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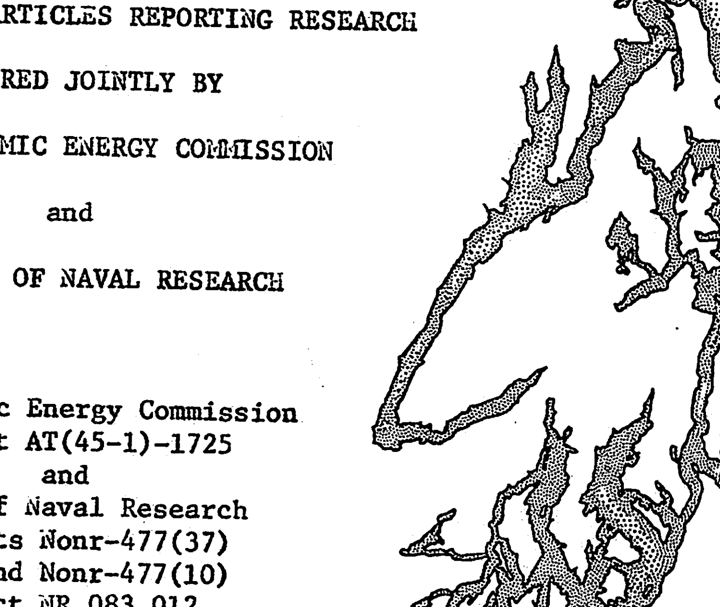

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Technical Report No. 214

*SERGESTES SIMILIS* HANSEN AND *S. CONSOBRINUS* N. SP. (DECAPODA) FROM THE NORTHEASTERN PACIFIC, by Darrelyn S. Milne. Crustaceana *14*(1):21-34. 1968.

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SONAR REFLECTION PROFILING ON THE COLUMBIA RIVER AND IN LAKE WASHINGTON, by C. R. B. Lister, John T. Whetten, and Bates McKee. Northwest Science *41*(4):152-154. 1967.

Technical Report No. 216

DISTRIBUTION AND MOVEMENT OF RADIOACTIVE CONTINENTAL SHELF SEDIMENT, NORTHWESTERN UNITED STATES, by M. Grant Gross. Collected Preprints of the International Sedimentological Congress. 4 p. 1967.

Technical Report No. 217

CONTINENTAL SHELF SEDIMENT, NORTHWESTERN UNITED STATES, by M. G. Gross, D. A. McManus, and H-Y Ling. Journal of Sedimentary Petrology *37*(3): 790-795. 1967.

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MAZAMA ASH FROM THE CONTINENTAL SLOPE OFF WASHINGTON, by Chester F. Royce, Jr. Northwest Science *41*(3):103-109. 1967.

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A DEVICE FOR RELEASING A PISTON CORER AND DEACTIVATING THE PISTON, by James L. Woodruff. Deep-Sea Research *14*:809-810. 1967.

Technical Report No. 220

SINKING RATES OF RADIOACTIVE FALLOUT PARTICLES IN THE NORTH EAST PACIFIC OCEAN, 1961-62, by M. Grant Gross. Nature *216*(5116):670-672. 1967.

# CONTINENTAL SHELF SEDIMENT, NORTHWESTERN UNITED STATES

BY

M. G. GROSS, D. A. McMANUS, AND H-Y LING

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 37, NO. 3, PP. 790–795
FIGS. 1–6, SEPTEMBER, 1967

# CONTINENTAL SHELF SEDIMENT, NORTHWESTERN UNITED STATES[1,2]

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Department of Oceanography, University of Washington, Seattle, Washington

## ABSTRACT

The Columbia River is the dominant sediment source for the continental shelf near the northwestern United States. The Washington continental shelf is nearly covered by modern sediment derived from the Columbia River. This sediment moves generally northward away from the river mouth. Sand generally occurs at depths less than 90 m. Coarse silt occurs in deeper water. The modern sediments generally contain less than 1.5 percent $CaCO_3$ and less than 1 percent organic carbon.

Relict sediment covers the continental shelf off southern Vancouver Island and occurs along the seaward margin of the continental shelf off southern Washington and northern Oregon. These relict sediments exhibit complicated patterns of grain-size distributions and, in general, contain more organic carbon and calcium carbonate than the modern sediment.

## INTRODUCTION

Knowledge of the continental shelf sediment of the northwestern United States (fig. 1) is derived from reconnaissance studies made in the 1930's (Trask, 1932; Shepard, 1939) and regional studies of the Northeast Pacific Ocean sediment (Nayudu and Enbysk, 1964; Gross, 1965; McManus, 1965; Gross, in press). The more recent investigations have included some continental shelf sediments, but have not treated them in detail. Investigations of sediment associated radioactivity on the continental shelf near the Columbia River (Osterberg, Kulm, and Byrne, 1963; Gross, 1966; Gross and Nelson, 1966) have not included other sediment properties and have considered only parts of the continental shelf. This paper describes the grain-size distribution and the organic carbon and calcium carbonate contents of 125 samples collected from $1.7 \times 10^4$ km$^2$ on the continental shelf.

## SAMPLING AND ANALYTICAL PROCEDURES

Sediment samples were collected from RV Brown Bear between August 1961 and August 1965 using grab samplers (Van Veen, 1936; Shipek, 1965). Both sampling devices penetrate approximately 20 cm below the water-sediment interface. The samples were homogenized aboard ship and returned to the laboratory where they were subsampled for analysis. Sampling stations were located using loran and shipboard radar.

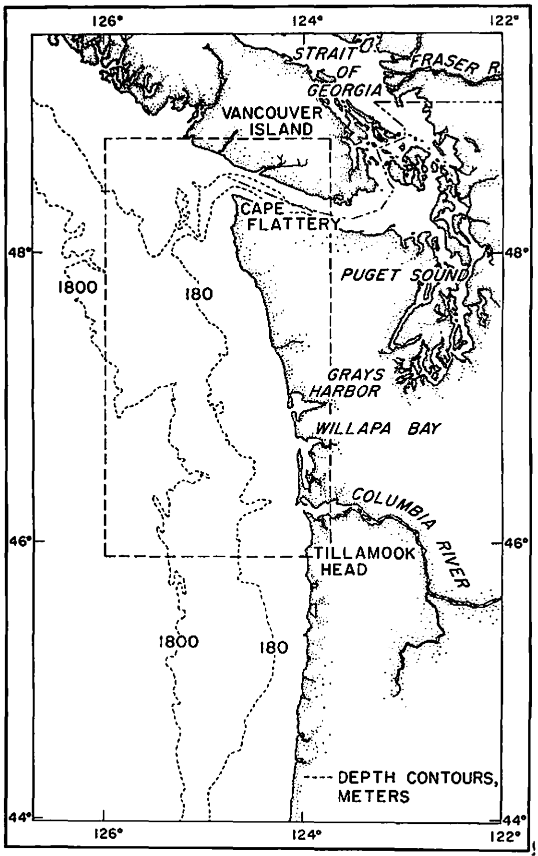


FIG. 1.—Continental shelf of the northwestern United States and Vancouver Island, showing the area included in this study.

Grain size analyses were made using sieve and pipette techniques (Krumbein and Pettijohn, 1938). The sediments (fig. 2) were classi-

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[2] Contribution No. 410 from the Department of Oceanography, University of Washington.

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fied according to the mean grain size (Inman, 1952). Our data for sediment on the continental shelf off Vancouver Island are supplemented by analyses from the Institute of Oceanography, University of British Columbia (1963). For these locations, shown in figure 2, median grain size is reported.

Total carbon concentrations were determined by combusting the sample with a radiofrequency induction furnace and collecting the gases in a burette. Equipment and procedures used were similar to those used by Curl (1962). The yield for sugars and the various amino acids was greater than 95 percent.

Organic carbon content (fig. 3) of the sediment was estimated by determining the total carbon concentration and subtracting from it the carbonate carbon, recovered as carbon

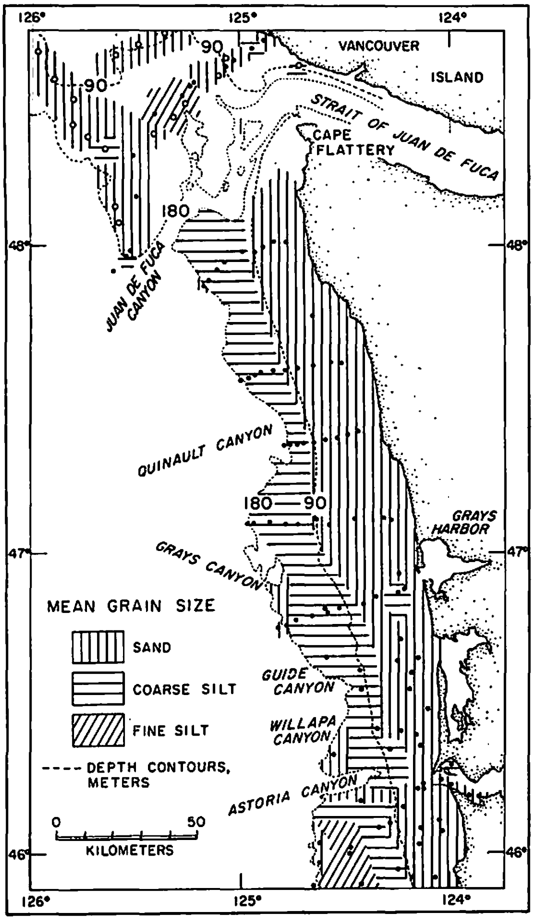


FIG. 2.—Distribution of sediment types on the continental shelf.
Sand—mean grain size >62 μ (4 φ)
Coarse silt—mean grain size 62–16 μ (4–6 φ)
Fine silt—mean grain size 16–4 μ (6–8 φ)
.Our data ₒData from Inst. of Oceanography, Univ. of British Columbia (1963)

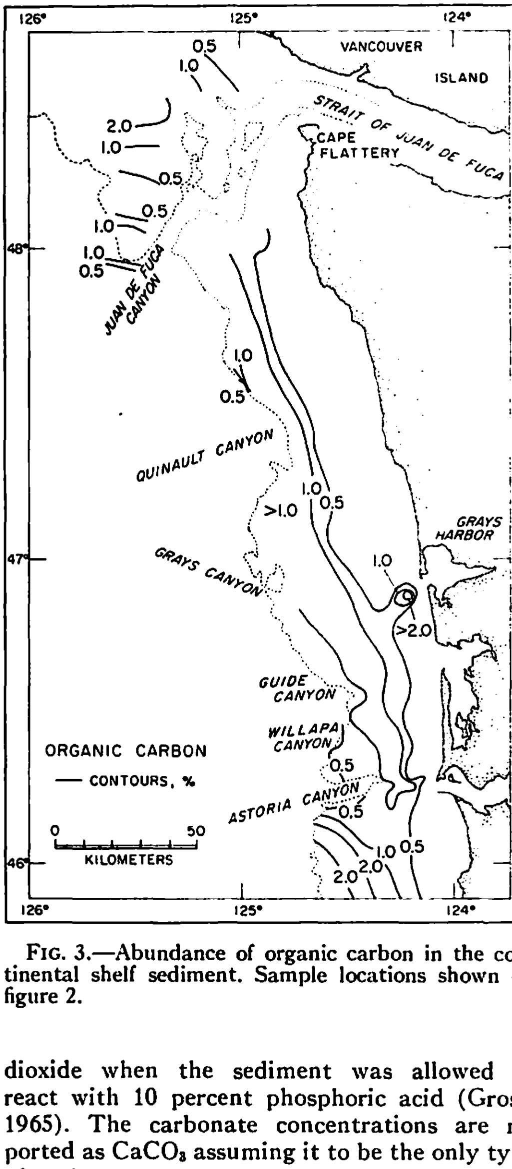


FIG. 3.—Abundance of organic carbon in the continental shelf sediment. Sample locations shown on figure 2.

dioxide when the sediment was allowed to react with 10 percent phosphoric acid (Gross, 1965). The carbonate concentrations are reported as $CaCO_3$ assuming it to be the only type of carbonate present.

The coefficients of variations and the detection limits for the analytical techniques are:

| | Coefficient of variation (%) | Detection limit (%) |
|---|---|---|
| Total carbon | 5 | 0.05 |
| Organic carbon | 10 | 0.05 |
| Calcium carbonate | 5 | 0.4 |

### SEDIMENT DISTRIBUTION

The continental shelf in this region can be divided into three relatively distinct areas: the Vancouver Island continental shelf, the northern Oregon continental shelf, and the Washington continental shelf. Each region has its own characteristic pattern of sediment distribution (fig. 2).

Off Vancouver Island the continental shelf is covered with sand-size sediment with irregularly distributed patches of silt. Obviously, the sample spacing and density (1 sample per 150 km$^2$) are not adequate to completely delineate the complicated pattern of sediment distribution.

The sample spacing and density (1 sample per 80 km$^2$) are also not adequate to delineate the sediment distribution patterns on the northern Oregon continental shelf. Sand occurs in water depths of less than 90 m, and coarse silt is present in a band roughly parallel to the coast in water depths between 90 and 150 m. Seaward of the nearshore sand and coarse silts is a band of fine silt not encountered elsewhere on the continental shelf. This material (mean grain size 7–10 $\mu$, 6.65–7.15 $\phi$) is deposited in an area where the topography is substantially more rugged than on the Washington continental shelf (Byrne, 1963). Sands occur also at the outer edge of the Oregon continental shelf and are especially noticeable south of Astoria Canyon.

On the Washington continental shelf the sediment is distributed in bands nearly parallel to the coast. Fine sand (mean grain size 90–180 $\mu$, 2.50–3.65 $\phi$) occurs near the present coastline, in water depths less than 90 m. Coarse silts occur on the outer part of the shelf, in water depths greater than 90 m (mean grain size 20–45 $\mu$, 4.5–5.6 $\phi$). Near Grays Harbor and the Columbia River estuary the coarse silt extends into shallower waters. Some areas along the outer edges of the Washington continental shelf are covered by sand. These are especially well developed north of Astoria Canyon and between Guide and Grays Canyons (fig. 2).

An interesting feature of the sediment distribution on the Washington shelf is the close correlation between the 90 m isobath and the limits of the nearshore sand. Except near the edge of the continental shelf, the sands are restricted to water depths of less than 90 m. This correlates closely with the mean depth of the regional halocline, 85 ± 15 m (Tully and Barber, 1960), which represents the lower limit of the downward transfer of freshwater. The depth of the halocline is controlled by the depth of mixing in the surface layers, presumably caused by wind and wave activity. Perhaps some features of the near surface distribution of water properties correspond to the distribution of such sediment properties as grain size on the shallower parts of the continental shelf.

## DISTRIBUTION OF ORGANIC CARBON AND CARBONATE

The abundance of organic carbon in the sediment (fig. 3) is controlled primarily by the grain size distribution, as shown in figure 4. The highest organic carbon concentrations occur in the fine silt; the lowest concentrations generally occur in the nearshore sands. Sediments especially rich in organic matter occur at the mouth of Grays Harbor and, to a lesser degree, at the Columbia River mouth. These sediments are deposited in areas of upwelling of nutrient-rich deeper water and locally intense photosynthetic activity (Anderson, 1964). The distribution of organic carbon in shelf sediments near Vancouver Island and northern Oregon is distinctly different from the distribution near the Washington coast.

From Grays Canyon to Astoria Canyon the sediment on the edge of the shelf is somewhat coarser (fig. 2) and contains substantially less organic carbon (fig. 3) than the sediments nearer the coast. This is clearly not the situation north of Grays Canyon, where sediments containing the maximum organic carbon concentrations occur at the edge of the continental shelf.

Most continental shelf sediment in this area contains less than 1.5 percent calcium carbonate (fig. 5). Near the Columbia River most sediment samples contain less than 0.4 percent calcium carbonate, the detection limits of the analytical technique used. Along the Oregon-Washington coast, the largest carbonate concentrations occur at the outer edge of the continental shelf. Carbonate is more abundant but more irregularly distributed in sediment on the Vancouver Island shelf.

## SOURCES AND MOVEMENT OF SEDIMENT

Erosion of the rugged coast along the northwestern United States in an obvious source of sediment. We have little data on coastal erosion in this area, but Byrne (1963) showed that up to

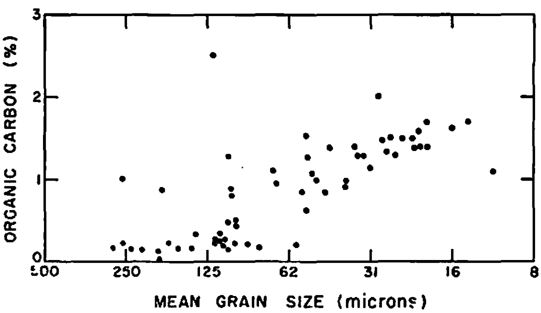


FIG. 4.—Variation of organic carbon concentrations as a function of mean grain size in continental shelf sediment near the Washington coast.

TABLE 1.—*River discharge of water and sediment along Washington—Oregon Coast*

| | Water discharge[1] ($10^6$ m$^3$/year) | Estimated Sediment discharge[2] ($10^3$ tons/year) |
|---|---|---|
| Northern Washington Coast, Cape Flattery to Grays Harbor | 50 | 0.75 |
| Grays Harbor | 31 | 0.46 |
| Willapa Bay | 12 | 0.18 |
| Columbia River | 625 | 7000–14,000[3] |
| Northern and Central Oregon Coast, Columbia River to Umpqua River (43°40′N) | 50 | 0.75 |

[1] Budinger and others (1964).
[2] Calculated, except for the Columbia River, by assuming a suspended sediment load of 15 parts per million (Van Winkle 1914a, b) and ignoring bed load transport.
[3] Van Winkle, (1914a, b); Hidaka (1966, p. 331).

75 percent of the northern Oregon coast undergoes erosion during certain seasons. Hence coastal erosion may be an important local source of sediment, especially north of Grays Harbor; its importance as a sediment source cannot be evaluated yet. Along the Washington coast southward from Grays Harbor and in the vicinity of the Columbia River mouth, the sandy spits and beaches apparently preclude coastal erosion.

Riverborne particulate matter is undoubtedly the major source of sediment deposited on the continental shelf in this region. The amount of sediment contributed by rivers to each part of the continental shelf varies greatly (table 1).

On the Vancouver Island shelf, most of the small rivers discharge directly into the heads of long narrow inlets, which generally have sills at their entrances (Pickard, 1963). These inlets probably act as settling basins for the riverborne suspended sediment and the sills at the mouth prevent bottom-transported sediment from moving out of the inlet. Thus, except for localized coastal erosion, there appear to be no major local sources contributing sediment to the Vancouver Island shelf.

Most of the discharge from the rivers emptying into Puget Sound and the Strait of Georgia enters the North Pacific Ocean through the Strait of Juan de Fuca (fig. 2). It seems unlikely that much sediment from these rivers is deposited on the continental shelf. Most of the suspended matter probably settles out of the water before reaching the ocean (Wang, 1955). Bottom-transported sediment would move along the trough crossing the shelf and down Juan de Fuca Canyon onto the deepsea floor, bypassing the continental shelf.

The river discharge (table 1) along the Washington coast (a distance of approximately 250 km) is somewhat greater than the river discharge along the Oregon coast between the Columbia River and the Umpqua River at 43° 40′N (a distance of approximately 290 km). Assuming a direct correlation between the water and sediment discharge, the sediment discharge along the Washington coast is probably somewhat larger than that along the Oregon coast. However, when we compare the discharge of the Columbia River with that of the coastal rivers, it becomes obvious that it is the dominant sediment source for the continental shelf of the Northwestern United States. If only a small fraction of its estimated sediment load (Van Winkle, 1914a, b; Hidaka, 1966, p. 331) passes through the estuary (Lockett, 1962) to be deposited on the continental shelf, this is many times larger than the sediment contributions of the smaller coastal rivers.

The grain size distribution, shown in figure 2, is consistent with a net northward movement along the Washington continental shelf of modern sediment derived from the Columbia River. Such sediment movements have been postulated from studies of sediment-associated radioactivity from the Columbia River (Gross, 1966; Gross and Nelson, 1966). The dominance of the Columbia River as a sediment source explains the relative simplicity of the grain size distribution of sediments on the Washington continental shelf. Contributions of local sediment sources are masked, except possibly at the mouth of Grays Harbor (figs. 3, 5).

### MODERN AND RELICT SEDIMENT

For the sediment on the continental shelves off northern Oregon and southern Vancouver Island, it is obvious that the movement of sediment derived from local sources cannot easily explain the observed complicated and discontinuous distributions of sediment properties. It seems highly probable that these areas of anomalous sediment properties are blanketed by relict sediment (Emery, 1952) deposited under conditions no longer prevailing in the area.

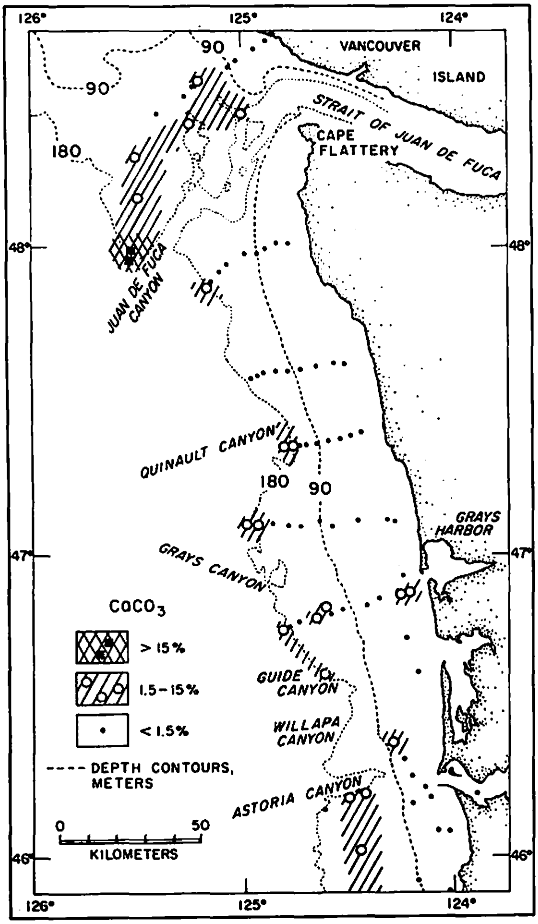


FIG. 5.—Abundance of calcium carbonate in the continental shelf sediment.

To differentiate the modern and relict sediments, we employed the criteria listed in table 2. A general discussion of the relationship between modern and relict sediments is given by Curray (1965). Our estimate of the distribution of modern and relict sediment in the region is plotted in figure 6.

The absence of modern sediment on the Vancouver Island shelf is not surprising. There are no major local sediment sources. The trough crossing the shelf prevents the movement of bottom-transported Columbia River sediment onto the Vancouver Island shelf.

Apparently the northward movement of Columbia River sediment has inhibited sediment deposition on the outer continental shelf off northern Oregon. It is conceivable that the bottom is actually covered by modern sediment, not derived from the Columbia River which would account for its anomalous properties. The sediment on the outer shelf between Astoria and Grays Canyons was considered to be relict because of the anomalous distribution of grain size (fig. 2) and the abundance of calcium carbonate (fig. 5).

TABLE 2.—*Criteria used to distinguish modern and relict sediment*

Modern sediment
- Continuous distribution of sediment properties, such as grain size or diagnostic radionuclides
- Obvious relationships to known sources of sediment
- Distribution trends or gradients related to known sediment sources or ocean features such as present current systems

Probable relict sediments
- Discontinuous distribution of sediment properties
- No obvious relationship to known sediment sources
- Anomalous chemical or physical properties, not obviously related to present sedimentary or ocean conditions

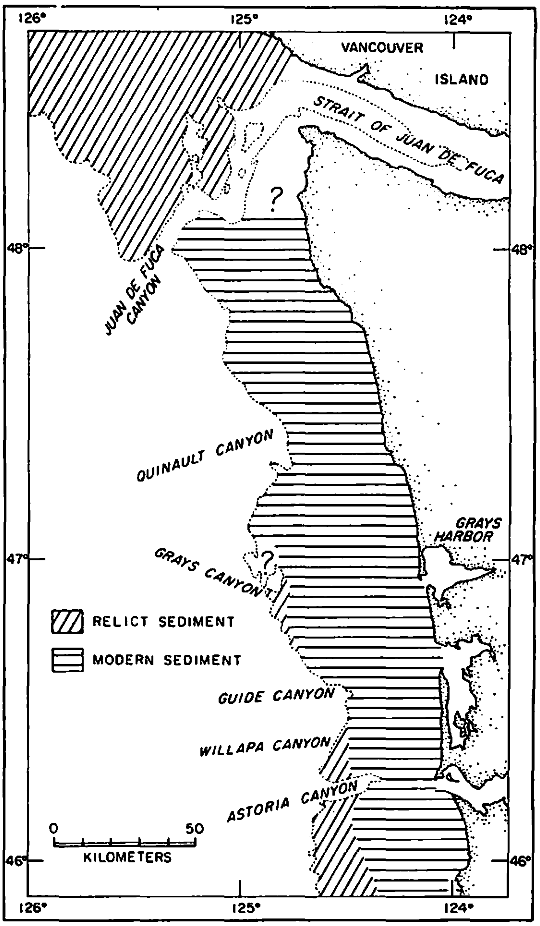


FIG. 6.—Generalized distribution of modern and relict sediment.

ACKNOWLEDGEMENT

We thank Larry G. Hanson and Sally M. Wienke for their analytical work. C. A. Barnes provided many stimulating discussions and commented on the manuscript.

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