ALLAN HANCOCK PACIFIC EXPEDITIONS

VOLUME 27 PART 1

SUBMARINE CANYONS OF SOUTHERN CALIFORNIA

PART I

TOPOGRAPHY, WATER, AND SEDIMENTS

BY

K. O. EMERY and JOBST HÜLSEMANN

UNIVERSITY OF SOUTHERN CALIFORNIA PRESS
LOS ANGELES, CALIFORNIA
1963

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SUBMARINE CANYONS OF SOUTHERN CALIFORNIA

Part I. Topography, Water, and Sediments

by

K. O. Emery and Jobst Hülsemann

INTRODUCTION

For many years submarine canyons have been known off southern California and have been studied in varying degrees of detail, largely by F. P. Shepard and his students and colleagues. Most of this work consisted of studies on topography (Shepard and Emery, 1941), lithology (Emery and Shepard, 1945), and general sediments (Cohee, 1938). Hydrographic and biological work has been sketchy. Some recent studies by Gorsline and Emery (1959) indicated the common presence of sandy floors along the canyon axes which mark the route of turbidity currents that move coarse sediment from beaches and inner shelves outward to the deep basin floors (Emery, 1960a). This preliminary sampling also suggested that benthic animals on the floors of the canyons differ from those at the same depths outside the canyons. Differences in environment, such as coarse sediment, moving sediment, or abnormal water conditions, may be important biological controls in the canyons.

Thirteen of the largest submarine canyons were selected for special studies of the topography, sediments, hydrography, and benthic biology. Many other canyons are present in the region, some of them larger than the smallest one described in this report. Among these fairly large but relatively poorly known canyons are several between Mugu and Hueneme Canyons, San Gabriel Canyon, Oceanside Canyon, Carlsbad Canyon, and several north and east of San Nicolas Island. These canyons were omitted not because they are unimportant, but because of time limitation and because the 13 canyons which were selected probably cover the range of variation expected within the fields of investigation. Basin slopes in the region also contain related but smaller features termed sea gullies (Buffington, 1951, in press; Emery and Terry, 1956); perhaps several thousand are present.

ACKNOWLEDGMENTS

Most of the field work was accomplished between December 1959 and May 1960 (Stations 6776 to 7055) through the aid of National Science Foundation Grant G-9060. A few samples collected during 1961 and 1962 were by-products of an additional National Science Foundation Grant G-12329. Many of the data for Santa Monica, Redondo, and San Pedro Canyons were collected during short cruises extending back to 1951; most of these cruises were financed by Captain Allan Hancock, but some were part of a contract for studies of Santa Monica Bay for Hyperion Engineers, Incorporated. Appreciation is due J. R. Grady for his careful analyses for nutrients in the waters and to many other students of the Department of Geology who participated in the ship work during class or special field trips. All field measurements were made aboard the Allan Hancock Foundation's research vessel VELERO IV.

TOPOGRAPHY

Methods

The 13 submarine canyons of this study occur along the mainland and off islands and banks (Fig. 1). For each of them 6 to 13 sounding lines were run at right angles to the canyon axis, as shown by navigational charts, and at approximately equal intervals along it. The lines are long enough to show the relationship between the sides of the canyons and the adjacent mainland or island shelf, basin slope, or basin floor. Soundings were made with the Precision Depth Recorder (Luskin, Heezen, Ewing, and Landisman, 1954) attached to an Edo echo sounder. Instrumental error is less than 1 part in 3000, so the chief error in depth results from variation of the speed of sound in sea water and the reflection of sound from areas of the bottom within the sound cone and shallower than the point directly beneath the ship. The profiles are based upon soundings uncorrected for sound velocity. Since the echo sounder is calibrated for a sound velocity in sea water of 1463 meters per second and the actual sound velocity for these depths is about 1.2 per cent faster (Emery, 1960b), the profiles are about 1.2 per cent too shallow. More important, however, is the effect of echoes from the sides of the narrow canyons; these often obscure the echoes from the narrow bottom. Comparison of wire depths for samples taken in the canyons with simultaneous echo soundings corrected for sound velocity show that some of the echo soundings are as much as 50 meters too shallow, with greatest errors in the narrowest part of the canyons (Fig. 2). In contrast, the average difference between wire and echo depths for flat shelves and basin floors is less than about 3 meters.

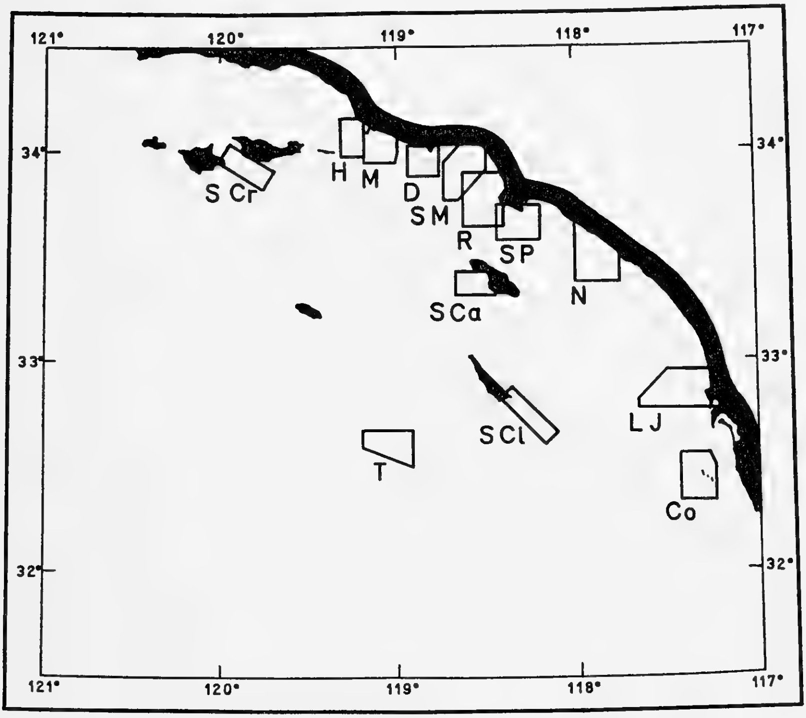


Fig. 1.—Index map showing areas which were sounded and sampled off southern California, for which contours, profiles, and sample positions are shown in Figures 3 through 15.

H, Hueneme Canyon; M, Mugu Canyon; D, Dume Canyon; SM, Santa Monica Canyon; R, Redondo Canyon; SP, San Pedro Sea Valley; N, Newport Canyon; LJ, La Jolla Canyon; Co, Coronado Canyon; SCr, Santa Cruz Canyon; SCa, Santa Catalina Canyon; SCI, San Clemente "Rift Valley," T, Tanner Canyon.

Positions were determined at 5-minute intervals by a radar range and bearing on a prominent coastal point, such as a pier end or a steep cliff. Since the ship speed was 9 to 10 knots, positions are about 1.5 km apart.

In the laboratory the tapes of continuously recorded soundings were reduced to half scale with a pantograph and the reductions were traced directly for Figures 3 through 15. U.S. Coast and Geodetic Survey navigational charts served as the source for contours of the index map for each of the canyons.

Characteristics

General:—The canyons off southern California have been described previously by Shepard and Emery (1941) and by Emery (1960a) who also summarized the pertinent literature on them. Accordingly, only new data on topography and data needed for the proper interpretation of water characteristics and sediments will be presented here.

The canyons occupy parts of three physiographic environments of the sea floor: continental or insular shelf, basin slope, and basin floor. In each environment the canyons present a different aspect.

Shelf Portion:—The shelf is largely or entirely crossed by 8 of the 13 canyons of this study. Santa Monica, San Pedro, and Coronado canyons only indent the shelf; however, filled extensions of all three canyons are known on the adjacent land through well borings, and a filled channel across the shelf from the head of San Pedro Sea Valley was discovered by jet borings made by Richfield Oil Company. The other two exceptions are Tanner Canyon which begins deep on the saddle between Cortes and Tanner banks, and San Clemente Rift Valley which is different in many ways from other submarine canyons. Among the 8 canyons which do cross most of the shelf, Hueneme, Redondo, and Newport have now-filled extensions on land, as shown again by well borings. Each of the 8 also lies off a prominent land valley, except Santa Cruz Canyon which heads into the shelf saddle between Santa Cruz and Santa Rosa islands. Hueneme, Redondo, Newport, La Jolla, Santa Cruz, and Santa Catalina extend in nearly straight courses across the shelves, but Mugu and Dume are broadly curved.

The depth of the canyon edge, or lip, is not uniform across the shelves. Transverse profiles across the shelf portions of Hueneme, Mugu, Santa Monica, Redondo, San Pedro, Newport, La Jolla, Coronado, and Santa Catalina canyons (see Figs. 3-15) show a seaward deepening of the canyon edge. This deepening is somewhat greater than the general slope of the shelf and, moreover, the profiles show some lateral slope of the shelf toward the canyons. Both facts mean that the topographic effect of the canyons extends somewhat beyond the narrow gorge of the canyons.

Below the canyon edge, the profiles show steep slopes—too steep in fact for completely satisfactory use of an essentially non-directional echo sounder. The measured slopes are minimal ones; still, as shown by the left-hand part of the top panel of Figure 16, the indicated slopes of the walls nearest the heads of the canyons are 10° to 40°. Observations made by divers in shallower waters reveal yet steeper, even vertical to overhanging walls. These parts of the submarine canyons probably represent the steepest areas of the sea floor.

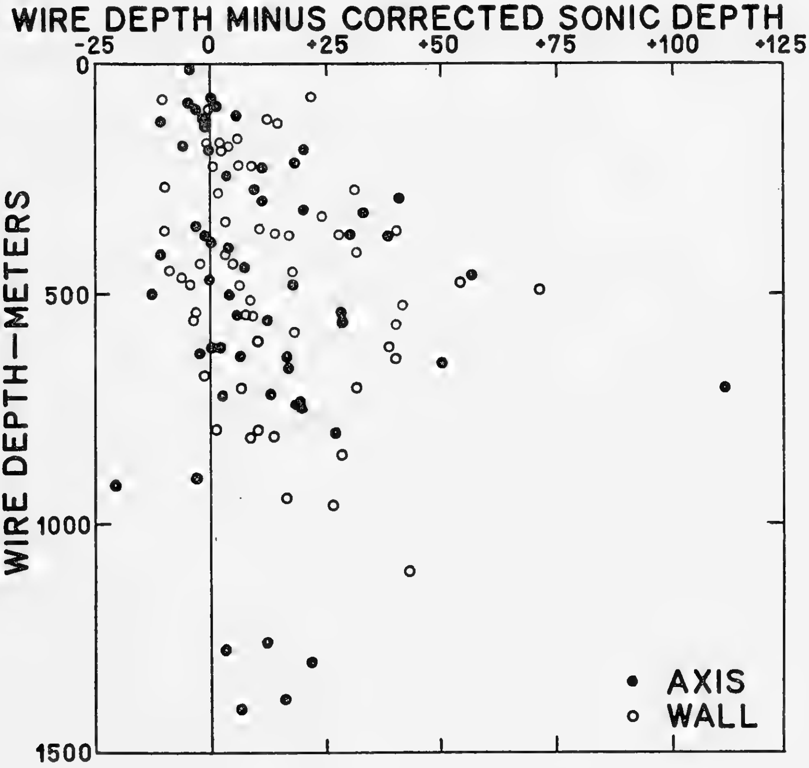


Fig. 2.—Plot of difference between wire depth and sonic depth corrected for sound velocity. The dominantly shallower sonic depth is the result of echoes from steep canyon walls which obscure the echo from directly beneath the ship. The sounding differences at sites in canyon axes and on canyon side walls are similar.

Shepard and Beard (1938) reported that the axial slope of California submarine canyons is steepest at the head—14.5°, moderate at the middle—5.5°, and gentlest at the seaward end—4.0°. The new profiles were made too far from the shallows at the heads of the canyons to cross the steepest part of the canyon axes, but axial slopes which they did encounter in the shelf portions usually exceeded 5°. All except three canyons (Coronado, Santa Catalina, and Tanner) have longitudinal profiles that are concave upward. As shown by Figure 16, there is only a slight correlation between steepness of canyon walls and of canyon axes.

Heights of canyon walls in the shelf portion range upward to 480 meters and average about 170 meters. In five canyons (Hueneme, Santa Monica, Redondo, Newport, and Santa Cruz) the greatest wall heights occur at the outer part of the shelves; in all the others, the greatest heights are slightly farther seaward, near the top of the basin slopes.

Basin-slope Portion:—Basin slopes in the region average about 8°. The portion of some of the canyons traversing the basin slope is longer than that across the shelf, but for other canyons the reverse is true. All except Newport, San Clemente, and Tanner canyons have broadly curved courses down the basin slopes. For four canyons the curvature is to the right and for six to the left; this curvature appears to be the result of differential erosion along structural irregularities in the basin slopes.

Just as for the shelf portions, the intersections of the canyon walls with the basin slopes are not usually abrupt, but the basin slopes bend gradually inward toward the canyons. Indicated steepnesses of the canyon walls range up to 40°, averaging slightly less than for the shelf portion. In both portions the opposite walls exhibit considerable asymmetry, with one-third of all pairs of profiles having one wall more than twice as steep as the opposite wall. Heights of the walls range up to 500 meters and average 170 meters for 79 measurements, the same as the average for the shelf portions of the canyons. The heights of both walls are about equal, except where the canyon lies at the foot of a basin slope.

The echograms present a minimum width of the canyon floors because of reflections from the canyon walls, as discussed also by Northrop (1953) for Hudson Canyon. Often a faint echo from a horizontal surface can be detected through the traces produced by echoes from the walls. This faint echo, the presence of flat bottoms on some echograms, the collection of several samples from about the same wire depth on a profile across a canyon, plus the observations of divers in shallow water indicate that the canyons in both shelf and slope portions may have flat floors. The width is uncertain but it is believed to commonly range up to 200 meters.

Basin-floor Portion:—At the foot of the basin slopes both the general bottom topography and the canyons exhibit a change. The general steepness is much less and both contours and samples show that the basin slope is bordered by a broad concave fan or apron built up of sediments carried through the submarine canyons (Gorsline and Emery, 1959; Emery, 1960b). Fans from adjacent canyons may coalesce to form a general bajada-like feature whose steepness ranges downward from about 1.5°. Beyond the fans are basin plains which are so flat that the depth may change only 1 meter in 6 km.

Extensions of the submarine canyons have been recognized only across the fans, where they take the form of low winding channels. These channels are bordered by natural levees which often cause the floor of the channel to be higher than the surface of the adjacent fan. Such levees are shown by profiles for Mugu, Dume, Santa Monica, Redondo, San Pedro, Newport, La Jolla, Coronado, Santa Cruz, and Santa Catalina canyons and they may occur at others. The first recognition of levees in the region appears to have been by Buffington (1952) for San Pedro, Newport and La Jolla canyons. Heights of the levees above the channels range up to about 50 meters, but 25 meters is probably a better average height. The channels are probably less than 200 meters wide and their axial slopes range from 3° to 0.4°, as shown by the data of Figure 16.

Lithology and Age

Rocks have been dredged from the walls of many of the canyons. Most common are sedimentary and volcanic rocks of Miocene age (Fig. 17). Pliocene shales were obtained at San Pedro Sea Valley, San Gabriel Canyon (about 20 km east of San Pedro Sea Valley), and Coronado Canyon. Landward extensions of canyons have been filled with Recent sediments. Therefore, the age of the canyons is pre-Recent and at least parts of some of them are post-Pliocene. The strata which crop out on the walls represent seaward extensions of the same strata encountered in outcrops or in wells on the adjacent land, but not enough samples are available to reveal the tops and bottoms of individual beds or to show whether the beds dip seaward or have structural peculiarities.

Fig. 3.—Hueneme Canyon. Profiles with (X 19) vertical exaggeration. Insert map with contours in meters shows positions of profiles, bottom samples (solid dots), and hydrographic casts (circles).

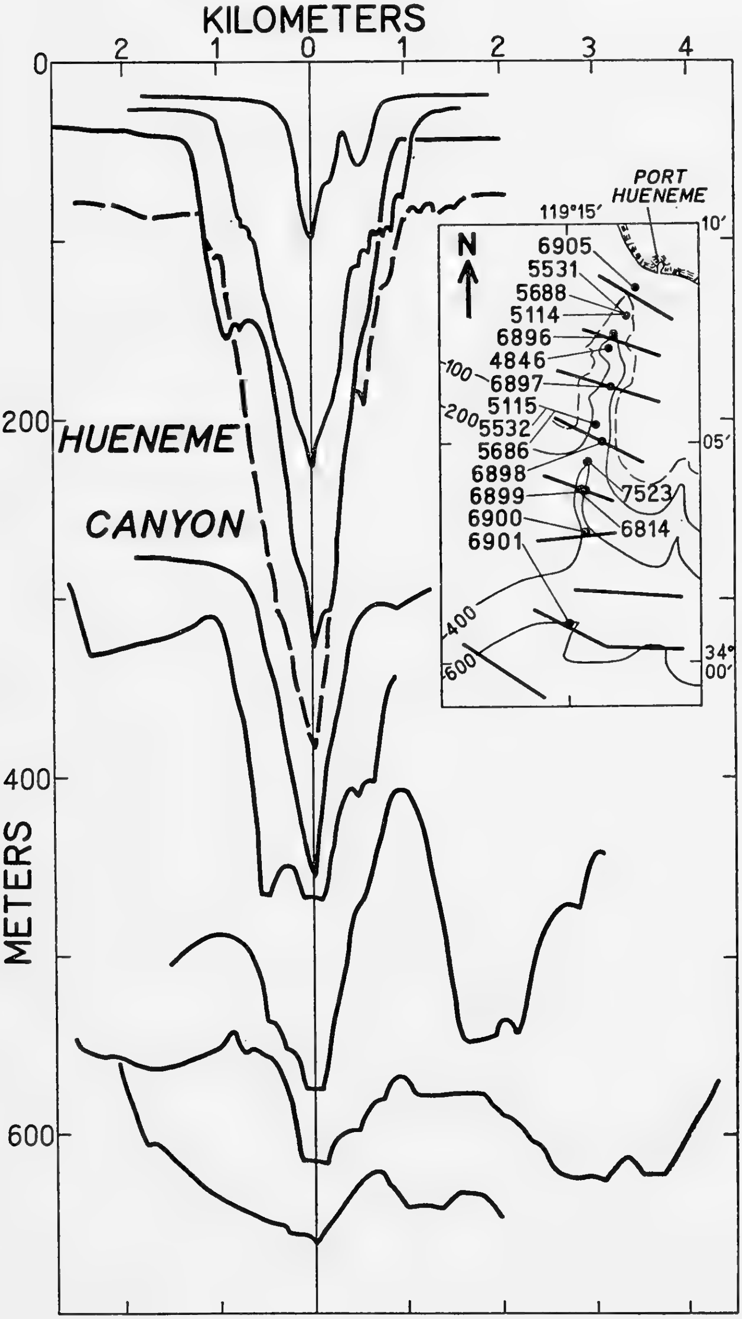

KILOMETERS
2
1
0
1
2
3
4
0
200
400
600
METERS
HUENEME
CANYON
PORT
HUENEME
119°15′
10′
05′
34°
00′
N
6905
5531
5688
5114
6896
4846
100
6897
5115
200
5532
5686
6898
6899
6900
6901
7523
6814
400
600

Fig. 4.—Mugu Canyon. Symbols same as for Figure 3.

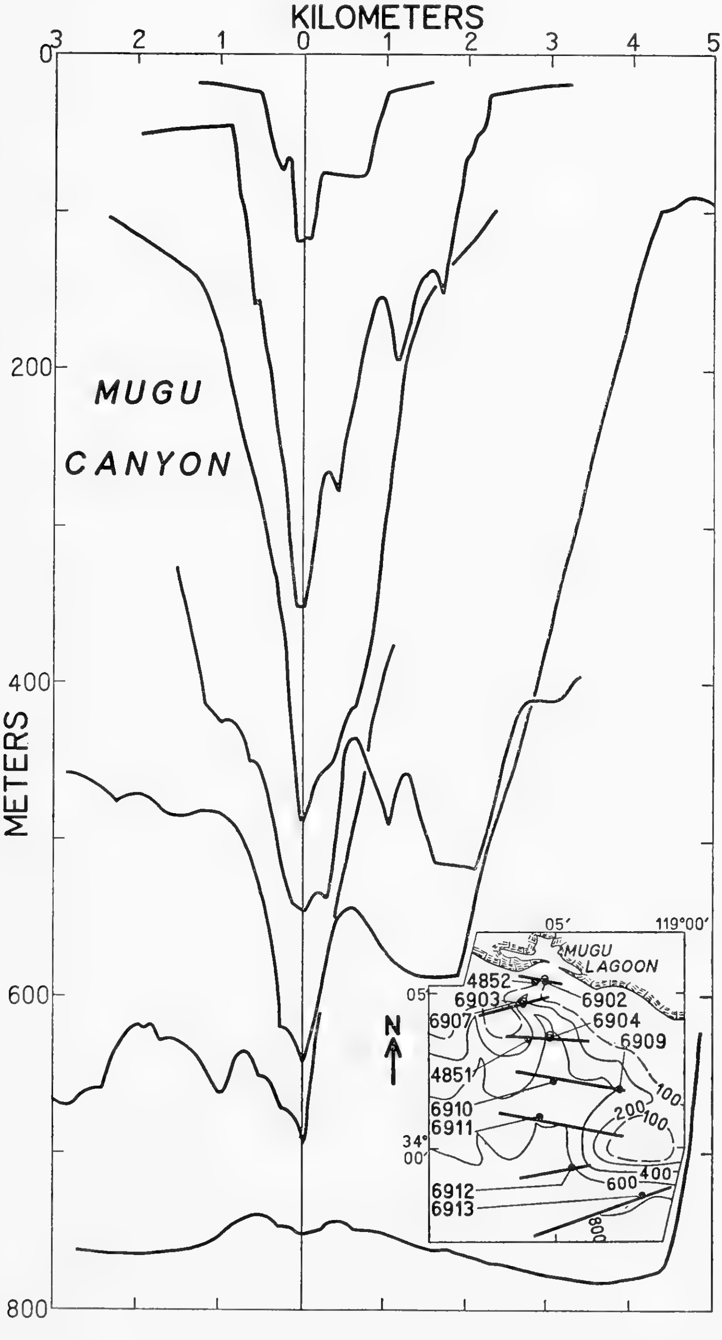

KILOMETERS
3
2
1
0
1
2
3
4
5
METERS
0
200
400
600
800
MUGU
CANYON
N
05′
119°00′
MUGU
LAGOON
4852
05′
6903
6902
6907
6904
6909
4851
100
6910
200
100
6911
34°
00′
400
600
6912
6913
800

Fig. 5.—Dume Canyon. Symbols same as for Figure 3.

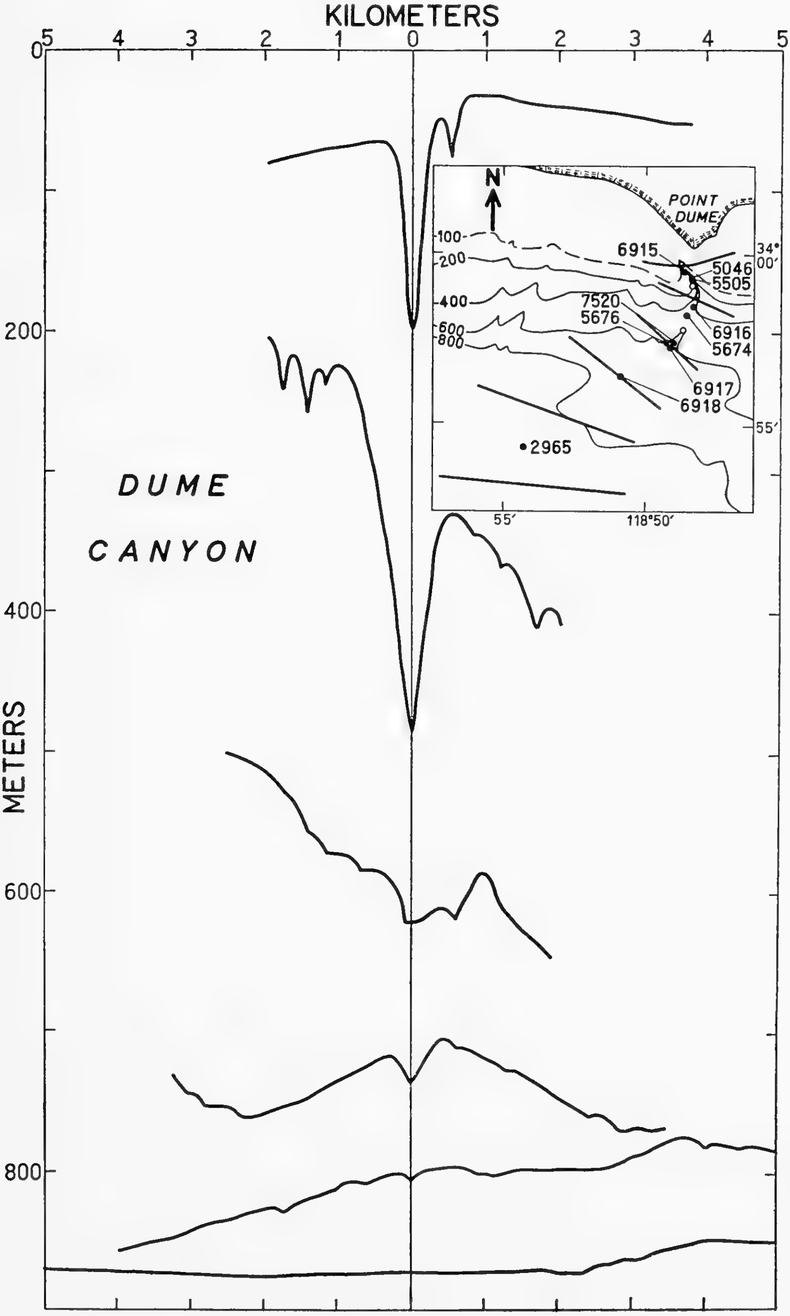

KILOMETERS
5
4
3
2
1
0
1
2
3
4
5
0
200
400
600
800
METERS
DUME
CANYON
N
POINT
DUME
100
200
400
600
800
6915
5046
5505
7520
5676
6916
5674
6917
6918
2965
34°
00′
55′
55′
118°50′

Fig. 6.—Santa Monica Canyon. Symbols same as for Figure 3.

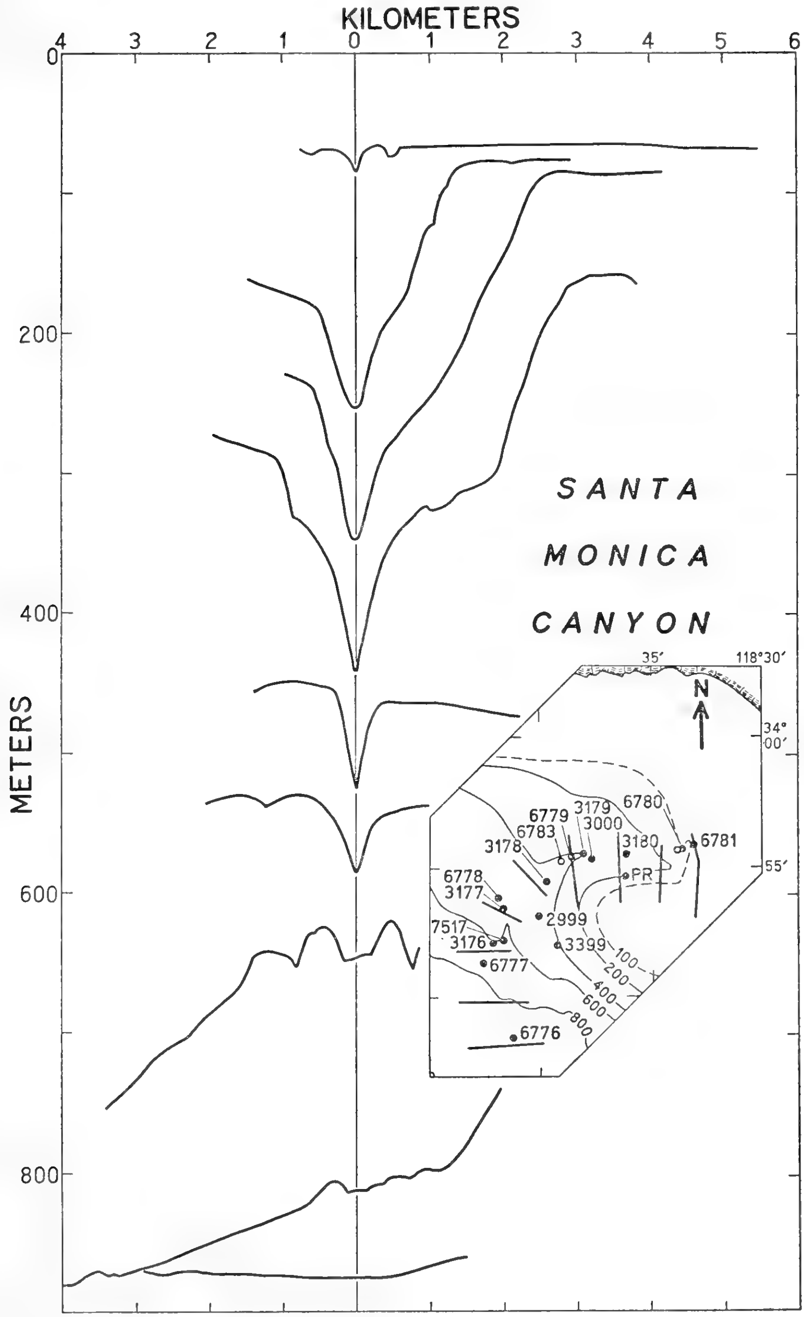

KILOMETERS
4
3
2
1
0
1
2
3
4
5
6
METERS
0
200
400
600
800
SANTA MONICA CANYON
35′
118°30′
N
34° 00′
55′
6780
3179
6779
3000
6783
3180
6781
3178
PR
6778
3177
2999
7517
3176
3399
100
6777
200
400
600
800
6776

Fig. 7.—Redondo Canyon. Symbols same as for Figure 3.

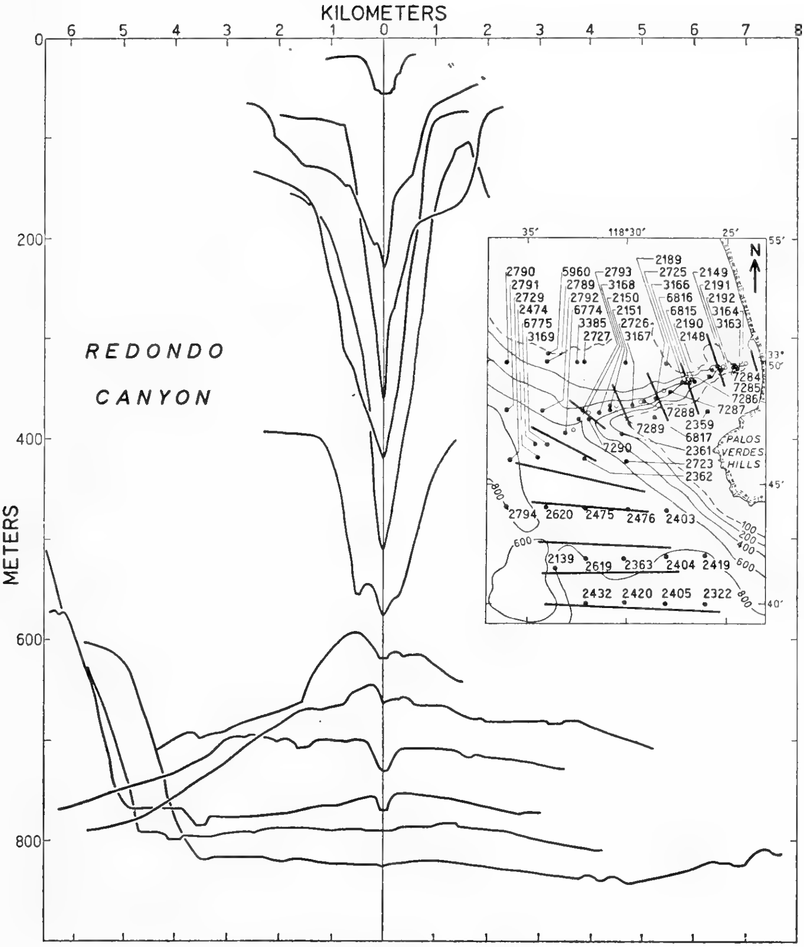

KILOMETERS
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
0
200
400
600
800
METERS
REDONDO
CANYON
35′
118°30′
25′
55′
33°
50′
45′
40′
N
2790
2791
2729
2474
6775
3169
5960
2789
2792
6774
3385
2727
2793
3168
2150
2151
2726
3167
2189
2725
3166
6816
6815
2190
2148
2149
2191
2192
3164
3163
7284
7285
7286
7287
7288
2359
7289
6817
2361
2723
2362
7290
PALOS
VERDES
HILLS
800
2794
2620
2475
2476
2403
100
200
400
600
600
2139
2619
2363
2404
2419
2432
2420
2405
2322
800

Fig. 8.—San Pedro Sea Valley. Symbols same as for Figure 3.

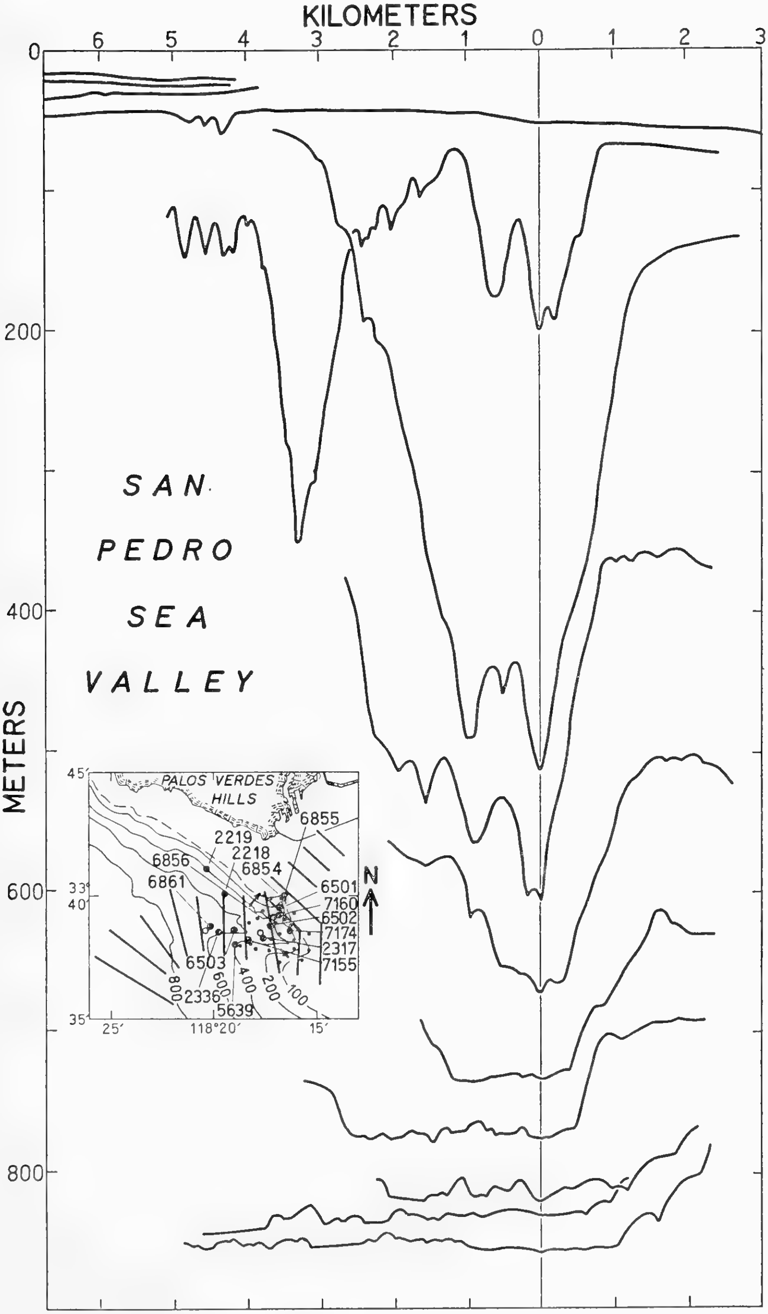

KILOMETERS
6
5
4
3
2
1
0
1
2
3
0
200
400
600
800
METERS
SAN PEDRO SEA VALLEY
45′
PALOS VERDES HILLS
6855
2219
2218
6856
6854
6861
6501
7160
6502
7174
2317
7155
6503
800
600
400
200
100
2336
5639
33°40′
35′
25′
118°20′
15′
N

Fig. 9.—Newport Canyon. Symbols same as for Figure 3.

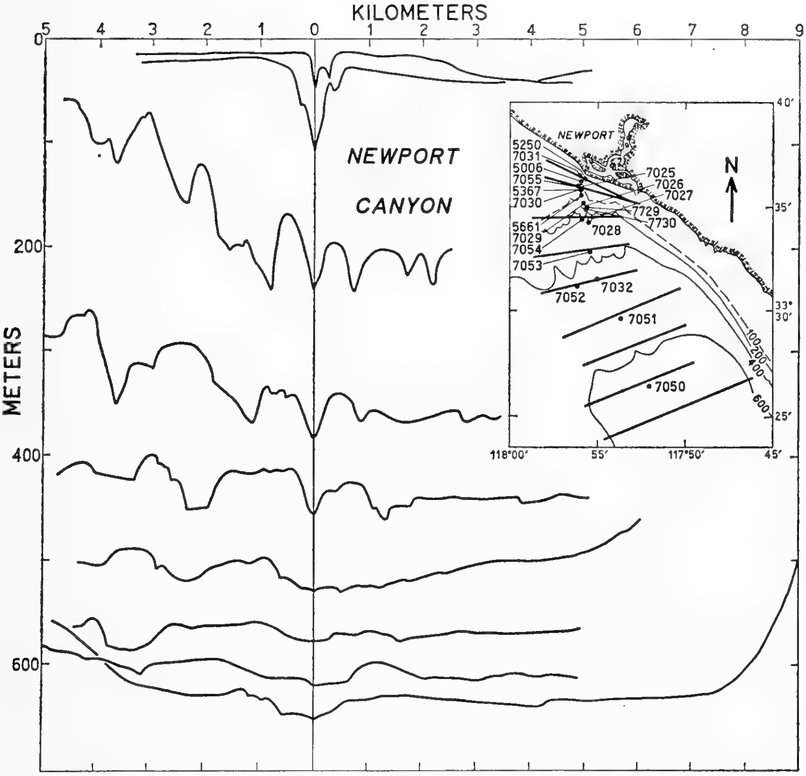

KILOMETERS
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
METERS
0
200
400
600
NEWPORT
CANYON
NEWPORT
N
5250
7031
5006
7055
5367
7030
5661
7029
7054
7053
7025
7026
7027
7729
7730
7028
7052
7032
7051
7050
100
200
400
600
40′
35′
33° 30′
25′
118°00′
55′
117°50′
45′

Fig. 10.—La Jolla Canyon. Symbols same as for Figure 3.

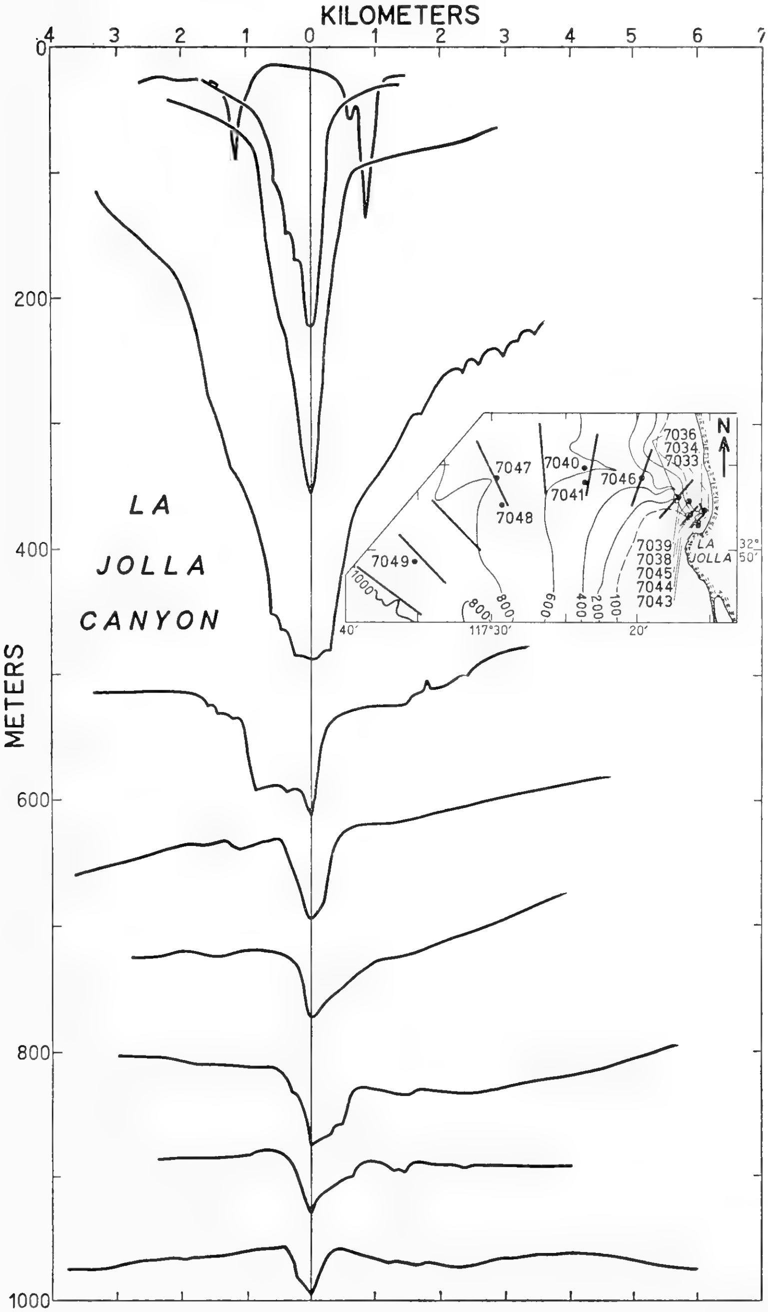

KILOMETERS
4
3
2
1
0
1
2
3
4
5
6
7
METERS
0
200
400
600
800
1000
LA
JOLLA
CANYON
7036
7034
7033
N
7047
7040
7046
7041
7048
7049
7039
7038
7045
7044
7043
LA
JOLLA
32°
50′
1000
800
800
600
400
200
100
40′
117°30′
20′

Fig. 11.—Coronado Canyon. Symbols same as for Figure 3.

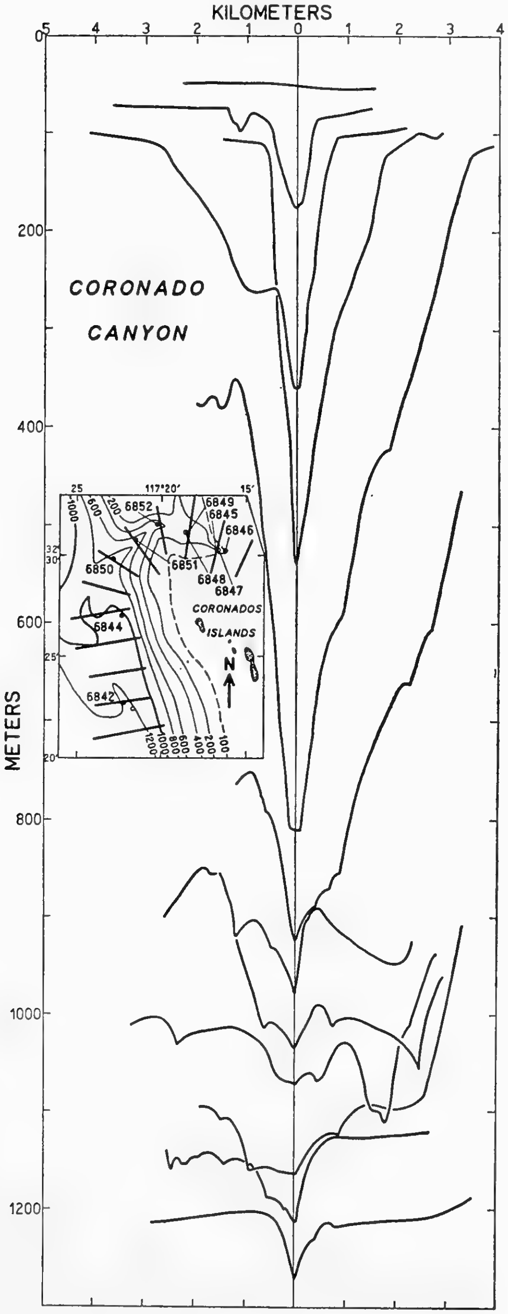

KILOMETERS
5
4
3
2
1
0
1
2
3
4
0
200
400
600
800
1000
1200
METERS
CORONADO
CANYON
25
117°20′
15′
32°
30′
25′
20′
1000
600
200
6852
6849
6845
6846
6850
6851
6848
6847
CORONADOS
ISLANDS
6844
6842
N
1200
1000
800
600
400
200
100

Fig. 12.—Santa Cruz Canyon. Symbols same as for Figure 3.

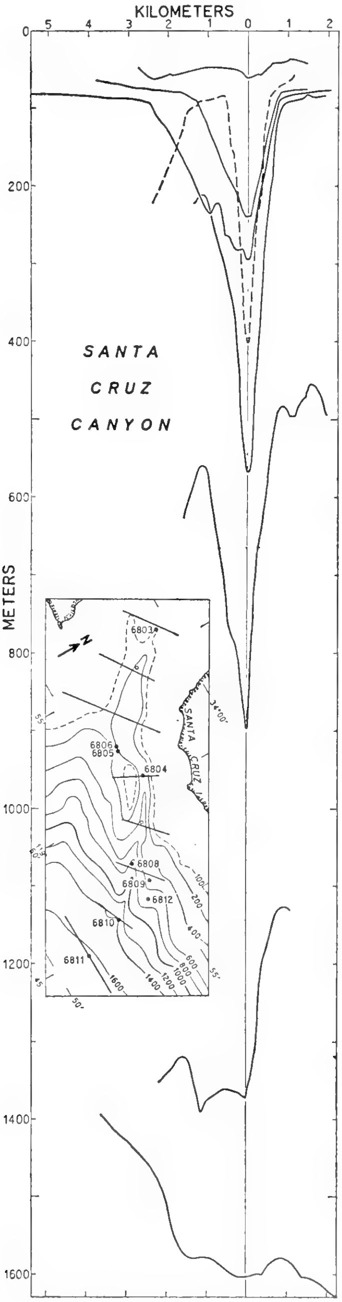

KILOMETERS
5
4
3
2
1
0
1
2
0
200
400
600
800
1000
1200
1400
1600
METERS
SANTA CRUZ CANYON
N
6803
6806
6805
6804
6808
6809
6812
6810
6811
SANTA CRUZ
34°00'
55'
50'
45
100
200
400
600
800
1000
1200
1400
1600

Fig. 13.—Santa Catalina Canyon. Symbols same as for Figure 3.

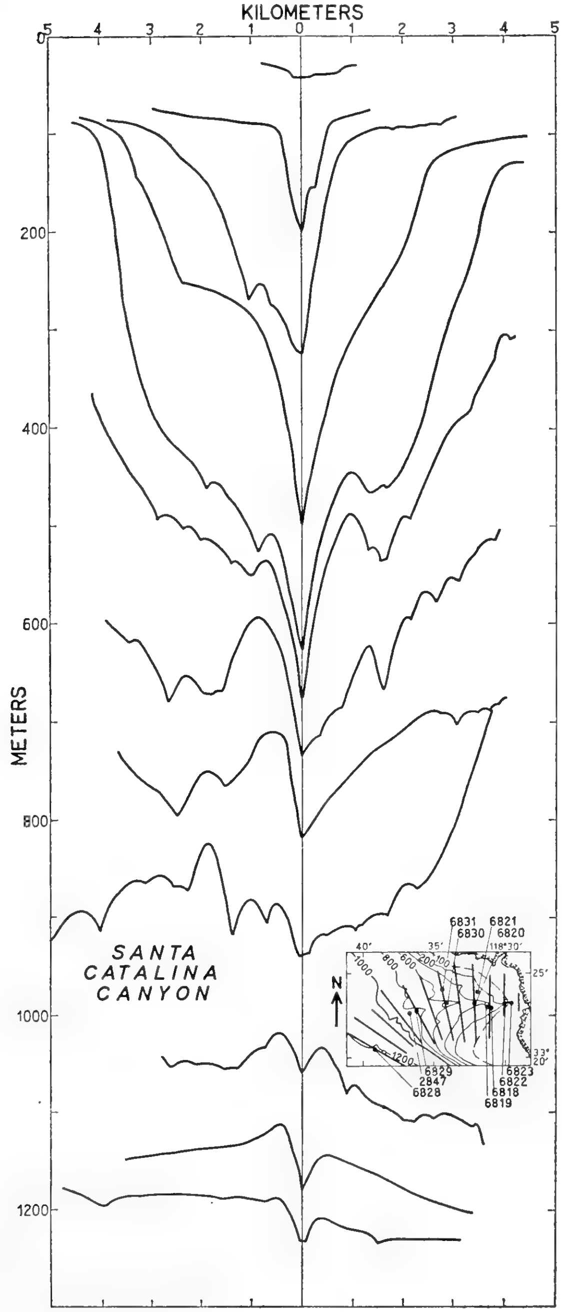

KILOMETERS
5
4
3
2
1
0
1
2
3
4
5
0
200
400
600
800
1000
1200
METERS
SANTA CATALINA CANYON
N
40′
35′
118°30′
25′
33° 20′
1000
800
600
200
100
1200
6831
6830
6821
6820
6829
2847
6828
6823
6822
6818
6819

Fig. 14.—San Clemente "Rift Valley." Symbols same as for Figure 3.

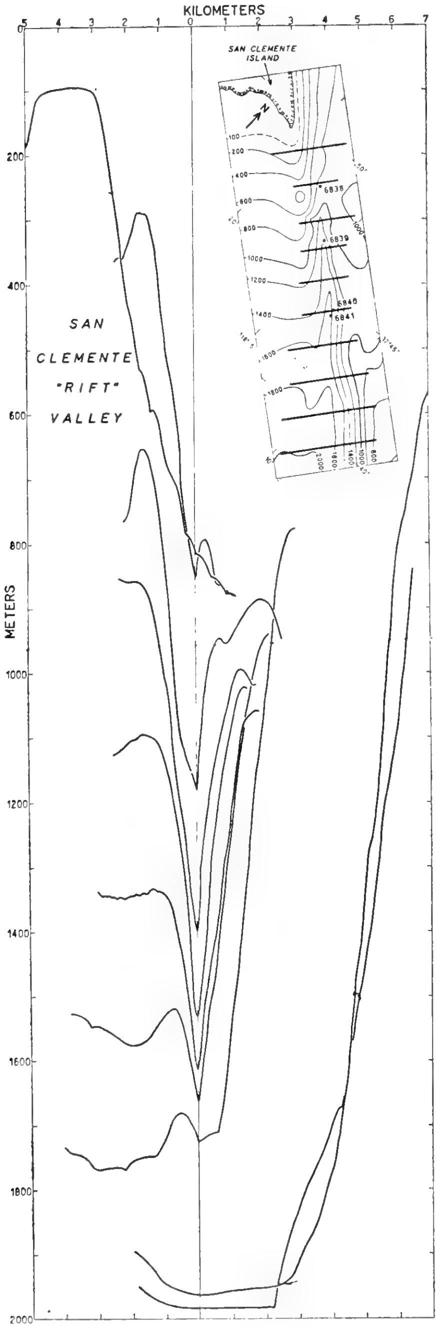
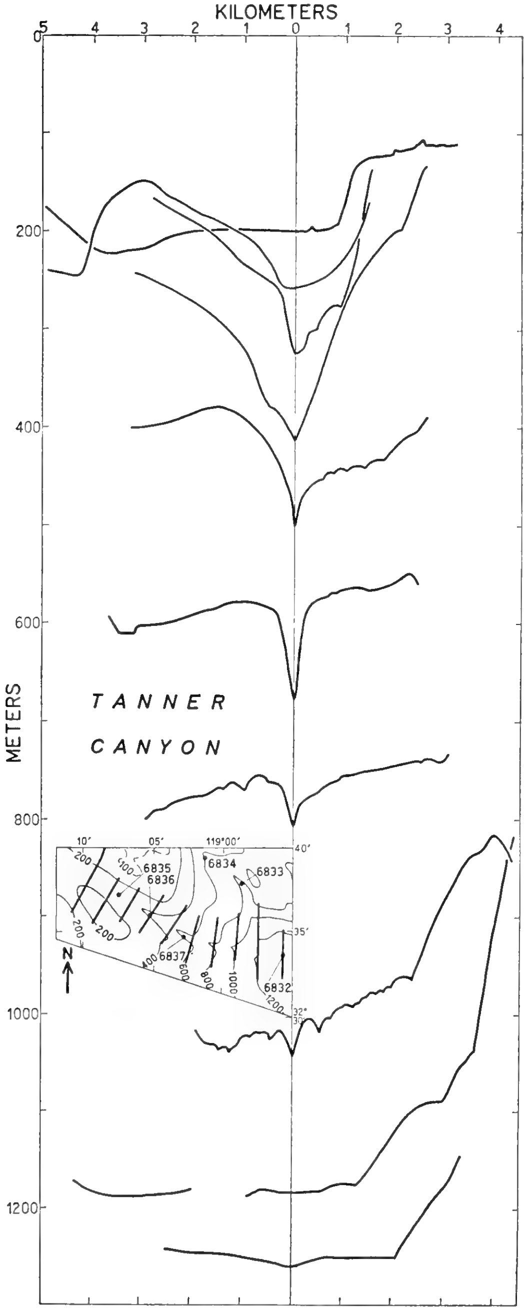

KILOMETERS
5
4
3
2
1
0
1
2
3
4
5
6
7
METERS
0
200
400
600
800
1000
1200
1400
1600
1800
2000
SAN CLEMENTE "RIFT" VALLEY
SAN CLEMENTE ISLAND
N
100
200
400
600
800
1000
1200
1400
1600
1800
2000
6838
6839
6840
6841
50'
40'
118°5'
32°45'
1000
1600
1400
1000
600

Fig. 15.—Tanner Canyon. Symbols same as for Figure 3.


KILOMETERS
5
4
3
2
1
0
1
2
3
4
0
200
400
600
800
1000
1200
METERS
TANNER
CANYON
10′
05′
119°00′
40′
35′
32°
30′
200
100
200
200
400
600
800
1000
1200
6832
6833
6834
6835
6836
6837
N

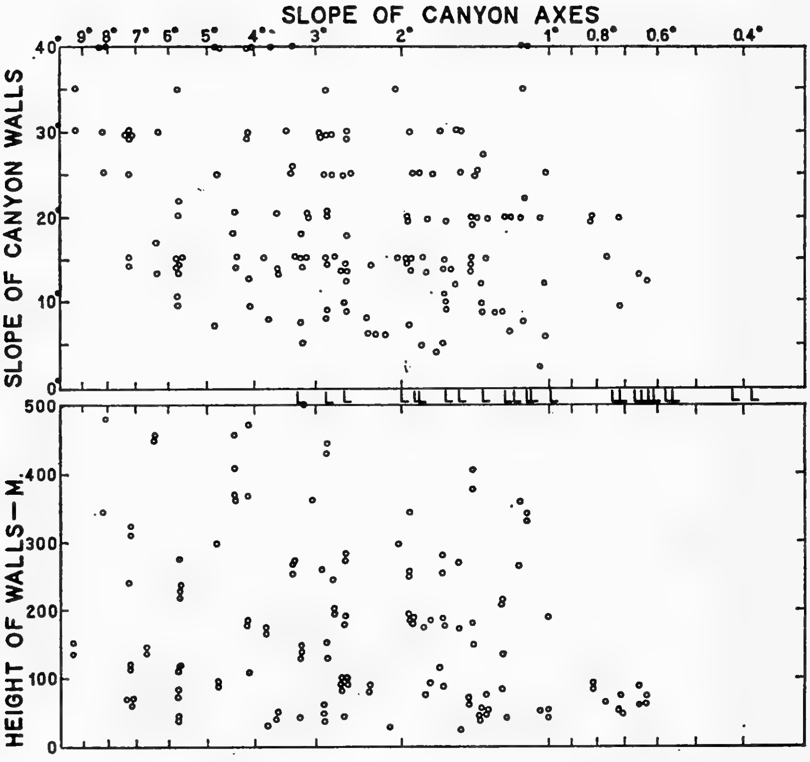


Fig. 16.—Relationships of wall steepness and height to slope of canyon axes. Symbol *L* indicates presence of natural levees.

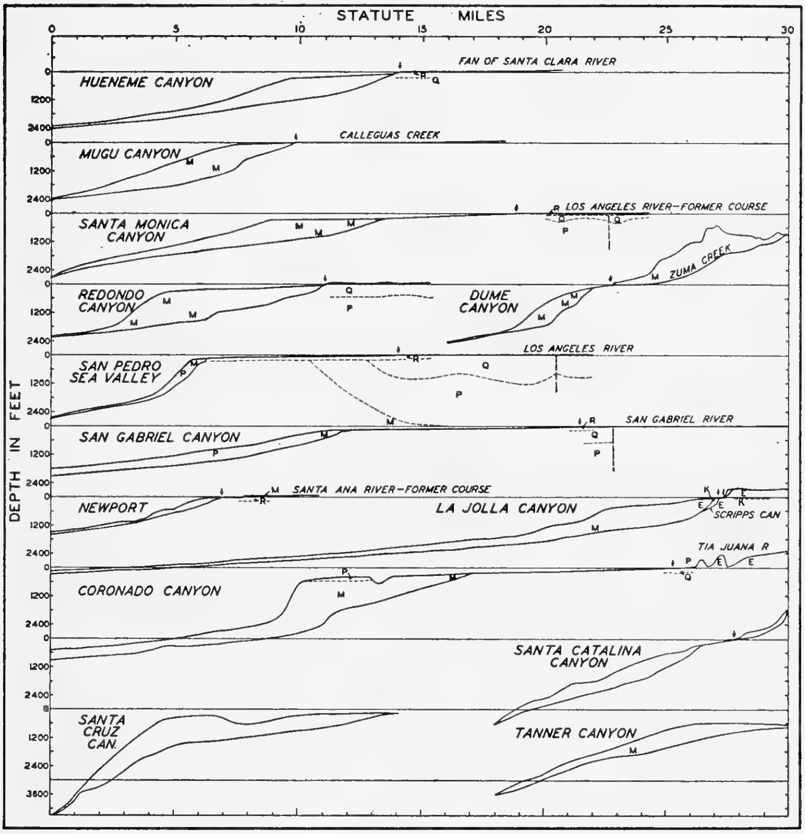


Fig. 17.—Profiles of submarine canyons compared with lithology where known. Symbols are as follows: arrow, shoreline; K, Cretaceous; E, Eocene; M, Miocene; P, Pliocene; Q, Quaternary; R, postglacial (on sea floor letters show sites of dateable rock samples). From Emery (1960a, fig. 48).

WATER

Those who have spent much time aboard ship watching traces being drawn by echo sounders frequently observe echoes from dense schools of fish which are often present at the tops of slopes, including those at the sides and heads of submarine canyons. Some verification is provided by the reportedly greater catch of fish at the head and sides of the canyons than on the nearby shelf. It has been suggested that fish are concentrated in these areas because of the presence of abundant food brought by currents from deep in the canyons. Many of the fish caught from piers at the heads of Redondo and Newport canyons are species characteristic of deep cold water, confirming the observation by some skin divers that water may be colder at the head of a canyon than at either side and that at times the water appears to be rising from the canyon. A few current-meter measurements in six canyons of the area (Shepard, Revelle, and Dietz, 1939) showed flows in the direction of the canyon axes but with no preference for up or down canyon. Possibly the water moves too slowly to be indicated reliably by such meters; a better technique might be the measurement of properties of the water itself.

Two to eight water stations were occupied along the axes of most of the 13 canyons at positions shown by open circles in Figure 3 through 15. Each station was positioned over the canyon axis by first making a topographic profile and then by stopping the ship at such a position that it would drift over the deepest point of the profile by the time that water-sampling gear had been lowered. In a few instances the drift varied so that the station was slightly to one side of the axis. Water samples were collected in Nansen bottles carrying two protected reversing thermometers. In Redondo Canyon a series of four water samples were obtained at each station just above the bottom through use of a bottom water sampler described by Rittenberg, Emery, and Orr (1955).

For each sample, temperature was corrected from the reversing thermometers, salinity was computed from standard titration for chloride, oxygen content was measured by Winkler analysis, and contents of silicate, phosphate, and nitrate were determined by standard colorometric methods using a Beckman DU spectrophotometer. The results are listed in Table 1 for the eleven canyons which were sampled. Profiles of six canyons with positions of water samples are presented in Figure 18, and more completely with water characteristics for Redondo Canyon in Figure 19.

The measurements show no marked difference in the character of the water at the canyon head from that near the seaward end of the canyon. The water is also within the range of seasonal and areal variation of that in the adjacent basins (Emery, 1954). Close examination of Table 1 and Figure 19, however, does show some slight inclination of the isopleths in a few of the canyons. At Redondo Canyon the temperature and oxygen content is higher and the salinity and nutrients are lower near the head than farther seaward. This difference is just what is to be expected of local upwelling. A similar conclusion is indicated by the less complete data at Dume Canyon, but on the other hand possible downwelling may have occurred at Mugu and La Jolla canyons. Clearly, upwelling was not marked at the times of the surveys, but then the wind and sea conditions were fairly calm at these times. At times of strong winds, movements of water along the canyons may be more intense.

It seems evident that the water is not of such unusual character as to present an abnormal environment for benthic animals; thus any abnormalities in size of individuals or groupings of the fauna must be due to some aspect of the environment other than the water within the canyon.

A major abnormality in the benthic fauna is indicated by the fact that 22 samples from six canyons (Table 2) consist almost exclusively of *Capitella,* a polychaete worm which ordinarily lives in estuarine water (Hartman, 1962). These same samples are free of marine worms and of other marine animals except carnivores such as squid, which may not really inhabit the sites. Since *Capitella* lays its eggs in the tubes in which it lives, wide dispersion through sea water is unlikely. It is suggested that the samples represent sites at which fresh water escapes into the ocean from aquifers which have been intersected by cutting of the canyons. Escape of fresh water is known to occur from many nearshore areas of the sea floor of the world. Accounts of its escape from submarine canyons go back at least to Benest (1899). Johnson (1938-1939) even postulated an origin for submarine canyons on the basis of submarine erosion by escaping ground water, but his concept is now generally considered less plausible than others.

It is quite reasonable that a submarine canyon should be a local focus for escape of ground water because it is the farthest landward point of outcropping horizontal strata, and thus a point of steep pressure gradient of confined waters. The coarse sediment which floors the canyon should form no impediment. The rate of escape of the water is likely to be so low that a dilution of the overlying sea water cannot be detected. Thus, the benthic fauna may be the best indicator of escaping fresh water. At shallow depths escape is less likely, at least for Hueneme and Redondo canyons, owing to probable sea-water intrusion into aquifers produced by artificially lowered water tables of the adjacent land.

TABLE 1

CHARACTERISTICS OF WATER IN SUBMARINE CANYONS

HUENEME CANYON 23 December 1959

	Station	6813	6814		6813	6814
	Distance (km)	1.8*	8.6		1.8	8.6
	Bottom (m)	234	439		234	439
	Above axis (m)	0	0		0	0
		Temperature (°C)			Silicate (μg-A/L)	
Depth (m)	222	8.26	—	222	33	—
	420		7.13	420		38
		Salinity (‰)			Phosphate (μg-A/L)	
Depth (m)	222	34.09	—	222	2.3	—
	420		34.25	420		2.7
		Oxygen (ml/L)				
Depth (m)	222	1.59	—			
	420		0.74			

*Distance from 100-m contour.

MUGU CANYON 12 March 1960

Station	6906	6907	6908		6906	6907	6908
Distance (km)	0.0	1.9	4.4		0.0	1.9	4.4
Bottom (m)	116	369	484		116	369	484
Above axis (m)	0	0	0		0	0	0
	Temperature (°C)				Silicate (μg-A/L)		
Depth (m) 0	14.0	14.2	14.6	0	7	5	6
101	9.62	9.21	9.45	101	45	51	45
183		8.50	8.58	183		63	62
353		7.70	7.23	353		81	96
469			6.71	469			114
	Salinity (‰)				Phosphate (μg-A/L)		
Depth (m) 0	33.57	33.55	33.46	0	0.6	0.5	0.5
101	33.86	33.97	33.89	101	2.1	2.2	2.1
183		34.09	34.09	183		2.6	2.3
353		34.20	34.23	353		2.7	2.8
469			34.31	469			2.9
	Oxygen (ml/L)				Nitrate (μg-A/L)		
Depth (m) 0	—	—	—	0	0.2	—	0.1
101	2.72	2.05	1.51	101	13	15	13
183		—	1.01	183		17	15
353		1.06	0.54	353		18	20
469			0.52	469			20

DUME CANYON 10 March 1960

Station	6893	6894	6895		6893	6894	6895
Distance (km)	0.2	1.5	3.7		0.2	1.5	3.7
Bottom (m)	220	387	558		220	387	558
Above axis (m)	20	65	0		20	65	0
		Temperature (°C)				Silicate (μg-A/L)	
Depth (m) 0	14.8	14.7	14.4	0	2	2	4
91	10.13	10.06	10.09	91	35	35	32
204	8.46	8.46	8.56	204	64	64	61
372		7.25	7.40	372		87	86
539			5.96	539			129
		Salinity (‰)				Phosphate (μg-A/L)	
Depth (m) 0	33.57	33.57	33.53	0	0.2	0.3	0.2
91	33.77	33.69	33.73	91	1.5	1.5	1.5
204	34.13	34.11	34.07	204	2.3	2.0	2.2
372		34.20	34.23	372		2.6	2.6
539			34.34	539			2.8
		Oxygen (ml/L)				Nitrate (μg-A/L)	
Depth (m) 0	—	—	—	0	0.1	0.1	0.2
91	3.11	3.11	3.16	91	< 0.1	0.1	9
204	1.60	1.59	1.71	204	< 0.1	< 0.1	17
372		0.89	—	372		19	17
539			0.28	539			20

SANTA MONICA CANYON 20 December 1959

Station		6782	6783	6796
Distance (km)		1.0	9.2	27.1
Bottom (m)		204	458	890
Above axis (m)		0	0	0
			Temperature (°C)	
Depth (m)	0	—	—	—
	192	9.21	—	—
	447		8.06	—
	768		—	5.19
	864		5.15	5.12
			Salinity (‰)	
Depth (m)	0	—	—	—
	192	33.77	—	—
	447		33.98	—
	768			34.34
	864			
			Oxygen (ml/L)	
Depth (m)	0	—	—	4.55
	192	3.10	—	2.11
	447		1.83	—
	768			0.07
	864			0.04

	6782	6783	6796
	1.0	9.2	27.1
	204	458	890
	0	0	0
		Silicate (μg-A/L)	
0	—	—	—
192	25	—	—
447		37	—
768		—	95
864		87	105
		Phosphate (μg-A/L)	
0	—	—	—
192	1.8	—	—
447		2.6	—
768			3.5
864			3.6

REDONDO CANYON 8 June 1956

	Station	4276	4275	4274	4273	4272	4271	4270	4268
	Distance (km)	0.1	1.9	4.7	6.7	8.6	10.5	12.7	14.2
	Bottom (m)	94	193	370	370	366	517	578	603
	Above axis (m)	0	0	0	30	100	0	0	0
				Temperature (°C)					
Depth (m)	0	17.7	17.0	16.9	16.5	16.4	17.0	17.4	16.9
	6	17.07	16.0+	15.88	16.16	—	15.63	—	16.29
	18	10.86	11.09	13.19	13.11	14.38	14.80	15.49	—
	30	10.50	10.45	—	13.12	12.89	—	—	13.8+
	76	9.16	9.15	9.12	—	—	—	—	—
	93		—	—	—	—	—	—	—
	152		8.22	8.82	—	9.09	9.10	9.04	9.05
	192			—	—	—	—	—	—
	229			8.21	—	—	8.87	8.79	—
	305			7.81	8.31	—	8.34	8.31	8.08
	369								
				Salinity (‰)					
Depth (m)	0	33.75	33.84	33.75	33.80	33.66	33.64	33.64	33.80
	6	33.78	33.77	33.75	33.78	33.62	33.60	33.66	33.78
	18	33.77	33.75	33.69	33.78	33.60	33.60	33.62	—
	30	33.82	33.82	—	33.77	33.60	—	—	33.71
	76	34.04	34.05	34.16	—	33.73	33.73	33.86	—
	93	34.09	—	—	—	—	—	—	—
	152		34.36	34.25	—	34.00	34.02	34.16	34.22
	192		34.37	—	—	—	—	—	—
	229			34.36	—	—	34.16	34.23	—
	305			34.38	34.29	—	34.29	34.34	34.38
	369			34.43	34.44	—	—	—	—
	517						34.33	—	—
	578							34.34	—
	602								34.51

REDONDO CANYON (continued)

	Station	4276	4275	4274	4273	4272	4271	4270	4268
	Distance (km)	0.1	1.9	4.7	6.7	8.6	10.5	12.7	14.2
	Bottom (m)	94	193	370	370	366	517	578	603
	Above axis (m)	0	0	0	30	100	0	0	0
				Oxygen (ml/L)					
Depth (m)	0	5.61	6.10	5.44	5.46	6.07	5.94	5.95	5.87
	6	6.10	5.01	3.55	6.26	6.18	6.29	5.82	6.12
	18	3.30	3.57	3.84	5.43	6.38	6.42	6.30	5.25
	30	2.94	3.18	—	5.02	4.89	—	—	—
	76	2.14	2.23	2.28	—	1.53	2.82	2.70	—
	93	2.13	—	—	—	—	—	—	—
	152		1.17	0.89	—	2.08	1.99	—	1.85
	192			—	—	—	—	—	—
	229			0.79	—	—	1.56	1.43	—
	305			—	0.88	—	1.18	1.19	0.82
	369			0.60	0.94	—	—	—	—
	517					—	0.39	—	—
	578					—	—	0.40	—
	602					—	—	—	0.33
				Silicate (μg-A/L)					
Depth (m)	0	6	6	6	5	6	5	4	4
	6	6	5	7	4	5	5	4	4
	18	17	16	7	6	5	6	7	7
	30	20	20	—	9	9	—	—	—
	76	31	27	22	—	24	24	—	8
	93	30	—	—	—	—	—	—	—
	152		40	33	—	31	31	26	31
	192		35	—	—	—	—	—	—
	229			37	—	—	33	33	—
	305			39	32	—	48	36	37
	369			48	44	—	—	—	—
	517						55	—	—
	528							58	—
	602								68

REDONDO CANYON (continued)

Station	4276	4275	4274	4273	4272	4271	4270	4268
Distance (km)	0.1	1.9	4.7	6.7	8.6	10.5	12.7	14.2
Bottom (m)	94	193	370	370	366	517	578	603
Above axis (m)	0	0	0	30	100	0	0	0
	Phosphate (µg-A/L)							
Depth (m)								
0	0.3	0.3	0.5	0.4	0.3	0.3	0.3	0.3
6	0.4	0.5	0.2	0.4	0.3	0.3	0.3	0.3
18	1.2	1.8	0.6	0.7	0.3	0.5	0.4	0.5
30	1.9	2.0	—	0.8	1.0	—	—	—
76	2.4	2.4	1.7	—	2.4	2.3	—	0.7
93	2.1	—	—	—	—	—	—	—
152		2.8	2.2	—	2.3	2.5	2.0	2.5
192		2.5	—	—	—	—	—	—
229			2.6	—	—	2.6	2.5	—
305			2.9	2.8	—	3.2	2.7	2.7
369			2.7	3.5	—	—	—	—
517						3.5	—	—
578							3.6	—
602								3.6

SAN PEDRO SEA VALLEY 13 February 1960

	Station	6855	6856	6857	6858		6855	6856	6857	6858
	Distance (km)	0.2	2.1	3.7	8.0		0.2	2.1	3.7	8.0
	Bottom (m)	187	404	549	682		187	404	549	682
	Above axis (m)	0	0	0	0		0	0	0	0
			Temperature (°C)					Silicate (μg-A/L)		
Depth (m)	0	12.0	13.2	13.8	14.4	0	—	13	12	13
	91	9.72	9.90	9.93	9.74	91	43	38	37	39
	172	8.91	8.88	9.11	9.00	172	66	56	56	53
	366		7.46	7.55	7.42	366		86	87	87
	533			6.22	6.22	533			123	123
	666				5.34	666				158
			Salinity (‰)					Phosphate (μg-A/L)		
Depth (m)	0	—	33.49	33.40	33.37	0	—	1.3	1.3	1.1
	91	33.71	33.69	33.75	33.69	91	2.0	2.2	2.0	2.2
	172	33.89	33.96	33.95	33.95	172	2.6	2.6	2.4	2.6
	366		34.20	34.18	34.14	366		3.2	—	3.1
	533			34.25	34.27	533			3.5	2.9
	666				34.33	666				3.7
			Oxygen (ml/L)					Nitrate (μg-A/L)		
Depth (m)	0	—	5.72	5.88	5.93	0	—	4	4	3
	91	2.94	3.35	3.07	3.01	91	16	15	14	18
	172	2.04	1.92	2.07	1.88	172	18	20	18	16
	366		0.78	0.80	0.73	366		18	20	23
	533			0.30	0.29	533			22	21
	666				0.15	666				23

NEWPORT CANYON 5 May 1960

Station		7025	7026	7027		7025	7026	7027
Distance (km)		—0.2	1.5	2.6		—0.2	1.5	2.6
Bottom (m)		62	182	253		62	182	253
Above axis (m)		0	0	0		0	0	0
		Temperature (°C)				Silicate (µg-A/L)		
Depth (m)	0	17.0	—	16.4	0	6.9	5.7	4.7
	47	10.22	10.31	10.23	47	39.9	38.2	35.2
	166		8.92	8.67	166		60.4	61.6
	238			8.28	238			68.8
		Salinity (‰)				Phosphate (µg-A/L)		
Depth (m)	0	33.51	33.62	33.58	0	0.53	0.30	0.28
	47	33.75	33.82	33.82	47	1.88	1.82	1.77
	166		33.95	34.07	166		2.27	2.36
	218			34.22	238			2.64
		Oxygen (ml/L)						
Depth (m)	0	—	—	—				
	47	2.71	2.92	2.81				
	166		2.40	1.57				
	238			1.07				

LA JOLLA CANYON 6 May 1960

Station		7033	7034*	7035	7036		7033	7034	7035	7036
Distance (km)		0.2	0.3	1.4	4.2		0.2	0.3	1.4	4.2
Bottom (m)		102	163	250	369		102	163	250	369
Above axis (m)		2	0	9	7		2	0	9	7
		Temperature (°C)					Silicate (µg-A/L)			
Depth (m)	0	16.2	16.2	16.8	16.8	0	10.9	10.8	11.8	12.5
	87	9.60	—	9.30	9.42	87	49.0	—	54.9	51.8
	148		8.95	—	8.97	148		64.7	—	61.9
	235			8.25	8.14	235			75.9	75.9
	359				7.53	359				84.4
		Salinity (‰)					Phosphate (µg-A/L)			
Depth (m)	0	33.62	33.62	33.64	33.66	0	0.38	0.46	0.28	0.36
	87	33.93	—	34.02	33.98	87	2.05	—	2.13	2.13
	148		34.11	—	34.14	148		2.39	—	2.39
	235			34.22	34.23	235			2.64	2.55
	359				34.29	359				2.76
		Oxygen (ml/L)								
Depth (m)	0	—	—	—	—					
	87	2.54	—	2.16	2.64					
	148		1.67	—	1.51					
	235			1.12	1.18					
	359				0.76					

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*Scripps Branch

CORONADO CANYON 1 February 1960

	Station	6847	6848	6843		6847	6848	6843
	Distance (km)	0.8	4.1	21.8		0.8	4.1	21.8
	Bottom (m)	174	356	1203		174	356	1203
	Above axis (m)	0	0	0		0	0	0
			Temperature (°C)				Silicate (µg-A/L)	
Depth (m)	0	14.5	—	—	0	5.2	5.7	0.7
	91	10.16	10.09	—	91	35.6	36.8	24.3
	152	9.25	9.12	—	152	52.8	52.7	—
	183		—	9.33	183		58.0	51.4
	341		7.78	7.73	341		79.6	80.8
	549			6.12	549			104.5
	1187			3.62	1187			197.3
			Salinity (‰)				Phosphate (µg-A/L)	
Depth (m)	0	33.58	33.58	33.49	0	0.7	0.7	0.7
	91	33.75	33.77	33.62	91	2.2	2.0	1.7
	152	33.96	33.95	—	152	2.7	2.5	—
	183		34.04	34.00	183		2.6	2.3
	341		34.16	34.19	341		3.0	3.1
	529			34.25	529			3.6
	1187			34.54	1187			3.5
			Oxygen (ml/L)				Nitrate (µg-A/L)	
Depth (m)	0	5.91	5.76	5.84	0	2.5	2.1	2.8
	91	3.60	3.59	—	91	13.3	16.6	10.4
	152	2.53	1.88	—	152	16.3	18.9	—
	183		1.62	2.48	183		20.3	17.9
	341		0.88	1.13	341		20.8	22.1
	529			0.31	529			21.8
	1187			0.68	1187			25.5

SANTA CRUZ CANYON 22 December 1959

Station		6802	6807		6802	6807
Distance (km)		3.7	14.2		3.7	14.2
Bottom (m)		220	581		220	581
Above axis (m)		0	5		0	5
		Temperature (°C)			Silicate (μg-A/L)	
Depth (m)	208	9.65	—	208	26	—
	531		5.90	531		97
		Salinity (‰)			Phosphate (μg-A/L)	
Depth (m)	208	33.78	—	208	1.9	—
	531		34.20	531		2.9
		Oxygen (ml/L)				
Depth (m)	208	2.70	—			
	531		0.28			

SANTA CATALINA CANYON 28 June 1960

Station	6824	6825	6826	6827		6824	6825	6826	6827
Distance (km)	0.4	2.6	7.4	16.1		0.4	2.6	7.4	16.1
Bottom (m)	206	363	716	1245		206	363	716	1245
Above axis (m)	5	0	0	90		5	0	0	90
Depth (m)	Temperature (°C)				Depth (m)	Silicate (μg-A/L)			
0	—	14.8	14.9	15.0	0	—	—	—	—
88	11.54	—	—	—	88	22	—	19	19
192	9.01	—	9.09	9.22	192	53	—	52	51
347		7.60	7.59	7.50	347		86	40	83
701			6.53	5.17	701			117	164
1230				4.06	1230				208
Depth (m)	Salinity (‰)				Depth (m)	Phosphate (μg-A/L)			
0	—	—	—	—	0	—	—	—	—
88	33.58	—	33.58	33.58	88	1.3	—	1.3	1.3
192	33.95	—	34.00	33.92	192	2.4	—	2.3	2.3
347		34.22	34.22	34.22	347		3.1	2.9	3.1
701			34.29	34.40	701			3.3	3.3
1230				34.52	1230				3.5
Depth (m)	Oxygen (ml/L)				Depth (m)	Nitrate (μg-A/L)			
0	—	—	—	—	0	—	—	—	—
88	4.14	—	4.26	4.20	88	10.5	—	17.6	16.8
192	2.60	—	2.24	2.38	192	17.9	—	24.4	25.2
347		1.07	0.93	0.73	347		24.6	27.9	26.4
701			0.53	0.55	701			26.4	28.1
1230				0.26	1230				35.5

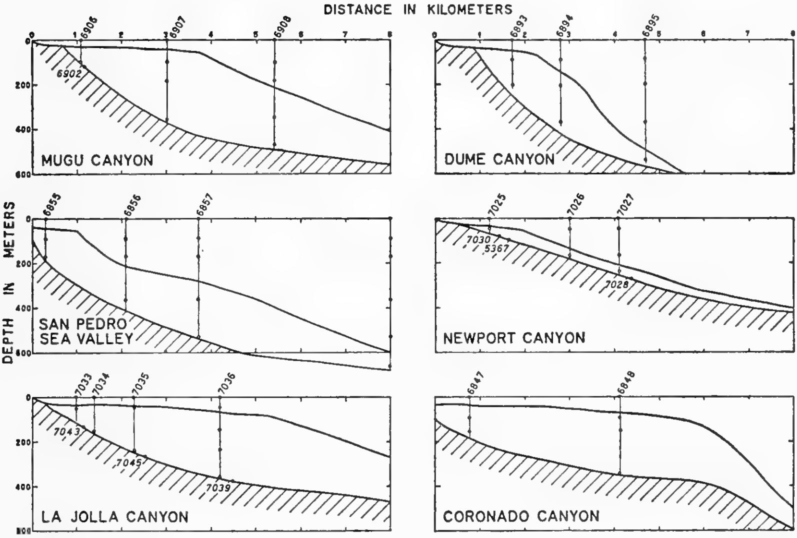

Fig. 18.—Positions and depths of water samples in six canyons at stations shown by open circles in Figures 3 through 15. The solid dots and italicized station numbers along the canyon axes indicate samples having abundant specimens of the polychaete worm *Capitella*.

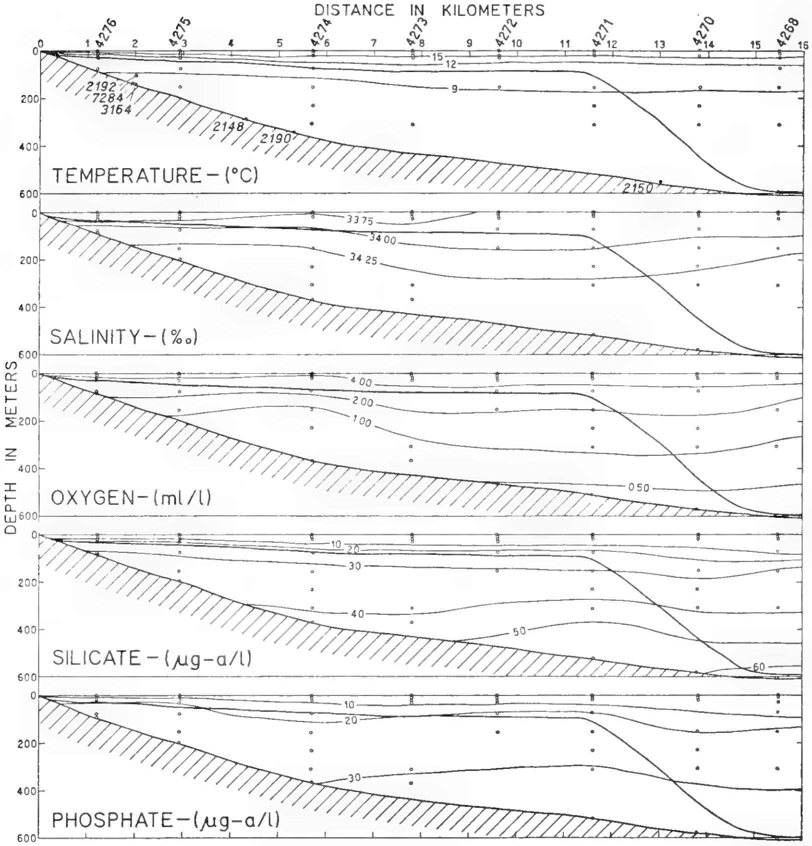

Fig. 19.—Characteristics of water in Redondo Canyon. Symbols same as for Figure 18.

TABLE 2

CAPITELLA BOTTOMS IN CANYONS (from Hartman, 1962)

Canyon	Sample Number	Depth (m)	Number of Specimens*
Hueneme	6897	338	1
	6899	456	52
Mugu	6902	119	9
Santa Monica	6781	116	9200+
	6780	183	55
Redondo	2192	113	1
	7284	137	1
	3164	148	17
	2148	298	27
	2190	344	133
	2150	575	1
Newport	7030	85	2
	5367	97	2
	7730	235	7
	7028	272	1
La Jolla	7043	135	595
	7045	274	14145
	7039	371	948
	7046	517	36
	7041	545	1
	7040	637	3
	7047	793	5

*Sampler covers an area of 0.6 square meters of ocean floor.

SEDIMENTS

Sampling Methods

This study is based entirely upon surface samples, though cores were used in some previous work by Gorsline and Emery (1959) in a few submarine canyons. More than 90 per cent of the samples were taken with a large clam-shell bucket which covers an area of 0.6 square meter and encloses as much as 0.18 cubic meter of mud; these samples were taken primarily for the biological work to be described by Hartman. Most are the result of attempts to sample the axes of the canyons using the same procedure as that for positioning water-sampling stations. Because of ship drift, however, some of the attempts missed the axes and these samples are from the steep side slopes of the canyons. About 10 per cent of the samples were obtained with a small snapper having a volume of about 500 cc. Some snapper samples are from water-sampling stations, but others are independent samples designed to learn the nature of sediments on the walls of the canyons. Of a total of 211 samples, some kind of sediment analysis was made for 176. In 16 samples two different kinds of sediment were noted; these were separated and analyzed individually.

Texture

Textural analyses were made by a combination of standard pipette procedure for fine ($<$ 62 micron) fractions and settling tube for the coarse fractions. Percentages of gravel, sand, silt, and clay are reported in the Appendix, along with median diameter and Trask sorting coefficient. The Trask coefficient was used so that results would be comparable with those of the many other analyses of sediments in the region (Emery, 1960a).

A comparison of the median diameters of samples from within 10 meters of the floor of the canyons with those of samples from higher on the walls is given in the top panel of Figure 20. The frequency curves show that the sediment from the axes is only slightly coarser than that from the walls. Clean coarse, even gravelly, sediment is present in many samples from the canyon floors, but other coarse sediment occurs high on the canyon walls and atop the adjacent shelf. Fine green silty clay is common on the canyon walls but it also is interbedded with clean sands along the canyon axes. The average median diameter of the 95 axial samples is 69 microns and for the 60 wall samples it is 40 microns. A similar average median diameter of 70 microns was obtained by Cohee (1938) for 29 small dredge samples mostly from the walls of Hueneme, Mugu, Dume, Newport, and Coronado canyons.

The sorting coefficients for axial and wall samples exhibit even smaller differences than do median diameters, so no distinction was made on most panels of Figure 20 for the two sources of sediments. Sorting coefficients for all canyon sediments average about 2.5 but in a general way the sorting coefficients are lower for sediments having median diameters coarser than 50 microns than for finer sediments: about 1.8 versus 3.2.

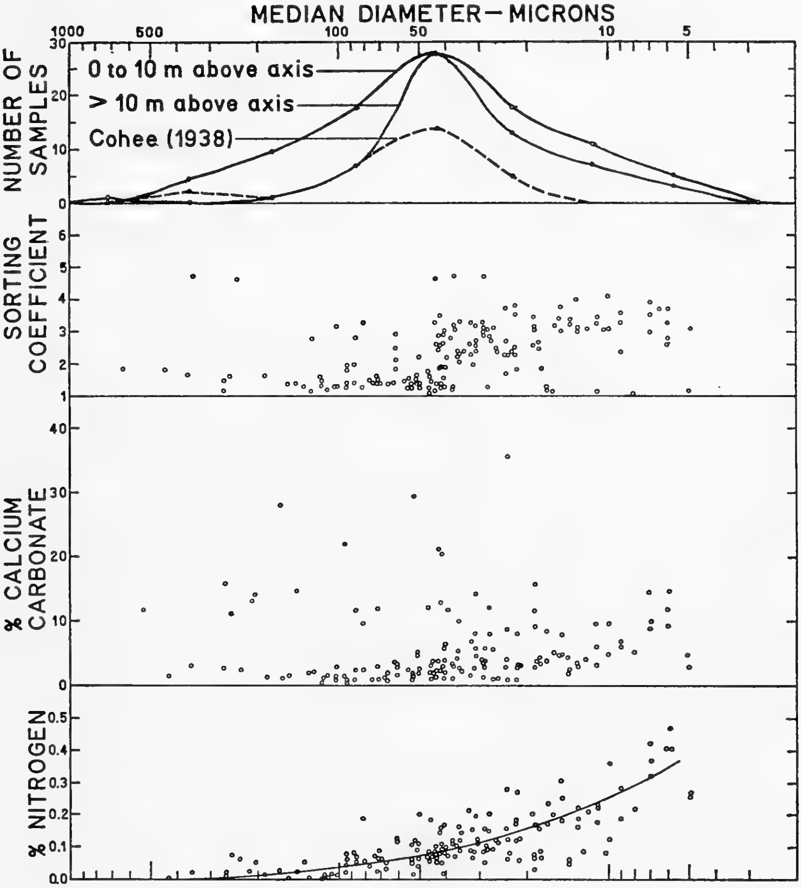

Fig. 20.—Relationship of median diameters of samples from submarine canyons to frequency of occurrence, sorting coefficient, and contents of calcium carbonate and Kjeldahl nitrogen.

Calcium Carbonate

Dried and weighed sediment samples were treated with sulphuric acid, heated, and the evolved carbon dioxide was measured volumetrically. From these volumes the percentages of calcium carbonate were computed on the assumption that all of the carbonate was combined with calcium.

The results (Fig. 20) exhibit a range from 0 to 36 per cent calcium carbonate. Nearly all values lower than 10 per cent are from canyons along the mainland. Most values higher than 10 per cent are from the offshore Santa Cruz, San Clemente, and Tanner canyons. As a secondary trend, the higher percentages for nearshore canyons occur in the finer-grained samples, and for the offshore canyons they are in the coarser-grained samples. Calcium carbonate grains coarse enough to be identified as to source organism consist dominantly of shell fragments in the coarse sediments and of foraminiferal tests in the fine sediments.

Organic Matter

The content of organic matter in the sediment samples was measured as nitrogen using micro-Kjeldahl equipment and as carbon using a Leco (Laboratory Equipment Company) carbon analyzer. The latter device measures the carbon dioxide evolved by fusing the sample at 1300° C in an induction furnace. Kjeldahl nitrogen would serve as an excellent measure of total organic matter except that nitrogen constitutes only about 6 per cent of total organic matter and it is more subject to oxidation than is carbon, as indicated by an increase of C/N ratio with depth of sediment burial or lapsed time (Emery, 1960a). Carbon comprises about 55 per cent of total organic matter but it is very difficult to measure satisfactorily, owing to the difficulty of combusting some carbonaceous materials and to the variable ease by which carbon is released from calcium carbonate. As a result, organic carbon in samples was measured in two different ways: by combusting the residue left from carbonate analysis (direct method), and by combusting a total sample and subtracting carbonate carbon (difference method). The direct method may yield results that are too low owing to partial breakdown of organic matter by the acid treatment for carbonate, or too high because of incomplete breakdown of carbonate carbon by the acid. The second method can yield erratic results because of the need for two separate subsamples.

In general, the results by the two methods of carbon analysis agree (Fig. 21), but there are some individual variations and the direct method is considered the more reliable. A plot of direct organic carbon against Kjeldahl nitrogen (Fig. 22) reveals good agreement for about 95 per cent of the samples. A best-fit straight line through the plotted values for these samples yields an average C/N ratio of 8.9, nearly the same as the average for the surface sediments of the basins (Emery, 1960a, p. 276).

When plotted against median diameter, the nitrogen (Fig. 20) as well as the organic carbon exhibits a close relationship. Percentages of nitrogen decrease from an average of about 0.4 per cent for sediments of 5 microns median diameter to less than 0.05 per cent for sediments of median diameter coarser than 100 microns. This relationship to grain size is typical and it results from the similarity in settling velocity of organic matter and of fine-grained silts or clays and from adsorption of organic matter on clay minerals. Average total organic matter is 2.16 per cent when computed from organic carbon (1.7 times the average of 1.27 per cent organic carbon) and 1.87 per cent when computed from nitrogen (17 times the average of 0.11 per cent nitrogen). Perhaps the best figure for average total organic matter is the average of the two values, or 2.0 per cent.

Comparison with Sediments of Adjacent Areas

Sediments of the canyons reveal differences which depend upon the degree of isolation from sources of detrital material. These differences are best illustrated by a comparison of sediments from canyons cutting the mainland shelf, the island shelves, and the bank tops (Table 3). Most pronounced is an increase in average percentage of calcium carbonate from mainland canyons to island canyons to bank canyons. The average median diameter exhibits little change, except for an increase in Tanner Canyon, the only one off a bank. Percentage of organic matter increases from mainland to island canyons probably because the slower rate of deposition of similar average grain sizes of detrital sediment in the latter permits less dilution of organic matter.

When compared with sediments of the source areas (mainland shelf, island shelves, and bank tops) and with those of the sites of final deposition (basin floors), the sediments of the canyons are found to be intermediate in nearly all the averages (Table 3). Sediments of the canyons are finer grained than those of the shelves and coarser than those of the basin floors. Sorting coefficients are also intermediate, except at Tanner Canyon where only six samples are available, most of which are coarse grained. The average content of calcium carbonate also is intermediate between values for shelf and basin sediments except for the mainland canyons, which have a very low content for some unknown reason. Average contents of organic matter are intermediate in all instances. These

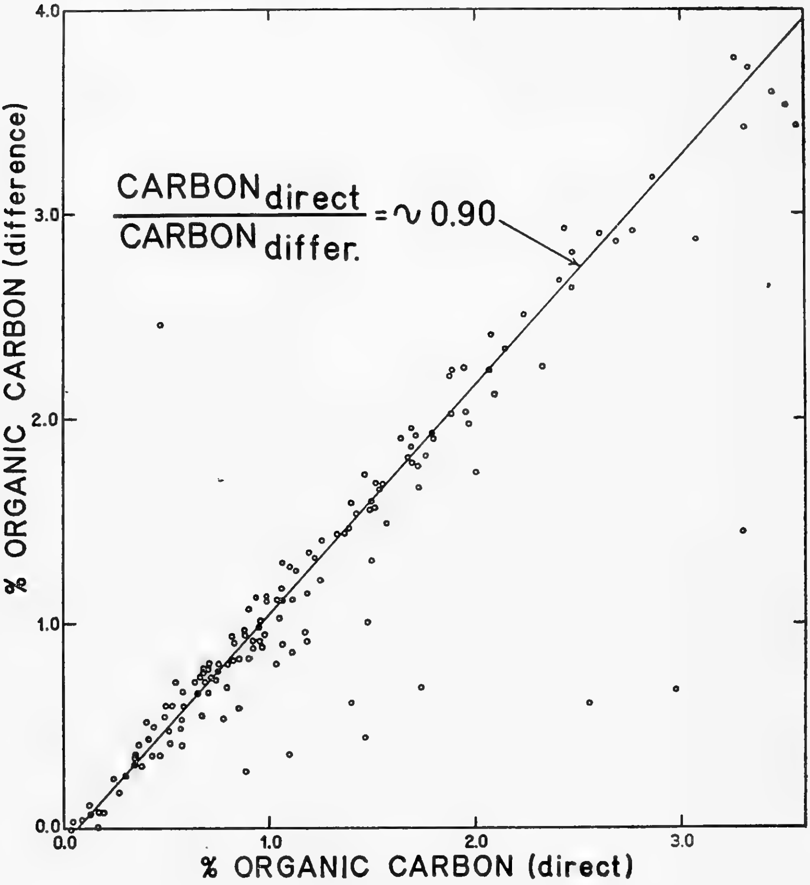

Fig. 21—Results of separate determinations for organic carbon on sub-samples, based on (1) analysis for carbon in residue from carbonate analysis, and (2) on analysis for total carbon minus carbonate carbon.

generally intermediate characteristics of the sediments in canyons with respect to sediments of shelves and basins are reasonable in view of other lines of evidence which indicate that the canyons serve as the routes through which at least the coarser sediments reach the basins for permanent deposition. However, the averages of Table 3 do not reveal whether the movement through the canyons is chiefly by rapid turbidity currents or by slow creep.

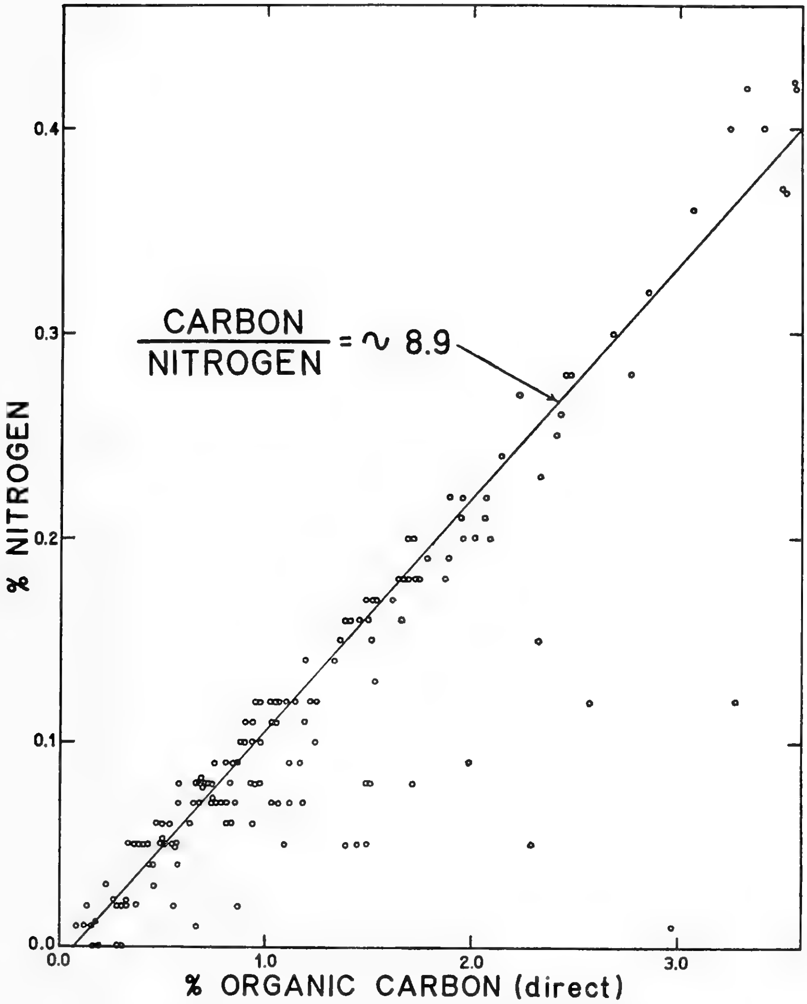

Fig. 22.—Comparison of carbon and nitrogen analyses on samples from submarine canyons.

TABLE 3

SEDIMENTS OF SUBMARINE CANYONS AND OTHER ENVIRONMENTS[1]

	Median Dia. (μ)	Sorting Coefficient (Trask)	$CaCO_3$ (%)	Organic C (%)	Nitrogen (Kjeldahl) (%)	Organic Matter (%)
Mainland Shelf	130 (1773)[8]	1.6 (804)	9.2 (591)	—	—	0.9 (273)
Mainland Canyons[2]	65 (144)	2.4 (143)	3.8 (138)	1.11 (118)	0.11 (133)	1.9[9] (133)
Nearshore Basins[3]	6.5 (326)	3.7 (180)	10.3 (132)	—	0.37 (39)	6.3 (39)
Island Shelves	260 (298)	1.7 (290)	27 (256)	—	—	0.6 (168)
Island Canyons[4]	62 (19)[10]	3.0 (20)	12.3 (26)	1.75 (28)	0.14 (28)	2.7 (2.8)
Moderate Offshore Basins[5]	4.0 (117)	3.8 (113)	12.0 (139)	—	0.45 (23)	7.6 (23)
Bank Tops	270 (284)	2.3 (164)	56 (166)	—	—	0.8 (146)
Bank Canyons[6]	98 (6)	1.9 (6)	23.7 (6)	2.09 (6)	0.07 (6)	2.4 (6)
Offshore Basins[7]	4.0 (50)	3.1 (48)	21.5 (66)	—	0.38 (8)	6.4 (8)

[1] Non-canyon data from Emery (1960a, pp. 181, 220).

[2] Hueneme, Mugu, Dume, Santa Monica, Redondo, Newport, La Jolla, Coronado.

[3] Santa Barbara, Santa Monica, San Pedro, San Diego.

[4] Santa Cruz, Santa Catalina, San Clemente.

[5] Santa Cruz, Santa Catalina, San Clemente.

[6] Tanner.

[7] San Nicolas, East Cortes, No Name.

[8] Number in parentheses is number of samples.

[9] Organic matter for canyons = average of 1.7 X organic carbon and 17 X nitrogen.

[10] Omitting station 6809 from Santa Cruz Canyon—exceptionally coarse.

SUMMARY AND CONCLUSIONS

In many ways submarine canyons are intermediate between shelves and basin floors. Their axial slopes are intermediate in steepness; thus the canyons not only dissect the basin slopes but their heads extend landward of the shelf break. Where the heads of the canyons are very close to shore they may serve as local sites for upwelling in response to the action of wind in driving surface water toward the open sea. This upwelling, however, appears to be weak and probably discontinuous. It does not establish a very unique ecological environment, but the minor differences in the waters of canyons or basins which do exist may possibly be significant for some animals.

Canyons which cross much of the width of shelves and of basin slopes receive sediments in at least three different ways. Most important quantitatively is grain-by-grain deposition of silts and clays carried in suspension from the mouths of streams and from the turbulent shore zone. When deposited, this sediment forms a homogeneous blanket of green mud on the steep walls of the canyons as well as on the basin slopes and floors farther seaward. The steepness of the canyon walls, possibly aided by animal activities, allows the sediment to move downslope to the canyon axes. This movement not only exposes rock outcrops on the sides of the canyons but also produces interbeds of the green mud with coarser sediment on the canyon floors. Whether the mud moves downslope slowly and continuously or rapidly and intermittently is unknown. The outer parts of the canyons, the channels on the basin floors, also receive the grain-by-grain deposits, but because of the gentle slopes of the sub-sea aprons there probably is little mass movement of this sediment.

Second most important, but probably of greatest interest, is the deposition of sand and fine gravels which move down coast along beaches and atop the inner part of the shelves, under the influence of longshore currents. These currents are partly the inshore portions of the general southern California eddy but mostly they are produced by the diagonal approach to shore of the dominant waves from the northwest (Emery, 1960a). Where canyons extend close in to shore, they serve as traps for this moving sediment. The sediment may accumulate slowly until it finally moves out en mass, causing a sudden deepening of the water of the canyon head (Shepard, 1951a, and other papers). The moving mass may become transformed into a turbidity current which carries sand into deep water (Shepard, 1951b), building up sub-sea fans or aprons at the mouths of the canyons (Gorsline and Emery, 1959; Emery, 1960b). These sands have the same general grain size as the nearshore sediments of the shelves and they contain shallow-water foraminifera and remains of other animals and plants, including bits of wood from land. Within the canyons the sands form narrow bands traversing the canyon axes between the steep walls covered by green mud. Movement of this mud downslope to the intermittently moving axial sand produces the observed bedded character of the sediment on the floors of the canyons. The sands in canyons near the mainland contain lower percentages of calcium carbonate than do the muds, in agreement with the low content of calcium carbonate in sands atop the mainland shelves as compared with that of muds on the basin slopes and floors. In contrast, the sands in offshore canyons have more calcium carbonate than the muds, again in response to the shelly nature of sands of island shelves and bank tops.

Third, and least important, are small quantities of sediment from the outer parts of the shelves which are moved into the canyons, probably by occasional storm waves. Their presence is attested by occasional grains of glauconite and phosphorite, authigenic sediments which are most common on bank tops and on the outer parts of shelves.

As shown by Menard (1955) and by Emery (1960a), the quantities of sediment in sub-sea fans and aprons far exceed the volume of rock which has been removed during erosion of the canyons. Since the fans consist mostly of sand, it is evident that the canyons act as conduits for movement of sand from near shore to deep water. As pointed out by others, this movement may act as a sort of giant chain saw cutting downward into the bedrock floors of the canyons. Deepening of the axes steepens the side walls and allows more sliding of muds from the canyon walls, possibly leading to lateral enlargement of the canyons. Future work from manned or televised deep-diving vehicles should go far toward investigating this interesting geological agent of erosion.

Downcutting of canyon axes by moving axial sands should clear away a strip through the blanketing muds or prevent the muds from being deposited. Any aquifer which has been exposed through erosion by the same sand or by other possible canyon-forming agents is thereby exposed to the sea water. If the internal water pressure is greater than hydrostatic pressure of sea water at the outcrop, fresh water should leak to the sea. If the reverse is true, owing to over-pumping or perhaps to natural causes, sea-water intrusion should occur. Because of widespread over-pumping in the intensely cultivated and highly populated coastal areas of southern California, sea-water intrusion is well known. It is generally made manifest by increasing salinity of water wells (Emery, 1960a). Deeper aquifers, largely untapped by water wells, may be expected to behave differently than the over-pumped shallow ones.

Accordingly, it should occasion no great surprise to learn that the deep aquifers still discharge fresh water, as did the shallow ones during the nineteenth century. The quantity of discharge must be small compared with the volume of sea water within the canyons. Accordingly, one should not expect to detect it through water analyses, except perhaps of interstitial waters of axial sands or by visual inspection from deep-diving vehicles. The finding of fresh-water worms and the absence of marine animals in more than a score of axial sediment samples serves as a clear indication of seaward loss of water from deep aquifers. Probably most of the loss of fresh water from these aquifers occurs through the canyons because they represent the points of outcrop of aquifers nearest land and thus are the focal points of the steepest pressure gradients.

LITERATURE CITED

BENEST, H.

1899. Submarine gullies, river outlets, and fresh-water escapes beneath the sea-level. Geogr. Jour., 14:394-413.

BUFFINGTON, E. C.

1951. Gullied submarine slopes off southern California (Abstr.). Geol. Soc. America, Bull., 62:1497.

1952. Submarine "natural levees." Jour. Geol., 60:473-479.

in press. Geophysical evidence on the origin of gullied submarine slopes, San Clemente, California. Jour. Geol.

COHEE, G. V.

1938. Sediments of the submarine canyons off the California coast. Jour. Sediment. Petrol., 8:19-33.

EMERY, K. O.

1954. Source of water in basins off southern California. Jour. Mar. Res., 13:1-21.

1960a. The sea off southern California: a modern habitat of petroleum. 366p. Wiley, New York.

1960b. Basin plains and aprons off southern California. Jour. Geol., 68:464-479.

EMERY, K. O., AND F. P. SHEPARD

1945. Lithology of the sea floor off southern California. Geol. Soc. America, Bull., 56:431-477.

EMERY, K.O., AND R. D. TERRY

1956. A submarine slope of southern California. Jour. Geol., 64:271-280.

GORSLINE, D. S., AND K. O. EMERY

1959. Turbidity-current deposits in San Pedro and Santa Monica basins off southern California. Geol. Soc. America, Bull., 70:270-290.

HARTMAN, OLGA

1962. A new monstrillid copepod parasitic in capitellid polychaetes in southern California. Zool. Anz., 167:325-334.

JOHNSON, D. W.

1938-39. Origin of submarine canyons. Jour. Geomorphol., 1:111-129, 230-243, 324-340; 2:42-60, 133-158, 213-236.

LUSKIN, B., B. C. HEEZEN, M. EWING, AND M. LANDISMAN

1954. Precision measurement of ocean depth. Deep-sea Res., 1:131-140.

MENARD, H. W.

1955. Deep-sea channels, topography, and sedimentation. Amer. Assoc. Petrol. Geologists, Bull., 39:236-255.

NORTHROP, JOHN

1953. A bathymetric profile across the Hudson Submarine Canyon and its tributaries. Jour. Mar. Res., 12:223-232.

RITTENBERG, S. C., K. O. EMERY, AND W. L. ORR

1955. Regeneration of nutrients in sediments of marine basins. Deep-sea Res., 3:23-45.

SHEPARD, F. P.

1951a. Mass movements in submarine canyon heads. Amer. Geophys. Union, Trans., 32:405-418.

1951b. Transportation of sand into deep water. Soc. Econ. Paleontologists and Mineralogists, Spec. Pub., 2:53-64.

SHEPARD, F. P., AND C. N. BEARD

1938. Submarine canyons: Distribution and longitudinal profiles. Geogr. Rev., 28:439-451.

SHEPARD, F. P., AND K. O. EMERY

1941. Submarine topography off the California coast: Canyons and tectonic interpretations. Geol. Soc. America, Spec. Pap. 31, 171p.

SHEPARD, F. P., R. REVELLE, AND R. S. DIETZ

1939. Ocean bottom currents off the California coast. Science, 89:488-489.

APPENDICES

HUENEME CANYON

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand (>62μ)	% Silt (62–4μ)	% Clay (<4μ)	Sorting coefficient [Trask]	$CaCo_3$ %	Organic C (direct) %	N (Kjeldahl) %
4846	34°07′15″	119°13′45″	309	0	.031	9	63	28	3.2	4.1		.10
5114	08′00″	13′20″	165	20	.128	89	9	2	1.2	2.2		.01
5115	05′30″	14′10″	373	0						5.7		.03
5531	08′00″	13′15″	178	7						5.2		.06
5532	05′25″	14′10″	376	0	0.032	16	72	12	2.0	2.6		.07
5686	05′35″	14′10″	374	0						1.7		.02
5688	08′00″	13′18″	183	0						4.4		.07
6814	03′55″	14′44″	439	0	.019	11	67	22	2.6	3.0	.76	.07
6896	07′18″	13′43″	271	16	.051	45	42	13	2.2	2.0	.46	.03
6897	06′14″	13′44″	338	9	.095	65	31	4	1.8	1.6	.30	.02
6898	05′00″	13′55″	373	46	.018	5	74	21	2.6	3.3	.83	.08
6899	03′55″	14′28″	456	9	.165	36/52*	10	2	15.1	1.0	.34	.02
6900	03′00″	14′28″	473	11	.022	11	70	19	2.5	2.5	.64	.06
6901	01′00″	15′00″	621	2	.154	90	8	2	1.4	1.6	.17	.00
6905	08′30″	13′00″	98	0	.116	86	14	0	1.5	1.3	.08	.01

*36/52 = gravel/sand

MUGU CANYON

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand (>62μ)	% Silt (62–4μ)	% Clay (<4μ)	Sorting coefficient [Trask]	$CaCo_3$ %	Organic C (direct) %	N (Kjeldahl) %
4851	34°03′30″	119°05′55″	171	325	.042	41	43	16	1.6	2.3		.08
4852	05′14″	05′45″	15	105	.110	94	3	3	1.3	1.8		.01
6902	05′20″	05′22″	119	0	1.986	29/53	12	6	4.1	1.9	.26	.02
6903	04′42″	06′12″	352	0	.029	35	39	26	4.7	2.5	.34	.05
6904	03′45″	05′12″	475	0	.268	6/89	4	1	1.2	2.5	.67	.01
6907	04′42″	06′12″	367	0	.435	6/93	1	0	1.8	1.4	.18	0
6909	01′50″	02′30″	352	230	.014	5/7	62	26	3.3	2.5	.83	.06
6910	02′13″	05′05″	548	35	.024	15	65	20	2.7	2.5	.82	.06
6911	01′00″	05′35″	644	0	.072	61	33	6	1.5	1.5	.34	.02
6912	33°59′20″	04′23″	721	0	.051	35	57	8	1.5	2.0	.44	.04
6913	58′30″	01′44″	792	0	.008	2	63	35	1.0	5.5	1.95	.22
7521	57′16″	118°59′25″	850	0								

Dume Canyon

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand (>62μ)	% Silt (62–4μ)	% Clay (<4μ)	Sorting coefficient [Trask]	$CaCo_3$ %	Organic C (direct) %	N (Kjeldahl) %
2965	33°54′23″	118°54′11″	905	0								
5046	59′10″	48′15″	398	0						2.9		.12
5505	59′15″	48′15″	374	27						9.8		.03
5674	58′17″	48′27″	507	30								
5676	57′22″	49′15″	652	0								
6895	47′50″	48′35″	556	0	.082	79	14	7	1.3	2.4	1.87	.18
6915	59′25″	48′40″	299	0	.014	11	72	17	3.3	1.9	.58	.04
6916	58′30″	48′15″	530	15	.022	19	59	22	3.5	3.1	1.64	.18
6917	57′12″	49′00″	711	0	.013	11	62	27	3.0	4.3	1.89	.22
6918	56′25″	50′48″	741	0	.012	10	61	29	3.1	4.0	2.07	.21
7520	57′18″	48′36″	580	0								

Santa Monica Canyon

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand ($>62\mu$)	% Silt (62–4μ)	% Clay ($<4\mu$)	Sorting coefficient [Trask]	CaCo$_3$ %	Organic C (direct) %	N (Kjeldahl) %
2999	33°53′11″	118°40′00″	454	105	.035	14	68	18	2.4			
3000	55′12″	37′30″	268	132								
3176	51′58″	41′57″	612	30	.009	2	72	26	2.4			
3177	53′26″	41′36″	542	30	.016	6	67	27	3.2			
3178	54′38″	39′48″	431	70	.010	10	68	22	3.1			
3179	55′39″	38′00″	362	50	.038	20	61	19	1.3			
3180	55′30″	35′55″	330	0	.043	37	51	12	2.6			
3399	52′08″	39′15″	463	190	.042	14	73	13	1.3	12.8		
6776	48′30″	41′20″	873	0	.006	3	59	38	2.8	8.9	3.26	.40
6777	51′25″	42′30″	810	0	.007	1	61	38	3.0	8.2	2.85	.32
6778	53′53″	41′55″	583	15	.044	41	44	15	2.6	3.4	.98	.10
6779	55′29″	38′32″	475	0	.125	63	28	9	2.8	2.4	.68	.08
6780	55′47″	33′20″	183	0	.102	70	24	6	3.2	2.8	.68	.08
6781	55′58″	32′52″	116	0	.233	14/70	15	1	4.6	2.4	.94	.06
6783	55′18″	39′00″	454	0	.041	35	48	17	2.9	4.0	1.54	.17

REDONDO CANYON

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand (>62μ)	% Silt (62–4μ)	% Clay (<4μ)	Sorting coefficient [Trask]	$CaCo_3$ %	Organic C (direct) %	N (Kjeldahl) %
2139	33°41′28″	118°33′38″	801	fan								
2148	49′32″	25′53″	298	0								
2149	49′54″	25′27″	239	0								
2150	47′56″	31′16″	575	30								
2151	48′06″	30′39″	542	60								
2189	48′33″	28′30″	422	0								
2190	49′19″	26′38″	344	10								
2191	49′42″	25′18″	232	7								
2192	49′58″	24′20″	113	35								
2322	40′02″	26′03″	853	fan								
2359	48′00″	26′03″	57	shelf								
2361	47′03″	30′07″	310	basin slope	.060	48	40	12	2.0			
2362	46′02″	31′52″	652	fan	.031	20	60	20	1.9			
2363	41′55″	30′06″	794	fan								
2403	44′08″	28′00″	741	fan								
2404	41′58″	28′00″	810	fan								
2405	41′58″	28′00″	846	fan								
2419	42′00″	26′03″	808	fan								
2420	40′00″	30′04″	848	fan								
2432	40′02″	32′01″	834	fan								

REDONDO CANYON (Continued)

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand ($>62\mu$)	% Silt (62–4μ)	% Clay ($<4\mu$)	Sorting coefficient [Trask]	$CaCO_3$ %	Organic C (direct) %	N (Kjeldahl) %
2474	33°46′03″	118°34′08″	751	fan								
2475	44′02″	32′03″	686	fan								
2476	44′00″	29′59″	715	fan								
2619	42′02″	32′01″	800	fan								
2620	44′02″	33′59″	774	fan								
2723	46′00″	30′00″	602	fan								
2725	50′00″	28′00″	107	300		rock and gravel						
2726	50′00″	30′00″	130	370	.026	4	79	17	2.4			
2727	50′00″	32′00″	122	430	.058	47	45	8	1.5			
2729	45′59″	35′50″	825	fan								
2789	49′59″	34′05″	167	basin slope	.005	2	53	45				
2790	49′58″	36′00″	334	basin slope	.027	24	58	18	2.8			
2791	48′00″	36′03″	769	fan	.007	2	54	44				
2792	47′59″	33′59″	556	basin slope	.023	13	65	22	3.0			
2793	48′00″	32′00″	465	125	.038	36	42	22	4.7			
2794	44′02″	36′00″	796	fan								
3163	49′53″	24′32″	111	37	.006	2	70	28	2.6			
3164	49′52″	24′37″	148	0	.039	36	56	8	2.8			
3166	49′15″	27′14″	363	5	.029	33	56	11	3.1			
3167	48′16″	29′38″	519	40	.043	40	50	10	2.9			

REDONDO CANYON (Continued)

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand (>62μ)	% Silt (62–4μ)	% Clay (<4μ)	Sorting coefficient [Trask]	$CaCO_3$ %	Organic C (direct) %	N (Kjeldahl) %
3168	33°47′40″	118°32′10″	554	35	.043	35	53	12	2.6			
3169	46′33″	33′42″	706	fan	.013	4	81	15	2.5			
3385	50′00″	32′23″	120	430	.042	17	75	8	1.3	20.8		
5960	50′18″	33′50″	146	400	.072	62	33	5	1.4	11.7		.07
6774	47′04″	32′50″	660	fan	.015	9	63	28	3.4	4.7	1.68	.18
6775	46′32″	34′15″	786	fan	.009	2	63	35	3.3	6.9	2.46	.28
6815	49′14″	26′54″	282	86	.027	24	55	21	3.1	5.7	1.12	.09
6816	49′13″	27′04″	378	8	.051	36	53	11	1.5	5.2	1.96	.20
6817	47′56″	28′32″	76	shelf	.019	19	58	23	3.4	15.7	.78	.07
7284	49′53″	24′31″	137	0	.031	17	66	17	2.4	4.2	1.89	.19
7285	49′52″	25′38″	246	0	.015	5	80	15	3.0	4.8	2.41	.25
7286	49′22″	26′54″	378	0	.062	53	34	12	2.5	3.3	1.22	.12
7286	49′22″	26′54″	"	"	.044	40	45	15	3.3	3.9	1.20	.14
7286	49′22″	26′54″	"	"	.043	41	43	16	3.5	4.0	1.42	.16
7287	48′45″	27′53″	431	0	.038	38	45	17	3.2	2.8	1.10	.12
7287	48′45″	27′53″	"	"	.029	29	51	20	3.3	3.9	1.51	.15
7288	48′29″	29′14″	503	0	.062	50	36	14	2.9	3.1	.98	.09
7288	48′29″	29′14″	"	"	.088	76	17	7	1.4	2.4	.57	.05
7289	48′14″	30′50″	560	0	.353	95	4	1	1.7	3.0	.26	.02
7289	48′14″	30′50″	"	"	.036	34	47	19	3.3	4.2	1.33	.14
7290	27′35″	26′58″	611	0	.036	25	59	16	2.2	5.2	.94	.08

San Pedro Sea Valley

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand ($>62\mu$)	% Silt (62–4μ)	% Clay ($<4\mu$)	Sorting coefficient [Trask]	$CaCO_3$ %	Organic C (direct) %	N (Kjeldahl) %
2218	33°40′01″	118°19′59″	459	250								
2219	41′02″	20′21″	437	300								
2317	38′00″	17′57″	522	0								
2336	38′09″	19′52″	666	20								
5639	37′54″	18′50″	461	200								
6501	39′34″	16′47″	319	0								
6502	38′48″	17′15″	547	0								
6503	38′36″	18′58″	661	0								
6854	39′45″	16′28″	187	0	.013	18	53	29	4.0	2.8	1.76	.16
6855	39′45″	16′28″	187	0	.022	20	55	25	3.8	3.2	1.72	.17
6856	39′00″	16′50″	404	0	.009	13	55	32	3.6	3.6	1.70	.18
6861	38′40″	20′10″	716	0	.011	9	60	31	3.3	4.6	2.07	.22
7155	38′08″	18′20″	468	150								
7160	39′14″	16′54″	406	100	.019	15	62	23	3.1	4.3	1.52	.17
7160	39′14″	16′54″	″	″	.082	57	30	13	3.3	4.9	.55	.05
7161	37′50″	16′44″	220–90	250						1.4	.52	.05
7161	37′27″	16′18″										
7162	37′48″	15′24″	92	0	.054	42	54	4	1.4	1.5	.41	.05
7163	37′21″	15′38″	61	119	.067	58	42	0	1.4	1.1	.23	.03
7164	37′15″	16′49″	133	357	.054	35	59	6	1.3	1.6	.37	.05
7165	37′42″	16′00″	158	72	.044	14	82	4	1.2	1.9	.50	.05
7166	38′08″	16′03″	262	0	.036	28	55	17	2.4	2.6	1.06	.12

San Pedro Sea Valley (Continued)

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand ($>62\mu$)	% Silt 62–4μ	% Clay ($<4\mu$)	Sorting coefficient [Trask]	$CaCO_3$ %	N (Kjeldahl) %	Organic C (direct) %
7167	33°38′26″	118°15′24″	58	57	.067	55	39	6	1.4	2.4	.38	.05
7168	38′45″	16′18″	174	191	.051	56	37	7	1.4	2.3	.53	.06
7169	38′28″	16′43″	386	64	.029	26	54	20	3.1	3.3	1.36	.15
7170	38′14″	17′12″	545	0	.013	16	68	16	3.1	3.6	1.79	.19
7171	37′48″	17′14″	184	316	.054	64	31	5	1.3	1.6	.41	.05
7172	39′05″	16′36″	271	119	.038	41	43	16	1.2	3.4	1.25	.12
7173	39′10″	16′06″	58	172						2.7	.71	.08
7174	38′36″	16′16″	221	200	.047	47	45	8	1.4	2.5	.66	.07
7175	39′34″	18′22″	430–180	300	.041	36	53	11	1.9	3.0	.87	.09
7175	40′06″	17′32″										
7176	39′48″	17′17″	67	198	.042	82	18	0	1.4	3.1	.51	.05
7177	39′22″	17′38″	414	0	.018	14	66	20	2.7	3.7	1.50	.16
7178	39′00″	17′46″	481	29	.024	15	74	11	2.3	4.4	1.40	.16
7179	38′50″	17′06″	402	68	.011	9	58	33	1.1	3.5	1.70	.18
7180	37′52″	18′00″	350	210	.044	46	40	14	1.4	2.5	.70	.08
7181	38′06″	18′12″	500	90	.017	12	70	18	1.3	4.0	1.50	.17
7182	38′00″	18′58″	445	185	.047	47	39	14	1.8	2.3	.68	.07
7183	38′43″	18′17″	564	56	.016	9	63	28	1.1	5.4	1.68	.20

NEWPORT CANYON

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand (>62μ)	% Silt (62-4μ)	% Clay (<4μ)	Sorting coefficient [Trask]	$CaCO_3$ %	Organic C (direct) %	N (Kjeldahl) %
5006	33°36′10″	117°56′00″	37	0						6.6		.12
5250	36′14″	55′54″	37	0	.055	48	42	10	1.6			
5367	35′46″	55′57″	97	0						1.7		.16
5661	35′35″	55′58″	140	10						2.5		.11
7025	35′52″	55′56″	62	0	.027	15	64	21	2.7	.9	1.03	.12
7026	34′57″	55′45″	182	0	.029	27	53	20	3.0	1.1	.95	.08
7027	34′13″	55′28″	253	0	.041	43	39	18	3.0	1.2	.73	.08
7028	34′13″	55′28″	272	0	.024	30	56	14	1.7	.9	.70	.08
7029	35′05″	55′45″	170	4	.026	5	75	20	2.5	1.1	1.05	.11
7030	35′43″	55′54″	85	3	.022	9	79	12	1.8	.9	1.14	.12
7031	36′24″	55′54″	16	0	.046	44	49	7	1.4	1.0	.57	.05
7032	31′28″	54′58″	478	2	.038	36	56	8	3.1	1.3	.74	.07
7050	26′27″	52′00″	642	0						.7	.03	0
7051	29′36″	53′44″	553	0	.116	87	10	3	1.6	.2	.03	0
7052	31′10″	56′08″	420	58	.036	16	67	17	2.3	2.7	.88	.10
7053	32′45″	55′20″	396	0	.088	60	29	11	2.8	1.0	.68	.08
7054	34′23″	55′48″	178	91						5.7	.39	.02
7054	34′23″	55′48″	"	"	.041	32	55	13	1.9	1.7	.59	.07
7055	35′53″	56′02″	76	46	.033	18	64	18	2.6	1.7	.86	.09
7685	15′00″	43′30″	734	0								
7728	20′30″	44′54″	741	0								
7729	35′00″	55′36″	211	20								
7730	34′54″	55′30″	235	0								

LA JOLLA CANYON

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand ($>62\mu$)	% Silt (62-4μ)	% Clay ($<4\mu$)	Sorting coefficient [Trask]	$CaCO_3$ %	Organic C (direct) %	N (Kjeldahl) %
7033	32°51′30″	117°15′55″	102	2	.189	94	3	3	1.6	1.2	.16	.01
7034	52′18″	15′48″	163	0						1.2	.58	.08
7036	53′12″	17′12″	369	7	.072	69	23	8	1.5	1.0	.81	.09
7038	52′48″	16′32″	121	200	.041	35	48	17	2.6	2.2	.94	.10
7039	53′12″	17′00″	371	13	.095	92	5	3	1.4	.9	.44	.04
7040	54′42″	23′38″	637	0	.103	92	6	2	1.3	.8	.16	.01
7041	54′02″	23′30″	545	90	.010	3	67	30	3.1	9.8	3.07	.36
7043	57′23″	15′55″	135	0	.144	94	5	1	1.4	1.6	.14	.02
7044	52′21″	15′27″	79	0	.077	72	22	6	1.5	1.1	.51	.06
7045	52′06″	16′24″	274	11	.095	88	9	3	1.3	.8	.48	.06
7046	54′18″	19′44″	517	0	.074	72	25	3	1.4	1.2	.76	.07
7047	54′21″	29′33″	793	0	.062	53	38	9	2.1	3.1	1.06	.12
7048	52′43″	29′11″	708	90	.007	1	61	38	3.5	9.9	3.56	.42
7049	49′37″	35′12″	976	0	.011	4	57	39	3.4	5.8	2.33	.23
7049	49′37″	35′12″	"	"	.102	82	11	7	1.3	1.6	.18	.01

Coronado Canyon

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand ($>62\mu$)	% Silt ($62\text{-}4\mu$)	% Clay ($<4\mu$)	Sorting coefficient [Trask]	$CaCO_3$ %	Organic C (direct) %	N (Kjeldahl) %
6842	33°22′50″	117°22′12″	1265	0	.041	40	50	10	1.6	6.4	1.25	.10
6843	22′45″	118°21′43″	1203	0	.024	18	60	22	3.3	8.5	2.77	.28
6844	27′00″	22′18″	1105	17	.017	12	60	28	1.2	8.6	2.15	.24
6844	27′00″	22′18″	"	"	.044	41	45	14	4.6	21.4	1.18	.09
6845	30′16″	117°16′50″	177	2	.046	38	52	10	1.5	3.2	.97	.08
6846	30′15″	16′04″	123	9	.072	66	31	3	1.6	3.3	.80	.07
6847	30′15″	16′48″	174	0	.051	38	55	7	1.5	4.4	1.05	.11
6848	30′58″	18′34″	356	0	.033	16	71	13	2.3	6.7	1.95	.21
6849	30′58″	18′34″	344	9	.005	1	54	45	3.1	4.9	2.43	.26
6850	29′48″	22′58″	960	9	.032	31	55	14	3.3	14.1	2.33	.15
6851	30′42″	21′37″	812	5	.022	5	78	17	2.3	7.6	2.23	.27
6852	31′20″	20′12″	566	29	.005	6	49	45	1.2	3.3	3.82	.27
6852	31′20″	20′12″	"	"	.036	32	59	9	2.1	10.0	1.46	.16

SANTA CRUZ CANYON

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand (>62μ)	% Silt (62-4μ)	% Clay (<4μ)	Sorting coefficient [Trask]	$CaCO_3$ %	Organic C (direct) %	N (Kjeldahl) %
6803	33°59′32″	119°55′55″	89	0	.268	93	7	0	1.5	16.1	.56	.02
6804	56′25″	50′32″	459	0	.250	90	10	0	1.6	12.3	1.04	.07
6806	56′06″	52′17″	221	120						36.6	1.51	.08
6806	56′06″	52′17″	"	"						10.4	7.36	.38
6808	54′30″	47′22″	902	0	.028	31	45	24	1.3	12.0	2.09	.20
6808	54′30″	47′22″	"	0	.047	46	36	18	1.1	12.0	1.74	.18
6809	54′39″	46′24″	623	350	3.46	88	8	4	4.7	30.7	2.30	.05
6810	53′00″	45′32″	1387	0	.006	7	52	41	3.7	14.1	3.41	.40
6810	53′00″	45′32″	"	"	.088	68	22	10	2.0	11.8	1.19	.07
6811	51′20″	44′53″	1624	fan	.006	3	57	40	3.3	11.3	3.44	.46
6812	54′17″	45′42″	676	400	.054	49	38	13	1.8	11.6	1.19	.11

SANTA CATALINA CANYON

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand ($>62\mu$)	% Silt ($62\text{-}4\mu$)	% Clay ($<4\mu$)	Sorting coefficient [Trask]	$CaCO_3$ %	Organic C (direct) %	N (Kjeldahl) %
2847	33°22′30″	118°36′58″	914	0								
6818	22′53″	30′57″	362	37	.028	17	64	19	2.9	8.0	.76	.09
6819	22′54″	31′07″	379	0	.031	16	66	18	2.6	7.8	.94	.11
6820	23′11″	32′11″	559	0	.040	40	47	13	2.2	11.9	1.12	.07
6821	23′46″	31′57″	266	300								
6822	23′10″	30′01″	216	0	.029	7	76	17	2.9	6.0	.90	.10
6823	23′10″	29′38″	88	0	.018	8	68	24	2.5	4.3	.85	.07
6824	23′10″	30′01″	206	5	.010	1	65	34	4.1	4.7	.96	.12
6825	23′10″	31′15″	363	0	.031	13	67	20	2.7	5.9	.98	.12
6826	22′51″	34′08″	716	0							1.06	.07
6827	20′17″	38′45″	1245	90	.015	17	56	27	3.8	8.1	2.69	.30
6828	20′30″	39′05″	1272	0	.007	4	59	37	3.9	14.4	3.51	.37
6829	22′47″	36′10″	853	27							1.49	.08
6830	22′58″	34′00″	708	9						3.0	1.53	.13
6831	23′57″	34′25″	549	190	.019	4	73	23	3.2	11.8	2.01	.20

SAN CLEMENTE RIFT VALLEY

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand ($>62\mu$)	% Silt ($62\text{-}4\mu$)	% Clay ($<4\mu$)	Sorting coefficient [Trask]	$CaCO_3$ %	Organic C (direct) %	N % (Kjeldahl)
6838	32°48′10″	118°17′50″	950	7						16.7	1.49	.05
6839	46′30″	15′43″	1406	0	.203	91	7	2	8.9	14.0	1.40	.05
6840	44′35″	12′45″	1620	186						.6	.13	.01
6841	44′29″	12′30″	1591	250						24.1	1.46	.05

TANNER CANYON

Sample No.	Lat.	Long.	Depth [m]	Height above axis [m]	Median diameter [mm]	% Sand ($>62\mu$)	% Silt ($62\text{-}4\mu$)	% Clay ($<4\mu$)	Sorting coefficient [Trask]	$CaCO_3$ %	Organic C (direct) %	N (Kjeldahl) %
6832	32°33′36″	118°55′40″	1298	3	.024	29	46	25	3.7	35.2	3.29	.12
6832	33′36″	55′40″	"	"	.095	69	22	9	1.9	22.2	1.73	.08
6833	37′54″	58′40″	813	7	.134	93	7	0	1.3	14.6	1.10	.05
6834	39′24″	119°01′24″	603	13	.062	62	29	9	1.8	27.9	2.57	.12
6835	37′06″	07′15″	298	0	.218	99	1	0	1.3	13.0	.87	.02
6836	36′00″	05′18″	496	11								
6837	34′36″	02′48″	641	53	.053	67	27	6	1.5	29.4	2.98	.01