Benthic Study of the Southern California
OCS Region

VOLUME II, REPORT 16.0

SUBTIDAL BENTHIC SEDIMENT ANALYSIS IN THE SOUTHERN CALIFORNIA BIGHT - BIOTURBATION AND BIOGENIC SEDIMENTARY STRUCTURES

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16.1 ABSTRACT

Widespread occurrence of several different types of physical and biogenic sedimentary structures have been studied by X-radiography of 163 sediment slabs and tube cores from the Southern California Borderland. Core materials were subdivided into those containing: (1) primary laminations (thin beds or layers), (2) burrows and tubes (indications of animal activity), (3) mottle structures (discontinuous pockets of biologically manipulated sediments), (4) homogeneous bioturbated sediments (structureless sediments), depending on the principal type that occurs.

The different types of sedimentary structures are usually formed on, or within 30 centimeters of, the depositional interface. The differences between environments which display the various structures are differences in: (1) levels of dissolved oxygen in bottom waters (2) sediment stability as a function of wave energy and water depth, (3) the abundance of infaunal animals and the ways in which they disturb sediments, (4) rates of sediment deposition. Regular laminations are characteristic of areas of either rapid deposition (nearshore or bank environment) or slow deposition in areas of relatively few bottom animals (anoxic basins); they are either primary–formed by fluctuations of sedimentation; or secondary-formed by wave disturbance. Burrows, tubes, and mottle structures are secondary biogenic features formed by benthic animals altering existing sediments by their locomotion and feeding. Homogeneous bioturbated sediments are secondary deposits in that their fabric is formed by several generations of reworking by animals. The appearance and texture of Borderland sediments is largely due to burrowing and deposit feeding organisms.

It is suggested from the nearly ubiquitous biological mixing of Borderland sediments, that pollutants produced by offshore drilling or mining operations would not remain in the same place where they were initially deposited. At times of high rates of pollutant delivery to the depositional interface, areas of greater infaunal animal activity should trap disproportionate amounts of pollutants. At times of low rates of pollutant delivery, when the sediment has become the major pollutant reservoir, areas of greater infaunal animal. activity should lose their pollutant load more rapidly either by biological resuspension or back diffusion. This mechanism may well be responsible for the large local differences in the inventory of fallout radioactivity from deep Pacific sediment cores (Bowen, 1976).

16.2 INTRODUCTION

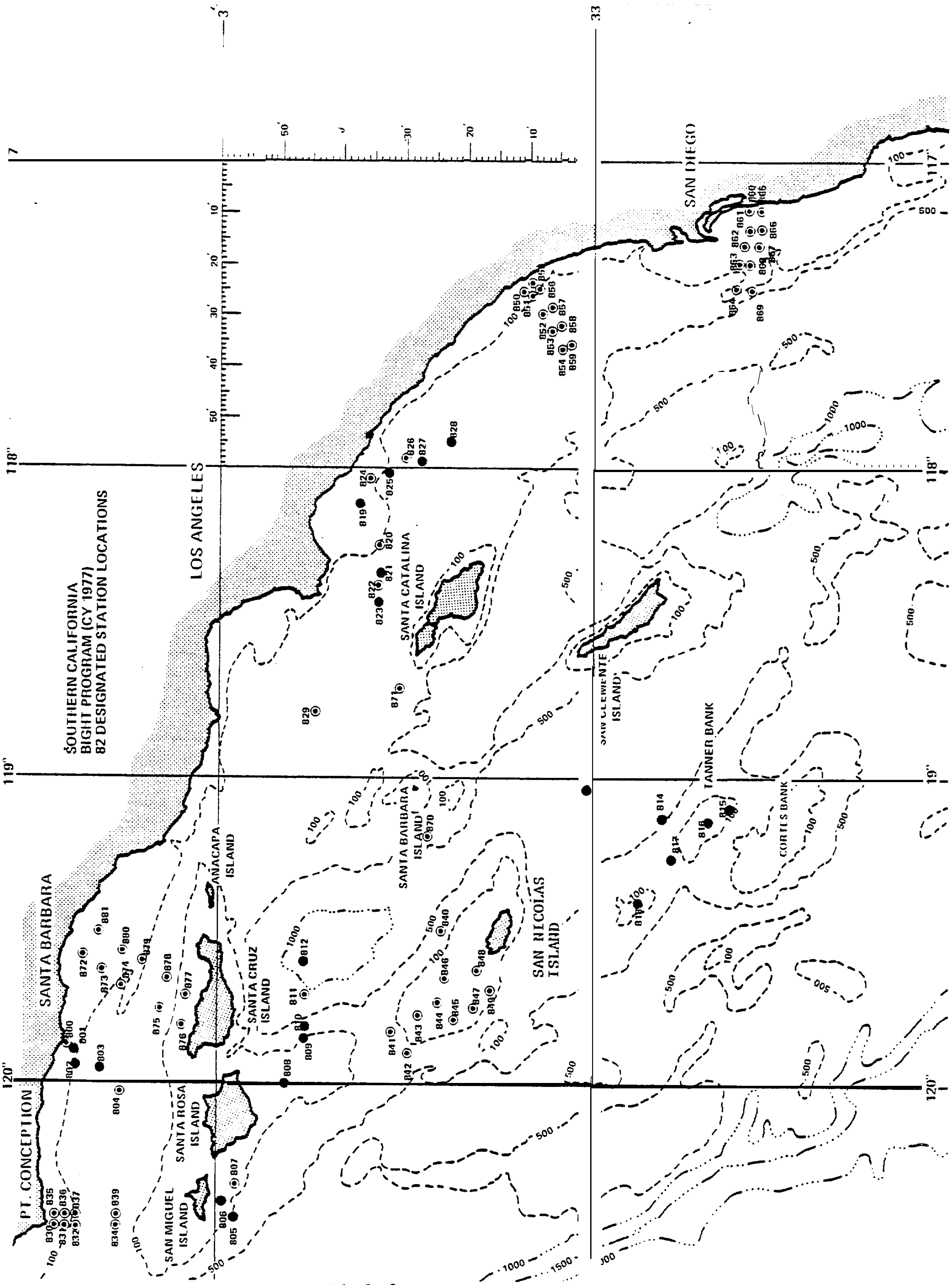
The sea floor off southern California consists of a series of troughs and basins separated by high ridges some of which protrude above sea level to form the Southern California Islands. The basins and many of their intervening sills are at depths that are much greater than usual for the continental shelf. The peculiar topography within the Southern California Bight has been given the name Continental Borderland by Shepard and Emery (1941). It lies offshore from the continental shelf of the mainland but inshore of the continental slope which extends down to regions of abyssal plains.

The basins and ridges are somewhat elongated and most are aligned in a northwest-southeast direction, parallel to the major structural features of the mainland; a few of these ridges bear islands which are also elongated along a northwest-southeast trend. However, in the north there is a transverse ridge, locally rising above sea level to form an east-west chain of islands concordant with the predominantly east-west tectonic grain of the Transverse Ranges (Emery, 1960; Vedder et al., 1974; Greene, 1976), (Figure 1).

Sedimentation and circulation are controlled by the block-faulted topography of the Borderland. The 14 basins range from ones that are about 200 km from shore and have received little sediment to inner shore basins that have received so much sediment that their floors are broad and flat (Gorsline and Emery, 1959). The high sediment flux of nearshore basins is the result of mass movement of sand-sized material down submarine canyons and basin slopes (Gorsline and Emery, 1959) and nepheloid layer transport of silt and clay (Drake et al., 1972; Drake and Gorsline, 1973).

Delivery of coarse-grained detrital material to the outer basins is extremely limited given their distance from the mainland and the intervening basins which act as sediment traps (Emery, 1960). Here, nepheloid layer sedimentation and planktonic biological components are the major source of sediment as evidenced by their uniform clay mineral assemblages and elevated percent carbonate trends (Fischer et al., 1976).

In the Borderland, as elsewhere in the World Ocean, substrate grade, water turbidity, the energy regime, and the oxygen content of the water are known to influence the composition and distribution of the benthic fauna (Finery, 1960). In turn, the life styles and mobility modes of the benthos will markedly modify many of the mass and physical properties of sediment including its water content, compaction, and erodibility (Rhoads, 1974; Ronan, 1975) as well chemical gradients in methane, ammonia, hydrogen sulphide and organic phosphorous compounds (Rhoads, 1974).


SOUTHERN CALIFORNIA
BIGHT PROGRAM (CY 1977)
82 DESIGNATED STATION LOCATIONS
PT. CONCEPTION
SANTA BARBARA
LOS ANGELES
SAN DIEGO
SAN MIGUEL ISLAND
SANTA ROSA ISLAND
SANTA CRUZ ISLAND
ANACAPA ISLAND
SANTA BARBARA ISLAND
SANTA CATALINA ISLAND
SAN NICOLAS ISLAND
SAN CLEMENTE ISLAND
TANNER BANK
CORTES BANK
120°
119°
118°
117°
33
100
500
1000
1500

Bioturbation, the mixing of sediment by animal activity, can result in the complete destruction of laminations and the structures constructed by infaunal animals. This homogenization of sediment occurs almost everywhere at a rate which depends on the abundance of animals, the ways in which they disturb sediment, and the rate of sedimentation. Thick deposits of undisturbed sediment are expected only in basins where bottom water oxygen has been low enough to prohibit survival of benthos or where sedimentation rates have been extremely high (Rowe, 1974).

This report, which is part of an overall base line study, quantifies the results of X-radiographic analysis of 163 sediment samples (tube cores and slabs) from the Southern California Bight. Benthic sampling occurred in specific areas over the Borderland from Coal Oil Point on the north, to the Tanner-Cortes Bank on the south. The majority of samples were taken in High Density Sampling Areas (HDSA's) which correspond to the lease tract areas designated for petroleum development by the Bureau of Land Management (BLM).

16.3 METHODS

Sediments collected from the winter (BLM leg No. 01, cruise No. T113) and summer (BLM leg No. 08, cruise No T123) biological box coring cruises were X-rayed to document the degree to which Borderland sediments are bioturbated by the burrowing and feeding behavior of benthic invertebrates. A total of 94 sediment slabs from biological box cores and 69 sediment tube cores from geochemical box cores were processed.

Initial preparation for sample X-raying consisted of carefully cutting away the plastic core wrapper. Those samples which did not contain large stones or shells were trimmed with a fine wire to remove disturbed surface sediment and level the slab to uniform thickness. Each sample was X-rayed in duplicate lengthwise using a Hewlett-Packard Faxitron radiographic X-ray unit and Kodak Type AA Industrial film ready packs.

The intensity of sediment reworking was quantified by superimposing a ruled transparency on each radiograph and calculating the percentage of the sample occupied by laminations, burrows and tubes, mottle structures, and homogeneous bioturbated sediment. Also noted was the percentage of the sample occupied by erratics (collectively: stones, clay chips, and wood) and bioclastic material. The following bedding classification is based on physical and biogenic sedimentary structures as well as texture.

16.3.1 Laminated Sand or Mud

Laminated sand or mud consists of thinly bedded sediment in obvious layers. In box-cored sediments, the stratification is horizontal or low dipping, and laminations may be parallel or subparallel. Individual lamina have sharp or relatively sharp contacts with adjacent material and therefore stand out as distinct units from the general mass of sediment if it is homogeneous, or from adjacent layers if the sediment is variable. For laminations to persist, biological activity in the sediment must be low.

16.3.2 Mottled Sand or Mud

Mottled structures, or mottles, consist of peculiar, irregularly shaped lenses, pockets, and pods of sediment randomly enclosed in a matrix of contrasting texture. The contacts between contrasting textures generally are sinuous. Distributions of mottles, as well as their shapes, are highly irregular thereby imparting a mottled appearance to core sections. Mottles commonly are a few millimeters to several centimeters in diameter. In cross section, individual mottles are ordinarily but not necessarily elliptical. On X-radiography, mottles are distinguished from matrix material by their irregular shape and/or by their contrasting texture or color.

Texture of the irregular mottles may be either coarser or finer than the matrix, or there may be nearly equal distribution between coarse and fine lumps in the sediment. Shell fragments are sometimes present within mottle structures.

True mottles are not produced by distortion of soft-sediment during sampling. They have been found with all types of sampling equipment and are well developed when there is no question of the undisturbed nature of the sample (Moore and Scruton, 1957). Mottle structures are produced by animal activity (e.g., by feeding and burrowing), and the relative intensity of mottling is a useful indicator of the amount of biological mixing a sediment has undergone (Moore and Scruton, 1957). Sediments which are intensely mottled grade into homogeneous (or massive bedded) bioturbated sediments as the sharpness of contact and textural contrast decreases between mottles and matrix.

16.3.3 Homogeneous Bioturbated Sands and Muds

Cores in which the sediments display no visible internal structure complete the list of bedding types normally found in the unconsolidated marine deposits of Southern California. These sediments are massive in apperance, and internal structures cannot be recognized even with the help of X-rays. Their relatively uniform texture may be fine-grained (clay and silty clays), coarse-grained (sand), or any intermediate texture. Structurally homogeneous deposits are common in the Borderland. They can be produced either by extremely rapid deposition, uniform deposition, complete winnowing, or by complete secondary (biologic) mixing. The concentration of biogenic sedimentary structures in the Borderland cores strongly suggests animal activity as the agent which mixes the sediment and gives it the appearance of a homogeneous mass.

16.4 RADIOGRAPHY AND THE INTERPRETATION OF SEDIMENT TEXTURE
Inner Basin Margins - Point Conception

In recognition of the zoogeographical significance of Point Conception, a HDSA of 10 stations was established in 1977 by BLM to study the biota and sediments. As this is a new HDSA no information on sediment textural properties was available in Fischer et al., (1976), or the other sources consulted.

Radiography

We have X-radiographed samples from all 10 HDSA stations and found that the shelf sediments range in grain size from fine sands (nearshore) to silt-sized material (offshore). Clay and cobble erratics tend to be quite rare, while bioclastic deposits (mostly mollusc shell) are an important constituent of some shallow water samples (stations 830, 836, 856) (Table 1). Laminations are absent from the area.

Small, pencil-thin network burrows, probably constructed by annelids, are common in deep water samples, while large single burrows are most typical of shallow water samples. Because of the relatively uniform nature of the sediment, mottle structures tend to be indistinct and difficult to recognize. Indeed, textural contrast was especially poor for deep water samples where grain size was relatively invariant and bioclastic materials rare. In general, secondary biologic mixing (bioturbation) of these sediments has given them a massive homogeneous appearance.

In the slab samples, where bioturbation can be most accurately measured, over 55 percent (and up to 87.5%) of the sediment is completely bioturbated (Table 1).

16.4.1 Inner Basin Margins

16.4.1.1 Coal Oil Point - Goleta Point

Prevous studies of the shelf sediments off Coal Oil - Goleta Point include Emery (1960), Fischer and Berry (1971), Gorsline et al. (1971), Welday (1976) and Wimberley (1963). In general, all of the above studies correlate quite closely with the more recent data of Fischer et al. (1976)

Table 1. Point Conception Area, Sedimentary Structure Analysis

	Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Material	Erratics	Grain Size	Core Length*
slabs	83002	0	17	0.9	37.6	55.0	1.5	5.0	fine	L
	83101	0	3	2.2	15.6	81.7	0.5	0	fine	S
	83201	0	25	1.1	14.7	84.2	0	0	fine	L
	83301	0	16	0.7	9.6	88.7	1.0	0	fine	L
	83401	0	7	0.4	28.2	71.4	0	0	fine	L
	83502	0	8	1.9	23.0	74.1	1.0	0	fine	L
	83603	0	4	2.9	5.6	61.5	30.0	0	fine	S
	83701	0	3	0.5	14.0	85.0	0.5	0.5	fine	S
	83801	0	12	2.4	14.1	83.5	0	0	fine	S
	83901	0	7	7.2	11.3	80.7	0.8	0	fine	L
tubes	83105	0		1.0	0	99.0	0	0	fine	S
	83203	0		3.0	20.0	77.0	0	0	fine	S
	83303	0		0.9	70.0	27.1	2.0	0	fine	L
	83404	0		2.1	75.0	22.3	0	0	fine	L
	83504	0		1.0	15.0	87.0	1.0	0	fine	S

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

As described by Fischer et al (1976), mean sediment size over the shelf ranges from fine sand (3.0ϕ) to silt (4.54). There is an east-west trending band of fine sediments which becomes coarser to the west of Coal Oil Point. Silt and clay percentages show a southwest-west trend of lower silt and clay values across the middle and outer shelf. Because of nepheloid layer transport, silt and clay values abruptly increase to 98% to 99+% along the basin margin.

Sediment-benthic faunal correlations

Animal-sediment relationships have been determined by Fischer et al. (1976) based on the faunal data of Fauchald and Jones (1976).

Shelf, fine-grained sands with low silt and clay content tend to be dominated by ophuroids. These same sediments also contain small holothurians and a mollusc, *Cyclocardia ventricosa*. Bottom photography of stations in this area have also revealed abundant heart urchin feeding trails.

Radiography

The variation in the burrowing among the shelf samples indicates that some property of the sediment, or the overall environment, is variable. Subtle differences in grain size distribution or in organic content could significantly affect the overall pattern in sediment reworking. Shelf samples to the west of Coal Oil Point contain few distinct burrows and mottle structures and overall are more highly reworked (i.e., uniformly bioturbated) than are shelf samples from the southeast (Tables 2 and 3). This trend must depend fundamentally on the relative local rates of sedimentation and the nature and intensity of biological processes within the sediment column.

Benthic animals are essentially absent from the deeper part of Santa Barbara Basin where the oxygen content of bottom water is very low (Emery and Hulsemann, 1962). Samples from stations 803 and 804 display layers consisting of thin laminae of detrital silts and clays due to winter stream runoff and of diatoms produced during spring and fall blooms (Emery and Hulsemann, 1962). Dissolved oxygen concentrations (do.) of less than 0.1 ml/L inhibit animal activity resulting in the preservation of laminations (Finery and Hulsemann 1962). Concentrations of do., rise to over 0.3 ml/L near the sill depth where an impoverished deposit-feeding fauna is present (Emery, 1960). The feeding of these animals produces bioturbation and concomitant destruction of the sedimentary laminations. Samples 80314, 80324, and 80328 are only partly laminated since they contain burrows, mottles, and thoroughly bioturbated portions (Tables 2 and 3).

Table 2. Coal Oil Point-Goleta Point, Sedimentary Structure Analysis (Slab Samples)

Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Material	Erratics	Grain Size	Core Length *
80108	0	6	0.1	5.5	93.1	0.1	0	fine	s
80153	0	9	4.2	7.9	88.0	0.9	0	fine	L
80201	0	10	3.1	6.2	90.1	0	0	fine	L
80207	0	8	2.2	4.9	93.8	0	0	fine	L
80226	0	13	4.0	6.7	89.3	0	0	fine	L
80307	0	6	0.9	56.4	42.2	0.5	0	fine	L
80324	1.4	9	3.3	32.5	62.8	0	0	fine	L
87201	0	8	1.9	14.3	83.6	0.1	0.1	fine	s
87301	0	18	3.1	16.3	77.4	3.2	0	fine	L
87401	0	21	1.0	33.5	65.4	0.1	0	fine	L
87501	0	11	3.2	23.8	72.5	0.5	0	fine	L
87601	0	4	3.7	20.2	60.8	15.3	0	coarse	s
87701	0	20	2.6	31.3	25.1	41.0	0	coarse	L
87801	0	6	1.9	15.4	80.7	2.0	0	fine	L
87901	0	12	1.3	3.7	94.5	0.5	0	fine	L
88001	0	2	0.5	14.0	85.0	0.5	0.5	fine	s
88201	0	10	6.9	6.2	86.9	0	0	fine	L

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

Table 3. Coal Oil Point-Goleta Point Area, Sedimentary Structure Analysis (Tube Core)

Sample #	Laminations	Burrows & Tubes Area	Mottles	Bioturbation	Bioclastic Material	Erratics	Grain Size	Core Length*
80002	0	1.6	20.0	77.4	1.0	0	fine	S
80009	0	3.3	5.0	91.7	0	0	fine	S
80131	0	0 . 6	20.0	77.4	2.0	0	fine	S
80167	0	4.0	5.0	91.0	0	0	fine	S
80214	0	11.0	3.0	86.0	0	0	fine	S
80233	0	2.4	10.0	87.6	0	0	fine	S
80311	45.0	1.0	30.0	21.0	4.0	0	fine	L
80328	20.0	4.2	10.0	65.8	0	0	fine	L
80421	100	0	0	0	0	0	fine	L
80437	100	0	0	0	0	0	fine	L
87303	0	3.0	75.0	20.0	2.0	0	fine	L
87403	0	0	20.0	80.0	0	0	fine	L
87693	0	0	15.0	70.0	15.0	0	coarse	S

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

H-1-6.0-1
Tubes

Four stations on the leeward side of Santa Cruz Island are included in the Coal Oil Point - Goleta Point grouping. Stations 875 and 878 are located deeper than 280 meters in a fine silty-sand substrate. Over 70 percent of the sediment is bioturbated with distinct mottles and burrows mostly confined to the upper 10 cm of sample material (Table 3). Thorough mixing of the sediment by the biota (mainly ophiuroids ?) insures the absence of laminations, and spatial separation from the shallow banks around Santa Cruz Island reduces the input of bioclastic skeletal materials.

Stations 876 and 87’7 are island bank stations situated in less than 90 m of water. The substrate is a mottled medium sand rich in bioclastic skeletal material (Tables 2 and 3). This is especially true of station 877 where mottle structures containing shelly debris are conspicuous and texturally distinct from their surrounding matrix. Overall, the shallow bank samples are less intensely burrowed than the finer grained, more texturally mature samples from the deeper water.

16.4.1.2 Huntington Beach - Newport Beach - Dana Point

Within the Huntington Beach - Newport Beach - Dana Point area the San Pedro shelf trends nearly east-west with a smooth gradational slope that is broken only by submarine terraces or other tectonic features (Finery, 1960). The study area is bounded to the east by the small Newport submarine canyon which is no longer believed to be active in channeling sediment into the northern San Diego Trough (Felix and Gorsline, 1971).

The sediments of the San Pedro shelf have been actively sampled over the past 25 years (Felix, 1969; Felix and Gorsline 1971; Gorsline and Grant, 1972; Lee, 1976; Moore, 1951). The following discussion of surficial sediments is taken from Gorsline and Grant (1972) and Fischer et al. (1976)

Over the shelf in this area, there is a general decrease in mean grain size from very fine sand (3.5ϕ) and coarse silt (4.5ϕ) in the northwest to fine silt (7.0ϕ) along the basin slope in the south-eastern corner of the area. Over the shelf the percentage of fine fraction (silt + clay) ranges from 20 to 50 percent of a sample. The “type sediment” for this area is a detrital green-gray sandy silt (Fischer et al., 1976). To the east at the shelf break, mean grain size abruptly becomes finer, suggesting down canyon nepheloid layer transport of fines along the Newport submarine canyon.

Samples from the southeast Huntington Beach - Dana Point area are outer shelf samples which display a correspondingly finer mean grain size. These samples are predominantly coarse silt (5ϕ) with a high fine silt and clay content (70 to 80%).

Sediment-benthic faunal correlations

Fischer et al. (1976) have made animal-sediment correlations based on the faunal distributions reported in Fauchald and Jones (1976). They report an impoverished molluscan fauna and a deep water Solenogaster assemblage that corresponds to the fine-grained high turbidity environment near the Newport submarine canyon.

The shelf faunas of the Huntington Beach - Newport area are grossly correlated with sediment types. The ostracod fauna (Euphilomedes sp) is confined to the green-gray silty sand facies. Finer sediments do not support this fauna.

In the Laguna Beach - Dana Point area several faunal distributions can be related to the fine sediments that parallel the shelf margin. There is a major change in crustacean diversity as well as in molluscan and polychaete faunas that parallel a band of fine sediment with a 95% silt + clay content. Besides the clay-rich substrate, high turbidity and sedimentation may control the faunal distributions in this area. There is a distinct change of polychaete faunas (4A to 4B) that occurs with a change to a coarser grain size with lower silt and clay percentages.

Radiography

The relatively uniform fine-grained nature of the shelf sediments in this area is reflected in the pattern of sediment reworking by the infauna. In general, any slab with well-defined burrows that cover over 2 percent of the core area was collected from the shallow water stations (stations 819, 825). Slabs which were highly burrowed were generally also well mottled, although neither water depth or the percent cover of the burrows was important in this relationship (Table 4).

The fidelity of replication between samples taken from the same station was poor. For sample pairs 82507, 82524, 82707, 82725; and 82807, 82813, one member of the pair was highly mottled while the other was more homogeneous, displaying fewer burrows and more bioturbation. This suggests that biologically the environment is quite patchy, with motile animals throughly reworking descrete patches of the sediment.

16.4.1.3 Oceanside Area

In 1977, a HDSA of 10 shelf and slope stations was established by BLM near Oceanside, California. There are, as yet, no data for this area on sediment textural properties or animal-sediment relationships.

Table 4. Huntington Beach-Newport Beach-Dana Point Area, Sedimentary Structure Analysis

	Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Material	Erratics	Grain Size	Core Length*
Slabs	81917	0	10	1.5	9.4	88.6	0.5	0	fine	s
	81927	0	19	4.5	7.2	88.3	0	0	fine	s
	82507	0	35	4.2	36.0	59.8	0	0	fine	L
	82524	0	20	2.9	74.1	23.0	0	0	fine	L
	82707	0	9	1.0	15.0	84.0	0	0	fine	L
	82725	0	38	1.74	62.0	36.0	0.3	0	fine	L
	82807	0	2	0.3	18.3	80.9	0.5	0	fine	L
	82823	0	23	1.8	78.6	18.0	1.2	0	fine	L
Tubes	81911	0		2.8	18.2	77.7	1.3	0	fine	s
	81929	0		0.7	10.0	89.3	0	0	fine	s
	82004	0		0.0	0.0	100.0	0	0	fine	s
	82423	0		4.2	27.1	68.7	0	0	fine	s
	82444	0		3.7	12.2	83.5	0.6	0	fine	s
	82510	0		3.0	60.0	36.0	1.0	0	fine	s
	82529	0		2.0	25.0	73.0	0	0	fine	s
	82602	0		3.2	5.0	90.8	1.0	0	fine	L
	82712	0		1.3	18.0	80.7	0	0	fine	s
	82731	0		2.2	20.0	77.0	0	0	fine	s
	82812	0		0.2	10.0	87.8	0	2.0	fine	s

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

Radiography

Shelf and slope sediments are fine-grained detrital sands which contain almost no bioclastic materials (Table 5). In general, distinct burrow and mottle structures were most common in the deep water sediments from stations 853, 854, and 858 (Table 5). Samples from the extreme shallow water stations (stations 850, 855) show almost no primary or secondary internal structure (Table 5).

Close scrutiny of the deep water samples suggests that burrow and mottle structures produced near the sediment-water interface are destroyed by burial to depths below 8 cm by the sediment mixing activity of infaunal organisms. Sediment mottles appear to originate from the infilling of open burrows after the demise of the animal which constructed the burrow. Textural contrast between filled burrows and the surrounding matrix is poor because of the uniform fine-grained nature of these sediments. At depth in the cores, non-descript bioturbate textures result from smearing and fading of old burrows and mottles.

16.4.1.4 Del Mar Area

In 1977, an HDSA of 10 shallow water stations was established by BLM to study the shelf sediments and biota near Del Mar, California. As this is a new HDSA no background information on sediment textural properties was available from Fischer et al (1976) or other sources.

Radiography

X-radiographic examination of core materials shows that the substrate grades from a shallow water coarse-grained sand to an offshore coarse silt with bioclastic materials being only locally important. Slab and tube core samples from stations 861 and 866 are partly laminated. The laminations are horizontal, or slightly curved, bands of coarse and fine sediments. Each layer has a relatively uniform thickness - (<0.5 cm) but lacks internal thin or cross-laminations. Laminations are absent in fine-grained samples from nearby shallow water stations (stations 860, 862).

Distinct burrows are rare and small in size; they tend to be most abundant in samples from below the 100 m isobath. Similarly, mottle structures are characteristic visible features of samples from below 100 meters (Table 6). Mottle structures in deepwater sediments are distinct, whereas those from shallow-water sediments (< 100 m) are of the indistinct type. In all samples, homogeneous structureless sediments tend to form the basal layers. The massive uniform-grained nature of these sediments suggest total destruction of primary and secondary internal structures by burrowing organisms.

Table 5. Oceanside Area, Sedimentary Structure Analysis

H-I-16.0-15

	Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Materials	Erratics	Grain Size	Core Length*
Slabs	85001	0	3	0.7	17.9	81.3	0.1	0	fine	S
	85101	0	6	0.5	6.2	93.2	0.1	0	fine	L
	85203	0	8	0.6	56.4	42.8	0	0	fine	L
	85301	0	10	1.2	32.6	66.2	0	0	fine	L
	85401	0	14	3.8	7.4	88.8	0	0	fine	L
	85501	0	4	0.5	10.5	87.9	0	1.1	fine	L
	85601	0	21	2.1	23.1	74.5	0.3	0	fine	L
	85701	0	10	0.1	5.2	94.1	0	0	fine	L
	85801	0	12	1.5	16.7	81.8	0	0	fine	L
	85901	0	8	0.5	12.1	86.9	0.5	0	fine	L
Tubes	85104	0		2.2	11.0	86.8	0	0	fine	S
	85206	0		0.0	34.0	66.0	0	0	fine	S
	85304	0		0.4	48.0	51.6	0	0	fine	S
	85411	0		0.8	21.0	78.2	0	0	fine	S

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

Table 6. Del Mar Area, Sedimentary Structure Analysis

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	Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Material	Erratics	Grain Size	Core Length *
Slabs	86001	0	4	1.3	3.1	95.4	0.2	0	fine	L
	86101	6.0	1	0.2	3.9	95.8	0.1	0	coarse	L
	86201	0	5	0.7	9.1	87.1	3.1	0	fine	L
	86301	0	6	0.3	74.0	19.7	6.0	0	fine	L
	86405	0	5	0.3	87.2	12.4	0.1	0	fine	L
	86501	0	4	0.4	7.4	91.2	1.0	0	fine	S
	86604	12.0	2	0.4	9.5	72.7	0.1	0	coarse	L
	86701	0	4	0.3	22.6	77.0	0.1	0	fine	S
	86801	0	3	1.2	5.3	93.7	0	0	fine	S
	86902	0	3	0.5	11.6	87.8	0.1	0	fine	L
Tubes	86111	64.0		0.0	0.0	36.0	0.0	0	coarse	L
	86208	0		1.0	10.0	88.0	1.0	0	fine	S
	86810	0		6.2	93.8	0	0	0	fine	L
	86908	0		3.1	0	94.9	1.0	1.0	fine	S

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

16.4.1.5 Tanner - Cortes Banks

The general geology of the Tanner - Cortes Banks region has been reported on by several authors (Holzman, 1952; Emery, 1960; Green et al., 1975; Fischer, et al., 1976). Structurally the banks are two broad anticlinal folds separated by a synclinal topographic saddle. Cortes Bank, the larger and shoaler of the two, forms the south-western terminus of the Santa Rosa - Cortes Ridge. A broad saddle that has been heavily dissected by submarine canyons separates Tanner from Cortes Bank.

Essentially the bank tops are areas of non-deposition. Bank sediments, from the crest down to the shelf break at 110 m are patchy, mega-rippled deposits, which form a winnowed deposit of fine- medium sand (mean grain size = 2.2ϕ) (Fischer et al., 1976). Mean grain size decreases below the zone of active transport to form a fine to very fine silt (2.97-3.46) deposit. Negligible silt- and clay-sized material is found near the bank tops. In the saddle between the banks, the silt and clay content increases to over 60 percent of the sediment (Fisher et al., 1976). The constant winnowing of fine sediments form the bank tops to the saddle and slope produces a very slow sedimentation rate (Emery, 1960).

Sediment-benthic faunal correlations

Benthic faunal distribution data for the banks is not yet available. Preliminary study suggests that the topographic irregularity and variable energy and substrate regimes along the bank crests is mirrored by the patchy distribution of impoverished echioderm and molluscan faunas (Fauchald and Jones, 1976). Only crustaceans appear to demonstrate a preference for the relatively coarse bank top sediments (Fauchald and Jones, 1976).

Radiography

Burrowing in the high energy bank top environment is probably restricted by the instability and coarseness of the substrate. Several sand-silt laminae are present at the top of samples 81650 and 81817, while the lower portion of each core is either pebbles or shells. Biological activity is confined to several centimeters of mottled and bioturbated sand between the two contrasting sediment types (Table 7).

As water depth increases, the input of shelly debris and pebbles becomes less. The fine-grained sands from below the bank tops, and the topographic saddle between the banks, have been intensely reworked by burrowing organisms. In surficial sediments from stations 814, 815, and 817, most burrows have been degraded to mottle structures, while the basal portion of each core has been homogenized. In slab sample 81512, there is a planar layer of bivalve

Table 7. Tanner-Cortes Bank, Sedimentary Structure Analysis

	Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Material	Erratics	Grain Size	Core Length*
Slabs	81402	0	7	1.3	8.3	90.4	0	0	fine	S
	81419	0	44	2.0	30.0	68.0	0	0	fine	L
	81503	0	2	0.3	20.5	67.8	11.4	0	fine	S
	81512	0	6	2.5	10.0	82.5	5.0	0	fine	S
	81658	0		0	0	0	0.2	99.8	coarse	L
	81702	0	1	0.1	2.0	97.8	0.1	0	fine	S
	81735	0	3	0.6	79.0	18.9	1.5	0	fine	S
	81816	0	2	0.9	70.2	24.9	4.0	0	coarse	S
	81827	0	10	1.7	11.5	84.9	2.5	0	coarse	S
Tubes	81410	0		1.2	0	98.8	0	0	fine	S
	81427	0		2.0	3.0	95.0	0	0	fine	L
	81650	10.0		0	20.0	0	0	70	coarse	S
	81675	0		0	20.0	80.0	0	0	coarse	S
	81712	0		0	15.0	80.0	5.0	0	fine	S
	81747	0		0	11.0	87.0	0	2.0	fine	S
	81817	10.0		0	28.0	17.0	45.0	0	coarse	S

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

shells that occurs about eight cm below the sediment-water interface. This shell layer may be a fossil channel deposit or may be related to the course of a submarine canyon.

16.4.1.6 San Nicolas Island

In 1977, a HDSA of 10 stations was established by BLM to study the shelf and slope sediments of San Nicolas Island. As this is a new HDSA, no information on sediment textural properties was available in Fischer et al. (1976) or other sources consulted.

As with other island sites surveyed, the substrate grades from a shallow water coarse-grained bioclastic sediment to an offshore fine-grained sand with only local occurrences of skeletal material. The fanual groups represented by skeletal debris are molluscs, ectoprocts, corals, echinoderms, and foraminifera. Taken together they can account for up to 70 percent of some shallow water samples. No data is as yet available on sediment-benthic faunal correlations.

Radiography

Eight of the ten sampling stations occur at depths of 125 m or less. Radiographic inspection of the shallow water samples show that the island shelf is a mosaic of coarse and fine sediments, which contain a variety of physical and biogenic sedimentary structures (Table 8).

Irregular laminations, or alternating bands of coarse and fine sediments, are present in samples 84405, 84603, and 84810. The laminations display little parallelism and wedge or lens out in core section. Distinct burrows and mottles are rare although there is considerable evidence for bioturbation (Table 8). Samples from the other shallow water stations (i.e. , 841, 843, 845, 847) generally contain more erratic and bioclastic material than the samples with laminations. The absence of bedding and the overall higher rate of bioturbation give these other cores a more homogeneous "massive bedded" appearance.

Irregular, non-parallel laminations are also present in fine-grained slope sediments from stations 840 and 842. Bedding is most pronounced in sample 84202 where tabular sandy bioclastic layers alternate with massive bedded fine silts. Burrowing and bioturbation is confined to a narrow layer at the top to this slab.

In slab sample 84005, only remnants of primary bedding remain. An active infauna has eradicated all but 4 narrow lunate layers which are near the base of the core. Each fine-grained layer wedges out laterally into a bioturbated coarser matrix. Burrows can be found in the top 5 cm of the core, while distinct mottles penetrate to the base of the core.

Table 8. San Nicolas Island, Sedimentary Structure Analysis

	Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Material	Erratics	Grain Size	Core Length*
Slabs	84005	4.0	4	0.5	7.8	86.8	0	0.5	fine	L
Slabs	84202	84.1	2	0.3	1.1	10.5	2.0	2.0	fine	S
Slabs	84303	0	1	0.5	4.4	72.0	0.1	23.0	coarse	S
Slabs	84402	0	4	0.4	6.7	92.8	0.1	0	coarse	S
Slabs	84505	0	1	0.3	4.6	55.1	40.0	0	fine	S
Slabs	84603	11.1	1	0.5	0	88.4	0	0	coarse	S
Slabs	84703	0	4	12.5	7.7	73.3	0.5	6.0	fine	S
Slabs	84801	0	8	0.5	12.5	81.7	2.0	3.3	coarse	L
Tubes	84111	0		0	35.0	29.0	0	36.0	fine	S
Tubes	84405	3.0		1.0	10.0	86.0	0	0	coarse	S
Tubes	84810	10.0		0	0	18.0	70.0	2.0	coarse	S

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetrating depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

16' 4.1.7 Northern Catalina Ridge

The sampling area lies at the northern edge of a ridge which rises to form Santa Catalina Island, three kilometers to the south. We received sediments from station 871, which is located on a steep facing slope at a water depth of 319 meters.

Typical sediment along the ridge flanks is a gray silty very fine- to fine-grained (3Ø) sand with 20 to 40% carbonate and about 20% silt and clay content (Fischer et al., 1976). Sediment dispersion along the ridge entails winnowing of the fine fractions from the ridge (mean grain size 20) , as evidenced by the low silt and clay fraction over the ridge and the clay mineral distribution. Clays are presumably carried in suspension off the crest and redeposited on the northern slope (Fischer et al., 1976).

Sediment-benthic faunal correlations

Fischer et al. (1976) believe that turbidity may be the dominant sediment "control of faunal distributions in the sampling area. The low density and diversity of echinoderms and crustaceans may be due to turbidity produced by the winnowing of fine-grained ridge sediments and their redeposition on the north slope.

Radiography

Although the sediment at the sampling site was a fine-grained silt, the box corer did not penetrate the bottom well. Both the sediment slab and tube core are short (< 12cm) disturbed samples, in which burrows are difficult to recognize. Over 75 percent of the sample is bioturbated to a homogeneous texture (Table 9). Mottle structures appear only in the upper part of the samples. Only a single burrow was found in the slab sample, and erratics are confined to the tube core (Table 9).

16.4.1.8 Santa Barbara Island

As part of the 1977 BLM effort, several sampling stations were established to the west and northwest of Santa Barbara Island. As this in a new HSDA, no information on sediment textural properties or animal-sediment relationships was available in Fischer et al. (1976) or the other sources consulted.

Radiography

We have examined but a single sediment slab and tube core from station 270, located in 397 m of water due west of the island. Radiographic inspection of the slab and tube sample suggests that most of the sediment is a fine sand or coarse silt. Erratic clay and cobble fragments occur throughout the tube core, but occupy less than 3 percent of its volume (Table 10). Bioclastic material is rare; tiny fragments of mollusc shell are scattered throughout the samples.

Table 9. Northern Catalina Ridge, Sedimentary Structure Analysis

	Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Material	Erratics	Grain Size	Core Length*
Slabs	87102	0	3	1.0	22.3	76.7	0	0	fine	S
Tubes	87105			0	12.0	86.0	0	2.0	fine	S

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

Both the sediment slab and tube core are highly mottled (Table 10). The texture of the irregular mottles tends to be finer than the bioturbated matrix. Shell fragments generally are incorporated into the mottle structures. Although mottles are distributed throughout the samples, there is no tendency towards alignment of the structures. Apparently the reworking of this sediment occurred at some earlier date, as distinct burrows are extremely rare in the samples.

16.4.2 Channel Island, Ridges, and Outer Banks

16.4.2.1 San Miguel Island

Shelf, slope, and submarine canyon deposits from San Miguel Island, the western and most exposed of the Northern Channel Islands Group, have been studied by Fischer et al (1976). Major sources for the offshore detrital sediment are the exposures of silt and coarse-gained, well sorted sands (Miocene - Late Cretaceus formations) and Pleistocene terrace deposits on the island (Weaver, 1969). Aeolian transport of fine-grained sediments from the island to the offshore has been documented by aerial photography (Fischer, 1969). Biogenic skeletal debris from molluscs, ectoprocts, corals, echinoderms, and coralline algae are locally important constituents (l0 - 30%) of sediments. Carbonate bioclasts are most abundant in the coarser sediment fractions.

Fischer et al. (1976) have shown that on the flat outer shelf, between the base of the steeper sloping mid-shelf and the steep upper shelf, the dominant modern sediment type is poorly sorted very fine sand to coarse silt. Mean grain size increases on the steep upper slope where sediments have a very low silt + clay fraction (< 10%). The deeper edge of this sand unit (steeper sloping mid-shelf) grades to a very fine sandy silt.

Sediment-benthic fanual correlations

Fauchald and Jones (1976) have shown that the fanual zones are nearly coincident with the outer shelf band of silty very fine-grained sand (*Cyclocardia* zone) and upper slope sand tongue (deep water fauna). Burrowing anemones and sipunculids (*Golfingia*) are common in most areas of fine-grained substrate.

Radiography

X-ray inspection of sediment samples shows fine-grained deposits which are generally massive bedded and homogeneous appearance. Erratics and biogenic skeletal material are only locally abundant, and laminations are totally absent from the sediment (Table 11). Burrows are abundant generally only in the upper few centimeters of sediment. The burrows tend to be small-diameter, singular struc-

Table 10. Santa Barbara Island, Sedimentary Structure Analysis

	Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Material	Erratics	Grain Size	Core Length*
Slabs	87002	0	1	0.2	34.0	62.4	0.6	2.8	fine	L
Tubes	87004	0		0.7	25.0	73.3	1.0	0	fine	S

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

Table 11. San Miguel Island, Sedimentary Structure Analysis

	Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Material	Erratics	Grain Size	Core Length*
Slabs	80502	0	7	1.5	3.8	94.5	0.1	0.1	fine	s
	80540	0	6	0.7	1.3	97.9	0.1	0	fine	s
	80608	0	5	1.2	1.2	84.5	10.0	0.2	fine	s
	80624	0	14	2.4	12.3	84.0	1.3	0	fine	s
	80633	0	9	3.8	6.2	84.7	5.3	0	fine	s
Tubes	80526	0		0	0	99.0	1.0	0	fine	s
	80564	0		2.0	0	97.0	1.0	0	fine	s
	80614	0		1.3	0	98.7	0	0	fine	s
	80639	0		3.1	5.0	91.9	0	0	fine	s
	80705	0		1.1	0	96.7	2.2	0	fine	s
	80719	0		1.8	3.0	95.2	0	0	fine	s

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

tures, although a large diameter burrow network occurs in the sample 80633. When mottle structures are present, they tend to be indistinct, probably because their definition depends on the presence of contrasting sediments which are absent in homogeneous deposits. Bioturbation by the infauna has produced a fine-grain deposit in which over 84 percent of the samples were almost structureless.

16.4.2.2 Northern Santa Rosa Ridge

This sampling area includes stations along the western flank of the northern Santa Rosa - Cortes Ridge and a number of stations along the eastern flank and the northwestern to central Santa Cruz Basin floor. The following information on sediment textural properties is largely derived from Fischer et al. (1976)

At ridge deposits shoaler than 200 meters, the mean grain size ranges from very fine to medium sand. The average grain size is fine sand (2.3ø) with a silt + clay content of less than 10 percent. Biogenic skeletal material, which ranges from 8 to 45% consists primarily of foraminifera and mollusc shell, with lesser amounts of ectoproct, echinoid and algal fragments.

Along the east flank of the ridge and down into the Santa Cruz Basin, grain size and carbonate content progressively decrease as silt and clay content increases.

Within Santa Cruz Basin the sediments are fine grained, fecal-pelleted silty clays with an average grain size ranging between 7.4 Ø and 8.2 Ø. Sediment deposition along the northern margin is largely via nepheloid layer transport of fine sediments, while turbidity currents are active within the central northern part of the basin.

Radiography

The two slab samples collected from along the ridge axis at station 810 consist of numerous large cobbles which are embedded in a fine silt matrix. There was no evidence of bioturbation in the silt-size fraction (Table 12). The tube core samples, which were collected from the base of the ridge directly adjacent to Santa Cruz Basin, are fine silts which show much evidence of biogenic mixing. In both samples there are several large sinuous burrow systems which emanate downward from the sediment-water interface. Deeper portions of the cores (i.e. at depths below 8 cm) show occasional mottles and much bioturbation (Table 12).

16.4.2.3 Santa Rosa Island

The southwestern shelf off Santa Rosa Island is a broad flat structure, most portions of which are shoaler than 150 meters (Fischer et al., (1976). The shelf broadens eastward in a lobate

Table 12. Northern Santa Rosa Ridge, Sedimentary Structure Analysis

	Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Materials	Erratics	Grain Size	Core Length*
Slabs	81021	0	0	0	0.0		0	100.0	cobbles	S
Slabs	81008	0	0	0	0.0	0.0	0	100.0	cobbles	S
Tubes	81104	0		1.9	15.0	83.1	0		fine	L
Tubes	81113	0		3.6	5.0	91.4	0		fine	L

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

bulge which marks the northern extension of the Santa Rosa - Cortes Ridge. Along its eastern flank the ridge is bounded by Santa Cruz Basin.

Sediments of the Santa Rosa Shelf are predominately fine-grained detrital sands which are locally rich in bioclastic skeletal material (Fischer et al., 1976). The faunal groups represented by skeletal debris are molluscs, corals, ectoprocts, echinoids, and foraminifera. Taken together, all categories of skeletal material can account for over 50 percent of some sediments.

Sediment-benthic faunal correlations

As discussd by Fauchald and Jones (1976), substrate type on the Santa Rosa shelf apparently controls faunal distribution patterns. Impoverished mollusc faunas correlate closely with bioclastic sediments that contain in excess of 50 percent carbonate, while crinoids are most abundant in clean detrital sands with high carbonate values.

Radiography

X-ray examination of sediment slabs and tube cores shows that the substrate is a fine-grained sand which is locally enriched in erratic cobbles, clay fragments, and skeletal materials. The heterogeneous nature of the substrate is well demonstrated at station 810 where from 0-60% of a given sample is taken up by erratic cobble and clay fragments (Table 13). Burrows are relatively rare, even in surficial sediments. Most burrows are of small diameter and singular with no evidence of burrow networks. Deeper, cobble-free parts of the samples are generally thoroughly bioturbated so that the sediment texture is massive and homogeneous. Laminations are absent from all core materials.

16.4.3 Inner Basins

The Santa Barbara, Santa Monica, and San Pedro Basins, and the San Diego Trough are modern, rapidly filling inner basins (Emery, 1960). Since the Pleistocene, the filling of these basins has occurred as alternations of coarse to fine elastic deposition by turbidity current, slumping (Gorsline and Emery, 1959), and suspension mechanisms (Drake et al., 1972; Drake and Gorsline, 1973; Moore, 1969), by nepheloid transport and dilute bottom suspensions of the silt- and clay-sized sediments (Fischer et al., 1976).

In their study of the inner basins, Gorsline and Emery (1959) have shown that the basin floors are covered by clay-silt to clay sized sediments. These sediments are characterized by fine grain size (7-8 Ø), lower carbonate content as compared to the "normal" ocean floor, and higher total organic carbon values (Fischer et al. 1976).

Table 13. Santa Rosa Island, Sedimentary Structure Analysis

	Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Material	Erratics	Grain Size	Core Length*
Slabs	80810	0	5	1.7	1.0	96.5	0.8	0	fine	S
Slabs	80826	0	4	0.8	1.5	63.7	0	34.0	fine	S
Slabs	80908	0	5	1.8	8.6	88.8	0	0.8	fine	S
Slabs	80911	0	0	0	0	0	0	Rock	0	--
Slabs	80927	0	1	0.1	3.4	95.6	0	0.5	fine	S
Tubes	80817	0		0	2.0	38.0	0	60.0	fine	S
Tubes	80851	0		0.6	11.0	86.4	1.0	1.0	fine	S
Tubes	80918	0		0	40.0	50.0	8.0	2.0	fine	S
Tubes	80935	0		0	24.0	70.0	3.0	3.0	fine	S

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

Radiography

Because the sill depth (737 m) for Santa Monica and San Pedro Basins is within the depth range of the oxygen minimum zone, the water contains little dissolved oxygen (<0.25 ml/L) (Gorsline and Emery, 1959). Accordingly, one would expect that the thin fine layers of sediment deposited on the basin floor would remain relatively undisturbed by animal activity. This expection proved correct for tube core samples from central Santa Monica Basin. The thin laminae in samples 82914 and 82935 show little evidence of animal activity. Several burrows (possibly of annelid worms) were found down the length of the core, but major disruption of the laminae was not evident (Table 15). How damaging this small amount of biological mixing of the sediments will prove to the age dating of the core is equivocal.

Laminations prove to be rare in slab and tube core samples from near and below still depth in San Pedro Basin. Burrow and mottle structures were abundant throughout the samples although deeper portions tended to be totally bioturbated (Table 14). When laminae were present they proved to be either discontinuous or totally isolated; no continuous rhythmic layering of the sediment was observed. The inference is made that San Pedro Basin is inhospitable for benthic life for periods of years and then conditions change, permitting animals to colonize the area and bioturbate the sediments.

16.4.4 Central Basins

Only two samples were received from San Nicolas Basin and but a single sample from Santa Cruz Basin. In mean grain size, the typical basin sediments are moderate olive-green clay-sized silts (7.70-7.79 Ø) composed of abundant fecal pellets (Fischer et al., 1976). In the central basin group, a progressive increase in calcium carbonate and total organic carbon from north to south was noted by Fischer et al. (1976). The higher carbonate and total organic carbon values found in San Nicolas Basin are attributed by Fischer et al. (1976) to its southeasterly position, distance from detrital sources, and its greater depth. No data on animal-sediment relationships in the two basins is as yet available.

Radiography

Although Emery (1960) provides a general account of oceanographic conditions and bottom life for the central basins, the factors which control the abundance and distributions of benthic animals remain poorly understood. In Santa Cruz Basin, the sill depth is at 1085 m where dissolved oxygen concentrations of 0.8 ml/L have been recorded (Emery, 1960). Although the taxonomic diversity of the bottom fauna is probably low, the dissolved oxygen concentration is sufficient to

Table 14. Inner Basins: San Pedro Basin Sedimentary Structure Analysis

	Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Material	Erratics	Grain Size	Core Length*
Slabs	82107	0	9	3.6	22.8	73.4	0	0	fine	L
Slabs	82131	0	18	1.4	57.0	41.4	0.1	0	fine	L
Slabs	82307	0	22	3.0	9.7	86.8	0.5	0	fine	L
Slabs	82342	0	33	4.4	39.4	56.1	0.1	0	fine	L
Tubes	82118	0		0.4	32.4	67.2	0	0	fine	L
Tubes	82136	0		1.6	24.8	72.0	1.6	0	fine	s
Tubes	82202	0		3.3	18.6	78.1	0	0	fine	L
Tubes	82325	0		2.3	27.2	66.4	0.7	3.4	fine	L

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

Table 15. Inner Basins: Santa Monica Basin, Sedimentary Structure Analysis

	Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Material	Erratics	Grain Size	Core Length*
No Slabs										
Tubes	82914	75.3		1.7	23.0	0	0	0	fine	L
	82935	99.8		0.2	0	0	0	0	fine	L

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

support life as evidence by the level of biological activity in the slab and tube core sediments. Indeed, over 75 percent of each sample was homogeneous because of bioturbation. Burrows and mottle were locally abundant especially in the upper part of the samples.

Sediment samples from San Nicolas Basin were collected from below the sill at a water depth of 1754 m where bottom waters are nearly depleted of dissolved oxygen (do. = 0.5 ml/L) (Emery, 1960). Other studies have shown that dissolved oxygen values equal to 0.5 ml/L severely restrict the activity of bioturbating organisms, while values lower than this result in the preservation of laminated sediments (Emery and Hulsemann, 1962; Calvert, 1964).

Only partial preservation of primary layering occurs in San Nicolas Basin. Progressive alteration of a primary layered deposit by burrowing organisms has produced a sediment which has only remnant lamination (Table 16). Given sufficient time and present bottom water condition, the laminations and mottle structures will totally disappear as the burrower population completes the alteration cycle to a homogeneous bioturbated sediment. Accurate age dating of these sediments will prove most difficult.

16.5 DISCUSSION AND CONCLUSIONS

16.5.1 Introduction

Sedimentologists and stratigraphers place a considerable amount of importance upon primary sedimentary structures for interpreting depositional environments. Yet it is known that wherever the numbers of benthic organisms are high, and where the sedimentation rate is low, secondary bioturbate structures produced by the organisms may dominate (Reineck, 1967). The importance of animals in forming the final fabric of marine sediments can not be overstated. Were it not for burrowing and deposit-feeding organisms the texture of many of our marine sediments would be entirely different.

16.5.2 Laminations and Bioturbated Sediments

A distinct bedding type in the marine deposits of the Borderland is laminated sand or mud. This structure is probably present to some degree throughout the sampling area and is dominant in two environmental settings. In the offshore, laminations can generally be found in coarse sediments from shallow areas around Tanner-Cortes Bank (stations 813, 816, 818) and shoal areas around San Nicolas Island (stations 844, 846, 848). Seaward of the bank and shoal areas, laminated sediments are only rarely present (stations 813, 840, 842) as they tend to be replaced by bioturbated sediments.

Regular layers of fine sediments are the most prominent visible features in inner basin samples from Santa Barbara, Santa Monica and San Pedro Basins. With increased depth of water, laminations are best developed, most abundant, and thickest. Tube cores 80421 and

Table 16. Central Basins, San Nicolas & Santa Cruz Basins, Sedimentary Structure Analysis

	Sample #	Laminations	Burrows & Tubes #	Burrows & Tubes % Area	Mottles	Bioturbation	Bioclastic Material	Erratics	Grain Size	Core Length *
Slabs	81206	0	8	3.7	7.7	87.2	0	1.4	fine	L
Slabs	81239	0	47	9.5	12.3	77.2	1.0	0	fine	S
Slabs	81307	16.0	5	1.7	22.3	60.0	0	0	fine	L
Slabs	81351	14.0	12	0.8	27.4	57.8	0	0	fine	L
Tubes	81232	0		2.3	8.0	89.7	0	0	fine	
Tubes	81329	5.0		1.1	60.0	33.9	0	0	fine	

*Core length: sediment slabs or tube cores less than 25 cm in length (= penetration depth) are scored as short (S) cores, whereas samples longer than 25 cm are scored as long (L) cores.

80437 from Santa Barbara Basin and 82914 and 82935 from Santa Monica Basin are deep water samples that are almost 100 percent laminated. Samples taken close to the sill of a basin, such as 80311 and 80328 (from Santa Barbara Basin) and 82202 (from Santa Monica Basin) show evidence of biological activity and hence fewer and thinner laminations per core.

Regular layered structures rarely occur in the near shore, but are present in shallow water sediments (stations 861, 866) from the Del Mar area. The near shore is, of course, the highest energy environment; animals living here are subject to the most rigorous conditions, including frequent disruption of the substrate by wave activity. Thus, cross-bedding, and other types of non-parallel laminations, may be developed as there is little opportunity for the accumulation or '*overprinting" of one set of biogenic sedimentary structures on another. Generally, the biogenic activity recorded here is only a record of the most recent burrowing events.

Some small areas of laminated sediments also exist in the midst of otherwise highly reworked zones. Two deep water stations (stations 840, 842) adjacent to San Nicolas Island have finely laminated sediments. The water depth here (> 500 m) precludes wave energy from obliterating the "signature'" of animal reworking. The textural appearance of these very fine sediments suggests a highly plastic clay whose mass properties may preclude colonization by burrowing organisms, though this has not been definitely determined.

Outside of the above areas where laminated sediments are present, bioturbate textures characterize the Borderland sediments. Within a sediment, bioturbation ranges from specific individuals which cross-cut readily recognized physical sedimentary structures to repeated "overprints" and total reworking which has overwhelmed and completely obliterated any evidence of primary sedimentary structures.

Generally within a core, the abundance and distribution of biogenic structures is not uniform. Biogenic sedimentary structures tend to be most abundant and distinct within 10 cm of the sediment-water interface. Burrows, tubes, and mottle' structures appear to be destroyed upon burial due to the extensive burrowing activity of infanual organisms. In certain slope samples, scme gravitational sediment movement, probably resulting from mass flow down the slope, produces a shearing of mottle structures and inclined and/or smeared burrows. Near the base of a core, the sediments have had a long history of intensive bioturbation which is reflected by their nondescript homogeneous textures.

16.5.3 Bioturbation and the Redistribution of Pollutants in Sediments

The near ubiquitous biological mixing of Borderland sediments suggests that contaminants produced by offshore drilling or mining operations would not remain in the same place where they were initially deposited. Although quantification of mixing rates is difficult, Berger and Heath (1968) and Schink and Guinasso (1977) have proposed models that describe the vertical mixing of sedimenting particles through a homogeneous layer of continually mixed surface sediments of a particular thickness. Empirical demonstration of the applicablilty of these models to the mixing of exotic, or foreign, particles in sediment is almost totally lacking. A single exception being the experimental studies of Ronan (1977), where infanual polychaetes have been shown to disperse sediment-water interface laminae, formed from lead particles, down to depths of 17 cm within thirty days and to nearly obliterate the laminae in ninety days.

Clearly, additional field and laboratory study is needed of the stirring and/or reburial activities of infaunal organisms. In areas of significant horizontal drift of the finely divided superficial fraction of the sediment column, a locally high rate of deposit-feeder stirring must have the effect of trapping more of the passing, probably organic-rich stream, and thus of increasing the food supply of the deposit-feeders themselves (Rhodes, 1973). This mechanism seems to us to have interesting implications for the trapping of pollutants. At times of high rate of pollutant delivery to the sediment surface, areas of greater deposit-feeder activity should trap disproportionate amounts of pollutants. On the other hand, at time of low rates of pollutants delivery, when the sediment has become the major pollutant reservior, areas of greater deposit-feeder activity should lose their pollutant load somewhat more rapidly, whether by erosion or by back diffusion. Bowen and others (1976) believe that this mechanism operates in the deep ocean, and may well be responsible for the large local differences in the inventory of fallout radioactivity (plutonium or cesium 137) from closely spaced sediment cores in the deep Pacific.

16.6 REFERENCES

Berger, W.H. and G.R. Heath. 1968. Vertical mixing in pelagic sediments. J. Mar. Res. 26:134-143.

Bowen, V. T., H.D. Livingston, and J.C. Burke. 1976. Distributions of transuranium nuclides in sediment and biota of north atlantic ocean. Pages 107-120 in Transuranium nuclides in the environment. Inter. Atomic Energy Agency, Vienna.

Calvert, S.E. 1964. Factors affecting distribution of laminated diatomaceous sediments in Gulf of California. in T.H. Van Andel (cd.) Marine geodosy of the Gulf of California. AAPG, Tulsa, Oklahoma.

Drake, D.E., and D.S. Gorsline. 1973. Distribution and transport of suspended particulate matter in Huneme, Redondo, Newport, and La Jolla submarine canyons, California. Geol. Sot. Amer. Bull., 84:3949-3968.

Drake, D.E., R.L. Kolpack and P.J. Fischer. 1972. Sediment transport on the Santa Barbara-Oxnard shelf, Santa Barbara channel, California. Pages 307-331 in Swift, D.J., and others (eds.), Shelf sediment transport. Dowd en, Hutchinson and Ross, Inc. , Stroudsbrug, Penn.

Emery, K.O. 1960. The Sea Off Southern California, A Modern Habitat of Petroleum. John Wiley and Sons, Inc., New York, 366 p.

Emery, K.O., and J. Hulsemann. 1962. The relationship of sediments, life and water in a marine basin. Deep-sea Res., v. 8, p. 165-180.

Fauchald, K. and G.F. Jones. 1976. Southern California Baseline Studies and Analysis: Benthic Macrofauna: A Preliminary Report, Southern California Baseline Studies Analysis. Bureau of Land Management, p. 72.

Felix, D.W. 1969. Origin and Recent History of Newport Submarine Canyon. California Continental Borderland. Office of Naval Research, Geophys. Branch. Tech. Rept., NR083-144, p. 52.

Felix, D.W. and D.S. Gorsline. 1971. Newport submarine canyon, An example of the effects of shifting loci sand supply upon canyon position. Mar. Geology, v. 10:177-198.

Fischer, P.J. 1969. Migration rates of coastal dunes, Redondo Beach and San Miguel Island, California (unpublished research paper) University of Southern California, p. 24.

Fischer, P.J. and R. Berry. 1973. Environmental Hazards of the Santa Barbara Channel: Oil and Gas Seeps and Holocene Faulting. Assoc. Eng. Geologists, Spec. Pub., p. 417-132.

Fischer, P.J., R.W. Berry and W.E. Reed. 1976. Southern California Bight, Sediment Characterization and Analysis for Bureau of Land Management Baseline Study. p. 164.

Gorsline, D.S., and K.O Emery. 1959. Turbidity current deposits in San Pedro and Santa Monica basins off southern California. Geol. Sot. Amer. Bull., v. 70, p. 279-290.

Gorsline, D.S. D.J. and Grant. 1972. Sediment textural patterns on San Pedro shelf, California. Pages 576-600 in Swift, D.J. and others (eds.), Shelf sediment transport. Dowden, Hutchinson, and Ross, Inc., Stoudsburg, Penn.

Gorsline, D.S., B.M Brenninkmeyer, W.C Meyer, M.R. Plossel, G.I. Shiner and S.P. Vender Haar. 1971. General characteristics of nearshore sediments from El Capitan to Ventura, California. Pages 181-217 in Biological and oceanographical survey of the Santa Barbara oil spill, University of southern California. Sea Grant Pub. No. 2, v. 2.

Green, H.G. 1976. Late cenozoic geology of the Ventura basin, California. Pages 499-529 in Howell, D.G. 1976. (cd.), Aspects of the geological history of the California continental borderland. Amer. Assoc. Petroleum Geologist, Pacific Seal. Misc. , Pub. 24.

Green, H.G., S.H. Clarke Jr., MOE. Field, F.I. Linker and H.C. Wagner. 1975. Preliminary Report on the Environmental Geology of Selected Areas of the Southern California Continental Borderland. US Geological Survey Open-File Rept. 75-596.

Holzman, J.E. 1952. Submarine geology of Cortes and Tanner banks. J of Seal. Petroloty, 22:97-118.

Lee, C.F. 1976. Reflection Profiling and Trace Metal Geochemistry of the Newport Submarine Canyon Region. Newport Beach, California, (M. S. thesis) California State University, Northridge, in preparation.

Moore, D.G. 1951. Submarine Geology of San Pedro Shelf, California. (unpublished M. S. thesis), Geological Sciences, University of Southern California.

Moore, D.G. 1969. Reflection profiling studies of the California ontinental borderland-structure and quaternary turbidity basins. Geol. Sot. Amer. Spec. Paper no. 107, p. 142.

Moore, D.G. and P.C. Scruton. 1957. Minor internal structures of some recent unconsolidated sediments. Amer. Assoc. Petroleum Geologists, 41:2723-2751.

Reineck, H.E. 1967. Layered sediments of tidal flats, beaches and shelf bottoms of the north sea. Pages 191-206 in Lauff, G.H. (cd.) Estuaries. Amer. Assoc. Advancement—of Science, Washington D.C.

Rhodes, D.C. 1973. The influence of deposit-feeding benthos on the water turbidity and nutrient recycling. Amer. Journal of Sci., V. 272.

Rhodes, D.C. 1974. Organism-sediment relations on the muddy sea floor. Oceanogr. Marine Biol. Ann. Rev., 12.

Ronan, T.E. Jr. 1975. Structural, Function, and Paleoecological Aspects of a Modern Marine Soft-Sediment Community: An Experimental Field Study. (Ph.D. dissertation) University of California, Davis, p. 200.

Ronan, T.E., Jr. Formation and paleontologic recognition of structures caused by marine annelids. Paleobiology, 3:389-403.

Rowe, G.T. 1975. The Effects of the Benthic Fauna on the Physical Properties of Deep Sea Sediments. Plenum Publishing Corp., New York, p. 381-400.

Schink, D.R. N.L. and Guinasso Jr. 1977. Effects of bioturbation on sediment-seawater interactions. Mar. Geology, 23:133-154.

Shepard, F.P. and K.O. Emery. 1941. Submarine topography off the California coast, canyons and tectonic interpretations. Geol. Sot. Amer., Spec. Paper 31, p. 1-171.

Vedder, J.G., L.A. Beyer, A. Junger, G.W. Moore, A.E. Roberts, J.C. Taylor, and H.C. Wagner. 1974. Preliminary Report on the Geology of the Continental Borderland of Southern California. US Geol. Survey, Misc. Field Studies Map MF-624, p. 34.

Weaver, D.W. 1969. Geology of the Northern Channel Islands. Spec. Pub., Pacific Section, Am. Assoc. Petroleum Geologists and S.E.P.M. p. 200.

Wimberly, C.S. 1963. Sediments of the mainland shelf near Santa Barbara, California. Pages 191-201 in Clements, T. (cd.) Essays in Marine Geology in Honor of K.O. Emery. University of Southern California Press.

16.7 RECOMMENDATIONS

From our 1977 baseline data and results, several obvious omissions and suggestions for future study of borderland sediments emerge. At present, we find that we are unable to calculate reworking rates for samples. To calculate meaningful reworking rates we need to know local sedimentation rates and natural history information on the population density and "life style'" (motility and trophic modes) of the dominant benthos at the sampling sites. A synthesis of this information would enable us to identify the number of generations of mixing that a sediment has undergone and the "way" in which the sediment has been mixed. This type of information has important implications for predicting what will be the ultimate fate of pollutant particles which sediment to the sediment-water interface.

In the future, quantification of levels of biogenic activity in box-core sediments should be restricted to the slab samples only. Because of the continuous thickness change across a cylindrical tube core, radiographic resolution tends to be poor, and the accurate interpretation of any enclosed biogenic sedimentary structures difficult.