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Carbonate Surface Sediments of Tanner and Cortes Banks, California Continental Borderland

by Christine Louise Barton

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CARBONATE SURFACE SEDIMENTS
OF TANNER AND CORTES BANKS,
CALIFORNIA CONTINENTAL BORDERLAND

by

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ABSTRACT

The study of textural and petrographic characteristics of Tanner and Cortes Banks surface samples revealed deposits from 1 to 8 m thick are derived from biological community contributions continuing from 18,000 to 20,000 B.P. low sea level stands through the Holocene Transgression to present. Terrigenous sedimentation occurred primarily during the low sea level stand, with basaltic additions continuing through to present. Surficial debris is composed mostly of coarse bioclasts, with admixtures of Pleistocene and Recent components. Small quantities of micrite are the product of skeletal comminution, and of coccolith and diatom turnover. Strong seasonally alternating currents wash and rework bank top sediments. The occurrences of submarine cementation indicates the existence of local sheltered regions.

A comparison was made of grain size analysis data collected through use of the sieves and of the settling tube. Results indicate that sieve analyses generally produce data indicating a finer mean grain diameter than do settling tube analyses.

INTRODUCTION

Objectives and General Approach

Tanner and Cortes Banks comprise one of the important modern occurrences of shallow carbonate banks on a continental shelf. The presence of these carbonate bank deposits may be attributed to the lack of dilution by terrigenous clastic sediments, which are trapped by the intervening deep basins of the Continental Borderland. Inasmuch as most carbonate sediment is organically produced, it is usually considered to be a product of intrabasinal transport. Information can be gathered concerning primary sites of carbonate production and later paths of transport by examining a combination of textural and compositional data. Unfortunately, due to variances in growth rates, lifespans, and vulnerability to mechanical and biological erosive processes, little can be ascertained regarding the density of organisms in a community from constituent composition (Bathurst, 1975).

In order to more thoroughly describe the calcareous sediments of Tanner and Cortes Banks, the primary objectives of this study are as follows: to specify areal variations in texture; to specify areal variations in calcium carbonate percentages; to correlate texture and petrographic composition; to determine the petrogenesis of the sediments; to describe the controlling factors and present state of depositional conditions. Carbonate sediments were analyzed by sieving and settling tube to determine whether or not significant differences in resultant textural parameters are simply a function of method.

The general approach employed involved determination of textural parameters and of skeletal and lithologic composition for surface samples collected from the banks. If texture and composition are functions of bathymetry on Tanner and Cortes Banks, then an areal plot of mean grain diameters may indicate areal variations in composition. Bottom current and biological data were integrated with obtained data and with postulated Pleistocene sea level changes to determine the Quaternary history of the banks.

Ninety-one splits were taken from samples collected with a Van Veen grab sampler by the U. S. Geological Survey during the May-June 1975 cruise of the R/V VELERO IV, which was led by Greene and others (1975). In addition, 12 surface samples were contributed by divers participating in the Bureau of Land Management August and October 1975 biological study, and another 10 grab samples were obtained from the 1976 Bureau of Land Management cruises of the R/V VELERO IV. Since a large number of samples were available for study, no further sampling plan was devised. Sample locations are shown in Figure 1.

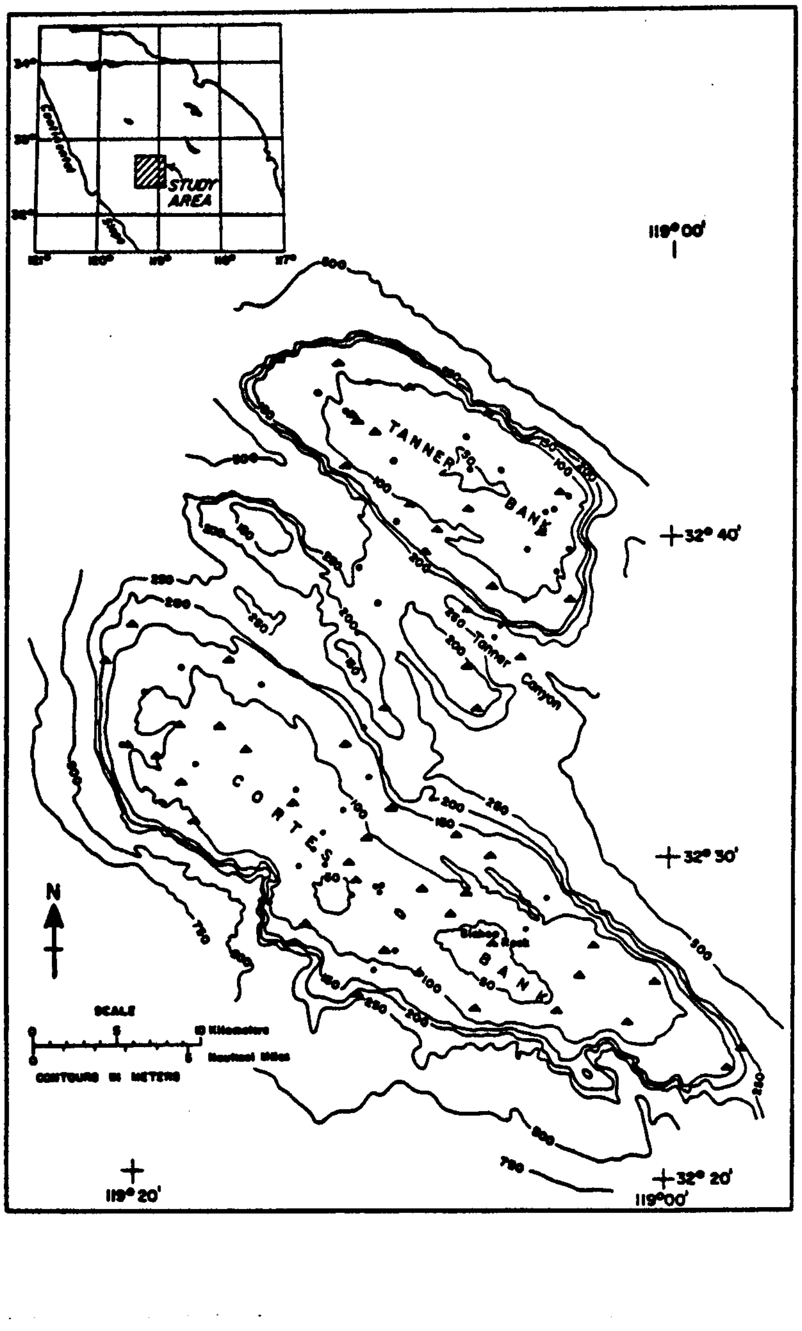
Geologic Setting

Tanner and Cortes Banks are 180 km west of San Diego, California, near the western edge of the Southern California Continental Borderland (Fig. 1). The banks form the southeastern end of the Santa Rosa-Cortes Ridge. The two banks are joined by a shallow saddle-like depression, and have a combined area of 707 square kilometers. The edge of the banks is marked by a break in slope at depths ranging from 110 m to 160 m. The minimum depth above the banks (4 m) occurs at Bishop Rock.

High resolution seismic reflection profiles taken by Greene and others (1975) revealed the geologic structure of Tanner and Cortes Banks in greater detail than had earlier studies (Shepard and Emery, 1941). Although structurally complex, discontinuous en echelon faults and folds trend approximately northwest through the banks. A series of north-trending en echelon folds and faults occur along the northern side of Cortes Bank. The two banks and the intervening saddle are major anticlinal features in Tertiary rocks (Greene and others, 1975).

Topographic highs of Tanner and Cortes Banks are composed primarily of Miocene basalt (Vedder and others,

Figure 1. Index map of Tanner and Cortes Banks showing sample locations. Dots indicate locations of samples analyzed only textually. Triangles indicate locations of samples analyzed both texturally and petrographically.


STUDY AREA
119°00'
TANNER BANK
Tanner Canyon
32°40'
CORTES BANK
Bishop Rock
32°30'
N
SCALE
CONTOURS IN METERS
32°20'
119°20'
119°00'

1974); Greene and others, 1975). Undifferentiated Miocene sedimentary and igneous rocks comprise another large portion of the bank tops. These strata are chiefly shale interlayered with basaltic to rhyolitic rocks (Vedder and others, 1974). Oligocene, Eocene and Paleocene sedimentary rocks of the northwestern ends of the banks are mostly interbedded sandstone and siltstone. The outer portions and slopes of both banks are composed of Miocene claystone and siltstone with lesser amounts of sandstone and conglomerate. Holocene, Pleistocene and Pliocene sediment and sedimentary rock more than 50 m thick are found in the intervening saddle and on the northeastern side of Cortes Bank. This material is chiefly semiconsolidated clay, silt, sand and gravel (Vedder and others, 1974). The bank crests display low to moderate relief, with bedrock ledges and boulder accumulations and patches of unconsolidated sediment. Lower slopes of the bank tops are overlain by sediment layers from 6 to 15 m thick. Thinner accumulations, from 1 to 2 m thick, cover more shallow regions on the bank tops. Wave-cut marine terraces encircle both bank tops, and also appear in seismic records (Greene and others, 1975) on the most northwesterly of the low ridges in the interbanks area. Overlying the destructional terraces are constructional marine terrace deposits of probable Pleistocene age. Terrace widths range from an average value of 0.5 km to as much as 4 km. Greene and others (1975) describe the terrace deposits, on which some profiles exhibit local surface erosion.

Previous Work

Holzman (1952) was the first to study Tanner and Cortes Banks in any detail. From 18 dredges and 48 snapper samples, Holzman dated <u>in situ</u> rocks as Miocene and characterized the surficial sediment patterns, which he concluded were controlled by topography, current activity, and depth of water.

Greene and others (1975), in their environmental investigation of Tanner and Cortes Banks, based their conclusions on high resolution seismic reflection profiles, side-scan sonography, underwater television coverage, and 212 sediment samples. This study revealed bank top sediments from 1 to 15 m thick, which are locally scoured by strong currents. Sediment studies revealed relatively well sorted, coarse bank top sediments resulting from an abundant supply of coarse biogenic debris and current reworking.

A recent biological investigation by Smith (1975) found these two bank top areas to be sites of large biological communities despite existing high energy conditions. These communities must be contributing sediment to lower banks and slopes, because divers participating in the study reported the bank tops to be swept clean of sediment in October of 1975 (Thomas J. O'Neil, personal communication, 1975). Diving was confined to the area above the 80 m contour on Tanner and Cortes Banks, whereas the limiting contour used in this paper is 150 m. The divers' definition of bank tops is clearly more limited than that used in this paper. This second definition includes those regions described by Greene and others (1975) as covered by sedimentary deposits from 1 to 15 m thick.

PROCEDURES AND RESULTS

Sample Preparation

Most samples were washed twice with a 50 percent acetone solution. If a large amount of decaying tissue was present in a sample, an 8 percent hydrogen peroxide solution was used to wash the sample four or five times. Next, all samples were washed two more times with distilled water, dried at 40°C, and carefully disaggregated using a rubber cork. Samples were then split to obtain a weight between 75 and 125 g, using a Sepor mechanical splitter. Wet sieving was unnecessary due to the small weight percent of fines in the samples. Approximately one quarter of the original sample was stored for possible future carbon-14 age determinations, and another one quarter to one-half was archived in the Sedimentary Petrology Laboratory at the University of Southern California.

Textural Analysis

A mechanical sieve shaker was chosen for use in grain size determinations for two reasons. Since composition is often related to grain size, sieving is a convenient method of segregating size fractions for compositional analysis. In addition, settling tube data for U. S. Geological Survey samples were available so the results obtained by the two methods could be compared.

All samples were sieved using a set of screens with mesh openings ranging from 0.062 mm (4.0ϕ) to 5.657 mm (-2.5ϕ) at 0.5ϕ intervals. The pan fraction was designated 0.062 mm to 0.044 mm (4.0ϕ to 4.5ϕ). Each sample was run for 15 minutes using a Fisher-Wheeler mechanical shaker. A Fortran IV computer program was used to plot histograms and to derive weight percent, cumulative weight percent, and standard moment statistics: mean phi diameter, mean mm diameter, phi standard deviation, phi skewness, and phi kurtosis.

Settling tube results acquired from the U. S. Geological Survey for 86 samples were compared to corresponding sieve results by graphical and statistical methods. Values for mean phi diameter, phi standard deviation, phi skewness and phi kurtosis were plotted as paired values in increasing order of settling tube values and of sieve values. No systematic increase or decrease of the difference between settling tube and sieve values can be detected from the plots. Mean size phi values are smaller (coarser) for the sieve results than for the settling tube results for 80 percent of the samples, with differences ranging from 0.93 mm to 0.27 mm. Nine percent of the sample means which differ by more than half a Wentworth size grade can be accounted for by the presence of more than 5 percent gravel in the sample. This coarse material cannot be included for settling tube determinations, resulting in a much finer mean size value for that method than for the use of sieves. The grand mean for the sieve mean sizes is 0.24 mm, and the grand mean for the settling tube mean sizes is 0.20 mm. Thus, the overall mean size is that of fine sand.

Phi standard deviation (sorting) values are larger for sieve data than for settling tube data for all samples. Standard deviation differences range from 0.87ϕ to 0.52ϕ. Only 4 percent of these differences are larger than half a Wentworth size grade, and can be explained by the presence of more than 5 percent gravel in the sample. Means of the sieve and settling tube phi standard deviation values were 0.55ϕ and 0.64ϕ, respectively, indicating moderate sorting (Folk and Ward, 1957). For 64 percent of the samples the skewness values obtained by sieving are smaller than those obtained by settling tube. Differences in paired values vary from 0.00 to 2.45. Seventy-six percent of the sieve skewness values and 62 percent of the settling tube skewness values are negative. Skewness mean values are -0.53 for the sieves and -0.24 for the settling tube, showing a tail or asymmetry in the coarser grain sizes. Sixty-seven percent of the sieve kurtosis values are larger than settling tube values, with a range of differences from 0.00 to

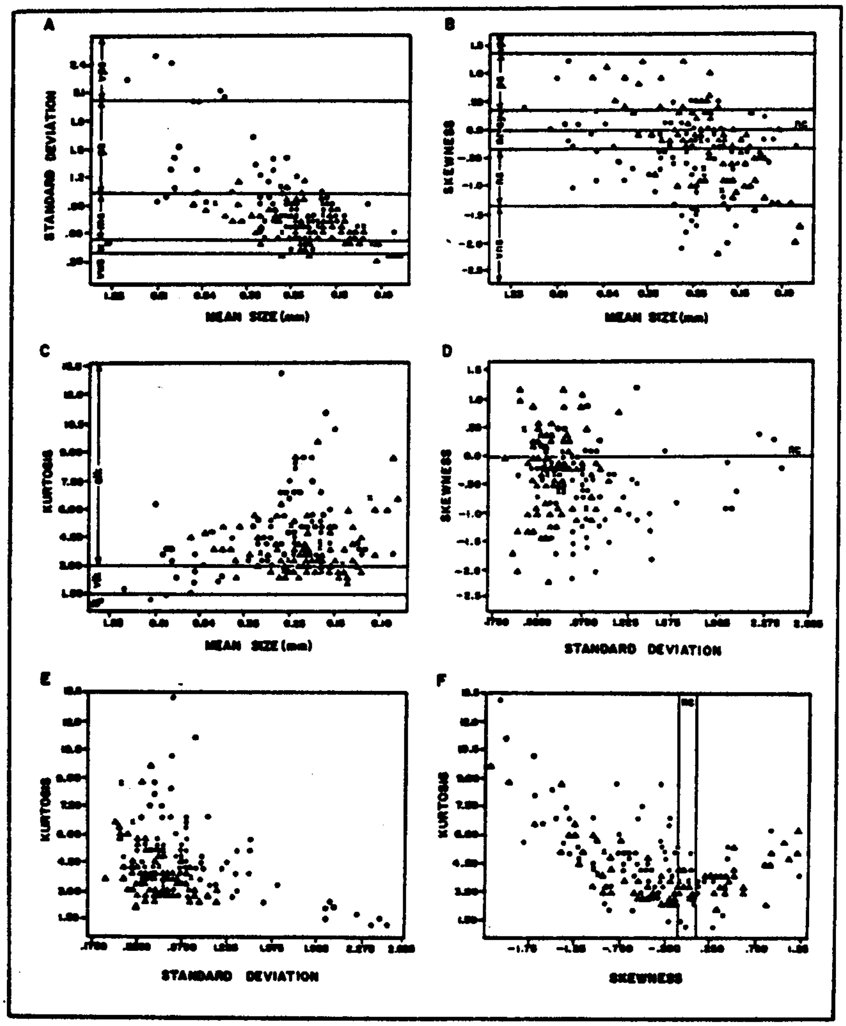
9.82. Sieve and settling tube means are 5.11 and 4.02, respectively. Therefore, the distribution appears to be extremely leptokurtic in the coarse tail.

In order to examine the relationships between the four moment measures, the Biomedical Computer Program (Dixon, 1975) for bivariate plotting was utilized to produce scatter diagrams for all possible pairs of the measures. Figure 2 shows the six resultant plots for both sieve and settling tube values.

Figure 2A shows a decrease in sorting with decrease in size. In this paper any correlation value greater or equal to 0.50 or less than or equal to -0.50 will be considered significant. The correlation between mean grain size and standard deviation for pooled sieving and settling tube values is -0.68. Thus, there exists a moderately negative correlation between these two sets of values. The correlation coefficients for sieve and settling tube data are -0.71 and -0.50, respectively. Figure 2A also shows that most points occur within the moderately-sorted field of Folk and Ward (1957). Sieve data for Figure 2A shows heteroskedasticity.

Mean grain size versus skewness (Fig. 2B) has a low combined correlation coefficient of -0.38, with sieve and settling tube coefficients of -0.34 and -0.63, respectively. Therefore, the settling tube plot shows that negative skewness increases with decreasing grain size. Figure 2B

Figure 2. Bivariate plots of moment measures for sieve and settling tube results. Dots indicate sieve data, triangles indicate settling tube data, x's indicate overlapping data. All labeled fields and normal curve lines from Folk and Ward (1957). A: mean size (mm) versus standard deviation; vws, very well-sorted, ws, well-sorted, ms, moderately sorted, ps, poorly sorted, vps, very poorly sorted. B: mean size (mm) versus skewness; vns, very negatively-skewed, ns, negatively-skewed, nr-sy, nearly symmetrical, ps, positively skewed, vps, very positively-skewed, nc, normal curve. C: mean size (mm) versus kurtosis; lk, leptokurtic, vlk, very leptokurtic, elk, extremely leptokurtic. D: standard deviation versus skewness; nc, normal curve. E: standard deviation versus kurtosis. F: skewness versus kurtosis; nc, normal curve.



A
STANDARD DEVIATION
MEAN SIZE (mm)
B
SKEWNESS
MEAN SIZE (mm)
C
KURTOSIS
MEAN SIZE (mm)
D
SKEWNESS
STANDARD DEVIATION
E
KURTOSIS
STANDARD DEVIATION
F
KURTOSIS
SKEWNESS

also shows the greatest number of values within the negatively skewed boundaries (Folk and Ward, 1957).

Little correlation can be seen in Figure 2C, the plot of mean grain size versus kurtosis. The correlation coefficients are: combined 0.25, sieve data 0.43, settling tube data 0.14. The distribution is extremely leptokurtic.

Little correlation is apparent for standard deviation versus skewness (Fig. 2D), and the distribution varies widely from normalcy (Folk and Ward, 1957). The combined correlation coefficient is -0.06, that for the sieves is 0.03, and that for the settling tube is 0.04.

The correlation coefficients for standard deviation versus kurtosis (Fig. 2E) are -0.34 for the combined plot, -0.52 for the sieve plot, and -0.40 for the settling tube plot. Thus, at least for the sieve data, and crudely for the settling tube data, standard deviation increases with decreasing kurtosis. This appears to be especially true for kurtosis values smaller than 3.00.

Figure 2F, the plot of skewness versus kurtosis, appears to be nonlinear. The increase of skewness with decreasing kurtosis values to a skewness value of 0.00 leads to correlation coefficients of -0.31, -0.58, and -0.41 for combined, sieve, and settling tube plots. The change in direction of the curve occurs in the field of the normal curve, at 0.00 (Folk and Ward, 1957).

Several factors inherent in the subsampling procedure and in the methods used may account for much of the variation of grain size analysis results obtained by sieving and the settling tube. First, 75 to 125 g were used in the sieving procedure, whereas only 1 to 2 g could be used for the settling tube. It is very difficult to split a sample so that the subsample fairly represents the entire sample when the split is as small as 1 to 2 g. This problem is particularly evident when the sample is very coarse, as are a number of the Tanner and Cortes Banks samples.

The irregularity of shapes and variation in density of bioclastic carbonate grains have been found to greatly affect grain-size distribution of hydraulically deposited carbonate sediments (Maiklem, 1968). Actual settling velocities average from 50 percent to 100 percent slower than theoretical velocities determined by grain diameter for material within the 0.25 mm to 0.12 mm size range. For some shapes this difference in actual and theoretical settling velocities increases to over 300 percent for the 6.06 mm size interval. Thus a comparison of two sets of moment results for settling tube and sieving should illustrate these differences.

The largest variations between mean grain sizes for the two procedures are for the 20 percent of the samples shown by sieve analysis to be composed of from 4 percent to 56 percent material larger than 2.00 mm. Maiklem's (1968) conclusions can account for the fact that 80 percent of the settling tube analyses indicate coarser mean sizes than do corresponding sieve analyses. Sixty-two percent of the samples with differences of less than 0.50ϕ differ by less than 0.25ϕ. The remaining 38 percent of the differences lie between 0.25ϕ and 0.50ϕ. Thus, eliminating those samples with more than 4 percent gravel, most of the paired values vary by such small amounts that classification of mean size into size grades from very fine sand to granules would not be greatly affected by the method used. Therefore, even with density and shape effects, mean grain size calculations for the two methods produce much closer results than Maiklem predicts.

Maiklem (1968) stated that because of the influence of shape and bulk density, grain-size distribution data for bioclastic carbonates are of little value. If this were true, sediments from Tanner and Cortes Banks which differ significantly in percentages of various skeletal debris types should produce settling tube grain size results that vary in magnitude of difference between mean grain sizes according to proportions of various skeletal shapes and densities. Possibly, at least for the Tanner and Cortes Banks area, grain size and experimentally derived hydraulic equivalents are comparable.

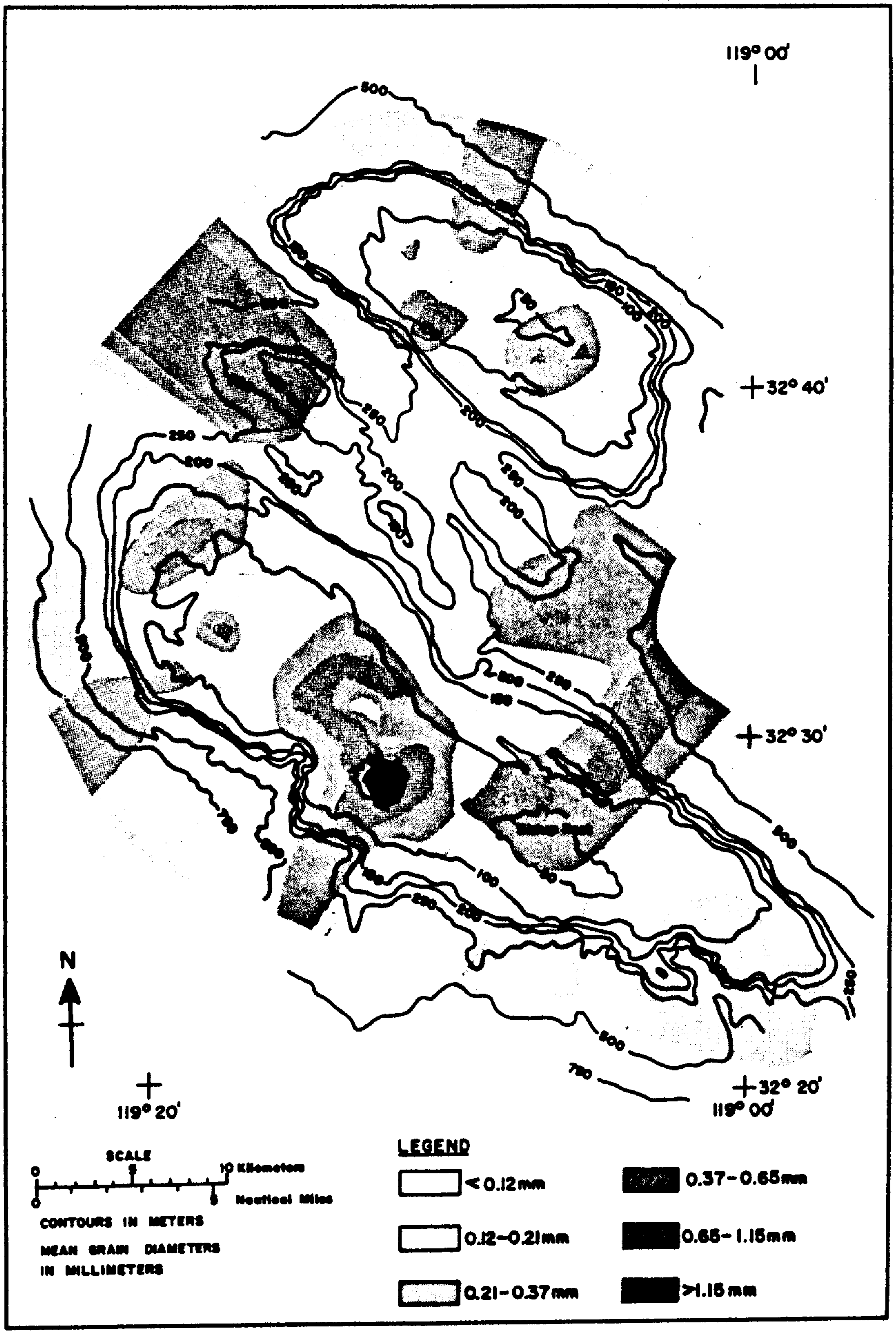
Differences in method may account for the variation of settling tube results in this study from those predicted by Maiklem (1968). In his experiments, carbonate fragments were introduced individually into the water column and velocities for each were calculated. No intergranular effects were examined. For this study a 1 to 2 g split of each sample was used. Thus, as grains dropped through the water they interacted with one another both through direct contact and by creating turbulence in the surrounding water. These interactions may effectively cancel the variations predicted by Maiklem.

The SYMAP (Dougenik and Sheehan, 1975) computer mapping program was used to construct a contour map of mean grain diameter values obtained by sieving. Figure 3 is based upon that computer-generated map. Coarse to very coarse sand (0.50 mm to 2.00 mm) is found primarily on the bank tops at the shallowest depths. There appear to be eight areas of coarse to very coarse sand. Two of these locations are in the shallow portions of Tanner Bank and four are on Cortes Bank high areas. The remaining two locations of coarse sand are in the intervening saddle-like region. However, sample control is poor here and these may be two very small patches of coarse sand.

Lithologic Composition

Two approaches were used to determine the relationship between composition and grain size. After completion of grain-size analyses, 5 samples were selected which

Figure 3. Contour map of mean grain diameters from sieve data for Tanner and Cortes Banks.



119° 00'
32° 40'
32° 30'
32° 20'
119° 20'
119° 00'
500
250
200
100
750
N
SCALE
0
5
10 Kilometers
0
5
Nautical Miles
CONTOURS IN METERS
MEAN GRAIN DIAMETERS IN MILLIMETERS
LEGEND
< 0.12mm
0.12–0.21mm
0.21–0.37mm
0.37–0.65mm
0.65–1.15mm
>1.15mm

represented a range of constituents from 0.88 mm to 5.60 mm. Grain thin sections were prepared from splits from each of the 13 size-fractions represented. In addition, the interval 0.25 mm to 0.35 mm was selected as the size fraction to be analyzed in all samples. This interval was selected because it was represented in all samples and contained most of the lithologic and biological constituents. Fifty-five of the 0.25 mm to 0.35 mm size fractions were selected from samples for petrographic analysis on the basis of areal location (Fig. 1). Thin sections were ground slightly thicker than the usual 30 μ for higher structure and color contrast. A solution of Alizarin red-S with 0.2 percent cold hydrochloric acid was used to stain the sections. This solution stains calcium carbonate red while leaving dolomite colorless (Friedman, 1959).

For most thin sections at least 300 grains were identified using the line method as described by Galehouse (1971). For some of the coarser-size intervals, significantly fewer than 300 grains were present, therefore all grains were counted. Based on the assumption that each thin section is representative of the size fraction from which it is split, identification of 300 grains will produce a number frequency value within 6 percent of the true number frequency at the 95 percent confidence level (van der Plas and Tobi, 1965). Since the samples were segregated into size fractions for petrographic study, grain cross-sectional areas may be considered roughly equivalent. Therefore, number frequency may be considered equal to area percentage (Galehouse, 1971).

Identification of carbonate skeletal fragments was based upon criteria set forth by Horowitz and Potter (1971) and Majewske (1969). Quartz grain classification was taken from Blatt and others (1972).

Approximate volumetric composition diagrams were constructed for the 5 analyses of 13 size fractions. Three of these diagrams are shown in Figure 4. Field areas are approximately proportional to the volumes of the constituents in the sample. Table I contains weight percentages to accompany fields shown in Figure 4. The petrographic results are listed in Table II.

A few general relationships between composition and grain size can be seen in Figure 4 and in Table I. The highest percentages of bryozoan fragments occur in the coarse to very coarse sand fractions, between 0.50 mm and 2.00 mm, and range from 61.3 percent in the 1.00 mm to 1.41 mm interval to 0.0 percent in the coarser than 5.66 mm interval. Very few coral fragments are present, but the highest percentage of 3.4 percent occurs in the 2.83 mm to 4.00 mm fraction. The fractions finer than 1.41 mm contain no identifiable coral fragments. The codiacean and dasycladacean algae are most abundant in the very fine sand interval, less than 0.18 mm with a maximum percent composi-

Figure 4. Composition of three surface samples from Tanner and Cortes Banks. Width of each field represents the proportion of each constituent in a particular size fraction. Height of each band represents the percentage of the total sample present in each size fraction. Size fractions designated are: A, greater than 5.66 mm; B, 4.00 mm to 5.66 mm; C, 2.83 mm to 4.00 mm; D, 2.00 mm to 2.83 mm; E, 1.41 mm to 2.00 mm; F, 1.00 mm to 1.41 mm; G, 0.71 mm to 1.00 mm; H, 0.50 mm to 0.71 mm; I, 0.35 mm to 0.50 mm; J, 0.25 mm to 0.35 mm; K, 0.18 mm to 0.25 mm; L, 0.12 mm to 0.18 mm; M, 0.09 mm to 0.12 mm. Constituents designated are: a, bryozoan grains; b, coral grains; c, codiacean algae grains; d, dasycladacean algae grains; e, echinoderm grains; f, foraminifera; g, mollusc grains; h, pelmatazoan grains; i, calcareous sponge spicules; j, siliceous sponge spicules; k, limeclasts; l, intraclasts; m, monocrystalline quartz; n, polycrystalline quartz; o, chert; p, potassium feldspar; q, plagioclase feldspar; r, basalt fragments; s, collophane. Table I contains weight percentages for the fields.

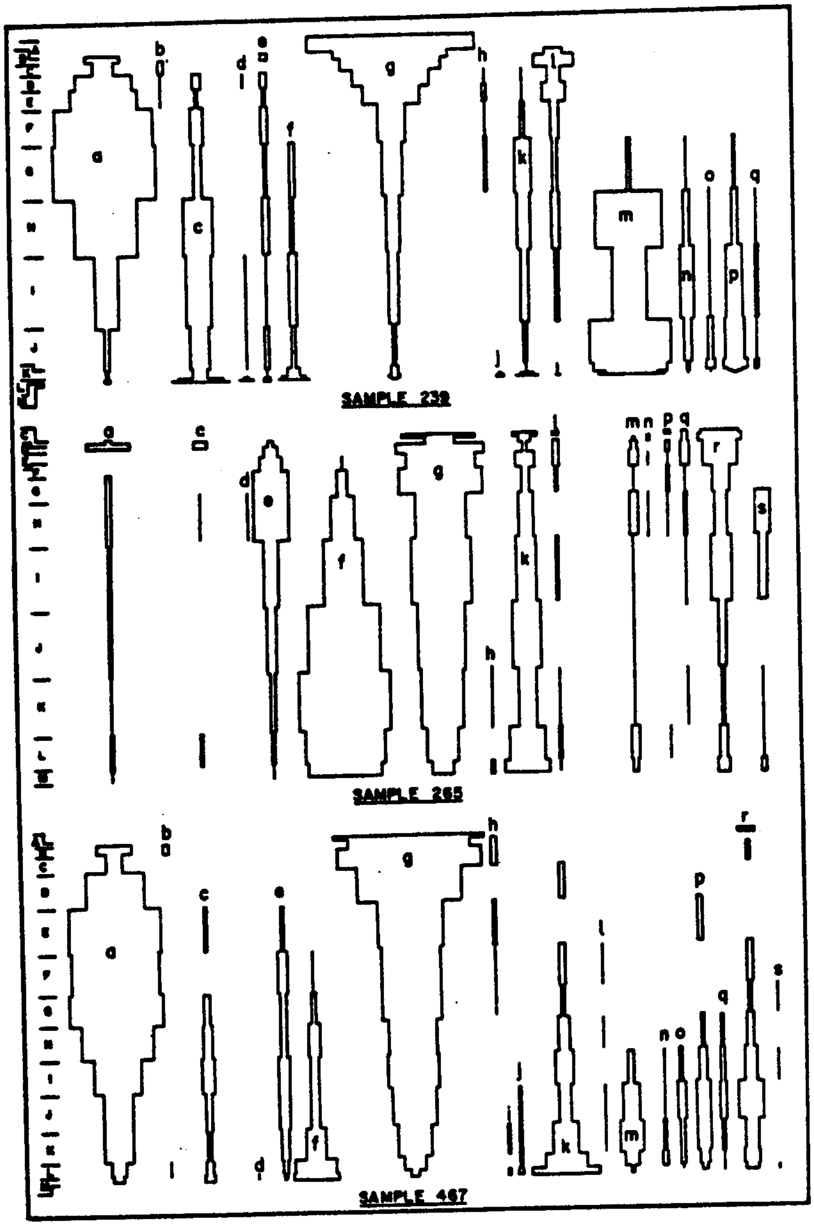

SAMPLE 239
SAMPLE 265
SAMPLE 467

Table I. Size interval and component weight percentages for 5 sediment samples.

Sample numbers	239	265	368	395	467
Size intervals					
Greater than 5.66 mm	4.7	-*	-	-	2.0
4.00 mm to 5.66 mm	1.8	-	1.1	-	2.6
2.83 mm to 4.00 mm	3.6	1.0	3.6	-	5.6
2.00 mm to 2.83 mm	4.6	1.9	7.9	0.7	10.0
1.41 mm to 2.00 mm	5.7	3.1	8.0	0.8	13.4
1.00 mm to 1.41 mm	10.4	4.4	7.8	1.3	12.1
0.71 mm to 1.00 mm	16.0	7.4	11.7	3.2	9.3
0.50 mm to 0.71 mm	16.4	13.0	16.9	5.9	9.8
0.35 mm to 0.50 mm	21.1	19.0	17.5	13.7	10.0
0.25 mm to 0.35 mm	12.3	19.2	14.0	23.2	11.0
0.18 mm to 0.25 mm	2.7	17.6	7.5	28.0	9.0
0.12 mm to 0.18 mm	0.6	9.4	2.9	17.1	4.2
0.09 mm to 0.12 mm	0.2	4.1	0.9	6.1	1.8
Constituents					
Bryozoan fragments	30.1	1.3	3.8	13.3	34.4
Coral fragments	0.2	-	-	-	tr**
Coadiacean algae	1.0	0.3	1.5	1.4	2.3
Dasycladacean algae	0.2	tr	0.1	0.1	tr
Echinoderm fragments	1.6	6.8	1.9	1.2	3.6
Foraminifera	1.7	30.8	2.1	28.9	4.8
Mollusc fragments	19.2	30.8	17.4	13.5	35.9
Pelmatazoan fragments	0.4	-	0.1	1.1	0.5
Calcareous sponge spicules	-	-	-	-	0.1
Siliceous sponge spicules	tr	0.1	tr	0.2	0.3
Limeclasts	4.8	12.9	6.1	20.3	5.9
Intraclasts	3.7	0.7	1.7	0.9	0.2
Monocrystalline quartz	14.8	1.9	6.9	3.1	3.1
Polycrystalline quartz	3.0	0.1	1.0	0.3	0.3
Chert	0.8	-	3.1	1.1	0.8
Potassium feldspar	4.4	0.3	18.4	5.6	3.0
Plagioclase feldspar	0.3	0.6	6.2	2.3	0.8
Basalt fragments	0.9	7.8	28.6	2.2	4.5
Collophane	-	2.1	0.5	3.3	0.1

* 0.0 percent.
** Between 0.0 percent and 0.1 percent.

Table I. Size interval and component weight percentages for 5 sediment samples (continued)

<u>Sample locations</u>

239 - Tanner Bank top, western end.
265 - Cortes Bank, between 100 and 150 m contour, northern end.
368 - Cortes Bank top, middle southern area.
395 - Cortes Bank, between 100 and 150 m contour, northern middle.
467 - Tanner Bank, top middle.

Table II. Range and mean percentages for components from point count data for all grain thin sections.

Components	Low	High	Mean	Standard Deviation	Standard Error of Mean
Bryozoan fragments	0.0	61.3	9.4	15.0	1.4
Coral fragments	0.0	3.4	0.1	0.4	0.0
Coadiacean algae	0.0	43.0	5.6	9.1	0.8
Dasycladacean algae	0.0	17.3	1.4	3.3	0.3
Red algae	0.0	4.6	0.1	0.5	0.0
Echinoderm fragments	0.0	22.0	3.4	4.3	0.4
Foraminifera	0.0	81.7	16.8	19.2	1.8
Mollusc fragments	0.0	100.0	16.0	19.5	1.8
Pelmatazoan fragments	0.0	7.6	0.4	1.0	0.1
Calcareous sponge spicules	0.0	0.7	0.0	0.1	0.0
Siliceous sponge spicules	0.0	3.3	0.2	0.5	0.0
Limeclasts	0.0	66.3	11.3	11.7	1.1
Intraclasts	0.0	23.7	1.4	3.3	0.3
Highly iron oxide stained clasts	0.0	25.4	0.7	3.3	0.3
Straight monocrystalline quartz	0.0	31.3	3.4	5.7	0.5
Undulose monocrystalline quartz	0.0	22.3	2.4	4.1	0.4
Polycrystalline quartz with <5 subcrystals	0.0	5.7	0.4	0.8	0.1
Polycrystalline quartz with ≥ 5 subcrystals	0.0	2.7	0.2	0.4	0.0
Chert	0.0	10.7	1.1	2.1	0.2
Potassium feldspar	0.0	50.0	7.0	9.5	0.9
Plagioclase	0.0	11.7	1.7	2.5	0.2
Epidote	0.0	4.3	0.2	0.7	0.1
Magnetite	0.0	1.1	0.0	0.1	0.0
Muscovite	0.0	14.3	0.7	2.3	0.2
Zircon	0.0	2.3	0.0	0.2	0.0
Unidentified minerals	0.0	6.0	0.2	0.8	0.1
Basalt	0.0	73.3	8.0	14.6	1.3
Limestone	0.0	1.8	0.0	0.2	0.0
Siltstone	0.0	8.0	0.9	1.6	0.1
Sandstone	0.0	8.0	0.4	0.9	0.1
Unidentified rock fragments	0.0	10.0	0.2	1.0	0.1
Collophane	0.0	38.7	1.4	4.1	0.4
Glauconite	0.0	1.7	0.2	0.2	0.0

tion of 33.2 percent. Coarse fractions contain little algae. Red algae is most abundant (4.6 percent) in the coarse to very coarse sand fraction (0.71 mm to 2.00 mm). Red algae apparently is absent in the fractions finer than 0.71 mm. The greatest quantities of echinoderm grains, up to 21.3 percent, are in the coarse sand range from 0.50 mm to 1.00 mm with diminishing numbers as low as 0.0 percent in the coarser and finer fractions. Benthic and planktonic foraminifera increase from 0.0 percent in the coarse intervals up to 55.2 percent in the fine to very fine sand of 0.09 mm to 0.25 mm. Mollusc fragments follow an inverse trend to the foraminifera, ranging from 100.0 percent in the pebbles to coarse sand (0.71 mm to 5.66 mm) down to 0.0 percent in the very fine sand (0.09 mm to 0.18 mm).

Pelmatazoans reach a maximum percentage of 7.6 percent in the granule to coarse sand fraction (0.71 mm to 2.00 mm) and a low of 0.0 percent in the fine to very fine sand fraction (0.09 mm to 0.12 mm). Limeclasts which are unidentifiable due to the absence of visible microstructure range from 0.0 percent in the pebbles (4.00 mm to 5.66 mm) to 40.7 percent in medium to very fine sand (0.09 mm to 0.35 mm).

Trends also occur among the non-carbonate clastics. Monocrystalline quartz ranges from 49.0 percent in the fine- to medium-sand interval (0.18 mm to 0.35 mm) to 0.0 percent in the pebble and granule interval (2.83 mm to

5.66 mm). Potassium feldspar increases from 0.0 percent for pebbles (4.00 mm to 5.66 mm) to 23.7 percent for fine to very fine sand (0.09 mm to 0.18 mm). Basalt fragments constitute up to 66.3 percent for pebbles through very coarse sand (1.00 mm to 4.00 mm) and are least abundant for medium through very fine sand (0.09 mm to 0.25 mm).

Intraclasts compose up to 23.7 percent of the pebble through very coarse sand interval (1.41 mm to 4.00 mm) and occur least often in fine and very fine sand (0.09 mm to 0.18 mm).

With the exceptions of mollusc fragments, foraminifera, limeclasts, potassium feldspar, and intraclasts, the trends described above are approximate and are not always present for the 5 samples. The trends that are seen probably reflect the varying resistance of skeletal types to mechanical and biological erosion. For example, although corals are not well represented at the petrographic scale in these sediments, there is a reasonably large population of <u>Allopora</u> on the banks (Smith, 1975). Thus, the skeletal structure of this coral is not very resistant so that the skeletal material is quickly reduced to silt. Another possibility is that the life span of <u>Allopora</u> is long and therefore sediment contribution is relatively low. Molluscs and foraminifera contribute breakage-resistant chambered and arcuate skeletal debris. Therefore, these two bioclastic types are most abundant in the size intervals of fine to very fine sand which correspond to their life form sizes. Molluscs predominate in the coarse divisions and foraminifera in the fine. The algal types are of segmented, branching, and encrusting skeletal structures. The segmented skeletons of Halimeda contribute medium to fine sand-sized sediment and the branching and encrusting algae add to the coarser sizes. Bryozoans are well-calcified branching organisms and therefore provide coarse, resistant bioclasts. Echinoderms are also sand donators (Wilson, 1975).

Carbonate clasts with no discernible microstructure appear most often in the fine to very fine sand range because, as the clasts become smaller, the internal structures become more difficult to see. Limeclasts may, in part, simply reflect the imperfections of optical microscopy.

Intraclasts are particles derived by breakage of penecontemporaneously deposited carbonate sediment within a depositional basin. The probable reason for the recognition of a large number of intraclasts in the coarse size fractions is that the fragments break down into their constituent components at smaller sizes.

Several statistical tests were run on the data obtained by modal analysis for the 0.25 mm to 0.35 mm size fraction. Biomedical Computer Programs (Dixon, 1975) were used for missing value correlation, multivariate factor analysis, and multivariate cluster analysis.

Estimates of correlations among compositional variables were calculated using all existing pairs of values. The same levels of significance cited earlier in this paper were considered in examining the resultant correlation coefficients. From among those coefficients lying within the significance ranges, only the relationships with reasonable geological explanations are considered. These product-moment correlation coefficients are shown in Table III.

Dasycladacean and codiacean algae show a coefficient of 0.68, which is explicable since both are erect, segmented calcareous algae, which often occur together on Tanner and Cortes Banks. The only other bioclastic constituents which appear to occur together are siliceous and calcareous sponge spicules, with a correlation of 0.58. This association may also be explained by the similarity of size and shape, with these two clast types being selectively sorted by currents.

Among the terrigenous clastics, monocrystalline quartz with both straight and undulose extinction are moderately to highly correlated with several constituents. Straight-extinction monocrystalline quartz is correlated with polycrystalline quartz both with fewer than five subunits and with five or more subunits. Perhaps this indicates that the monocrystalline quartz and polycrystalline quartz are products of the breakdown of a common or similar

Table III. Correlation coefficients for compositional constituents.

	A	B	C	D	E	F	G	H	I
J	0.68								
K		0.58							
C				0.77					
E			0.76	0.62					
F			0.56		0.61				
G			0.52	0.56					
L			0.55				0.81		
M			0.82	0.64	0.66	0.52			
N								0.53	
O									0.83

A Dasycladacean algae
B Siliceous sponge spicules
C Straight monocrystalline quartz
D Undulose monocrystalline quartz
E Polycrystalline quartz with <5 subcrystals
F Polycrystalline quartz with ≥ 5 subcrystals
G Chert
H Plagioclase
I Collophane
J Codiacean algae
K Calcareous sponge spicules
L Potassium feldspar
M Siltstone
N Basalt
O Glauconite

source rock. In addition, monocrystalline quartz occurs with chert, potassium feldspar, and siltstone. There are several possible explanations for the association of these five constituents. Sandstones and siltstones of Pliocene through Paleocene ages underlie bank top sediments. Thus, these terrigenous clastics might be products of erosion of these strata. An alternative hypothesis is that the terrigenous clastics were derived from the adjoining Santa Rosa-Cortes Ridge during the Pleistocene lower stands of sea level. Strata similar to those cited above would have been exposed along the ridge northwest of Tanner and Cortes Banks. A third possibility is that during the Pleistocene lower sea level stand, fluvial and shallow marine conditions may have prevailed in this area. If these conditions did exist, then the siltstone and other terrigenous clastics may be intraclasts derived from reworking of resultant fluvial and shallow marine deposits.

An association between plagioclase and basalt is again a genetic one. Larger basalt clasts contain high percentages of plagioclase. Thus, the plagioclase clasts are probably products of the mechanical breakdown of basalt.

The correlation coefficient for collophane and glauconite is very high. This relationship appears to reflect their erosion from the same unit.

Another type of statistical analysis performed with results from modal analysis was a multivariate factor analysis. Factor analysis provides a means of isolating and identifying theoretical natural factors which account for much of the observed variance and specifies the relative importance of each cause for each variable. Osborne (1967) describes the steps followed in the derivation of factor loadings. The first nine of the thirty-three extracted factors account for 74 percent of the variance in the petrographic data. Only factor loadings with values less than or equal to -0.50 and greater than or equal to 0.50 were included when considering the interpretation for each factor. Table IV shows the important factor loadings. Only the first three factors account for sufficient variance to merit interpretation.

Factor 1 accounts for 20 percent of the total variance. As seen in Table IV, the variables with high positive values included in this factor grouping are, with the exception of plagioclase, the same as those inorganic groupings discussed in the correlation analysis. This listing supports the earlier discussion of possible common sources. These constituents are mutually exclusive with echinoderm grains and foraminifera, indicating that when the inorganic percentages are high, these bioclasts are less abundant. This relationship represents the dilution of organic components by inorganic clasts or reflects the intrabasinal and extrabasinal contributions to resultant

Table IV. Unrotated factor loadings.

Variables	Factors 1	2	3	4	7	9
Straight monocrystalline quartz	0.70					
Undulose monocrystalline quartz	0.85					
Polycrystalline quartz with <5 subcrystals	0.71					
Polycrystalline quartz with ≥ 5 subcrystals	0.66					
Chert	0.78					
Potassium feldspar	0.87					
Plagioclase feldspar	0.59					
Siltstone	0.71					
Echinoderm grains	-0.51					
Foraminifera	-0.61					
Codiacean algae		0.71				
Dasycladacean algae		0.61				
Sandstone		0.56				
Collophane			0.63			
Glauconite			0.65			
Siliceous sponge spicules			-0.50			
Calcareous sponge spicules			-0.63			
Bryozoan grains			-0.56			
Intraclasts				0.64		
Epidote					0.74	
Zircon						0.57

sediment.

Of the significant variables for Factor 2, codiacean and dasycladacean algae have been discussed. The relationship of sandstone fragments to the green algae is not clear, unless sandstone provides a substrate for attachment. Factor 2 explains 12 percent to the total variance.

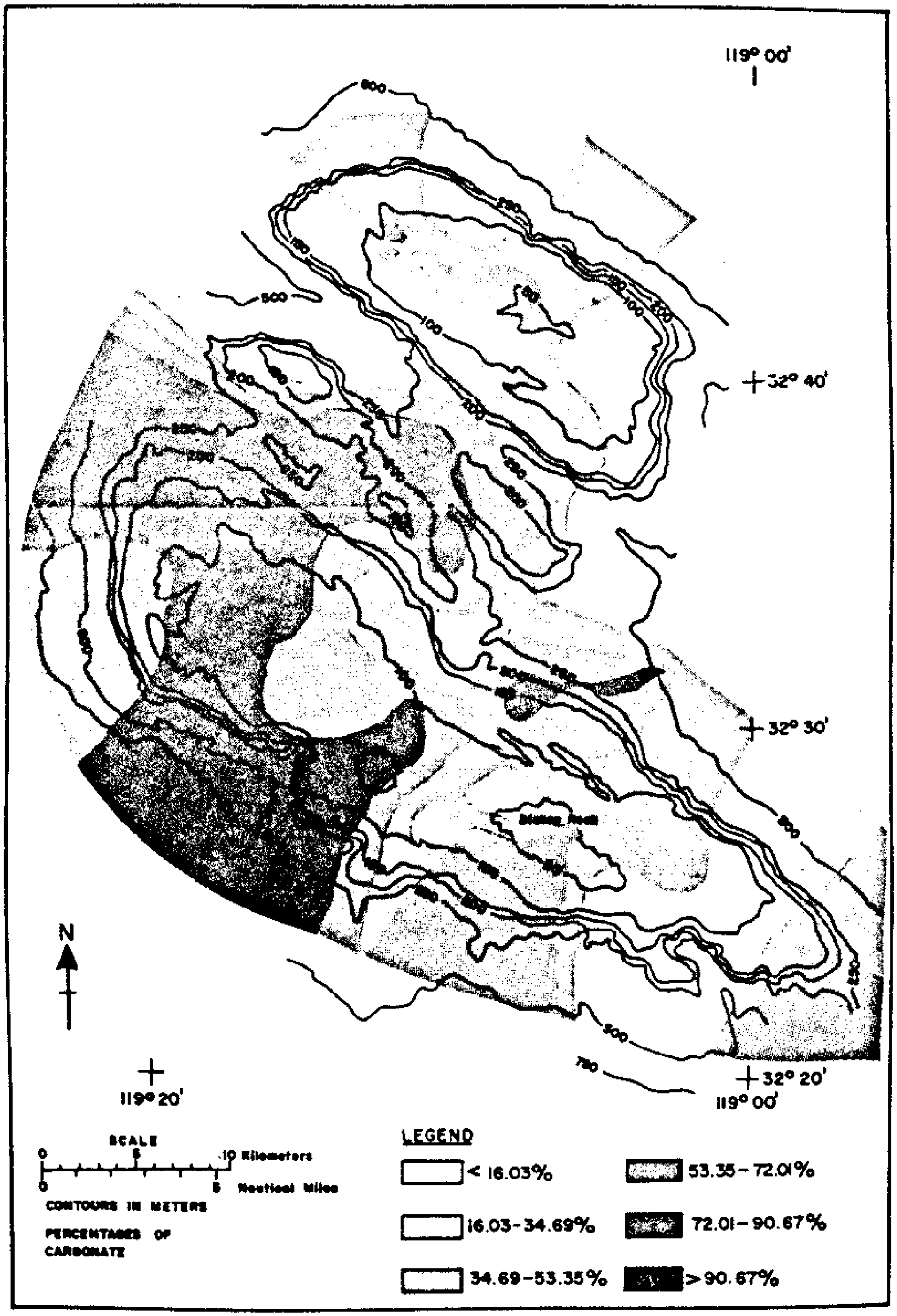
The collophane-glauconite relationship is supported by Factor 3, as is the siliceous and calcareous sponge spicule association. The authigenic minerals occur in mutual exclusion to the spicules plus bryozoan fragments, perhaps reflecting separate locales for terrigenous and organic sedimentation. Eight percent of the total variance is explained by this factor.

The last statistical test which was performed on the petrographic data was a multivariate cluster analysis of samples. The purpose of this analysis was to group samples on the basis of similar composition. These samples were clustered and then plotted on the bathymetric map to recognize the degree of areal grouping of the clusters. Although compositional clusters were identified, members of each of the groups were highly scattered about the banks area. Thus, it seems that composition varies widely and perhaps unsystematically in the Tanner and Cortes Banks region.

Inasmuch as trends for composition versus grain size are obscure, no extrapolation can be made for areal compositional patterns from the grain size contour map. However, two more series of calculations were performed with the petrographic data with results which are helpful in the search for sources. Total percent of bioclastic fragments was computed for the 0.25 mm to 0.35 mm interval of all samples. SYMAP (Dougenik and Sheehan, 1975) was used to generate the contour map shown in Figure 5. Distinct trends appear on this map. A large area of greater than 90.67 percent carbonate is evident on Cortes Bank top and in the saddle lying between Cortes and Tanner Banks, with a smaller elongate zone of greater than 90.67 percent organic debris on the northeastern bank slope of Cortes Bank. Localized areas of between 81.34 percent and 90.67 percent carbonate are found on Tanner Bank top. Lowest percentages of skeletal debris, of less than 25.36 percent lie slightly to the northwest of Bishop Rock and as a band across the southeastern portion of Cortes Bank. On Tanner Bank, the low carbonate regions are again patchy and cover a large part of the southeastern end of the bank and its slopes. A rather large patch of largely terrigenous clastic sediment lies in the middle northern saddle area toward Tanner.

When this map is superimposed on the mean grain size contour map (of Fig. 3), a few likely carbonate-contributing source regions appear. The bank top portion of the large greater than 90.67 percent carbonate area is

Figure 5. Contour map of carbonate percentages for Tanner and Cortes Banks.

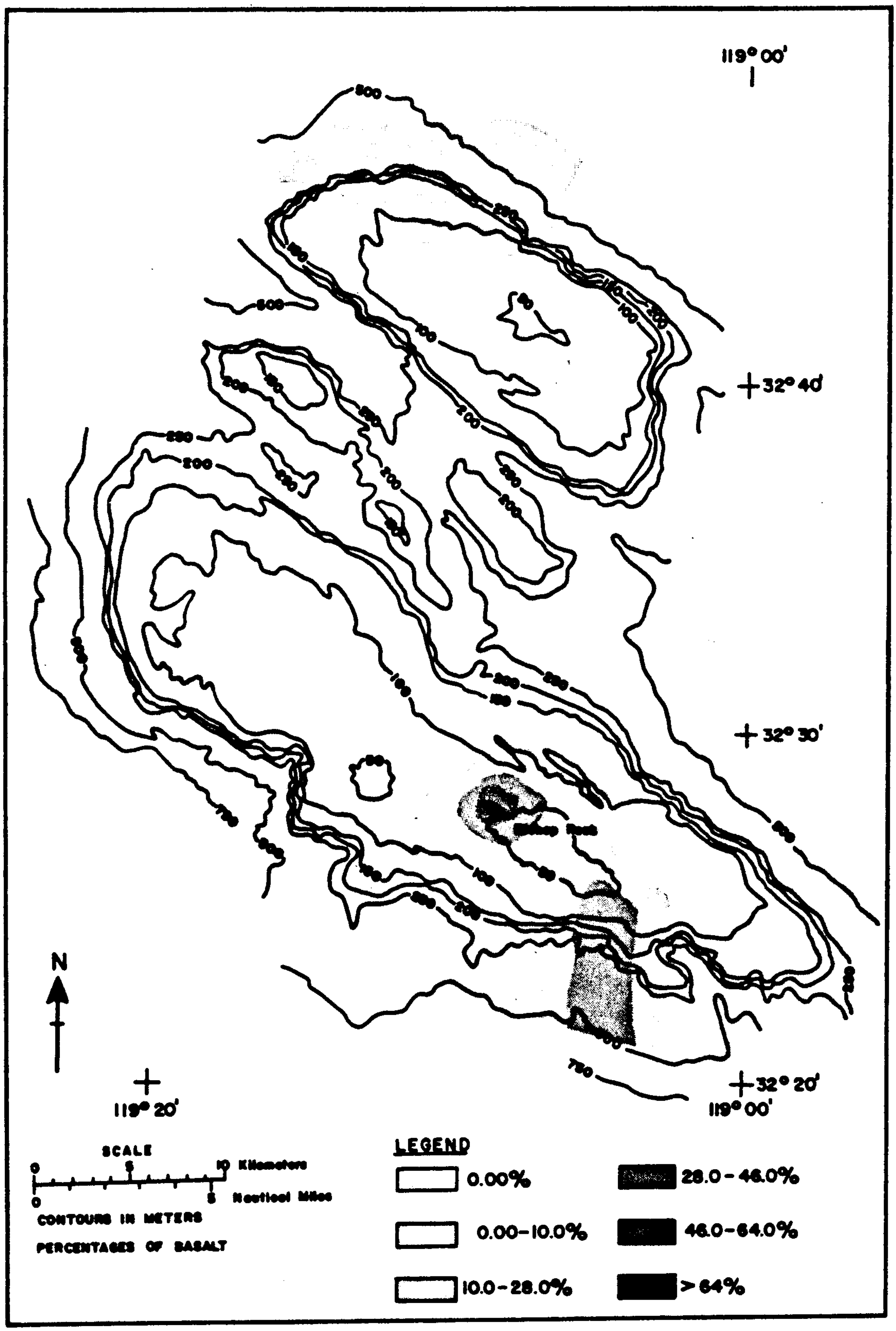


119° 00'
32° 40'
32° 30'
32° 20'
119° 20'
119° 00'
N
SCALE
0
5
10 Kilometers
0
5
Nautical Miles
CONTOURS IN METERS
PERCENTAGES OF CARBONATE
LEGEND
< 16.03%
16.03-34.69%
34.69-53.35%
53.35-72.01%
72.01-90.67%
> 90.67%

also the site of coarse carbonate debris. The patch of sediment containing from 81.34 percent to 90.67 percent carbonate lying near the 50 m contour on Tanner Bank comes close to overlapping two very coarse-grained sediment deposits. This second region also lies very close to the region above the 50 m contour described by Smith (1975) as a productive biological area.

Another set of computations of percent basalt fragments was made. SYMAP (Dougenik and Sheehan, 1975) was employed to create a contour map of basalt fragment percentages (Fig. 6). This map distinctly shows the region immediately west of Bishop Rock as the dominant source of basalt clasts. Many areas totally lacking in basalt are evident which overlap high carbonate percentage areas. The only other locale having greater than 19 percent basalt clasts is on the northern slope of Tanner Bank, where another basalt source probably exists. Inasmuch as this map was constructed using percentages obtained by examining the 0.25 mm to 0.35 mm intervals only, the map does not show areal changes in clasticity of the basalt fragments. From examination of the bulk samples with relationship to their locations, clasticity of basalt fragments was estimated. It appears that coarse basalt clasts (pebbles and granules) are scattered and intermixed with finer basalt clasts (coarse to fine sand) in the banks area, indicating that selective sorting by currents has altered any system-

Figure 6. Contour map of basalt clast percentages for Tanner and Cortes Banks.



119° 00'
32° 40'
32° 30'
32° 20'
119° 20'
119° 00'
N
SCALE
0 5 10 Kilometers
0 5 Nautical Miles
CONTOURS IN METERS
PERCENTAGES OF BASALT
LEGEND
0.00%
0.00-10.0%
10.0-28.0%
28.0-46.0%
46.0-64.0%
> 64%

atic trend of increasing coarseness toward the source which may have existed. Another possibility is that the pebbles and granules represent lag deposits.

Biological Community Sediment Contributions

Smith (1975) found a large, healthy, and diverse marine community on Tanner and Cortes Banks. Greatest diversity and density were discovered above the 50 m contour on Tanner Bank, and above the 50 m contour around Bishop Rock and the other shallow portion of Cortes Bank. From the 173 species listed by Smith for the extant biologic communities, the following eight organisms are probable major sediment contributors (Smith, 1976, personal communication): (1) the hydrozoan Allopora californica (Cortes Bank), (2) the anthozoan Balanophyllia elegans (both Tanner and Cortes Banks), (3) the anthozoan Paracyathus stearnsii (both banks), (4) the gastropod Calliostoma annulatum (Tanner Bank), (5) the gastropod Cypraea spadicea (Tanner Bank), (6) the gastropod Pedicularia californica (Tanner Bank), (7) the coralline algae Calliarthron sp. (Cortes Bank), (8) the coralline algae Lithothamnium proboscideum (Tanner Bank). Other hypothetical introducers of resistant debris from the list are siliceous and calcareous sponge species, pectin species, echinoderm species, and the dasyclad algae Heterosiphonia erecta. The basis for inclusion of species in the second group is simply the existence of this type of grain in the surface samples examined. THis evidence supports the contention that the shallow portion of Tanner Bank and unnamed shallow location on Cortes Bank are modern sources of organic debris for bank deposits.

Micrite Genesis

In order to cover the full textural range of Tanner and Cortes carbonate composition, scanning electron microscopy was used to examine the very fine-grained sediment. Micrite, or clay-sized carbonate, has been given various limiting sizes beginning with Folk's (1959) 1 to 4 μ range. As Bathurst (1975) noted, the 4 μ break is taken from the Udden-Wentworth scale which was created for use with terrigenous clastics. This fine-grained carbonate ranges across the 4 μ boundary so that the cutoff has little meaning when speaking of micrite genesis.

The origin of micrite is controversial, and it is most likely polygenetic. In thin section the grains appear generally equant and irregularly rounded (Pettijohn, 1975); however, scanning electron microscopy, as performed by Matthews (1966), Steiglitz (1972), and Lobo and Osborne (1973) revealed grain shapes and fabrics which appeared diagnostic of biogenic origin. From examination of pulverized carbonates of known biogenic origin, Lobo and Osborne (1973) observed fibrous, lamellar or platy structures associated with finely comminuted skeletal material.

In this study, extremely small quantities of silt- and clay-sized carbonate were available for examination. Therefore, three size ranges greater than 4 μ were separated along with the 4 μ interval for 5 samples. Pipette analysis was used to retrieve sample material at the 44.2 μm, 15.6 μm, 7.8 μm and 3.9 μm sizes from samples wet sieved through a 62 μm mesh screen. The pipette samples were then dried at 40°C and prepared for scanning electron microscopy. A small amount of black paint was spread on a disc-shaped metal mount. Then, as the paint began to dry, surface tension developed which held the micrite as it was strewn upon the paint as uniformly as possible. This type of mount produced a contrasting background for viewing the light-colored micrite. Each sample was then placed in a vacuum and coated with a very thin layer of Au-Pd. A Cambridge Stereoscan S4-10 Scanning Electron Microscope of the University of Southern California Engineering Department was used to examine all samples. Photomicrographs were taken at magnifications ranging from 2,000X to 20,000X.

Figures 7 and 8 illustrate the range of features observed in the samples. Five recognizable coccoliths occur among the generally fibrous and lamellar skeletal debris in Figure 7A. These were identified and dated by John McRaney (personal communication, 1976) as (a) <u>Emiliania</u>

Figure 7. Scanning electron microscope photomicrographs of micrite from Tanner and Cortes Banks. A: (a) Emiliania huxleyi, (b) Coccolithus pelagicus, (c) Cyclococcolithina leptopora, (d) Helicopontosphaera kamptneri, (e) Coccolithus pelagicus. B: (a) fragment with platy structure, (b) coccolith, (c) coccolith. C: (a) coccolith, (b) pinnate diatom fragment. D: (a) fragment with platy structure, (b) possible diatom fragment. E: (a) possible sponge spicule, (b) shell fragment with punctae, (c) fragment with lamellar structure, (d) coccolith. F: (a) coccolith, (b) fragment with platy structure, (c) fragment with fibrous structure, (d) punctate shell fragment.

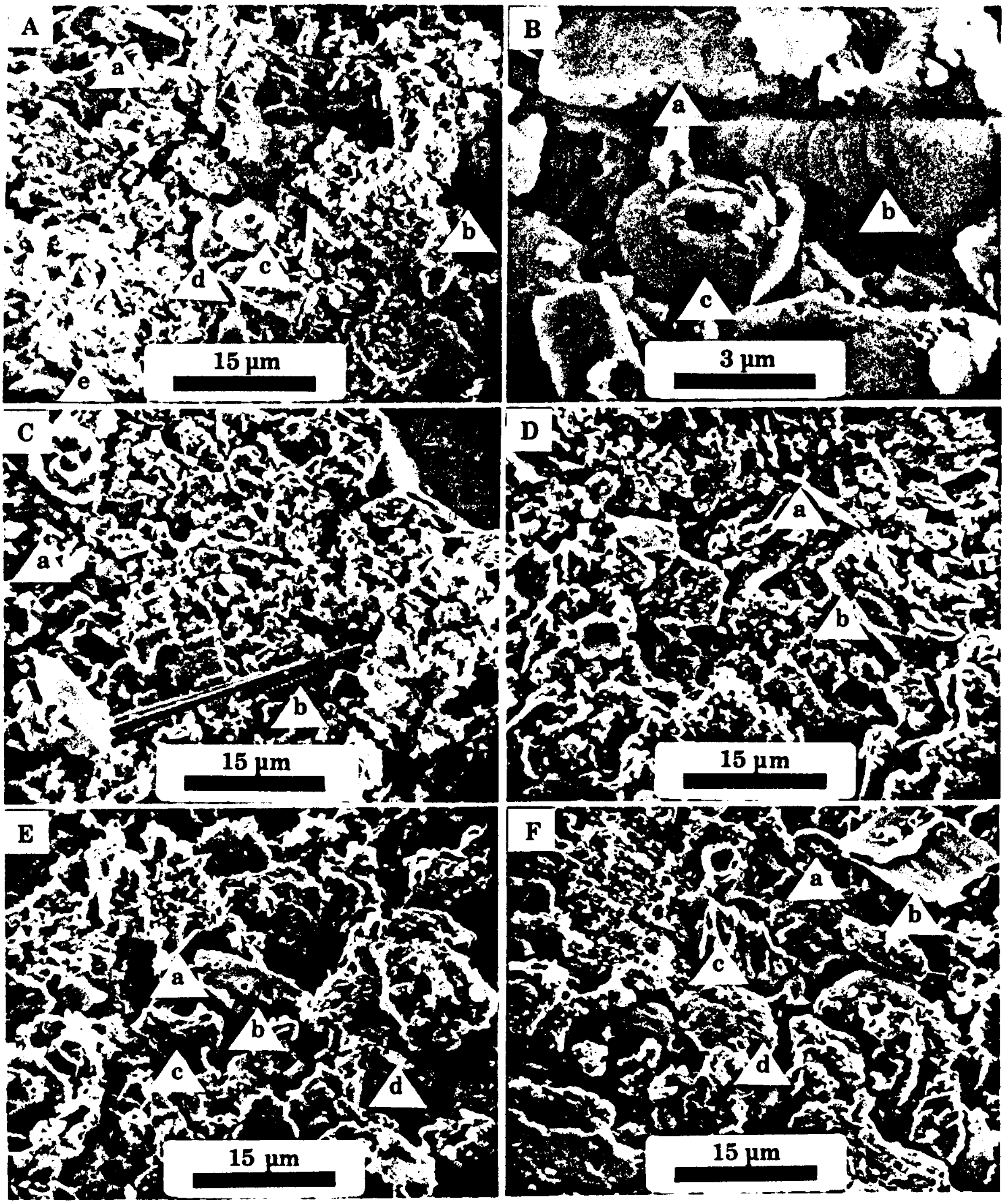
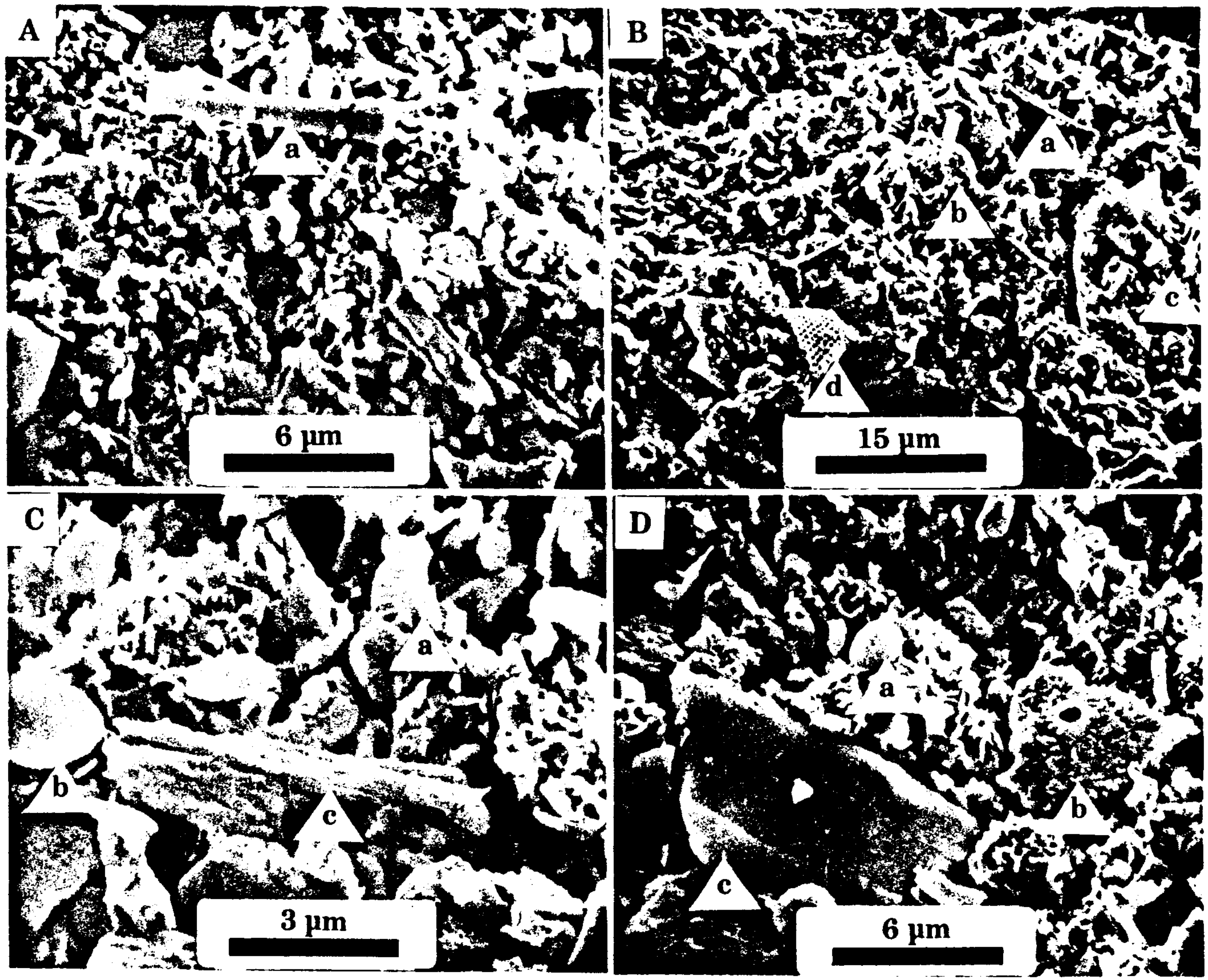

A
a
b
c
d
e
15 µm
B
a
b
c
3 µm
C
a
b
15 µm
D
a
b
15 µm
E
a
b
c
d
15 µm
F
a
b
c
d
15 µm

Figure 8. Scanning electron microscope photomicrographs of micrite from Tanner and Cortes Banks. A: (a) fragment of molluscan spine or sponge spicule. B: (a) side view of fragment with platy structure, (b) coccolith, (c) fragment with fibrous structure, (d) punctate shell fragment. C: (a) coccolith fragment, (b) coccolith, (c) fragment with lamellar structure. D: (a) coccolith, (b) shell fragment with puncta, (c) fragment with platy structure.



A
a
6 μm
B
a
b
c
d
15 μm
C
a
b
c
3 μm
D
a
b
c
6 μm

huxleyi (Late Pleistocene to Recent), (b) and (e) *Coccolithus pelagicus* (Jurassic to Recent), (c) *Cyclococcolithina leptopora* (Miocene to Recent), (d) *Helicopontosphaera kamptneri* (Oligocene to Recent). This group of species dates the micrite as Late Pleistocene to Recent. The scanning electron microscope micrographs present a strong case for an organic genesis for micrite, due to the presence of coccoliths, diatoms, platy, lamellar, and fibrous structures, punctate shell fragments, and rod-shaped fragments. Coccoliths and diatoms, evident in Figures 7A, B, C, D, E, F, and 8B, C, D are the result of planktonic contribution. Platy structures of Figures 7B, D, F and 8B, D, lamellar structures of Figures 7E and 8C, fibrous structures of Figures 7F and 8B, punctate shell fragments of Figures 7E, F and 8B, D, and rod-shaped fragments of Figures 7E and 8A are all products of skeletal comminution.

These photomicrographs were taken at the full range of size intervals examined with no major differences in micrite constituents observed. This occurrence supports the assertion of Bathurst (1975) that, at least for products of skeletal comminution, micrite genesis is not restricted by the 4 to 5 μ size boundary.

DISCUSSION OF RESULTS

Sediment Provenance

The only modern calcium carbonate additions indicated by this study are those due to trimming and turnover of existing marine communities in the rocky substrate shallow areas of Tanner and Cortes Banks. Planktonic and benthonic foraminifera, coccolithophorids and diatoms also contribute additional biogenic grains. Smith (1972) estimated turnover rates for a number of organisms living along the southern California inner shelf. His rates apply only to marine life above the 30 m depth and do not include all biologic sediment contributors of the outer banks. However, if standing crops were carefully calculated for Tanner and Cortes, and additional phylitic turnover rates gleaned from the literature, an estimate of yearly biogenic sediment additions to the bank tops can be made. Smith (1971) quotes Emery's (1960) calculations for total southern California shelf and bank top deposition of 20 $(g/m^2)/yr$, with 33 percent calcium carbonate. This would provide 6.6 $(g/m^2)/yr$ calcium carbonate contribution for the total area. Considering the high density of shell debris-producing organisms discovered by Smith (1975) on Tanner and Cortes Banks alone, this estimate appears to be too low by at least one order of magnitude.

A contour map of percentages inverse to those shown in Figure 5 would illustrate terrigenous clastic percentages. Thus, terrigenous material constitutes larger proportions of the surface sediment on the eastern sides of Tanner and Cortes Banks and in the northwestern portion of the intervening saddle. The monomineralic inorganic clasts appear angular to subangular in thin section with very angular basalt and other rock fragments. Inasmuch as no strong agent is probably actively eroding the submarine outcrops, this material is thought to be a relict of lower Pleistocene stands of sea level. Evidence for reworking of these clasts is provided by their occurrence, along with tiny foraminifera, within shell chambers of much of the biogenic debris as seen in grain thin sections. Fresher appearing basalt fragments may result from more recent erosion by strong surface currents noted by Bureau of Land Management divers (Steven H. Smith, personal communication, 1976).

Pleistocene Sea Level Fluctuations

Several lines of evidence indicate a close relationship between the depositional history of Tanner and Cortes Bank tops and Pleistocene changes in sea level. As noted earlier, Greene and others (1975) delineated destructional marine terraces overlain by 1 to 8 m thick constructional deposits for wide encircling regions of the bank tops. Both Greene and Holzman (1952) correlated these terraces with a relatively lower stand of sea level. The level most likely to have exposed much of Tanner and Cortes Banks is thought to have occurred 18,000 to 20,000 years before present at -124 m (Curray, 1965). This level was followed by the Holocene Transgression until present.

Increases of sedimentation rates discovered by Gorsline and others (1968) were attributed to Pleistocene subaerial exposure of the Santa Rosa-Cortes Ridge-Tanner Bank system on the eastern margin of Tanner Basin. Sediment from these sources would then have been transported into the basin by way of submarine canyon systems.

Many bioclasts examined exhibited iron oxide staining, indicating that one of several conditions has existed. Iron oxide staining has been documented as forming under the following conditions: (1) subaerial exposure (Swift and others, 1971), (2) oxidation of glauconite in sediments during a period of very slow sediment accumulation, (3) precipitation of iron for a fresh-water aquifer discharging under artesian conditions on the outer shelf or slope (Manheim and Horn, 1968; Pequegnat and others, 1972), (4) relative concentration of iron oxide precipitated from normal river discharge (Pequegnat and others, 1972). If the iron oxide staining is a result of (1) or (4), then the staining must have occurred during the period of subaerial exposure at the Pleistocene low sea level stand. Staining due to (2) would have had to occur after the formation of glauconite in the sediments. If an artesian aquifer exists on Tanner and Cortes Banks, the iron oxide staining could have occurred any time from the Pleistocene low sea level stand to the present. More support may be supplied by the living population of the red variety of _Allopora californica_ (Steven H. Smith, personal communication, 1976). This red coral is found north of Santa Cruz Island abundantly intermixed with the blue and purple varieties. However, the Tanner and Cortes red _Allopora_ is the only red coral of this species yet found between Santa Cruz Island and the United States-Mexico border. Here on Tanner and Cortes, the red coral is patchy in occurrence but has a large range over the bank tops. Since the larvae of this coral are not particularly motile, it has been postulated that populations were once widespread and dense on the banks. Thus, this _Allopora_ may be a remnant of larger Pleistocene populations. Thus, perhaps much of Tanner and Cortes bank tops were inhabited by this species, along with other abundant marine organisms some 18,000 to 20,000 years ago.

Underlying basement rock has been dated as Tertiary with basalt dated as Miocene (Vedder and others, 1974).

The following foraminiferal genera have been identified from Bureau of Land Management surface samples on Tanner and Cortes Banks (Gregg Blake, personal communication, 1976): *Angulogerina*, *Bolivina*, *Cassidulina*, *Cibicides*, *Ehrenbergina*, *Eponides*, *Hanzawaia*, *Hoeglundina*, *Islandiella*, *Nonionella*, *Planulina*, and *Rosalina*. Generic ages range from Miocene to Upper Pleistocene to Recent. These ages indicate certain foraminifera are present due to erosion of underlying strata during the 18,000 to 20,000 B.P. low stand of sea level or from Recent submarine highs, and others represent modern additions.

Since relict and modern biogenic sediments appear to be intermixed throughout the surface samples, a relevant designation for the resultant might be palimpsest sediments, as defined by Swift and others (1971).

Current Reworking

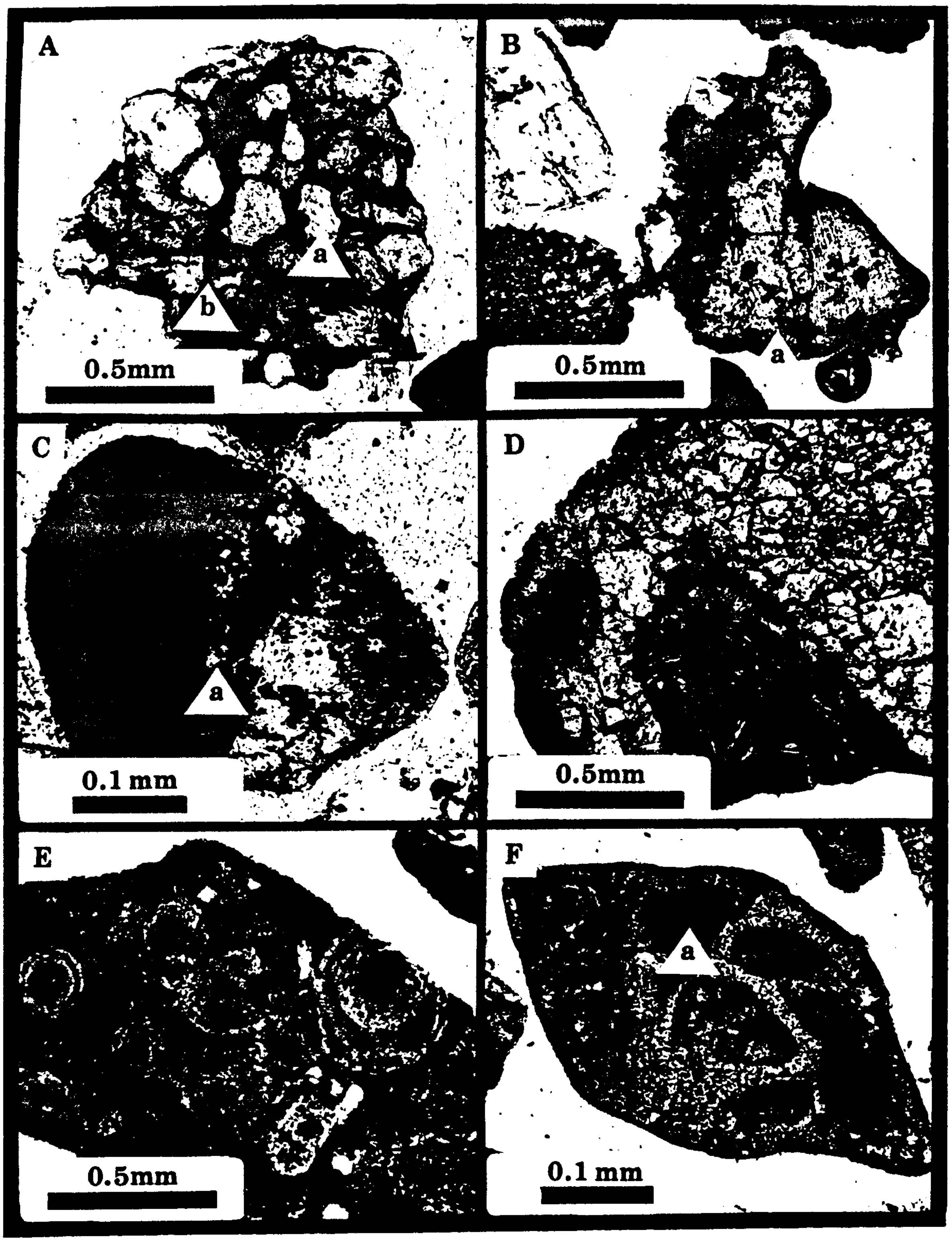
California Cooperative Oceanic Fisheries Investigations have been conducting monthly oceanographic surveys for the California Continental Borderland since 1947 (Reid and others, 1958). Emery's (1960) work included an analysis of currents off southern California. However, Emery's description was primarily limited to permanent currents due to density distribution in the sea for the area. A study financed by the U. S. Navy in 1965 (Marine Advisors, Inc., 1965) included information concerning intermediate depth currents which is extremely important to this study. For the Navy study proper applications of geostrophic methods were supplemented by a limited number of drogue measurements at 50 m and 100 m. Navy data indicate that currents due to density differences flow to the southeast during winter and spring months and are a part of the general flow of the California Current. These southeastward currents are part of a counterclockwise gyre with its center to the north of Tanner and Cortes Banks. In the fall, current direction changes and runs almost due west over the area. Velocities measured at 50 and 100 m depths produced values ranging between 0.07 and 0.26 knots (4 to 13 cm/sec), with no increase or decrease linked with changes in depth.

These relatively strong alternating currents probably effectively rework much of the surface sediment and wash out most fines produced. The medium- to high-energy shallow water environment was noted by Bureau of Land Management divers (Thomas J. O'Neil, personal communication, 1975). Sand waves with wave lengths of 1.2 to 1.5 m and heights of approximately 0.6 m were evident. One large pothole (2.7 m by 1.8 m) resembling those formed in intertidal reefs by tidal scouring was swept clean of loose sediment and rocks, with the exception of boulders from 0.6 m to 1.2 m in diameter. In addition, the foraminifera are all heavier and attached forms characteristic of high-energy environments. No obvious trends parallel with current directions can be observed on any of the contour maps created from the samples included in the present study. This may be due to the fact that there is not one constant dominant current direction for the region.

Intraclast Origin

Bureau of Land Management diver Thomas J. O'Neil reported a surficial encrusting material in the banks area which greatly resembled a carbonate submarine crust (personal communication, 1975). O'Neil observed that the crust was extremely friable and disaggregated easily when crushed by hand. Although he could not determine whether the crust was biogenic or inorganic in origin, O'Neil stated that the crust appeared to be forming at the present time. Otherwise, due to the friable nature of the carbonate crust, it could not have survived the existing high energy conditions. Since the crust is so friable, intraclasts found in the surface samples are probably products of an earlier more resistant carbonate crust. Figure 9 shows four intraclast types found in the Tanner and Cortes samples. Although the fragment composed of small detrital clasts and carbonate cement of Figure 9A suggest a calcareous sandstone source, Figures 9B, C, and D provide evidence for classification of the fragments as intraclasts. Figure 9B is a photomicrograph of a coarse

Figure 9. Thin section photomicrographs of grains from Tanner and Cortes Banks. A, intraclast with (a) angular terrigenous grains and (b) carbonate cement. B, skeletal fragment (a) encrusted with carbonate cement and angular terrigenous grains. C, basalt fragment with (a) carbonate filling the fractures. D, large carbonate intraclast with basalt fragment. E, oolitic collophane aggregate. F, benthic foraminifera test with (a) glauconite filling the shell chambers. All photomicrographs were taken with plane-polarized light.


A
a
b
0.5mm
B
0.5mm
a
C
a
0.1 mm
D
0.5mm
E
0.5mm
F
a
0.1 mm

skeletal fragment in contact with detrital inorganic clasts and carbonate cement. Various bioclasts are cemented both with other skeletal fragments and with terrigenous grains. Detrital grains appeared to be volumetrically dominant as compared to carbonate grains in the intraclasts. Infilling of fractures in a basalt clast by carbonate cement (Fig. 9C) indicates that cementation has occurred since the Miocene. Another association of calcium carbonate and basalt is seen in Figure 9D, with the basalt surrounded by carbonate.

The mean percent of intraclasts calculated for the samples examined petrographically was 1.4 with a variance of 10.9 and a range of from 0.0 percent to 23.7 percent of total composition. Percentages above 10.0 percent were seen only in the very coarse ranges of the samples. Of the three samples composed of more than 10.0 percent intraclasts (at the size intervals ranging from very coarse sand through pebbles), one was from the northwestern end of Tanner Bank and the other two were from locations near Bishop Rock on Cortes Bank. All three samples came from between the 90 and 100 m contours. Thus, submarine crusts are probably forming on both banks.

Bathurst (1975) describes intragranular cementation on the Recent sea floor that yields a rigid framework of grains as occurring only where grains lie quietly in contact for long periods. This condition could only exist in isolated sheltered portions of Tanner and Cortes Banks. Since few intraclasts were viewed in the finer fractions of the sediments, the framework formed probably is not very resistant to mechanical breakdown. Bathurst also notes that only aragonite and high-magnesian calcite have been found in such crusts. In most cases, as probably in this one, constant fresh supplies of supersaturated sea water are the source of the calcium. Some pumping mechanism is necessary for the maintenance of sea water flow through the pores of the sediment. This pump may be provided on the banks by the strong currents creating turbulence over a hydraulically rough bottom, as suggested by Bathurst (1975).

Glauconite and Collophane

Glauconite and collophane, or phosphorite, have been noted by Holzman (1952), by Pasho (1973), and by Greene and others (1975). Again these authigenic minerals were observed in samples from Tanner and Cortes Banks. Collophane occurred in two forms, one as individual grains often showing concentric layering, the other as seen in Figure 9E as an aggregate of numerous phosphatic oolites. The first form was the dominant one. Concentric layering indicates formation of collophane by direct precipitation from sea water. A range of from 0.0 percent to 38.7 percent collophane occurs in the surface sediments. The mean percentage is 1.4 with a variance of 16.6. Dietz and others (1942) dated foraminifera found within nodules of these bank tops as Miocene and Quaternary. Pasho (1973), in his study of marine phosphorites from the Continental Borderland bank tops concluded that these nodules represent fragments of underlying more extensive bedded deposits. These phosphorites were probably eroded during the Pleistocene low stand of sea level.

Glauconite appeared both as independent grains and as fillings in foraminiferal and other tests. Figure 9F is an example of glauconite infilling of a benthonic foraminiferal test. The presence of glauconite of these forms indicates that regions of little or no detrital sedimentation and relatively slow rates of sedimentation have existed at some time during the depositional history of the bank tops (Blatt and others, 1972). Requisites for the formation of the mineral are marine waters of near normal salinity, water temperatures of less than 15°C, reducing conditions, and an appropriate clay type of source material (Degens, 1965; Porrenga, 1967). Since most glauconite is foraminiferal infilling, reducing conditions were probably reached within the microenvironments of the shell chambers. However, reducing conditions do not appear to exist today on Tanner and Cortes Bank tops. All glauconites from off of the southern California coast that have been dated have been determined to be 1,000,000 to

2,000,000 years old (Donn S. Gorsline, personal communication, 1976). Therefore, both forms of glauconite were probably eroded from underlying Late Tertiary units 18,000 to 20,000 years ago.

CONCLUSIONS AND RECOMMENDATIONS

The investigation of grain size parameters and constituent composition of Tanner and Cortes Banks surface sediments provided support for the theory that the banks are destructional and constructional relicts of the low sea level stand of 18,000 to 20,000 years before present. During this low stand, basement rocks exposed subaerially were eroded to provide much of the terrigenous clastic sediment fractions now existing in the sediments. Collophane and glauconite were also eroded from exposed Miocene units. At that time there probably was a much larger community of marine organisms, with possible greater populations of Allopora californica in particular. Skeletal grains produced then probably were stained by iron oxide due to one of several possible conditions to be discussed later. With the later Holocene Transgression, biogenic material was continually added, although eventually biologic populations were diminished due to increasing water depths and increasing deposition of cover to the hard substrate needed for attachment. The last of the terrigenous additions seem to have come from the shallowest portion of the banks, from outcropping Miocene basalt. Foraminiferal and coccolith identification supplied dates of Miocene, Upper Pleistocene, and Recent for the present-day surface sediments. Thus, the biogenic and detrital components have been classified as palimpsest. Modern sediment contributions are comprised of bioclastics. The small amount of micrite in surficial samples is derived from skeletal comminution, coccoliths and diatoms. One reason for the minimal fine fraction is the existence of strong seasonally alternating currents which constantly wash and transport the sediments until well-sorted coarse deposits remain. A portion of the bank top sediments is undoubtedly transported to neighboring basins. The presence of authigenic minerals implies the existence at some time during the depositional history of the bank tops sediments of at least a few protected locales of little sedimentation or reworking due to water turbulence. A submarine carbonate crust is now forming on Tanner and Cortes Banks. Intraclasts found in the bank top sediments are probably products of earlier carbonate crusts, formed at some time between the Pleistocene low sea level stand and the present.

Although chemical studies were not pursued in this study, analysis for Ca, Fe, and Mg and weight percents of insoluble residues would be very useful in analyzing the economic value of the sediments. These determinations should be made not only for surficial sediments, but also for buried sediments, particularly in the thicker (7 to 8 m) units.

Collection of vibracore samples from Tanner and Cortes could provide a basis for not only chemical determinations, but also for the petrographic study of the entire sedimentary history of the banks. Also of interest would be carbon-14 dating of both surficial and buried skeletal material. Thus, perhaps some absolute determinations for Pleistocene sea level changes for the outer banks could be made.

Finally, the combination of a detailed study of standing crops of the marine organism community and estimates of rates of turnover could be very helpful in the calculation of carbonate sedimentation rates.

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