AN ABSTRACT OF THE THESIS OF

ROBERT EMIL PETERSON   for the   M.S.
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Title: CALCIUM CARBONATE, ORGANIC CARBON, AND QUARTZ

    IN HEMIPELAGIC SEDIMENTS OFF OREGON: A PRELIMI-

    NARY INVESTIGATION

Abstract approved: _____ Signature redacted for privacy.
                                    LaVerne Duane Kulm

An analysis of the amounts of calcium carbonate, organic carbon,

quartz, and the rates of sediment accumulation in hemipelagic sedi-

ments off Oregon has revealed that the accumulation rates of the total

sediment, organic carbon, and quartz were at least twice as high in

the late Pleistocene as they were during the Holocene. The accumula-

tion rate of calcium carbonate was at least 8 times as high. There

may have been a short transition period at the end of the last glacial

stage from about 14,000 to 12,500 years B.P. when the sedimentation

rate was very high -- up to 75 cm/1000 years.

There is evidence that the amount of organic carbon in deep-sea

sediments is a function of terrigenous influx, of preservation, and

possibly of depth of burial in the sediment. Turbidite sequences in

the deep-sea environment off Oregon contain much higher amounts of

organic carbon in the upper fine-grained portion of the sequence than

in the coarser basal sediment of the sequence, indicating that organic carbon is concentrated in the finer and slower settling parts of the flow. In lower continental slope sediments, the greatest amounts of organic carbon are found in the <4 micron size fraction.

Calcium Carbonate, Organic Carbon, and Quartz
in Hemipelagic Sediments off Oregon:
A Preliminary Investigation

by

Robert Emil Peterson

A THESIS

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APPROVED:

Signature redacted for privacy.

_____
Associate Professor of Oceanography
in charge of major

Signature redacted for privacy.

_____
Chairman of the Department of Oceanography

‹Signature redacted for privac.

_____
Dean of Graduate School

Date thesis is presented _____ July 7, 1969 _____

Typed by Sammy McMurphey for _____ Robert Emil Peterson _____

ACKNOWLEDGEMENTS

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HEMIPELAGIC SEDIMENTS OFF OREGON:

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INTRODUCTION

Objective of the Study

This study was initiated to define the changes that took place in the major components of hemipelagic sedimentation off Oregon during the transition from the last glacial stage to the present. The major components were considered to be calcium carbonate, opal, quartz, and clays, with organic carbon representing a minor, but possibly significant, component. During the course of laboratory analysis of the sediments chosen for study, it became apparent that only information on calcium carbonate, organic carbon, and quartz could be obtained, due to technical difficulties.

The surface distribution of calcium carbonate and organic carbon off the coast of Oregon and Washington has been described in several reports (Gross, 1965; Gross, 1967; Gross et al., 1969). The distribution of these two components with depth in the sediment has been described briefly by Duncan (1968) and Griggs (1968). Trends mentioned by other workers, such as the calcium carbonate maxima and minima associated with glacial and interglacial periods in the Atlantic and Indian Oceans (Broecker, Turekian, and Heezen, 1958; Olausson,

1960), and the higher concentrations of organic carbon in the sediments younger than the last glacial stage off Oregon (Duncan, 1968) appear to be supported by the present study. By determining accumulation rates on a dry-weight basis for these components, it is possible to gain even greater insight into how and why they have changed with time.

Definitions

The terms late Pleistocene and Holocene will be used to refer to the most recent glacial stage and the period of time since the retreat of the glaciers, respectively. The boundary between the two intervals is defined by an abrupt faunal change: planktonic foraminifera are dominant during the late Pleistocene, whereas radiolarians become dominant during the Holocene (Duncan, 1968). Duncan established the age of this boundary at 12, 500 $\pm$ 500 years B. P. (Before the Present).

By utilizing radiocarbon age determinations, the concentrations of calcium carbonate, organic carbon, and quartz, and an assumed bulk density for the sediments, it is possible to determine the rates of accumulation of the various components of the sediment. For convenience, sedimentation rate refers to the total sediment and is expressed in cm/1000 years. Accumulation rate refers to both the total sediment and to each of the components and is expressed in gm/cm^2 1000 years. Hemipelagic sediments are deep-sea sediments which contain an appreciable portion of terrigenous material.

Selection of Cores

Cores that best represent uninterrupted hemipelagic sedimentation were selected on the basis of physiographic setting and lack of visible breaks in the record of sedimentation. A small isolated basin south of the Blanco Fracture Zone (Figure 1) provides an environment which should be free of large-scale slumps or turbidity currents. Two cores (6604-2 and 6609-13) from the central portions of this basin and one (6604-3) from a high area separating the basin from Cascadia Channel were available (Figure 1).

Another core (6711-2) which was taken at the base of a small submarine valley on the lower continental slope off the Rogue River was also studied (Figure 1). This core contained only Holocene sediments, and it was used to determine the organic carbon and carbonate content of the <4, 4 to 20, 20 to 44, and >44 micron size fractions. A core from West Cascadia Basin (6808-4, Figure 1), which contained a long sequence of turbidite layers, was analyzed to reveal the distribution of organic carbon and calcium carbonate within each of the turbidite layers and to gain insight into the transport of organic carbon by marine processes.
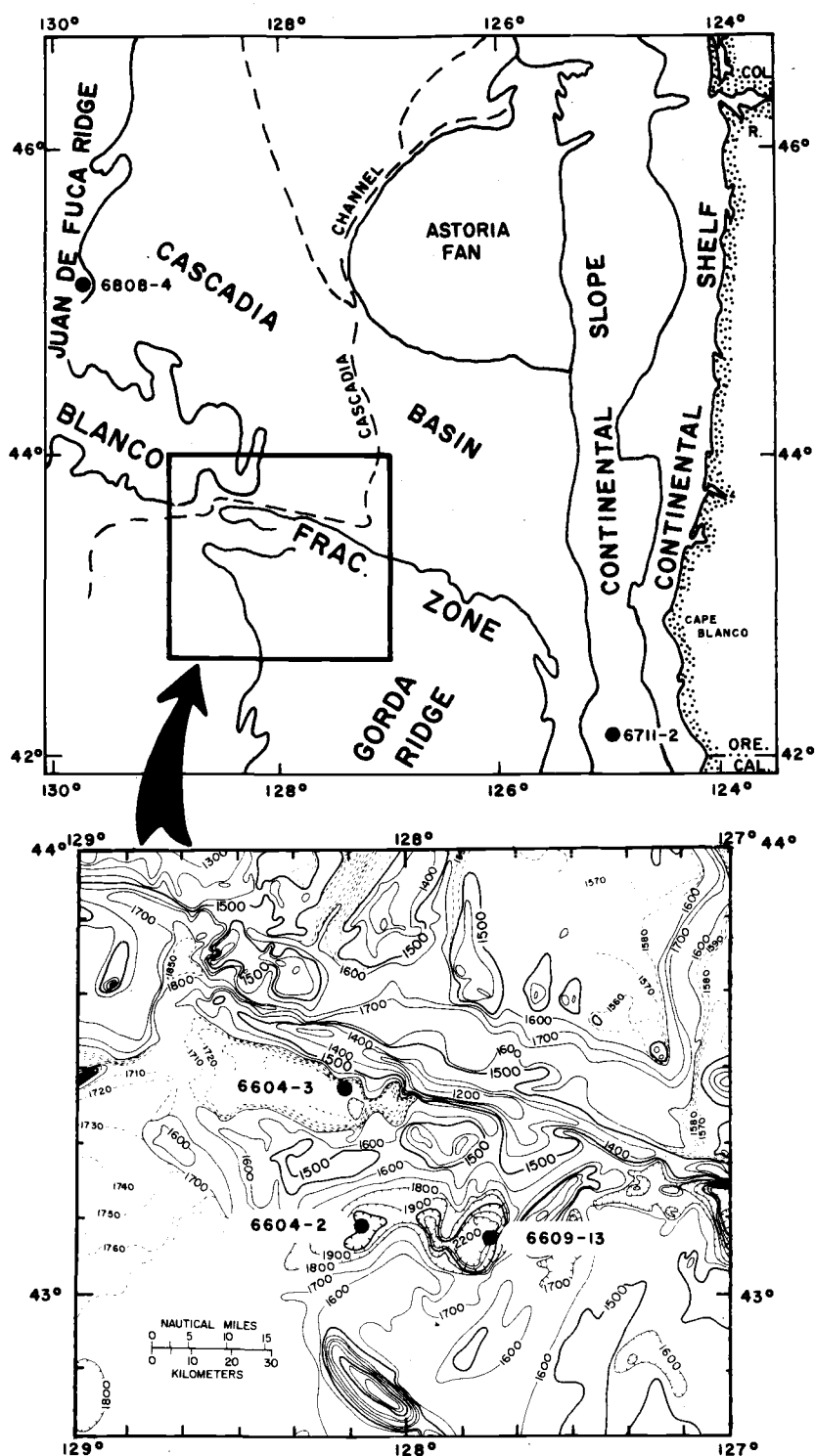
Figure 1.   Physiography off Oregon and
core location map.   (Contours
in fathoms.)

METHODS

Total Carbon and Organic Carbon Sample Preparation

Sediment samples were collected from sealed, damp cores which had been stored at 4°C. in a cooler for about three years. They were prepared as outlined in Appendix 5 and analyzed on a Leco 598 Carbon Analyzer with a Direct Digital Readout. This instrument burns the sample completely in pure oxygen, collects the carbon dioxide evolved, and compares the thermal conductivity of the evolved gas to that of pure oxygen. The ratio is a measure of the amount of carbon in the sample.

Two experiments were run to determine the possible effects caused by certain steps in the preparation of the organic carbon samples. The results of these experiments are shown in Table 1. The first set of samples was taken from the surface sediment of cores from the Panama Basin which had been stored at 4°C. for about two months. These samples were prepared and analyzed to determine the effect that drying at 100°C. might have on the carbon values. Half of the samples were dried at room temperature in a dessicator, both before grinding, and after acid leaching to remove any carbonates. The other half were dried in an oven at 100°C. according to the procedure shown in Appendix 5. These experiments indicate that drying at 100°C. does not remove any of the organic matter present in the sediment,

Table 1. Results of various methods of organic carbon sample prepara-
tion.

Method	Av. Total Carbon	Av. Organic Carbon	Calcium Carbonate
100°C. drying	7.74%	0.57%	59.8%
dessicator drying	7.65%	0.56%	59.1%

A. Comparison of two methods of drying sediment samples. Sample
used was surface sediment from the Panama Basin.

Method	Av. Total Carbon	Av. Organic Carbon	Carbon in Calcium Carbonate	Calcium Carbonate
HCl leached samples		1.50%*	0.16%	1.3%
H$_2$O$_2$ leached samples	1.66%*	1.34%	0.32%*	2.7%

B. Comparison of two methods used to determine carbon components.
Sample used was from 350 cm in core 6711-2. (*) values were
measured by the Leco Carbon Analyzer, and other values were de-
termined by subtraction of measured value from total carbon value.

and suggests that the organic matter in deep-sea sediment is not volatile at this temperature. Organic material in the second set of samples was removed by leaching with a 10% solution of hydrogen peroxide on a warm hotplate until no further reaction could be observed. The calcium carbonate was allowed to remain in the sediment. A split of the same sample was prepared as outlined in Appendix 5, and the two groups of samples were analyzed on the Leco. The results of this experiment are somewhat disturbing, since they may indicate flaws in the assumptions of certain accepted laboratory techniques -- i.e., hydrochloric acid leaching will remove all the calcium carbonate but no organic matter from a marine sediment, and hydrogen peroxide leaching will remove all of the organic matter. This second assumption is the one most likely to be in error, based on previous similar experiments done by van Andel (1969) on sediments from the Gulf of California.

Calculations of Values

Two crucibles were prepared for total carbon and two for organic carbon determinations. For each sediment sample, the percent carbon in each crucible subsample was determined by dividing the digital readout by the weight of the subsample. Duplicate values for total carbon and organic carbon were averaged. The percent calcium carbonate was determined using the equation

$$\% \text{ calcium carbonate} = (\% \text{ total C} - \% \text{ organic C}) \text{ X } 8.33$$

where the total and organic carbon values are the averages of duplicate determinations, and the 8.33 is a conversion factor calculated by dividing the molecular weight of calcium carbonate (100.1) by that of carbon (12). All carbonate is assumed to be calcium carbonate.

A National Bureau of Standards carbon standard with a carbon content of 1.2% was run ten times to gain an estimate of the accuracy of the method. The average value obtained was 1.172% carbon (Appendix 4). The average difference of values was 0.021%, and the standard deviation was 0.029%.

The precision and accuracy of the analytical technique, in combination with inherent sampling errors, lead the author to believe that the carbon values used in this study are correct to within $\pm$ 0.1% carbon. Since the calcium carbonate percentage is calculated from these values, its accuracy is $\pm$ 1.7% calcium carbonate (the estimated maximum error for a pair of carbon values multiplied by 8.33).

Size Analysis Method

A microtexture technique described by Allen (1969) was used to separate 5 samples from core 6711-2 into 4 size classes each. The size classes were as follows: <4 microns, 4 to 20 microns, 20 to 44 microns, and >44 microns. Calgon (sodium hexametaphosphate) was added to the water to disperse the sediment. After the size separation,

recovery of the sediment was at least 90%. Each size class was

analyzed for its total carbon and organic carbon content. The carbon

analyses were not run in duplicate due to the small amounts of sedi-

ment in some of the size classes.

Determination of Accumulation Rates

The sedimentation rates in cm/1000 years were converted to

accumulation rates in $gm/cm^2 1000$ years using a bulk density factor of

$0.70\ gm/cm^3$ (Broecker, Turekian, and Heezen, 1958). The rates of

accumulation of the sediment components were then calculated by

multiplying the total sediment accumulation rate by the percent concen-

tration of the various components. The concentration of a component

for a particular time interval was determined by averaging all the

values in that interval.

Quartz and Opal Determinations

An attempt was made to use an infrared technique described by

Chester and Elderfield (1968) to determine the opal and quartz contents

in some of the deep-sea sediments. The attempt was only partially

successful and for reasons not yet thoroughly understood. At least

part of the reason was the inexperience of the author with sophisticated

infrared techniques and the non-availability of an infrared spectrophoto-

meter of the type necessary for obtaining the best results from the

method.

Using this technique, it was possible to determine the percent quartz in seven samples from core 6609-13 and to establish that the quartz to opal ratio was greater than 1:3 in each of the samples. The standard curve used for the quartz determinations, and a typical spectrogram of a sample, is shown in Figure 2. The doublet peak at 12.5 microns is resolved into two peaks and indicates that the quartz. to opal ratio is greater than 1:3, but it is still not possible to establish the presence of opal in the sediment positively (Chester and Elderfield, 1968). The precision of quartz determinations made using the 14.4 micron peak has been estimated to be ± 6% (Chester and Green, 1968).

Wavelength
(microns)

12   13   14   15

A.

Percent Transmission

100

80

60

40

20

0

850 800 750 700 650

Wave Numbers
(cm^{-1})

B.

Absorbance

.250

.200

.150

.100

.050

.000

0   10   20   30   40   50

Percent   Quartz
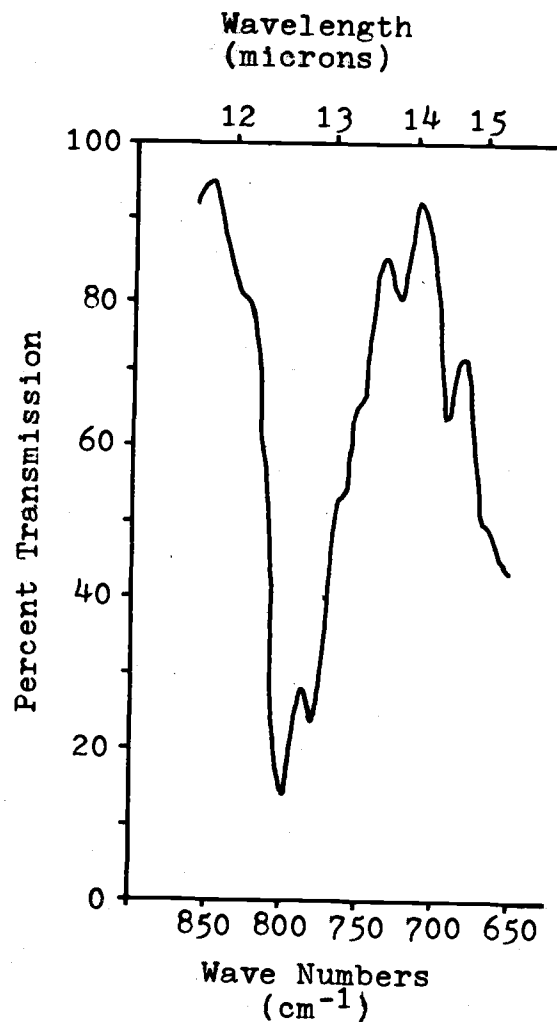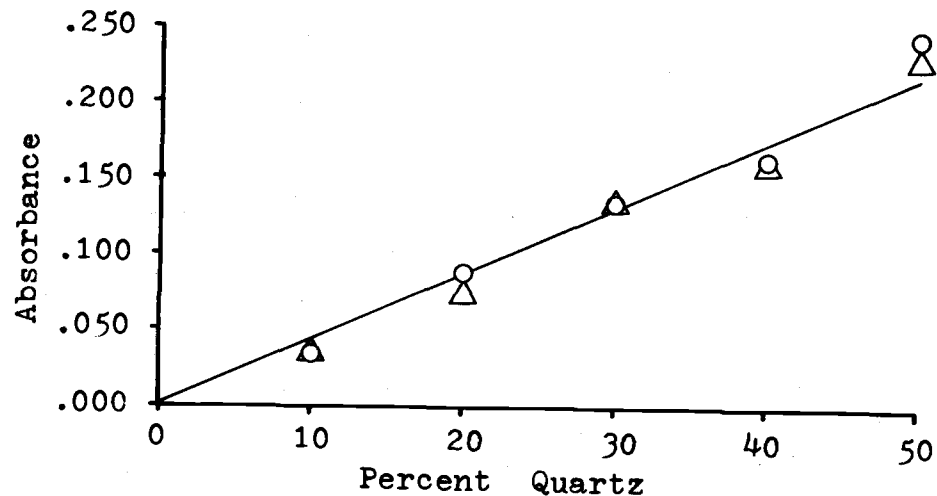
Figure 2   A. Infrared spectrogram of sediment from
              core 6609-13. Quartz peaks occur at
              799, 780, and 694 cm^{-1}, while opal has
              a peak at 797 cm^{-1}.
             B. Standard curve used for determination
              of quartz from 694 cm^{-1} peak. The
              absorbance is calculated by the form-
              ula   abs. = $- \log \frac{I}{I_o}$ where I is the
              % transmission maximum and I_o the min-
              imum of the peak.

SEDIMENT ACCUMULATION RATES IN SELECTED CORES

Results

The curves for the distribution of calcium carbonate with depth in three cores (6604-2, 6604-3, and 6609-13) are presented in Figure 3. From the shape of these curves alone, a good correlation exists between cores 6604-2 and 6609-13, the two cores which occupy the central portion of the small basin (see Figure 1). Using the faunal break at about 12,500 years in both cores, and the two radiocarbon dates in core 6609-13 (Figure 3), it is possible to establish age estimates for the major inflection points of the calcium carbonate curves.

The dates and correlation points in these two cores suggest two periods of sedimentation. The younger period, which has the lower sedimentation rate, is coincident with the Holocene, while the older period, with a much higher sedimentation rate, is coincident with the last major glacial advance (Fraser Glaciation) of the late Wisconsin Glacial Stage. It is assumed that an average value for the sedimentation rate for each time interval is sufficient to reveal differences between the two time intervals. From this correlation, the rates of accumulation for calcium carbonate, organic carbon, and quartz (in core 6609-13 only) have been calculated (Table 2). Core 6604-3, from the region between the small basin and Cascadia Channel, has been included in Figure 3 and in Table 2, even though its calcium carbonate
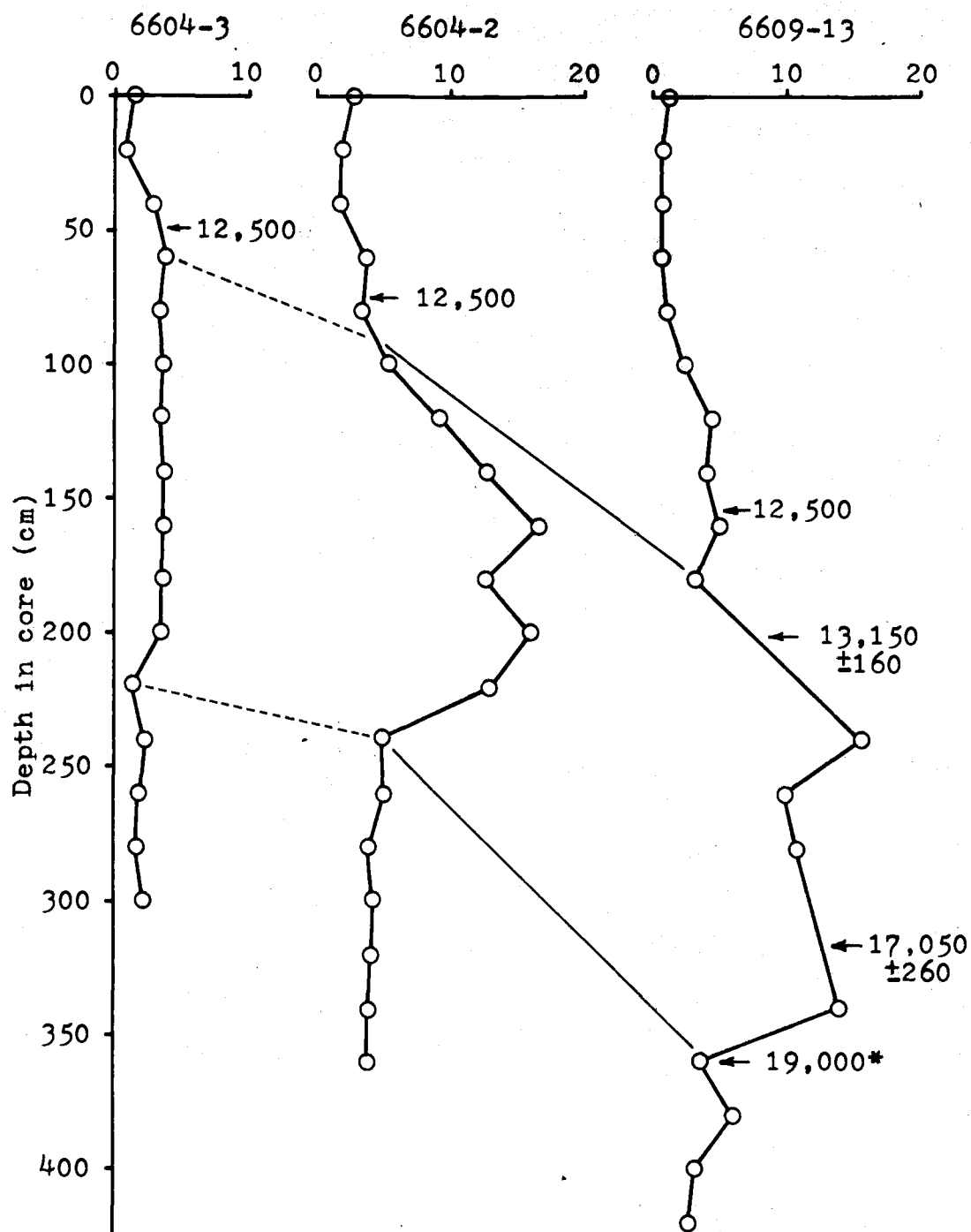
Figure 3   Percent calcium carbonate with depth in core:
two sedimentation intervals. (*) date is
extrapolated from C^{14} dates; 12,500 year date
is faunal boundary between Holocene and late
Pleistocene; see Figure 1 for core location.

Table 2. Sediment accumulation rates during the late Pleistocene and Holocene: two sedimentation intervals.

Interval	6604-3 depth = 3184m		6604-2 depth = 3786m		6609-13 depth = 4016m	
10^3yrs B.P.	$\frac{cm}{10^3yr}$	$\frac{gm}{cm^2 10^3yr}$	$\frac{cm}{10^3yr}$	$\frac{gm}{cm^2 10^3yr}$	$\frac{cm}{10^3yr}$	$\frac{gm}{cm^2 10^3yr}$
0-13	5	3.2	7	4.9	14	9.8
13-19	27	18.7	25	17.5	30	21.0

A. Sedimentation rates in cm/10^3years and accumulation rates in gm/cm^2 10^3years.

Component	10^3yrs B.P.	6604-3 %	6604-3 $\frac{gm}{cm^2 10^3yr}$	6604-2 %	6604-2 $\frac{gm}{cm^2 10^3yr}$	6609-13 %	6609-13 $\frac{gm}{cm^2 10^3yr}$
Organic carbon	0-13	0.45	0.01	0.99	0.05	0.88	0.09
	13-19	0.32	0.06	0.80	0.14	0.63	0.13
Calcium carbonate	0-13	2.28	0.07	2.73	0.13	2.56	0.25
	13-19	3.36	0.63	11.26	1.97	9.98	2.10
Quartz	0-13	--	--	--	--	22	2.2
	13-19	--	--	--	--	20	4.3

B. Concentration in percent and accumulation rates in gm/cm^2 10^3years of organic carbon, calcium carbonate, and quartz.

Table 3. Ratios of late Pleistocene accumulation rates to Holocene
rates.   Based on values in Table 2, page 14.

Core No.	Water depth (m)	Total sediment	Organic carbon	Calcium carbonate
6604-3	3184	5. 8	6. 0	9. 0
6604-2	3786	3. 6	2. 8	15. 1
6609-13	4016	2. 1	1. 4	8. 4

curve correlation with 6604-2 and 6609-13 is tenuous.

The following contrasts between sedimentation during the late Pleistocene and the Holocene are shown in Tables 2 and 3:

1. Depending on the core location, the overall accumulation rate of sediment was 2 to 5 times higher during the late Pleistocene than it was during the Holocene.

2. The accumulation rate of organic carbon was 1.4 to 6 times higher during the late Pleistocene than it was during the Holocene. However, the concentration of organic carbon in the sediment (% of the sediment which is organic carbon) was lower during the late Pleistocene than during the Holocene. The greatest quantities and the highest concentrations of organic carbon are found in the deepest parts of the basin during both time intervals.

3. The accumulation rate of calcium carbonate was 8 to 15 times higher during the late Pleistocene than during the Holocene. The concentration of calcium carbonate in the sediment was also higher during the late Pleistocene than during the Holocene. The greatest quantities and the highest concentrations of calcium carbonate are found in the deepest parts of the basin for both time intervals.

4. The accumulation rate of quartz, determined in core 6609-13 only, was 2 times higher during the late Pleistocene than during the Holocene. However, the concentration of quartz was slightly higher during the Holocene.

Before discussing these contrasts, it is important to mention two underlying assumptions -- the selection of two sedimentation periods (present to 13,000 years B.P., and 13,000 to 19,000 years B.P.) as being the most realistic interpretation of the late Pleistocene and Holocene history, and the assumption that the radiolarian-planktonic foraminifera faunal boundary and the radiocarbon date of $13,150 \pm 160$ years in core 6609-13 are not actually separated by a distinct sedimentation period. Since these assumptions may not be valid, a second correlation of the calcium carbonate curves for the three cores has been made (Figure 4). It suggests that the transition period between the late Pleistocene and Holocene, from about 14,000 years B.P. to 12,500 years B.P., is a distinct sedimentation interval. This transition period may have had an accumulation rate of sediment that was considerably higher than either the late Pleistocene or the Holocene, as is shown in Table 4. The general results which were found for the first correlation of the calcium carbonate curves (Figure 3) also apply to the second correlation, although the magnitude of the changes in
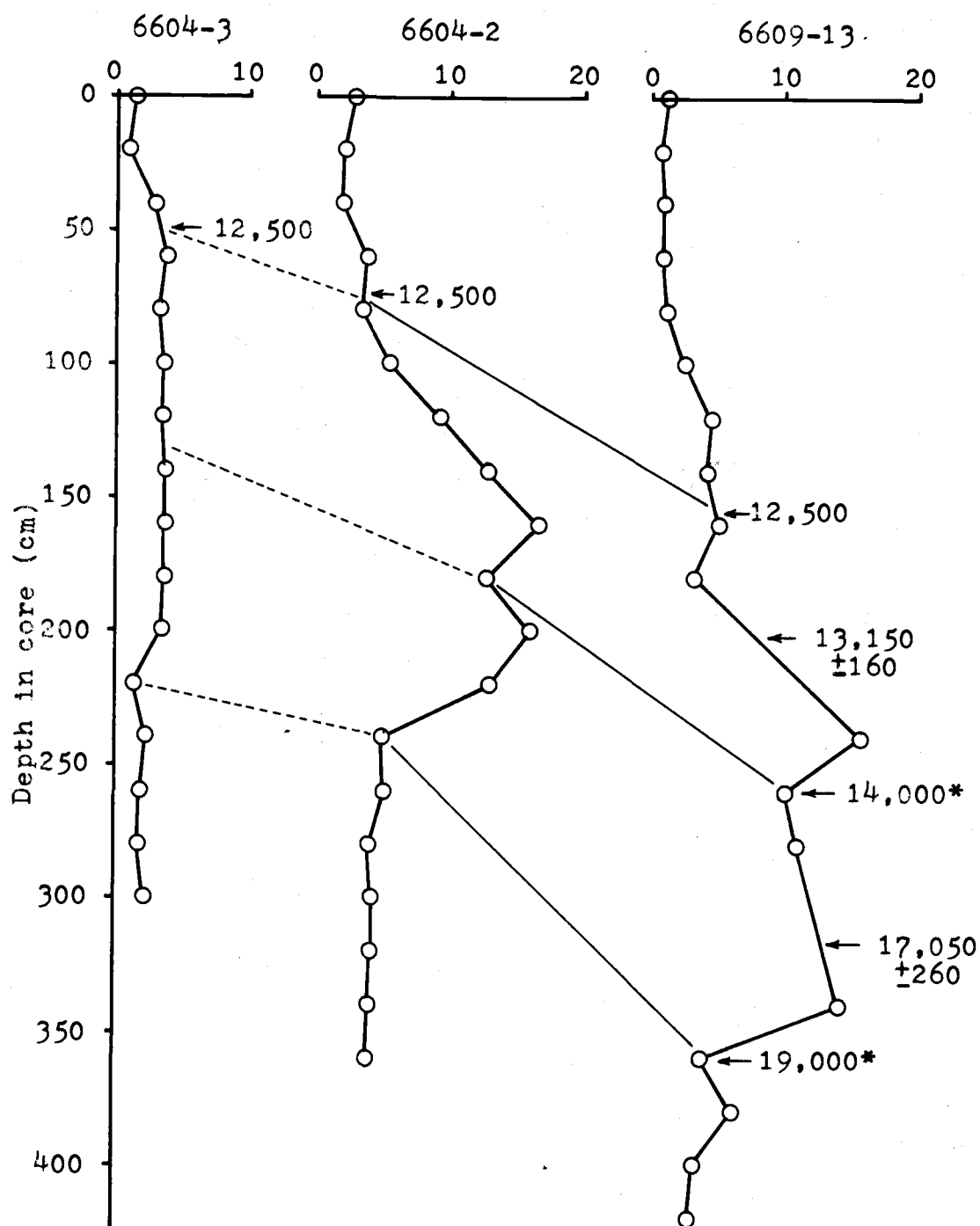
Figure 4   Percent calcium carbonate with depth in core:
three sedimentation intervals. (*) dates are
extrapolated from C^{14} dates; 12,500 year date
is faunal boundary between Holocene and late
Pleistocene; see Figure 1 for core location.

Table 4. Sediment accumulation rates during the late Pleistocene and Holocene: three sedimentation intervals.

Interval	6604-3 depth = 3184m		6604-2 depth = 3786m		6609-13 depth = 4016m	
10^3yrs B.P.	$\dfrac{cm}{10^3yr}$	$\dfrac{gm}{cm^2 10^3yr}$	$\dfrac{cm}{10^3yr}$	$\dfrac{gm}{cm^2 10^3yr}$	$\dfrac{cm}{10^3yr}$	$\dfrac{gm}{cm^2 10^3yr}$
0-12.5	4	2.8	6	4.2	12	8.7
12.5-14	53	37.3	75	52.5	75	52.5
14-19	18	12.6	11	7.8	18	13.0

A. Sedimentation rates in cm/10^3years and accumulation rates in gm/cm^2 10^3years.

Component	10^3yrs B.P.	6604-3 %	$\dfrac{gm}{cm^2 10^3yr}$	6604-2 %	$\dfrac{gm}{cm^2 10^3yr}$	6609-13 %	$\dfrac{gm}{cm^2 10^3yr}$
Organic carbon	0-12.5	0.48	0.01	0.89	0.04	0.91	0.08
	12.5-14	0.35	0.13	0.91	0.49	0.70	0.37
	14-19	0.30	0.04	0.72	0.06	0.59	0.08
Calcium carbonate	0-12.5	1.77	0.05	2.55	0.11	2.10	0.18
	12.5-14	3.59	1.34	9.98	5.24	8.78	4.61
	14-19	3.18	0.40	11.53	0.90	10.09	1.31
Quartz	0-12.5	--	--	--	--	23	2.0
	12.5-14	--	--	--	--	22	11.3
	14-19	--	--	--	--	20	2.6

B. Concentration in percent and accumulation rates in gm/cm^2 10^3years of organic carbon, calcium carbonate, and quartz.

accumulation rates is quite different.

Discussion

The total sediment accumulation is greater in the deeper parts

of the basin for all the time intervals mentioned. This is probably

best explained by the ponding of sediments in basins or troughs, which

has been revealed in subsurface seismic profiles off Oregon and other

parts of the world (Moore, 1966).

The increase in the amount of organic carbon in the late Pleisto-

cene sediments, as compared with the Holocene sediments, varies

almost directly with the increase in the rate of sedimentation in all

three cores (see Table 3). However, the concentrations of organic

carbon (% of sediment which is organic carbon) vary in the opposite

sense -- that is, the concentrations are lower in the late Pleistocene

sections than in the Holocene sections. It is possible to formulate

several explanations which satisfy the results mentioned above by

rearranging the controlling factors (i. e. the amount of organic carbon

in the terrigenous influx, the relative amounts of pelagic components

and terrigenous components, and the degree of preservation of organic

carbon). The author prefers the explanation which follows: there is

a greater amount of organic carbon in late Pleistocene sediments, be-

cause the supply of terrigenous organic carbon in the terrigenous influx

of sediment was greater, and the preservation of organic carbon was

greater due to more rapid rates of sedimentation, as suggested by
Gross et al. (1969). This would explain the pattern observed even
though the concentration of organic carbon in the terrigenous influx
may have been less during the late Pleistocene than during the Holo-
cene because of reduced amounts of vegetation in areas covered by
glaciers. An increase in the supply of some pelagic component, such
as planktonic foraminifera, during the late Pleistocene would also tend
to cause a lowering of the concentrations of organic carbon in the
sediments by dilution, even though the absolute amounts of organic car-
bon supplied per unit of time were increased. The concentration of
the terrigenous influx would be lowered also, and this may be shown
by the lower percentages of quartz in the late Pleistocene sediments
as compared with the Holocene sediments (Table 2).

The amounts and concentrations of organic carbon in core 6604-3
are lower than in the two cores from the basin during both time inter-
vals (Table 2). This core is from a topographically higher, and per-
haps more oxidizing, environment and has a rate of sedimentation that
is much slower than that of the other two basin cores. These two
factors could cause a reduction in the degree of preservation of organic
carbon in the sediment and thus account for the lower amounts and
concentrations than in the two basin cores.

There is also an indication that depth of burial may be a factor
controlling the amount of organic carbon preserved in the sediment.

In Figure 5, the concentration of organic carbon is virtually identical in cores 6604-2 and 6609-13, even though the sedimentation rates are very different. It is unlikely that the amounts of pelagic organic carbon supplied to and preserved on or near the sediment surface vary much over short distances within a certain physiographic environment (Kanwisher, 1968). The proximity of the two basin cores suggests that this is true for them also. The separation of the dotted curve of 6604-2 from 6609-13 in Figure 5 implies that the depth of burial may be a factor in the preservation of organic carbon.

The variations in calcium carbonate in these cores cannot be explained unequivocally. Appreciable dissolution of calcium carbonate can occur at depths of 1000 meters, and the rate of solution increases rapidly with greater depths (Berger, 1967). The factors which influence the solution of calcium carbonate in the ocean are pressure, temperature, and the degree to which the water is saturated with calcium carbonate (Krauskopf, 1967). It is difficult to evaluate the effects which dissolution may have had during the late Pleistocene, since there is very little known about the nature of the bottom waters during that time. It is apparent, however, that the calcium carbonate maxima and minima correspond to glacial and interglacial conditions, respectively. The calcium carbonate minima in certain parts of the world have been shown to coincide with periods during which there is evidence of solution of certain calcareous forms (Olausson and Peterson, 1968).
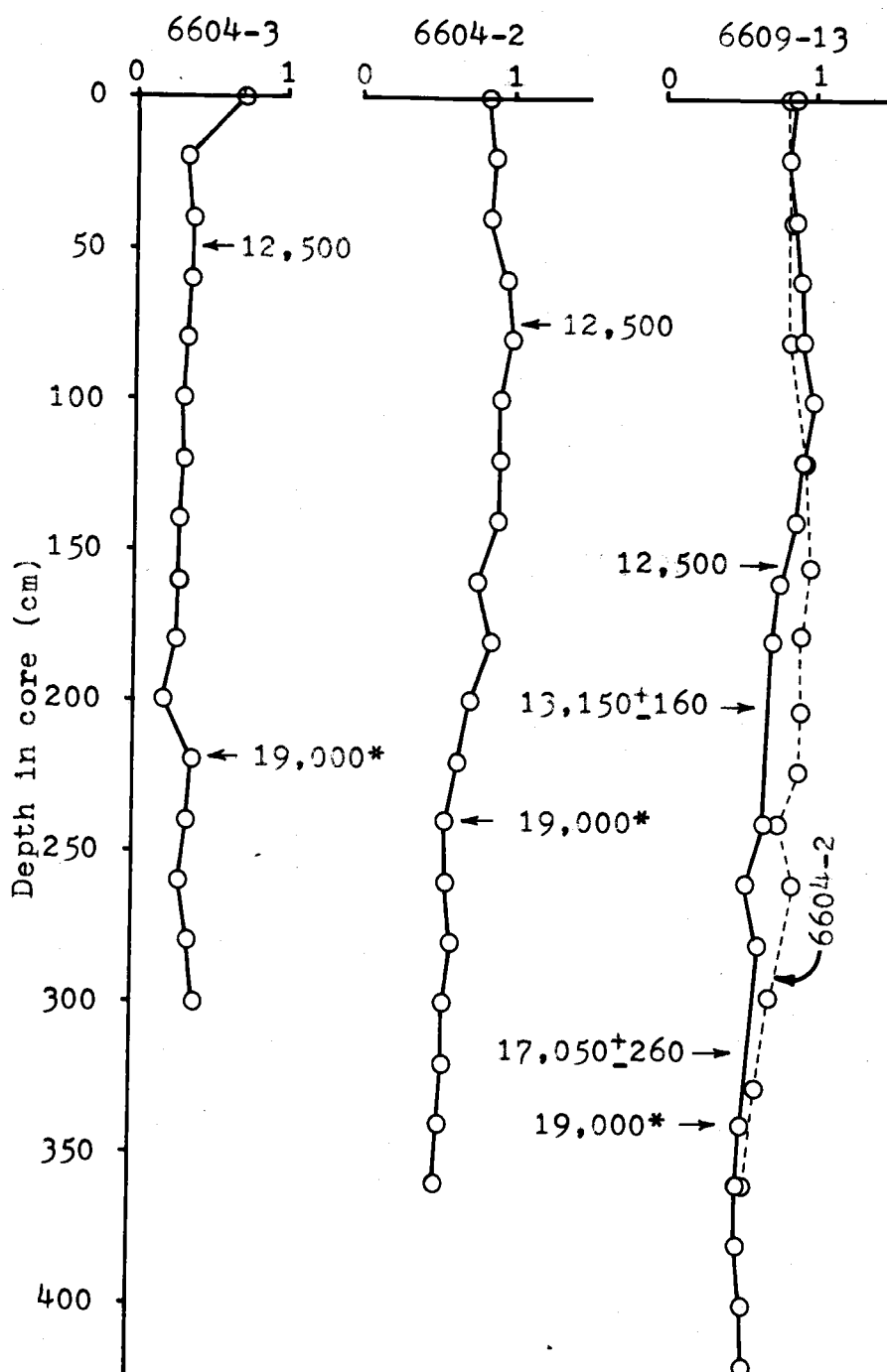
Figure 5   Percent organic carbon with depth in core.
(*) dates are extrapolated; 12,500 year
date is a faunal boundary; dotted curve is
6604-2 expanded to be time and depth
equivalent with 6609-13.

Duncan (1968) believes that there was greater productivity of calcareous organisms during the late Pleistocene than during the Holocene, but the evidence is not conclusive. So, it may be that the calcium carbonate maxima and minima are caused by greater or lesser periods of calcium carbonate production, by changes in amounts of dissolution of calcium carbonate, or by a combination of the two, which is most likely the case. An increase in the amounts of foraminifera being supplied to the bottom during the late Pleistocene is compatible with the explanation suggested above for the variations in organic carbon.

The terrigenous quartz in hemipelagic sediments off Oregon has been transported to its site of deposition almost entirely by marine processes. The rate of supply of quartz by eolian transport to Mt. Olympus, in Washington, is estimated to be 0.007 gm/cm^2 1000 years (Windom, 1969), which is much lower than the typical values of 2 to 4 gm/cm^2 1000 years found in sediments off Oregon (Tables 2 and 4). Quartz can, therefore, be used as an indicator of the intensity of erosion occurring on land. Although the number of measured values for quartz is very limited in this study, the data indicate that the rate of erosion was considerably greater during the late Pleistocene than during the Holocene.

CALCIUM CARBONATE AND ORGANIC CARBON IN CONTINENTAL
SLOPE SEDIMENT AND IN A BASIN TURBIDITE SEQUENCE

Continental Slope Sediment

Results. Five sediment samples from core 6711-2, which was taken

from the lower continental slope off the Rogue River, were size-sepa-

rated into fractions of $<$4 microns, 4 to 20 microns, 20 to 44 microns,

and $\geq$44 microns. Organic carbon and calcium carbonate analyses

were run on the size fractions, and the results are shown in Figures

6 and 7.

Figure 6 shows the size distribution of the sediment samples and

the distribution of organic carbon and calcium carbonate with respect

to size fractions. Most of the organic carbon is found in the 4 to 20

micron and $<$4 micron size fractions for each of the samples. In all

the samples except one, the amount of organic carbon in the $<$4 mi-

cron fraction is larger than the sum of the organic carbon in the other

three size fractions. The amounts of calcium carbonate in the samples

show a less definite tendency to be in a particular size fraction.

Figure 7 shows the percentages of calcium carbonate and organic

carbon in the size fractions. The $<$4 micron fraction has the highest

percentage of organic carbon, while the 20 to 44 micron fraction has the

lowest. Again the calcium carbonate displays less definite trends,

although the $>$ 44 micron fraction usually has the greatest percentage
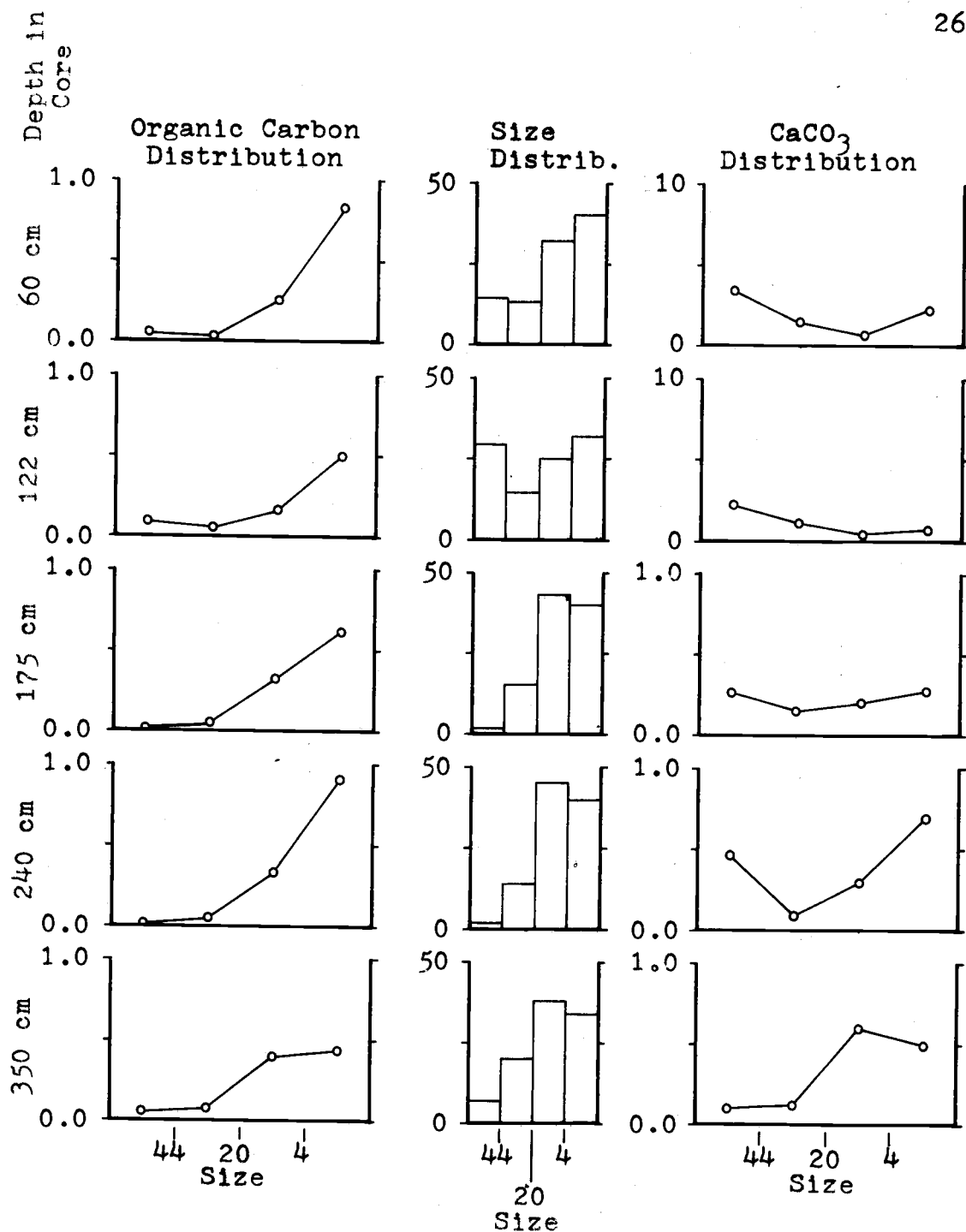
Figure 6   Organic carbon and calcium carbonate distri-
bution in core 6711-2; percent of total sed-
iment.   The size fractions are in microns,
and the size distribution is by percent of
the total sediment. Note calcium carbonate
scale change in 60 cm and 122 cm samples.
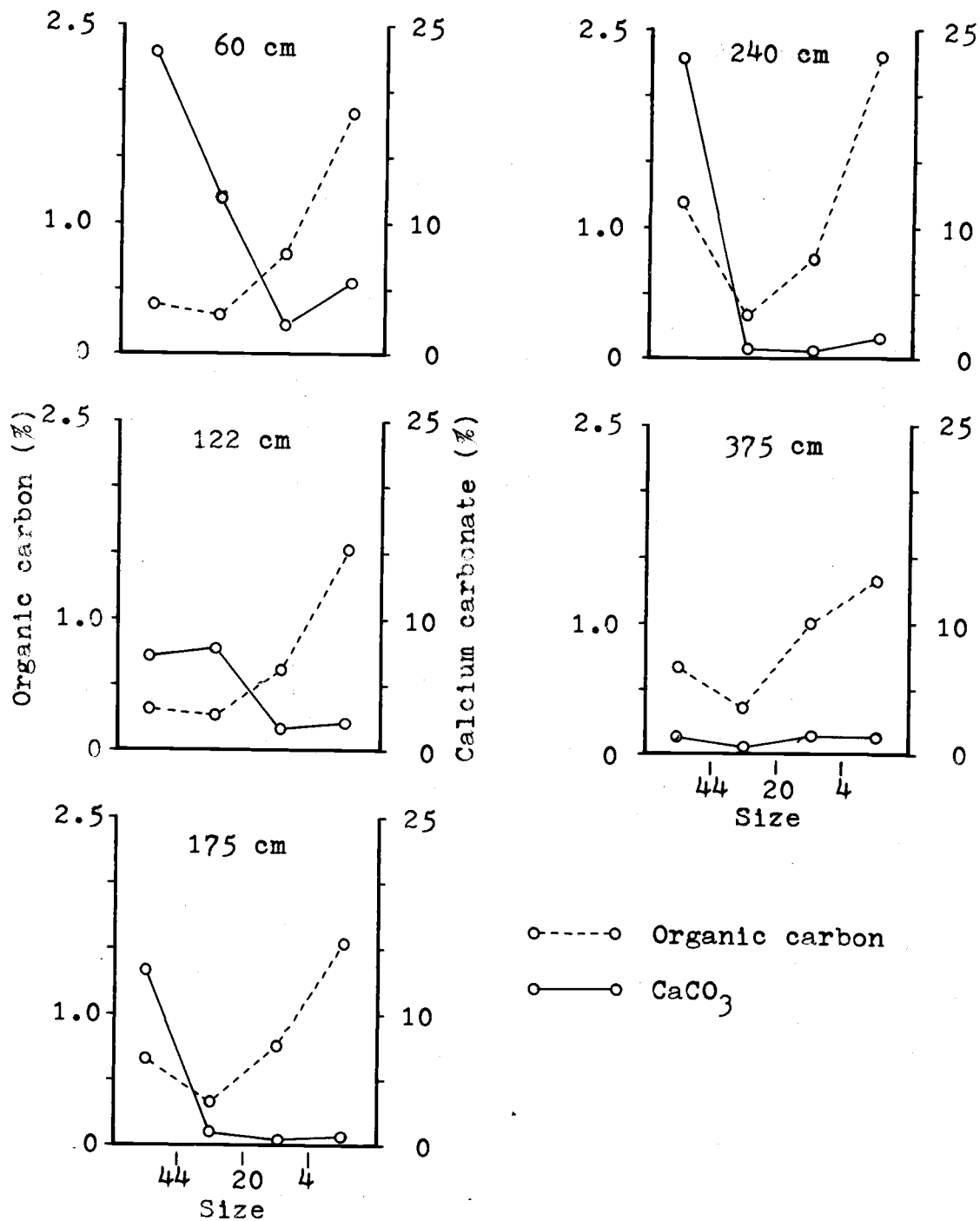
Figure 7   Organic carbon and calcium carbonate
           distribution in core 6711-2; percent
           of size fraction. The size fractions
           are in microns.

of calcium carbonate compared to the other fractions.

Discussion. The data suggest that most of the organic carbon which reaches the deep-sea environment off Oregon is of a size hydraulically equivalent to < 4 microns. Foraminifera, which were visible in the sediment, are responsible for the high values of calcium carbonate in the >44 micron fraction. The several high values in the 4 to 20 micron and <4 micron fractions probably reflect the presence of coccoliths, which average from 1 to 15 microns in size (Easton, 1960).

Basin Turbidite Sequence

Results. Near the upper part of the turbidite sequence in core 6808-4, the distribution of organic carbon seems to vary directly with the distribution of calcium carbonate (Figure 8). The highest organic carbon and calcium carbonate values occur at the top of the sequence in the foraminifera-rich zone or in the gray clay zone if the foraminifera-rich zone is absent. The lowest values occur in the silty laminae (Table 5). In the lower parts of the core, the turbidite sequences are not as well defined, and the variations in the organic carbon and calcium carbonate values are not nearly so marked.

Discussion. The lower organic carbon values in the silt layers as compared with those of the oozes can be explained in either of two ways. First, the source material of the turbidite may be lower in
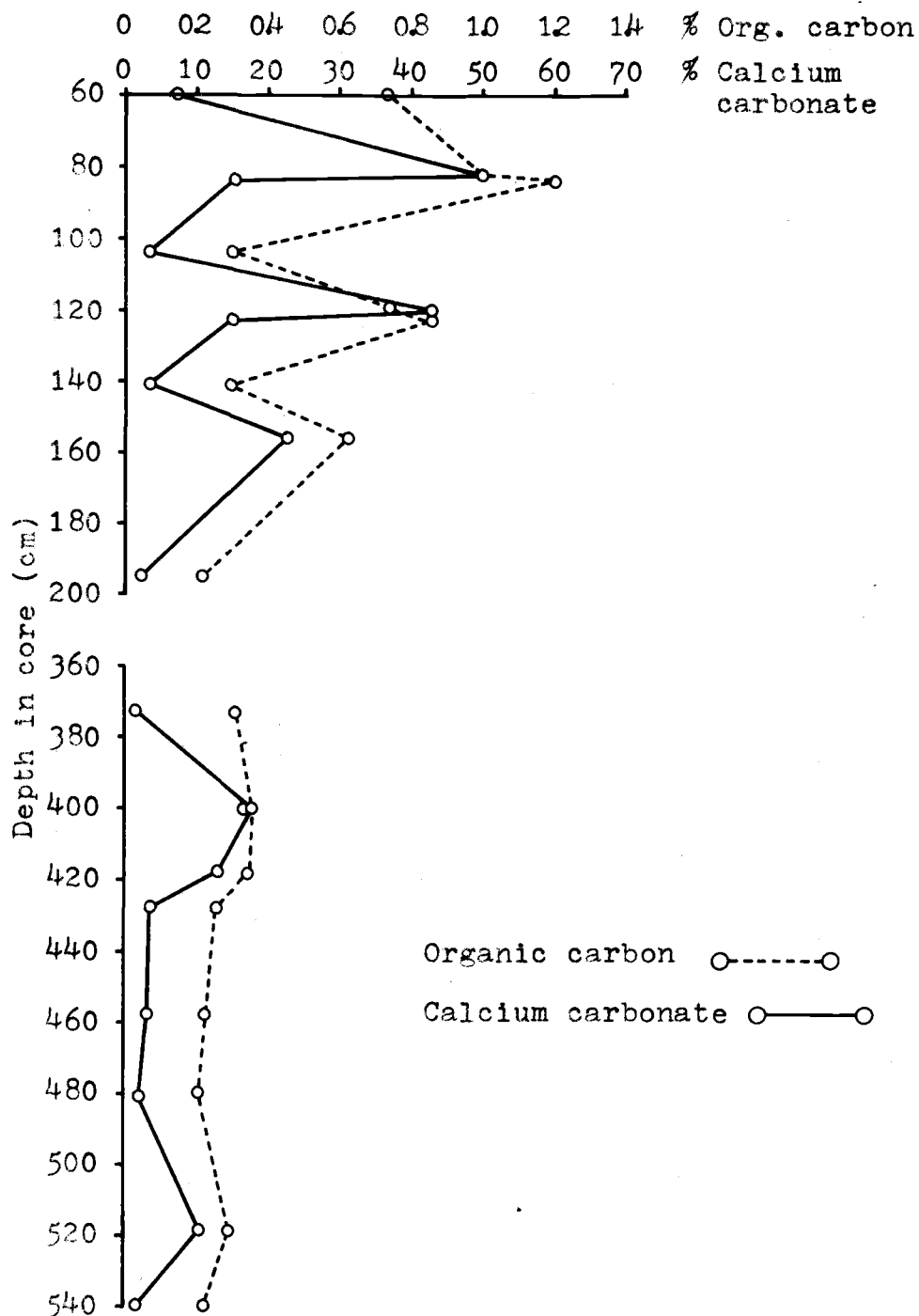
Figure 8   Percent organic carbon and calcium car-
bonate with depth in core 6808-4.

Table 5.   Percent calcium carbonate and organic carbon in turbidite
sequences in core 6808-4 from West Cascadia Basin.

Depth in Core (cm)	Lithology	Calcium Carbonate	Organic Carbon	Average Org. C
82	foram ooze	50.0	1.00	
84	gry. clay	15.2	1.24	0.85
104	gry. silt	3.5	0.31	
120	foram ooze	43.1	0.75	
123	gry. clay	15.0	0.86	0.64
141	gry. silt	3.3	0.31	
156	ol. gry. clay	22.8	0.62	0.42
195	ol. gry. silt	2.3	0.22	
400	yel. gry. clay	17.9	0.34	
418	yel. gry. clay	13.2	0.34	0.31
428	ol. gry. silt	3.9	0.26	
458	gry. clay	3.3	0.23	0.22
481	gry. silt	2.2	0.21	
518	gry. clay	10.9	0.30	0.26
541	gry. silt	2.0	0.23	

organic carbon than the pelagic sediments at the site of final deposition.

Second, the turbulent action of the turbidity flow may cause a separa-

tion of the organic material, with a resulting higher concentration of

it in the upper parts of the flow. This could happen if the organic

material is lighter in a hydraulic sense than the equivalently-sized

inorganic material of the flow. Griggs (1968) has also shown that the

concentration of organic carbon is higher in the fine-grained tails than

in the coarser basal layers of turbidite sequences in Cascadia Channel.

SUMMARY

During the last glacial advance in northwestern Washington and southwestern British Columbia, there was a much higher accumulation rate of sediment in the deep-sea environment off Oregon than there has been since the retreat of the glaciers. The glaciation was probably most intense during the period from about 19,000 years B.P. to about 13,000 years B.P., when the retreat began. There may have been a short transition period which lasted for about 1000 years at the beginning of the retreat when the accumulation rate of sediment was much greater than during the glacial stage or after it. This does not seem unreasonable, since during the initial retreat of the glaciers streams were rejuvenated, and there was an abundant supply of glacially-eroded material. Thus, the supply of terrigenous material to the ocean was at a maximum during the early melting stages of the glaciers and gradually tapered off as the glaciers melted, sea level rose, and streams began to reach equilibrium. Also, the reduction in stream gradients and widening of the continental shelf tended to decrease the amount of sediment reaching the deep-sea environment (Duncan, 1968).

The distribution of calcium carbonate, organic carbon, and quartz with depth in deep-sea sediments has helped to clarify the history of sedimentation during the late Pleistocene and Holocene. Organic carbon and quartz accumulated more rapidly during the late

Pleistocene than during the Holocene, apparently in direct response to the increased sedimentation rates. There are indications that the amount of organic carbon in deep-sea sediments is primarily a function of preservation, but that the depth of burial in the sediment may also be involved. During periods of more rapid sedimentation, there is more organic carbon preserved in the sediment due to a reduced residence time on or near the sediment-water interface. The organic carbon which reaches the deep-sea environment may be largely terrigenous. Most of the organic carbon is found in the < 4 micron size fraction in lower continental slope sediment. In turbidite layers found in a core from West Cascadia Basin, the organic carbon content is highest in the gray clays deposited at the tails of the flow, while the lowest concentrations are found in the silty laminae at the bottom of the flows. Since most of the quartz in deep-sea sediments off Oregon is believed to be terrigenous and has been transported to the sites of deposition by marine processes, it is a good indicator of the intensity of the erosion taking place on land.

The origin of the high amounts of calcium carbonate associated with glacial stages still cannot be demonstrated decisively, but it appears to be the result of a combination of two processes: increased dissolution of calcium carbonate during the interglacials and increased production during the glacials. There is evidence to demonstrate both of these processes in the Atlantic, the Indian, and the Pacific Oceans.

In the late Pleistocene sections off Oregon, the accumulation rate of
calcium carbonate is greater than in the Holocene sections by a factor
that is greater than the change in sedimentation rate. This indicates
that the terrigenous components were diluted during the late Pleisto-
cene by a carbonate-rich component -- probably planktonic foramini-
fera. An investigation of dissolution features on late Pleistocene and
Holocene foraminifera might yield more information about this problem.

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APPENDICES

APPENDIX 1: CORE LOCATIONS

Station	Latitude (north)	Longitude (west)	Water depth (m)	Physiographic environment*
6604-2	43°08. 5'	128°08. 0'	3786	BFZd
6604-3	43°27. 1'	128°11. 1'	3184	BFZt
6609-13	43°07. 2'	127°44. 4'	4016	BFZd
6711-2	42°07. 3'	124°58. 7'	1365	CSv
6808-4	45°09. 6'	129°50. 7'	2700	WCAP
6609-20	43°43. 3'	128°29. 0'	2597	BFZm

*Physiographic environment -- BFZd = Blanco Fracture Zone, depression; BFZt = Blanco Fracture Zone, trough; CSv = Continental Slope, valley; WCAP = West Cascadia Abyssal Plain; BFZm = Blanco Fracture Zone, mountain.

APPENDIX 2: CARBON VALUES (%)

Core	Depth in Core (cm)	Total Carbon	Organic Carbon	Calcium Carbonate	Quartz
6609-13	0	1.012	0.876	1.137	23.826
	20	0.936	0.837	0.825	
	40	0.984	0.876	0.895	22.894
	60	0.975	0.864	0.929	
	80	1.080	0.936	1.195	
	100	1.372	1.054	2.645	22.489
	120	1.508	0.939	4.736	
	140	1.426	0.893	4.444	
	160	1.414	0.782	5.269	22.073
	180	1.158	0.741	3.478	
	240	2.625	0.700	16.035	21.077
	260	1.826	0.584	10.346	
	280	2.028	0.670	11.312	20.843
	340	2.299	0.558	14.502	19.494
	363	1.040	0.536	4.202	
	380	1.340	0.546	6.614	
	400	1.018	0.576	3.678	
	420	0.996	0.590	3.378	
	440	0.801	0.577	1.866	
	460	1.127	0.475	5.431	
	480	0.618	0.514	0.870	
	500	0.693	0.570	1.020	
	520	1.020	0.553	3.886	
	540	0.578	0.483	0.787	
	580	1.136	0.623	4.277	
	600	1.234	0.736	4.144	
	620	1.246	0.592	5.448	
6604-2	0	1.170	0.844	2.711	
	20	1.126	0.890	1.966	
	40	1.075	0.848	1.887	
	60	1.408	0.969	3.653	
	80	1.415	1.004	3.419	
	100	1.574	0.926	5.406	
	120	2.040	0.930	9.246	
	140	2.450	0.920	12.745	
	160	2.774	0.790	16.522	
	180	2.391	0.882	12.566	
	200	2.640	0.740	15.819	

APPENDIX 2. (continued)

Core	Depth in Core (cm)	Total Carbon	Organic Carbon	Calcium Carbonate
6604-2	220	2.210	0.664	12.887
(cont.)	240	1.166	0.582	4.865
	260	1.208	0.592	5.140
	280	1.092	0.618	3.952
	300	1.086	0.583	4.190
	320	1.075	0.580	4.119
	340	1.034	0.558	3.961
	360	1.004	0.533	3.919
6604-3	0	0.892	0.711	1.504
	20	0.447	0.336	0.920
	40	0.728	0.381	2.895
	60	0.830	0.372	3.811
	80	0.765	0.354	3.424
	100	0.764	0.334	3.582
	120	0.750	0.325	3.544
	140	0.754	0.304	3.744
	160	0.719	0.302	3.469
	180	0.726	0.280	3.715
	200	0.624	0.208	3.465
	220	0.586	0.402	1.533
	240	0.631	0.356	2.295
	260	0.556	0.320	1.966
	280	0.606	0.392	1.778
	300	0.694	0.417	2.307
6808-4	6	2.018	0.734	10.687
	36	2.111	0.659	12.095
	59	1.584	0.730	7.105
	82	6.992	0.995	49.959
	84	3.066	1.244	15.181
	104	0.735	0.314	3.503
	120	5.925	0.746	43.145
	123	2.666	0.863	15.023
	141	0.708	0.314	3.290
	156	3.363	0.624	22.816
	195	0.494	0.218	2.299
	237	0.457	0.336	1.012
	279	1.656	0.245	11.749

APPENDIX 2. (continued)

Core	Depth in Core (cm)	Total Carbon	Organic Carbon	Calcium Carbonate
6808-4	321	0.356	0.252	0.862
(cont.)	373	0.497	0.314	1.520
	400	2.494	0.343	17.918
	418	1.928	0.345	13.190
	428	0.720	0.256	3.873
	458	0.620	0.226	3.282
	481	0.482	0.214	2.224
	518	1.606	0.298	10.900
	541	0.470	0.226	2.032
	570	6.558	0.334	51.846
	593	6.403	0.304	50.800
	627	0.790	0.460	2.749
	660	0.669	0.457	1.766
6711-2	19	2.059	1.420	5.323
	41	1.846	1.312	4.444
	60	2.404	1.284	9.330
	122	1.402	0.830	4.756
	154	1.060	0.956	0.620
	175	0.260	1.188	0.596
	200	1.393	1.262	1.091
	240	1.172	1.132	0.342
	350	1.536	1.534	0.017
	410	1.334	1.195	1.158
6609-20	20	5.448	0.254	43.262
	40	4.860	0.294	38.035
	60	3.486	0.264	26.835
	80	4.794	0.229	38.031
	100	3.518	0.196	27.676
	120	1.037	0.262	6.460
	140	1.436	0.282	9.617
	160	0.486	0.300	1.549
	180	0.556	0.339	1.803
	200	0.471	0.272	1.658
	260	0.905	0.310	4.956
	280	2.382	0.314	17.235
	300	4.056	0.302	31.279
	320	5.050	0.226	40.176

APPENDIX 2. (continued)

Core	Depth in Core (cm)	Total Carbon	Organic Carbon	Calcium Carbonate
6609-20	340	0.648	0.220	3.574
(cont.)	375	0.334	0.273	0.512
6706-5	17	1.414	1.356	0.483
	183	0.686	0.474	1.770
	255	0.696	0.533	1.354

APPENDIX 3: SIZE AND CARBON DISTRIBUTION IN 6711-2

Depth in Core (cm)	Size Fraction	Percent of Sediment	Percent of fraction			Percent of sediment		
			Total Carbon	Organic Carbon	Calcium Carbonate	Total Carbon	Organic Carbon	Calcium Carbonate
60	44	14.3	3.127	0.369	22.974	0.448	0.053	3.285
60	44-20	13.5	1.715	0.299	11.795	0.232	0.040	1.593
60	20- 4	32.4	1.029	0.762	2.224	0.334	0.246	0.719
60	4	39.8	2.498	1.824	5.614	0.995	0.724	2.233
122	44	29.4	1.154	0.305	7.072	0.338	0.088	2.078
122	44-20	13.9	1.195	0.266	7.738	0.167	0.038	1.076
122	20- 4	25.2	0.812	0.625	1.558	0.204	0.156	0.393
122	4	31.5	1.775	1.519	2.132	0.561	0.479	0.671
175	44	2.0	2.250	0.654	13.294	0.045	0.013	0.266
175	44-20	15.1	0.467	0.336	1.091	0.071	0.051	0.164
175	20- 4	42.6	0.810	0.756	0.450	0.345	0.324	0.192
175	4	40.3	1.621	1.537	0.700	0.653	0.621	0.282
240	44	2.0	3.905	1.176	22.732	0.078	0.024	0.455
240	44-20	13.6	0.459	0.339	0.700	0.062	0.046	0.095
240	20- 4	44.6	0.831	0.748	0.691	0.370	0.334	0.308
240	4	39.8	2.493	2.290	1.691	0.991	0.911	0.673
350	44	7.4	0.829	0.658	1.424	0.061	0.049	0.105
350	44-20	20.4	0.434	0.362	0.600	0.088	0.073	0.122
350	20- 4	38.4	1.189	1.003	1.549	0.457	0.384	0.595
350	4	33.8	1.505	1.320	1.541	0.507	0.446	0.520

Notes: 1. The size fractions are in microns.

2. The "percent of sediment" carbon values were determined by multiplying the "percent of fraction" carbon values by the percent of the sediment which the size fraction represents.

APPENDIX 4: NATIONAL BUREAU OF STANDARDS SAMPLES

Sample No.	1	2	3	4	5	6	7	8	9	10
Weight	.3044	.3039	.3052	.3122	.3079	.2094	.2102	.2017	.2000	.2048
Digital	.350	.351	.354	.359	.362	.246	.246	.238	.230	.256
% Carbon	1.150	1.155	1.160	1.150	1.176	1.175	1.170	1.180	1.150	1.250

Notes: 1. Standard used was a 1.2% carbon (in steel) sample; the average value supplied with the standard for all types of carbon analyses was 1.208%.

APPENDIX 5: CARBON ANALYSIS METHODS

Sample Preparation

1. Use three to five grams of sediment.
2. Dry at 100°C for 24 hours.
3. Dry-grind to uniform talc-like powder.
4. Shake powder in vial with mixing ball.
5. Weigh out exact amount of powder into Leco crucible; 0.2 grams for total carbon and 0.3 to 0.5 for organic carbon.
6. Moisten with pH neutral distilled water.
7. Dry total carbon samples in 100°C oven for 2 hours before Leco analysis.
8. Leach organic carbon samples of $CaCO_3$ using dilute HCl (1 part HCl in 7 parts H_2O); warm crucibles on 55°C hotplate; add acid dropwise until no reaction is seen, then twice more.
9. Wash organic carbon samples on filter flask apparatus with distilled water.
10. Dry organic carbon samples in 100°C oven for 2 hours before Leco analysis.

Leco Operation

1. Calibrate instrument with 0.081% carbon low standard and 0.866% carbon high standard, as per instructions on instrument.
2. Instrument settings: attenuator = 0, digital = 10.000 scale, grid tap = position 3, oxygen flow = 1.5 liter/minute, oxygen pressure= 4 to 5 pounds.
3. Add 1 scoop each of copper-tin accelerator and iron chip accelerator to crucibles before running.
4. Clean instrument about every 30 samples.

Calculation of Values

1. Total carbon % $= \dfrac{\text{Digital}}{\text{Weight}}$

2. Organic carbon % $= \dfrac{\text{Digital}}{\text{Weight}}$

3. $CaCO_3$ % = (Total carbon % - Organic carbon %) 8.33