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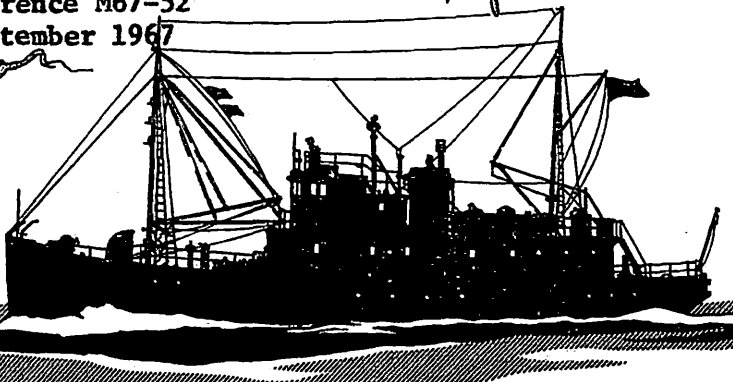

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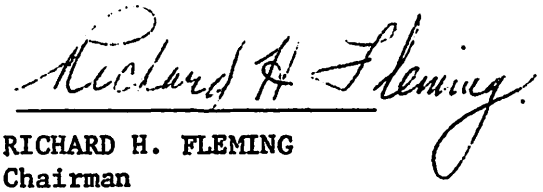

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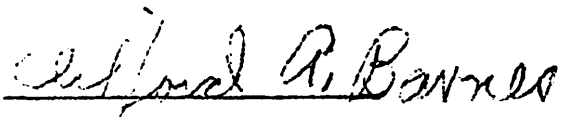

CLIFFORD A. BARNES
Principal Investigator

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Organic Carbon in Surface Sediment from the Northeast Pacific Ocean[1]

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ABSTRACT *The lowest concentrations of organic carbon occur in nearshore sand on the Continental Shelf and brown mud on Tufts Plain and the seamount province; highest concentrations occur in sediment on the continental slope at depths between 1000 and 2500 m. Destruction of organic matter is apparently the dominant process, and it is controlled largely by the dissolved oxygen concentration in the bottom water. Maximum concentrations of organic carbon occur near the depth of the oxygen minimum. Variations of primary productivity and differences in sediment grain size are of secondary importance.*

INTRODUCTION There has been little or no work on the organic matter of surface sediment in the Northeast Pacific, except for some analyses by Trask (1932, p. 128-133). This study of the distribution of organic carbon, based on the analyses of 102 surface sediment samples, must be regarded as preliminary because of the large area involved (approximately 7 x 10^5 km^2), and the small number of samples from each major physiographic province (Fig. 1). Despite the shortcomings inherent in such a study, it was undertaken to learn about the distribution of carbon, and the factors controlling the chemical composition of these sediments.

The lithology and skeletal remains in the surface sediment of the region were described by Nayudu and Enbysk (1964) and the carbonate content was discussed by Gross (1965). The circulation of the overlying waters was presented by Barnes and Paquette (1957); Budinger, Coachman, and Barnes (1964); and Barnes and Gross (1966). Anderson (1964) studied primary productivity in these waters.

ANALYTICAL TECHNIQUES Except for 14 cores from Willapa Canyon (Royse, 1964), the sediments (Table 1) were collected with grab samplers (Van Veen, 1936; Shipek,

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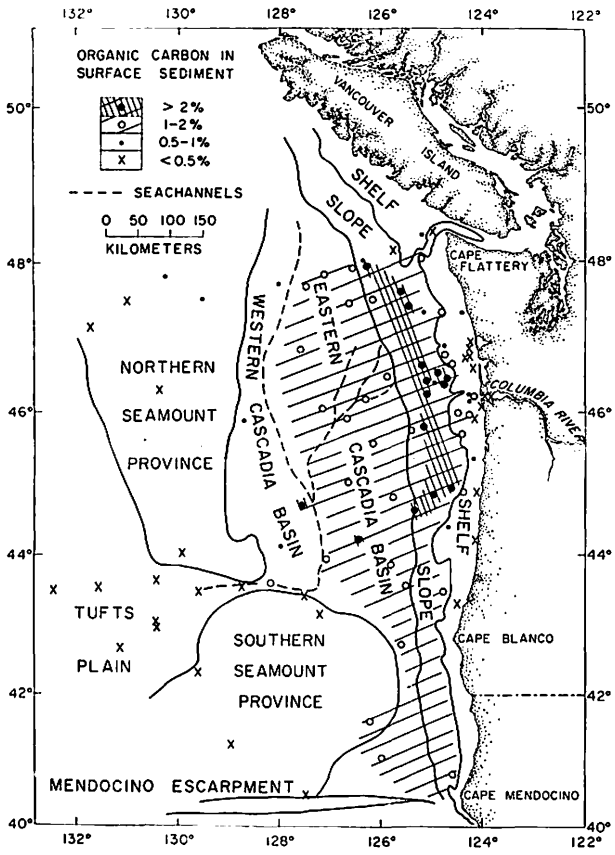
Int. J. Oceanol. & Limnol. Vol. 1, No. 1. p. 46-54.

TABLE I. RV *Brown Bear* cruises providing samples analyzed

Cruise no.	*Date*	*Area sampled*
BB-291	28 July-31 Aug 1961	Continental shelf and slope, Cascadia Basin
BB-308	7-19 June 1962	Continental Shelf
BB-311	24 July-14 Aug 1962	Cascadia Basin, Tufts Plain, seamount province
BB-312	13 Sept-18 Oct 1962	Continental shelf and slope, Cascadia Basin
BB-326*	13-23 June 1963	Continental Shelf and slope, Willapa Canyon

* Data from Royse (1964)

FIGURE 1. Organic carbon content of surface sediment near the Washington-Oregon coast.



1965) which penetrated approximately 20 cm or less below the water-sediment interface. The grab samples were homogenized and representative portions were taken for analysis.

The organic-carbon content was estimated by determining the total carbon content of the dry sediment and subtracting from it the carbonate-carbon, recovered as carbon dioxide, when the sample was allowed to react with 10% phosphoric acid (Gross, 1965). Total-carbon content was determined by combusting a sample heated by a radio-frequency furnace in dry purified oxygen. The carbon dioxide released by combustion of carbon compounds and decomposition of carbonate was collected and measured gasometrically. The gases were reacted with a catalyst to oxidize carbon monoxide to carbon dioxide, and with manganese dioxide to remove sulfur and nitrogen oxides. The yield for pure organic compounds (sugars, various amino acids) is approximately 95%. No correction of the data was made because of the approximate nature of the results reported here.

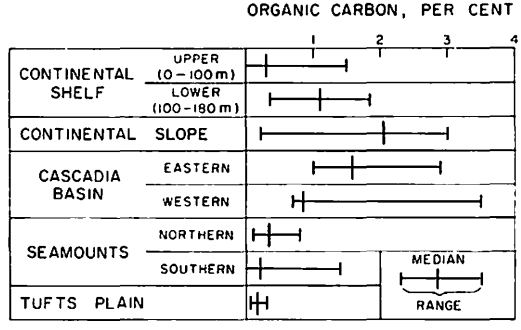
The coefficient of variation for the total carbon content of pure organic compounds is 5%, or less, of the amount reported. The amount of variation depends to a slight degree on the organic compound involved. The analyses of the carbonate content of the sediment was discussed previously (Gross, 1965). These results are reproducible to within 2% of the value reported. Considering the analytical errors, the heterogeneity of the sample, and the varying amounts of sample used in different analyses, I estimate the coefficient of variation to be 10% of the amount of organic carbon reported.

DISCUSSION

Distribution of Organic Carbon in the Sediment

Despite the sparsity of analyzed samples from this large area, distinct regional trends are apparent (Fig. 1). The organic-carbon content of the sediment is lowest in the nearshore areas on the Continental Shelf and in the areas far from the coast, such as Tufts Plain and the seamount provinces (Fig. 2). The maximum concentration of organic carbon occurs in

FIGURE 2. Range and median values of organic carbon content of surface sediment. See Fig. 1 for the approximate boundaries of the physiographic provinces.



sediment from the continental slope; concentrations of organic carbon greater than 2% are observed in only two other samples—one from western Cascadia Basin, the other from eastern Cascadia Basin (Fig. 1).

The largest concentrations occur in sediment on the lower portion of the Continental Shelf (depths between 100 and 180 m), on the continental slope, and in eastern Cascadia Basin. Sediments at greater depths and lying farther seaward from the coast have substantially less organic carbon.

Factors Controlling Abundance of Organic Carbon

The factors controlling the abundance of organic carbon in marine sediments are well known (Trask, 1932, p. 110). These are 1) production in the water column, 2) transportation, and 3) destruction by organisms or nonbiological processes. I will consider each of these in turn, to determine its effect on the organic-carbon content of the sediments.

Production of Organic Carbon

The abundance of organic carbon in a sediment is controlled by the amount of organic matter produced by marine organisms in the region or brought to the ocean by local rivers. Unfortunately no data are available on the amount of organic matter brought into the Northeast Pacific Ocean by rivers.

Anderson (1964) studied the primary photosynthetic productivity in this part of the Northeast Pacific Ocean and showed that there is little variation over the region. Average values are around 60 g C m^{-2} yr^{-1}. The discharge of the Columbia River has a distinct influence on the timing of events in the seasonal productivity cycle, but has no demonstrable effect on the amount of photosynthetic production.

Large-scale differences in productivity occur near the coast where wind-induced upwelling supplies nutrients to the surface waters. In these areas production is approximately 150 g C m^{-2} yr^{-1} (Anderson, 1964). Such highly localized occurrences of high productivity may influence the organic carbon content of the sediment in the immediate vicinity. However, the small number of widely spaced samples from the Continental Shelf does not permit an evaluation of the effect of local upwelling on the organic-carbon content of the sediment.

Except for the localized areas of high productivity caused by wind-induced upwelling, there is no evidence of large variation in the production of organic carbon over the region. Thus, excluding the Continental Shelf, I assume that there are no major variations in the production of organic matter in the surface waters. In the absence of evidence to the contrary, I also assume that rivers in the area are not major sources of organic matter. Consequently, the substantial variations in the content of organic carbon observed in the sediment (Fig. 1) must be explained by factors other than regional variations in photosynthetic production.

Transportation

One must consider the effect of transportation, because the organic carbon content of a sediment may be controlled by the amount of organic matter brought to the depositional site or removed from it by physical

processes. Trask (1932) concluded that organic matter generally is transported and deposited with the fine-grained or clay-sized material, and is generally absent from coarse-grained sediment such as sand. These data support his conclusion. The coarse-grained sediment uniformly contains substantially less organic carbon than does the finer grained (Fig. 3).

Variation in grain size is not the only factor controlling the organic-carbon content of a sediment, although grain size does appear to limit the maximum amount of organic carbon present in a particular sediment. For example, the fine-grained sediment on Tufts Plain has generally the lowest organic carbon content (Fig. 3).

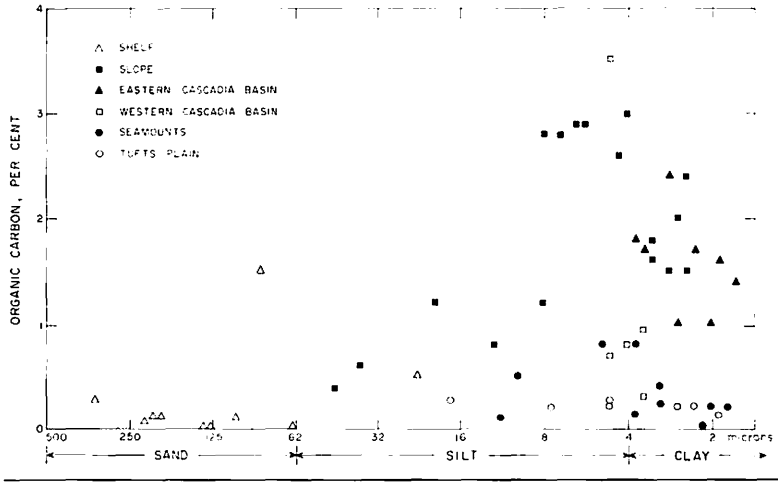
Destruction of Organic Matter

Neither the productivity in surface waters nor the effect of transportation can completely explain the observed distribution of organic carbon. Obviously, we must consider the destruction of the organic matter.

Other investigations have found that the dissolved oxygen concentration in the bottom water exercises a major control on the preservation of organic matter in sediment (Trask, 1932; Correns, 1939; Richards and Redfield, 1954; Calvert, 1964).

Fig. 4 shows the variations with depth of the dissolved oxygen concentration in ocean water near the Washington-Oregon coast. The major feature is the oxygen minimum at approximately 1000 m, which apparently varies little during the year or over the area studied. The concentration of organic carbon in sediment at various depth intervals is generally inversely correlated with the concentration of dissolved oxygen in the water. The highest organic-carbon content occurs in sediment at

FIGURE 3. Organic carbon content of surface sediment as a function of the mean grain size, in microns, of the sediment and the limits of the major sediment classes.

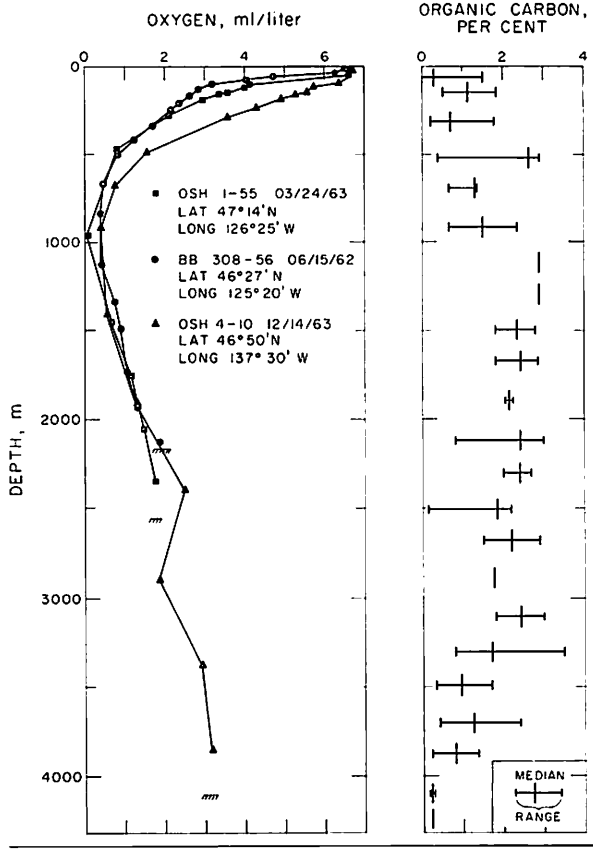


around 1000 m depth. The lowest organic-carbon content appears in the shelf sediment, doubtlessly influenced by the coarse-grain size of the Continental Shelf sediment, and in the very fine-grained sediment of Tufts Plain at depths of 4000 m or greater.

Although the data show considerable scatter, the general correlation between the abundance of organic carbon and the dissolved oxygen concentration in the waters leaves little doubt that the dissolved oxygen concentration of the waters near the bottom plays a major role in determining the amount of organic carbon preserved in the sediment. The details of the process are unknown; it may be due to inhibition of biological activity or nonbiological oxidation of the organic matter or both.

Obviously the rate of sediment accumulation also plays a role in deter-

FIGURE 4. Variation with depth in the dissolved oxygen content of seawater from the Northeast Pacific Ocean, and the organic-carbon content of surface sediment, grouped by 200-m depth intervals.

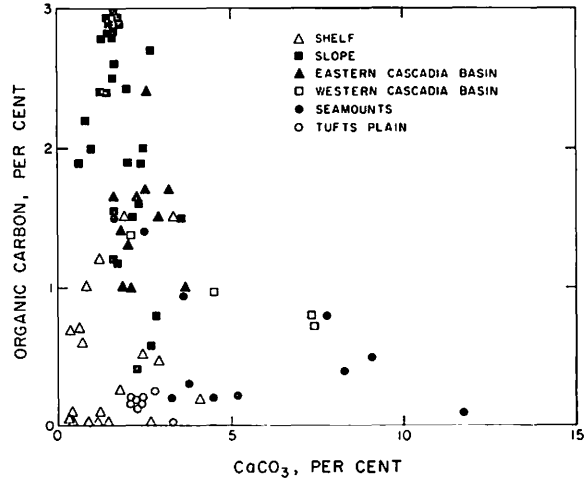


mining the organic carbon content, although the scarcity of data prevents a precise evaluation here. One can assess in a crude way the importance of the rate of sediment accumulation by comparing the concentrations of organic carbon and calcium carbonate in the sediment.

In general, those sediments from the seamount provinces and western Cascadia Basin containing large amounts of calcium carbonate have low organic carbon contents and vice versa (Fig. 5). This is consistent with the hypothesis that low rates of sediment accumulation do not favor the preservation of organic carbon. Sediment containing substantial amounts of calcium carbonate apparently receive relatively little lithogenous material or organic carbon per unit time. In these areas the calcareous remains of marine organisms are a major constituent of the sediment (Gross, 1965). Conversely, sediment containing large amounts of organic carbon appear to receive organic carbon and lithogenous material relatively rapidly. Here the rapid accumulation of lithogenous material buries the organic matter, protecting it from the destruction at the water-sediment interface.

The effect of different rates of sediment accumulation can be seen by comparing (Fig. 6) the amount of organic carbon in the sediment with the estimated concentration of dissolved oxygen at the depth from which the sample was collected (see Fig. 4). The influence of variable grain size is largely eliminated by using only sediment from the slope, eastern Cascadia Basin, and Tufts Plain whose mean grain size was smaller than 8 microns (see Fig. 3). These samples also contain less than 4% $CaCO_3$ (see Fig. 5).

FIGURE 5. Organic-carbon and calcium carbonate content of surface sediment.



Considering their inherent crudeness, the data demonstrate to a remarkable degree the influence of the dissolved oxygen concentration in the bottom waters. In almost two thirds of the samples, the abundance of organic carbon decreases with increasing dissolved oxygen concentration.

Significant deviations from the general trend are apparent in about 40% of the slope sediment samples (Fig. 6). In these samples it is obvious that the dissolved oxygen concentration is not the sole factor causing the low concentration of organic carbon. Most probably the rate of sediment accumulation is low on much of the slope, especially along the Oregon coast. Conversely the three sediment samples from eastern Cascadia Basin with unusually large organic-carbon contents probably result from rapid sediment accumulation. Thus it appears that with sufficient data one could delineate areas where the rate of sediment accumulation is appreciably greater or substantially less than the average for the region.

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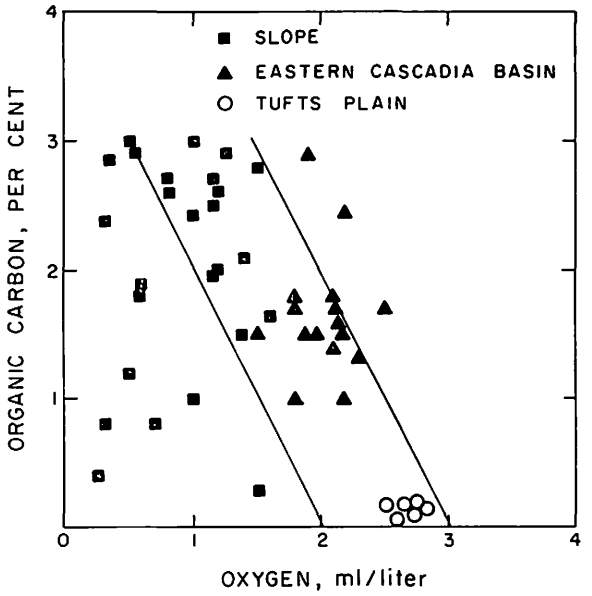
FIGURE 6. Organic-carbon content and the estimated dissolved oxygen concentration in the bottom water where the sample was taken.



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