Chromite | 4.6 |
| Ilmenite | 4.7 |
| Magnetite | 5.18 |

(Compiled from Hurlbut & Klein, 1977).