SUBMARINE CANYONS : DISTRIBUTION AND LONGITUDINAL PROFILES

by

FRANCIS P. SHEPARD and CHARLES N. BEARD.

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In the recent discussions of submarine canyons (1) there has been a tendency to base conclusions on the characteristics of selected examples, such as the canyons off Georges Bank, without much regard for the facts that the canyons are universal features and that they are associated with all kinds of conditions. Information on the distribution of many of the canyons has not been generally available, and there is practically no information regarding their longitudinal profiles. In discussing these matters it seems advisable to take the opportunity of naming the canyons in order to facilitate future reference to them.

BASIS FOR CANYON NAMES.

In choosing names for the canyons (Table I) the writers utilized practically all names used on charts and by earlier writers such as DAVIDSON (2) and HULL (3). In general, if a canyon heads towards a river mouth, the name of the river has been given to it. For other canyons the name of some shore feature or of a town in the vicinity was used. However, there are a number of canyons whose heads are so far from the shore that it seemed unwise to name them after shore features. For these canyons names of vessels were used, vessels being chosen that had played some part in the exploration of the canyons. In the lists in Table I the names of these canyons are underlined. One canyon off Georges Bank was named Georges Canyon because of its nearness to the dangerous Georges Shoal.

CANYON DISTRIBUTION.

The canyons located on Figure 1 include all about which any information could be obtained. Of these, 102 examples were chosen on the basis of the availability of enough soundings to permit the construction of the longitudinal profiles. These profiles will constitute the main subject of discussion in this paper. However, dots were placed on the map to show where other canyons have been discovered. For some of these canyons only a very small number of soundings are available, so that one cannot be certain that the canyon has the V-shaped, steep-walled profile of the typical submarine canyon. There are other types of submarine valley also, the two most notable being the submarine glacial trough and the submarine fault trough. These two types were omitted from the map, since it is evident from their characteristics that they are quite distinct in origin from the canyons (4).

The canyons are found off every long stretch of coast except the Arctic and Antarctic, and the fact that none are known to be there may be due to lack of soundings. On the other hand, the distribution of the canyons is not uniform: they are found in large numbers off some coasts and are rare or entirely lacking off others. There are numerous canyons off the east coast of the United States north of Chesapeake Bay and off the west coast from the Mexican border to Humboldt Bay in northern California; and there are many from the Columbia River to the northern boundary of the United States. Canyons are common off the coasts of Korea, Japan, Formosa, and Luzon; off those of Ceylon and a part of eastern equatorial Africa; and off practically all the borders of the Mediterranean Sea.

In most of the regions where canyons are either lacking or rare few soundings of the kind necessary for their discovery have been made. If the map (Fig. 1) had been made a few years ago, only one canyon, or perhaps three, could have been located off the entire east coast of the United States. This coast is bordered by a wide continental shelf, and detailed soundings had been made only on the shelf shoreward of the canyons. The same condition still exists for most of the broad continental shelves of other coasts of the world, so that future surveying will undoubtedly lead to the discovery of many more canyons.

On the other hand, certain adequately sounded areas off the coasts of the United States lack canyons. These areas have an extremely gentle continental slope. If the river origin of the canyons is correct, the explanation of the absence of canyons in these areas is simple. Either the continental slopes were too gentle to permit valleys of any large size to be cut, or the floors of the canyons had gradients so low that the canyons have been largely or completely

Eastern Coast of the United States

	Name	Head	Mid	End	Mean	Lat.	Long.
1	Corsair	3.9	7.9	4.0	6.0	41°26′ N	66°14′ W
2	Georges	17.1	11.0	7.1	10.2	41 16 N	66 16 W
3	Atlantis	9.8	11.7	4.5	9.1	41 17 N	66 26 W
4	Lydonia	9.8	2.5	7.5	4.5	40 32 N	67 44 W
5	Gilbert	10.0	7.4	3.8	4.7	40 23 N	67 55 W
6	Oceanographer	6.0	3.4	5.4	4.2	40 29 N	68 10 W
7	Hydrographer	4.0	3.9	6.5	5.0	40 13 N	69 07 W
8	Fire Island	6.7	4.7	6.2	5.3	39 32 N	72 05 W
9	Hudson	3.1	3.5	1.5	2.7	39 41 N	72 29 W
10	Manasquan	6.0	5.3	6.4	6.3	39 13 N	72 28 W
11	Metedeconk	8.2	6.2	4.5	6.2	39 12 N	72 31 W
12	Toms River	4.3	4.0	5.5	6.1	39 10 N	72 42 W
13	Delaware	6.3	3.7	3.1	3.8	38 30 N	73 30 W
14	Chesapeake	6.6	2.1	1.5	2.6	37 30 N	74 31 W
	Average	7.3	5.5	4.8	5.5		

The Mediterranean

	Name	Head	Mid	End	Mean	Lat.	Long.
88	Sefsaf	25.0	17.0	4.9	12.0	36°49′ N	3°33′ E
89	Sebaori	18.0	23.0	16.0	19.0	36 55 N	3 52 E
90	Axin	19.0	9.2	16.0	11.0	37 02 N	7 34 E
91	Nil	22.0	16.0	15.0	15.0	36 54 N	5 58 E
92	Zhour	18.0	12.0	1.8	10.0	36 58 N	6 12 E
93	Tamanart	18.0	15.0	17.0	16.0	37 04 N	6 32 E
94	Sanik	18.0	14.0	7.8	11.0	33 33 N	35 20 E
95	Arma	12.0	7.1	15.0	12.0	43 47 N	7 54 E
96	Roja	14.0	9.4	11.0	11.0	43 45 N	7 39 E
97	Marseille	13.0	11.0	4.0	7.6	43 20 N	5 19 E
98	Llobregat	2.8	6.1	2.1	3.7	41 16 N	2 11 E
99	Gibraltar	3.4	5.1	8.5	3.5	36 09 N	5 24 W
	Average	15.2	12.1	9.4	10.9		

Oceanic Islands

	Name	Head	Mid	End	Mean	Lat.	Long.
49	Kailiu	36.6	12.3	26.0	21.2	22°15′ N	159°37′ W
50	Honopu	30.0	27.4	8.9	19.2	22 11 N	159 41 W
17	Mameyes	3.3	9.9	2.9	6.6	18 27 N	65 43 W
16	Pinones	15.2	7.1	7.4	8.4	18 28 N	65 57 W
	Average	21.3	14.2	11.3	13.8		

Western Coast of the United States

	Name	Head	Mid	End	Mean	Lat.	Long.
20	LaJolla	15.5	10.3	3.2	8.4	32°51′ N	112°16′ W
21	Scripps	21.3	5.1	7.5	7.4	32 54 N	112 16 W
22	Oceanside	11.0	3.6	1.8	4.8	33 07 N	117 21 W
23	Catalina	13.7	6.0	6.3	7.7	33 23 N	118 29 W
24	Newport	8.4	5.2	4.8	6.3	33 36 N	117 55 W
25	Redondo	5.5	3.3	2.6	3.6	33 50 N	118 23 W
26	Dume	21.1	14.6	3.1	12.5	33 57 N	118 49 W
27	Mugu	24.0	8.4	4.7	6.4	34 05 N	119 07 W
28	Arguello	2.7	4.5	.5	2.9	34 38 N	120 48 W
29	La Cruz	3.4	3.3	3.4	3.4	35 43 N	121 25 W
30	Villa	7.0	3.5	3.3	4.1	35 49 N	121 28 W
31	Plaskett	8.1	2.9	3.9	4.4	35 55 N	121 31 W
32	Lucia	13.5	3.2	2.3	2.9	36 03 N	121 37 W
33	Partington	10.5	2.8	2.4	3.4	36 10 N	121 43 W
34	Mill Creek	8.2	4.2	2.1	4.4	35 58 N	121 31 W
35	Sur	3.6	3.4	.6	3.0	36 16 N	121 54 W
36	Carmel	30.0	3.9	9.5	7.6	36 32 N	121 56 W
37	Monterey	4.6	2.1	1.1	2.9	37 48 N	121 47 W
38	Delgada	7.2	6.0	3.9	5.5	40 07 N	124 47 W
39	Mattole	7.1	4.2	3.9	4.9	40 17 N	124 21 W
40	Mendocino	18.6	6.0	8.0	8.2	40 22 N	124 25 W
41	Columbia	3.5	2.3	1.5	2.0	46 16 N	124 20 W
42	Willapa	4.7	1.1	2.8	2.3	46 35 N	124 29 W
43	Guide	0.6	3.9	1.0	2.6	46 34 N	124 39 W
44	Chehalis	2.8	2.9	3.0	2.5	46 57 N	124 49 W
45	Quinault	9.2	1.6	2.7	4.2	47 18 N	124 45 W
46	Fraser	3.2	1.6	.9	1.9	48 04 N	125 17 W
47	Nizinat	7.9	2.5	1.4	2.5	48 13 N	125 42 W
48	Barklay	3.7	4.0	2.0	3.3	48 22 N	125 58 W
	Average	9.96	4.0	3.44	4.83		

Off Large Rivers

	Name	Head	Mid	End	Mean	Lat.	Long.
87	Congo	1.3	1.5	1.5	1.1	6°01′ S	12°35′ E
85	Indus	1.0	1.1	.9	1.0	23 45 N	67 35 E
80	Ganges	1.5	5.9	2.4	.8	21 27 N	89 41 E
15	Mississippi	1.2	1.1	1.0	1.1	28 40 N	90 03 W
9	Hudson	3.1	3.5	1.5	2.7	39 41 N	72 29 W
41	Columbia	3.5	2.3	1.5	2.0	46 16 N	124 20 W
101	Cap Breton	4.2	2.2	.9	1.9	43 39 N	1 28 W
100	Nazare	6.8	2.7	2.3	2.7	39 35 N	9 06 W
14	Chesapeake	6.6	2.1	1.5	2.6	37 30 N	74 31 W
	Average	3.24	2.5	1.5	1.7		

Coasts of Eastern Asia

	Name	Head	Mid	End	Mean	Lat.	Long.
51	Subokun	20.0	5.6	2.2	5.1	41°33′ N	129°40′ E
52	Yan To	9.7	7.5	5.6	7.0	40 42 N	129 29 E
53	Oryin	20.8	3.8	3.9	10.7	38 20 N	128 34 E
54	Pisen Chyang	24.8	.4	2.0	8.5	38 15 N	128 38 E
55	Hojozu	12.9	4.7	3.5	5.4	36 48 N	137 05 E
56	Yokata	10.5	8.3	10.8	10.0	36 46 N	137 11 E
57	Jinzu	20.0	7.6	6.4	8.4	36 46 N	137 13 E
58	Sagami	12.6	1.0	3.1	2.7	35 15 N	138 11 E
59	Uraga	1.9	1.9	2.5	2.6	35 14 N	139 46 E
60	Suruga	16.8	2.1	3.2	3.4	35 08 N	138 43 E
61	Suno Saki	10.8	3.7	5.6	5.1	34 55 N	139 46 E
62	Chotsui Pii	24.4	30.8	16.6	19.0	23 31 N	121 30 E
63	Ocho Pii	42.8	15.6	8.0	11.7	23 13 N	121 25 E
64	Torela	12.7	8.7	20.6	13.8	23 02 N	121 20 E
65	Tan Kan	5.6	2.0	1.5	1.9	22 24 N	120 23 E
66	Batulinao	2.4	2.6	1.9	2.3	18 22 N	122 02 E
67	Cagayan	4.7	1.9	1.8	2.4	18 23 N	121 37 E
68	Bacarra	14.7	9.1	8.5	10.0	18 18 N	120 31 E
69	Novotas	15.7	7.2	5.0	8.5	18 17 N	120 28 E
70	Laoag	8.2	3.9	9.4	7.0	18 13 N	120 27 E
71	Abra	12.1	6.1	7.0	7.2	17 31 N	120 23 E
72	Santa	18.7	4.3	3.0	4.9	17 29 N	120 25 E
73	Mainganay	15.0	15.4	5.8	8.8	17 24 N	120 27 E
74	Amburayan	13.3	3.1	4.2	5.5	16 56 N	120 35 E
75	Bucao	17.2	8.7	4.9	8.4	15 16 N	128 00 E
76	Panan	25.1	10.7	4.5	10.5	15 11 N	119 57 E
77	Santo Tomás	14.1	9.5	8.0	9.3	15 05 N	120 01 E
78	Pamatuan	17.0	10.5	5.8	10.5	14 57 N	120 01 E
79	Manila	6.0	3.9	1.4	3.8	14 16 N	120 29 E
	Average	14.4	6.4	3.4	7.0		

Indian Ocean Province

	Name	Head	Mid	End	Mean	Lat.	Long.
81	Trincomalee	60.0	27.0	6.7	12.7	8°30′ N	81°14′ E
82	Kumbukkan	19.6	5.5	5.0	9.0	6 23 N	81 44 E
83	Nilwala	3.8	23.2	17.5	15.9	5 54 N	80 32 E
84	Panadure	11.8	8.4	4.1	5.9	6 40 N	79 46 E
86	Mocambo	6.8	4.4	4.8	5.8	15 08 S	40 37 E
	Average	20.4	13.5	7.6	9.8		

Table 1

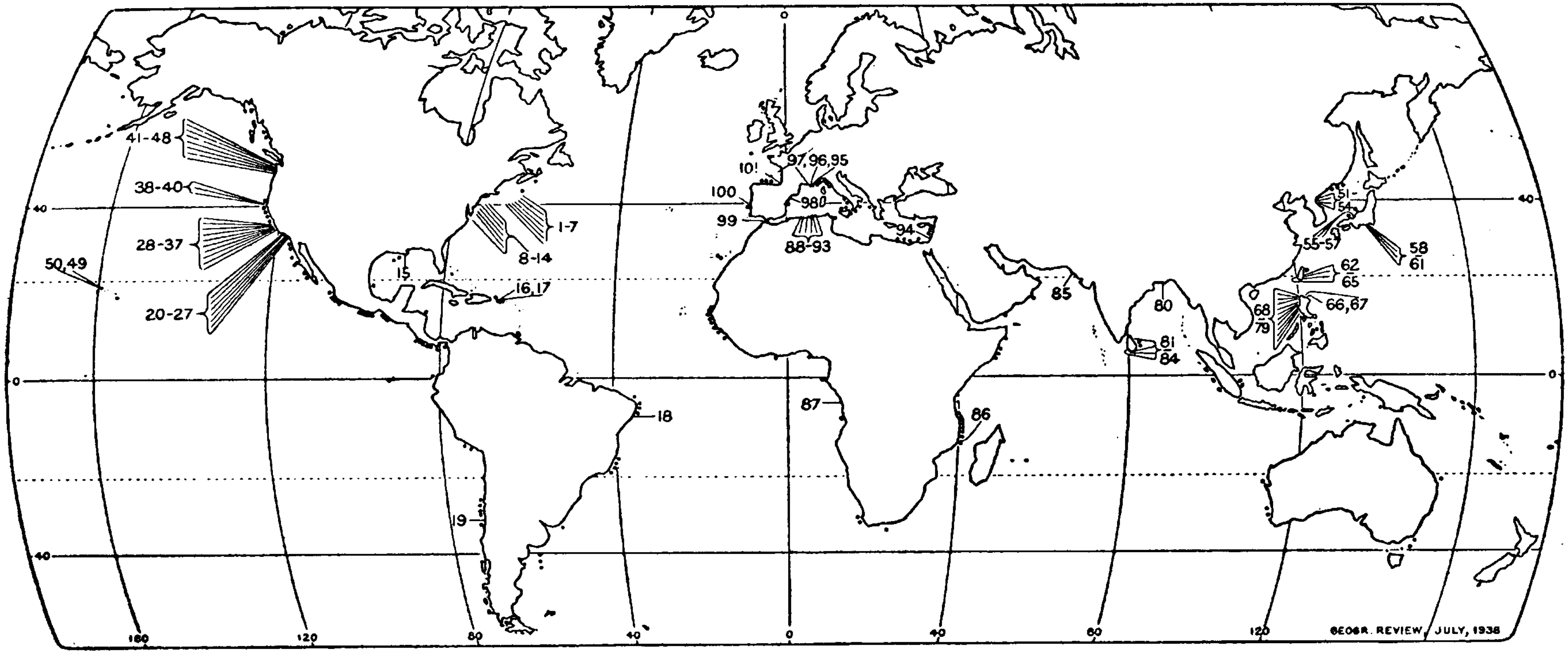

Fig. 1

Distribution mondiale des cañons sous-marins. Les numéros se rapportent aux cañons auxquels on a affecté des noms et pour lesquels on disposait de suffisamment de sondages pour établir les profils longitudinaux. Le Tableau I donne les noms des cañons en question (les noms soulignés dérivent des navires explorateurs), le tableau donne aussi leur position. Les pointillés indiquent l'emplacement d'autres cañons, dont certains douteux. On a laissé de côté les dépressions sous-marines ayant pour origine probable une dislocation glaciaire.

World distribution of submarine canyons. Numbers given where canyons have been named and where sufficient soundings for longitudinal profiles were available. Table I identifies these canyons by name (names underscored are those derived from exploring vessels) and position. Dots show location of other canyons, some of doubtful character. Submarine depressions of probable glacial diastrophic origin are omitted.

filled with sediments since submergence. Another possible explanation of the absence of canyons is that locally the continental slopes are of fault origin later than the time of canyon cutting; and another, that ponding up of the waters by a rim of islands has prevented the lowering of the sea along the slopes.

CONCLUSIONS REGARDING DISTRIBUTION.

It is unwise to make sweeping generalizations regarding the distribution of the canyons because of our present lack of data, but some tentative conclusions may be suggested as a basis for pursuit of the problem.

1. Most canyons are found either off rivers or off localities where rivers existed in the not remote past.
2. Canyons are as often related to small rivers as to large rivers.
3. Canyons are commoner off relatively straight coasts than off deeply indented coasts.
4. Canyons show no relation to latitude unless perhaps that they are absent in the Polar Regions.
5. Canyons are as common off supposedly stable coasts as off coasts where Quarternary or Tertiary movements are known to have occurred.

LONGITUDINAL PROFILES.

In constructing the longitudinal profiles of the canyons care was taken to use only soundings obtained at least relatively near the axes of the canyons. For only two canyons, Scripps

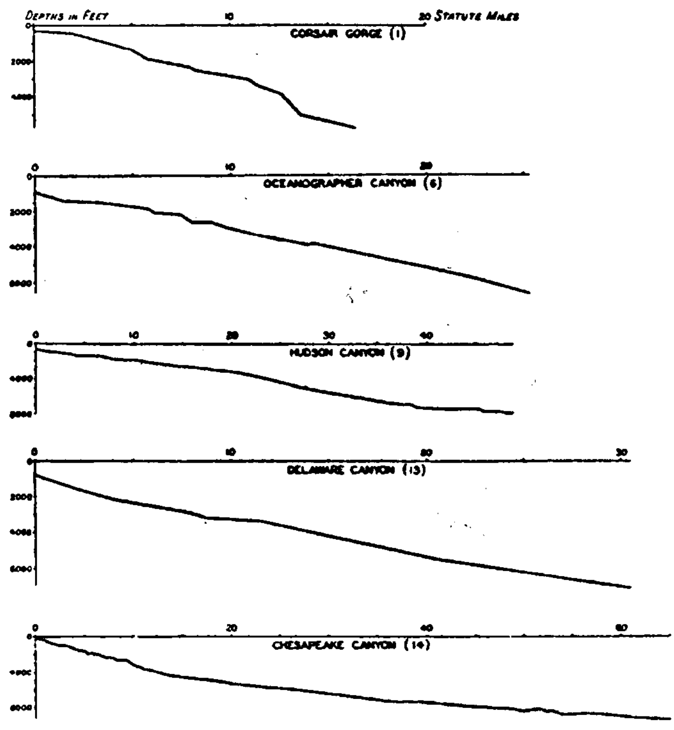

FIG. 2

A selection of longitudinal profiles from canyons off the eastern United States. (Numbers after name of canyon correspond to those on the map Fig. 1, and Table I)

Canyon and the head of Carmel Canyon, were there enough soundings to permit the profiles to be drawn with confidence. For all the other profiles interpretation was necessary. One of the most difficult problems had to do with the matter of the possible existence of sills interfering with the continuous outward slope of the canyon. A few such sills, all of doubtful existence, are given in the profiles (Figs. 2-5), but many others may exist. In the detailed charting of Carmel and Scripps Canyons (5) no sills were discovered; and, in general, the more detailed the soundings in any particular canyon, the less evidence there is for the existence of sills. In several of the west-coast submarine canyons, where, on the basis of echo-sounding surveys, sills had been thought to exist, vertical casts showed that their existence had been assumed owing to errors in the method.

Practically all the profiles, therefore, can give only the approximate inclination of the floors. However, by combining a great many cases it has been possible to obtain data regarding the heads and the central and lower sections of the canyons (Table 1) (6). Also, the combination of the average slopes of the canyons off different types of coast will be used in drawing certain general conclusions. Finally, canyon gradients from mountain slopes on land will be compared with the submarine gradients.

As few soundings have been made in the outer portions of the submarine canyons, it was impossible to extend the profiles to the greatest depths with any certainty. Therefore no information regarding the outer termini of the canyons can be obtained from these profiles.

EAST COAST OF THE UNITED STATES.

Most of the east-coast canyons that could be profiled were off Georges Bank, the New England coast, and the vicinity of New York City. The profiles (Fig. 2) of these canyons show an average gradient of 5 per cent. The degree of difference is slight, the steepest profile having a gradient of a little more than 10 per cent. The canyon with the lowest gradient is off Chesapeake Bay, and the one with the next lowest is Hudson Canyon; possibly, however, the gradient of Hudson Canyon (this does not include the shallow shelf valley) would prove to be as low as that of Chesapeake Canyon if it had been traced as far out to sea. The profiles of almost half of the east-coast canyons have a steeper gradient at the outer end than in the center. This is unlike typical river profiles, but it must be borne in mind that the surveys did not extend to the outer limits of the canyons. The survey of Chesapeake Canyon, which was carried out much farther than the others, shows a distinctly lower gradient in the outer part. However, there is no doubt that some of the canyons show evidence of steepening in depths of 4800 feet or even as much as 6000 feet.

WEST-COAST CANYONS.

Most of the 29 canyons off the west coast of the United States that were profiled are off the California coast. Their average gradient is 4.8 per cent, which is less than that of the east-coast canyons. It may be significant that the same thing is true of the two canyons off South America that could be profiled: the east-coast Tamandaré Canyon has an average gradient of 6.0 per cent; the west-coast Maipo Canyon has an average of 4.5 per cent. This somewhat greater steepness of the east-coast canyons becomes less significant when attention is called to the fact that the eastern continental slopes of the Americas are actually somewhat steeper than the western continental slopes. This of course is contrary to general opinion, but it can be readily determined from a study of the charts.

The west-coast canyons differ in another respect from those off the east coast. Their inner ends are for the most part considerably steeper than their average gradients. The well surveyed Carmel (taken from detailed survey of Mission Branch), Mugu, Scripps, and Dume Canyons reach the maximum with gradients of 30, 24, 21, and 21 per cent respectively. However, it is notable that the steep inner ends are found in canyons that reach within a very short distance of the coast. As all the east-coast canyons head well out on the shelf, they are better compared with California canyons of the same type. The two groups are similar; that is, their heads are only slightly steeper than their average slopes. It seems likely that the steep gradients of the canyons that head close to the coast are due to the deposition of sediment. The coarse sediment available at the head of many of the canyons would certainly stand at the slopes that are recorded. For example, inside the 30 per cent slope at the head of Carmel there is a steep beach composed of very coarse sand and gravel. The same kind of material was dredged from the head of the canyon near shore.

West-coast canyons also show steepening of gradient well out from the coast and at depths of as much as 6000 feet. Arguello Canyon (Fig. 3) is interesting in this regard. It is one of the longest American submarine canyons, being clearly traceable for as much as 70 miles. Twenty-six miles from its head it shows steepening between depths of 6000 and 8000 feet. At its outer extremity, however, its gradient decreases decidedly. Monterey Canyon (Fig. 3) also shows some steepening to a depth of about 6000 feet. Its outer part shows a very gentle gradient, but in this outer part it is really a trough rather than a canyon.

CANYONS OFF THE EAST COAST OF ASIA.

The canyons off the east coast of Asia are found principally off Honshu Island, Formosa, and Luzon. These canyons (Fig. 4) have a higher gradient than those off the United States, the average being 7 per cent. Their heads are decidedly steeper than the average, having gradients of 14.4 per cent. Ochi Pii Canyon, with a 43 per cent gradient, has the second steepest head known in submarine canyons. The contrast between head and outer portion is very strik-

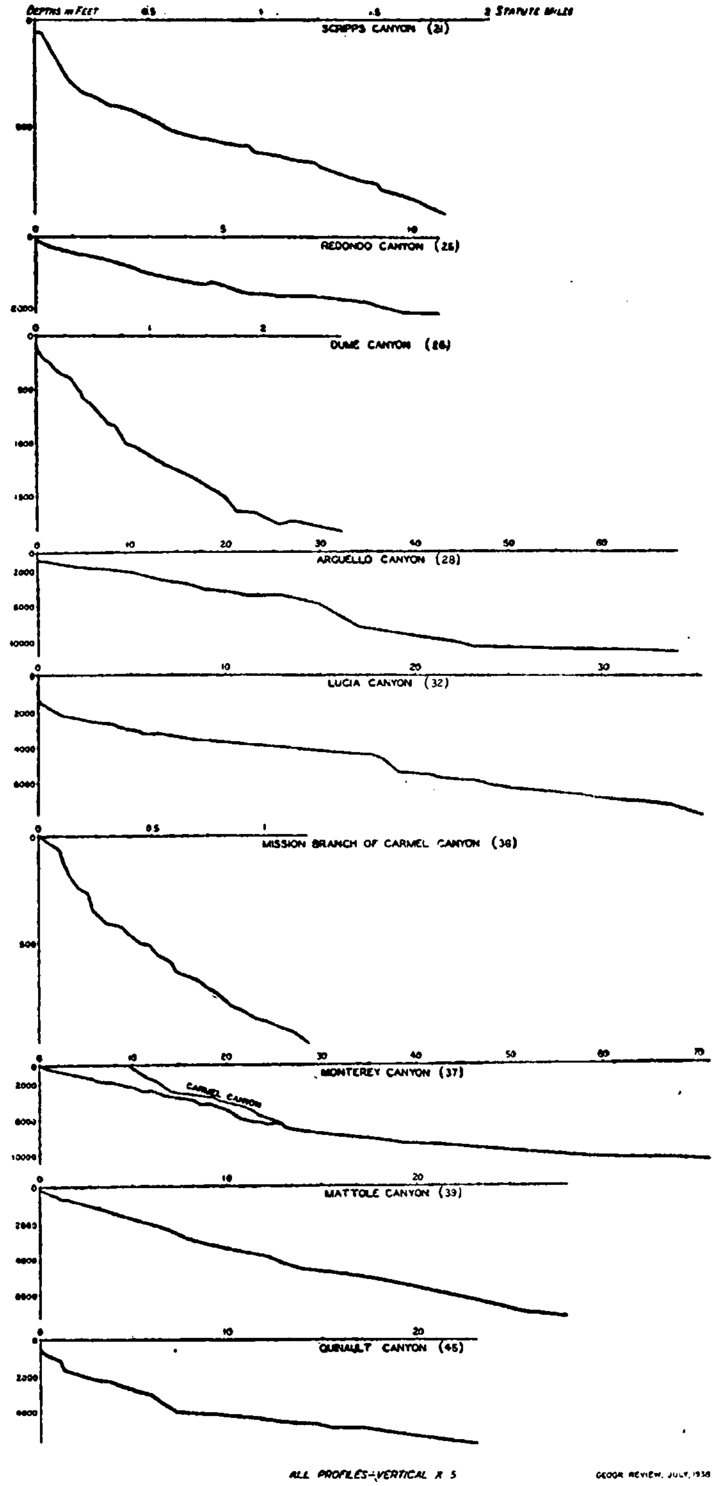

FIG. 3

A selection of longitudinal profiles from canyons off the western United States.

ing in several of the profiles — that of Pisen Chyang Canyon (off Korea), for example, with its 24 8 per cent grade at the head and its flattened center and end However, there are only a few soundings of this canyon.

Most of the profiles of the Philippine canyons show the concave upward curve of typical stream valleys. These are certainly the best graded of the known groups of submarine canyons. One of the Korean canyons also shows a fair degree of grading, but most of the canyons off Honshu and all of those off Formosa are very irregular. The latter show evidence suggesting that, if they are really river-cut valleys, they may have been deformed by diastrophism after the cutting.

Steepening takes place in Sagami Canyon at as great a depth as 8400 feet. Steepening in Chotsui Pii Canyon takes place at 6000 feet, and the steep slope extends at least to 9600 feet.

It will be noted that the profiles of the two canyons off the north coast of Luzon have a much greater gradient than most of the others in this group. Both of these canyons cross the relatively broad shelf off this coast, and Cagayan Canyon extends into the mouth of the Cagayan River, one of the largest rivers of the Philippine Islands. Congo Canyon, off the west coast of Africa, is, so far as the writers know, the only other canyon in the world that extends well into an estuary.

INDIAN OCEAN CANYONS AND MEDITERRANEAN CANYONS.

The most significant group of canyons in the Indian Ocean province is off Ceylon. Here there are canyons with an average gradient of 9.8 per cent. The most remarkable of these is Trincomalee Canyon, which extends into a bay of that name on the northeast coast of Ceylon. The head of this canyon has a measured slope of 60 per cent, though the slope decreases outward very decidedly. This 60 per cent slope is the steepest recorded in the profiles. Steepness of slope in the canyons off Ceylon is to be expected, since the continental slope around this island is one of the steepest in the world. The Indus and Ganges Canyons are dealt with under the heading of "Large Rivers".

The groups of canyons in the Mediterranean have an average gradient of 10.9 per cent, which is steeper than that of any of the group discussed so far. The canyons off the north coast of Africa have an average slope of more than 10 per cent, and the same is true of those off Syria and the Riviera. The slopes are relatively even. However, all these canyons are none too well sounded.

OCEANIC-ISLAND CANYONS.

Only two canyons off mid-ocean islands have been well enough charted to permit profiles to be constructed. These are off the north coast of Kauai Island of the Hawaiian group. With these strictly oceanic-island canyons two canyons off Puerto Rico have been included, though they are perhaps more closely associated with the continental canyons. The two Hawaiian canyons are very steep, having an average gradient of slightly more than 20 per cent, and the slopes of both are steeper at their heads than lower down. These steep slopes are suggestive of those found at canyon heads in tropical islands. The Puerto Rican canyons are not so steep : Mameyes has a relatively gentle slope at the head. This oceanic group has a combined average gradient of 13.8 per cent, which is the highest of all the group averages.

CANYONS OFF LARGE RIVERS.

In selecting the canyons to be discussed under this heading some liberties were taken, since there are cases of canyons that are off what were formerly large river mouths ; for example, Cap Breton, off the old mouth of the Adour ; Nazare, probably off the old mouth of the Tagus ; Chesapeake, presumably off the Susquahanna ; and Fraser, probably off the Fraser.

The average gradient for the river canyons is 1.7 per cent, which is well below the average for all groups. (7) This low gradient is probably of some significance in connection with the origin of the canyons.

The density-current hypothesis (8), which explains the origin of the canyons as by the creation of mud currents during the lowered sea levels of the Pleistocene, offers no reason for the development of particularly low gradients off the large rivers. On the other hand, if the sea level were lowered, the large rivers would be able to cut faster than the small ones and as a result would tend to develop lower gradients in their canyons.

Another point of importance is that the canyons off the large rivers are unusually long. They include most of the longest submarine canyons in the world. The canyon off the Congo begins well inside the estuary and extends seaward for a known distance of about 95 miles, beyond which point few soundings have been made. Furthermore, these canyons penetrate more

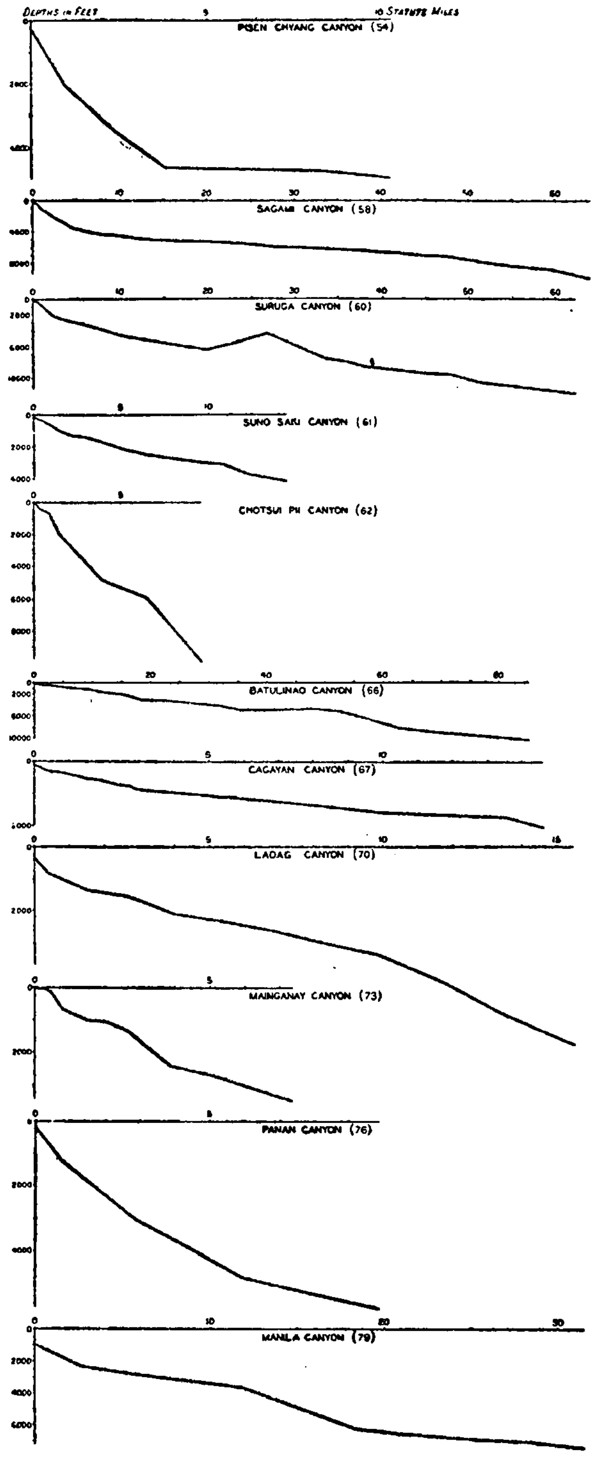

Fig. 4

A selection of longitudinal profiles of Canyons off eastern Asia.

deeply into the continental shelves than any of the other canyons. Hudson Canyon penetrates farthest into the eastern continental shelf of the United States, namely about 19 miles; the Mississippi Trough penetrates 22 miles into the Gulf-coast shelf; and Columbia Canyon penetrates 12 miles into the shelf off Oregon. Off western Europe, Cap Breton Canyon penetrates 30 miles into the shelf and Nazare Canyon 25 miles. Congo Canyon penetrates the shelf for 65 miles, and the Indus and Ganges Canyons penetrate for 67 and 69 miles respectively. One is certainly justified in asking the advocates of the submarine-current hypothesis why currents should be so important at these places.

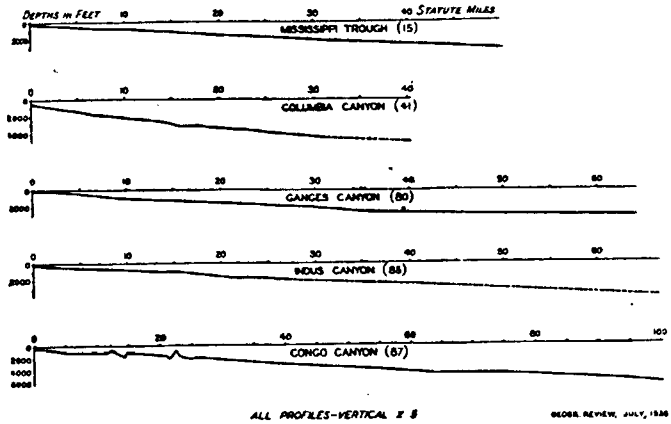

FIG. 5
A selection of longitudinal profiles of canyons off large rivers.

It is particularly important that the characteristics of canyons off large rivers are so well shown by the three canyons where the connection is so clear, namely the Congo, the Indus, and the Ganges.

Appalachian Mountains (East Side)

Thornton River (Luray Sheet, Va.)	1.6
Moormans River (Harrisonburg Sheet, Va.)	3.2
Mitchell River, tributary to Yadkin River, N. C.	1.4
Buck Creek, tributary to Catawba River, N. C.	1.96
Average	2.05

Wasatch Mountains (West Side)

Provo River, Provo, Utah	.7
Cottonwood Creek, 10 mi. SE Salt Lake City	4.9
Mill Creek, 6 mi. SE Salt Lake City (Head 14.2, Mid. 8.2, End 5.1)	4.6
Hobble Creek, Springville, Utah	3.4
Average	4.6

Sierra Nevada Mountains (East Side)

Mill Creek, N end Mono Lake	6.2
Independence Creek, W side Owens Valley, Cal.	11.8
Shepard Creek, W side Owens Valley, Cal.	12.1
Pine Creek (Mount Goddard Quadrangle, Cal.) (Head 18.0, Mid. 6.3, End 5.4)	7.0
Average	9.03

Coast Ranges (West Side)

Soberanes Creek, Santa Lucia Mts., Cal.	17.1
Rocky Creek, Santa Lucia Mts. near Point Sur	10.2
Little Sur River, 2 mi. N Point Sur (Head 11.8, Mid. 1.7, End 0.9)	2.8
Dume Canyon, Pt. Dume, Cal. (Santa Monica Mts.)	4.8
Trancas Canyon, 3 mi. NW Pt. Dume	5.7
Topanga Canyon and Garapito Creek, Santa Monica	3.5
Average	7.3

TABLE II.

It may also be of some significance that the slope off the Mississippi delta where it has crossed the continental shelf and is building on the slope is 1 per cent and the slopes off the Congo, the Indus, and the Ganges are respectively 1.1, 1.0, and 0.8 per cent. Possibly these slopes represent the angle of repose of typical river mud and the mud covers the old canyon floor till it reaches this gradient. It is obvious from the profiles of the troughlike valley off the Mississippi that it has a mud fill. Probably the Indus, with its very slope, also has such a fill.

COMPARISON WITH LAND VALLEYS.

No attempt has been made to go deeply into the subject of gradients of land valleys by way of comparison. However, some data are given in Table II for what they are worth. The average gradient observed was 6.07 per cent, as compared with the average gradient of 6.54 per cent for the oceanic canyons. Of course, another choice of land canyons might have given very different results. The four mountain ranges show a difference in gradients.

Land valleys are well known to show decreasing gradients along their length. The submarine canyons have the same tendency, as is shown by the averages of 11.62, 6.63, and 4.76 for the head, center, and end portions, Furthermore, it is true of both land valleys and submarine canyons that most of the large rivers have much lower gradients than the small.

CONCLUSIONS IN REGARD TO PROFILES.

Once again it must be stated that our observations are only preliminary; but, despite this' it is believed that the following summary on longitudinal profiles may be useful in solving the riddle of the origin of submarine canyons.

1. Most of the submarine canyons have floors that slope outward practically continuously, as do canyons on land.

2. Also like land canyons, most of the submarine canyons have profiles that are steeper at the head and become gentler outward, so that they are concave upward.

3. The canyons off large rivers have the gentlest gradients.

4. Most of the steepest canyons are found off islands, both continental and oceanic.

5. The canyons off the Pacific coast of America have gradients slightly less steep than those off the Atlantic coast.

6. The canyon gradients are closely related to the gradients of the continental slopes into which the canyons are cut except where the canyons off large rivers have cut deeply into the continental shelves.

7. The gradients of the canyons are not appreciably related to the width of the continental shelves inside.

8. The steepness of the gradients is not distinctly related to the supposed stability of the coast off which the canyons are found.

9. On the other hand, the evenness of slope outward does seem to be greater off the supposed stable coasts than off the coasts that are well known to be unstable.

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(1) The following references in chronological order cover most of the discussion on the subject:
F. P. Shepard: "Submarine Valleys", *Geogr. Rev.* Vol 23, 1933, pp. 77-89;
W. M. Davis: "Submarine Mock Valleys", *ibid.* Vol. 24, 1934, pp. 297-308;
H. C. Stetson and others: "Geology and Paleontology of the Georges Bank Canyons", *Bull. Geol. Soc. of America*, Vol. 47, 1936, pp. 339-440.
H. H. Hess and Paul MacClintock: "Submerged Valleys on Continental Slopes and Changes of Sea Level", *Science*, Vol. 83 (N. S.) 1936, pp. 332-334.
F. P. Shepard: "Submerged Valleys on Continental Slopes and Changes of Sea Leval", *ibid.*, pp. 620-621.
R. A. Daly: "Origin of Submarine Canyons", *Amer. Journ. of Sci.* Ser. 5, Vol. 31, 1936, pp. 401-420.
F. P. Shepard: "The Underlying Causes of Submarine Canyons", *Proc. Natl. Acad. of Sci.* Vol. 22, 1936, pp. 496-502.
Idem: Daly's: "Submarine Canyon Hypothesis", *Amer. Journ. of Sci.* Ser. 5, Vol. 33, 1937, pp. 369-379
P. H. Kuenen: "Experiments in Connection with Daly's Hypothesis on the Formation of Submarine Canyons". *Leidsche Geol. Mededeelingen*, Vol. 8, 1937, pp. 327-351.

(2) Georges Davidson: "The Submerged Valleys of the Coast of California, U. S. A., and of Lower California, Mexico", *Proc. California Acad. of Sci.* 3rd Ser. (Geology), Vol. I, 1897-1904, pp. 73-103.

(3) Edward Hull: "Monograph on the Sub-Oceanic Physiography of the North Atlantic Ocean", London, 1912.

(4) F. P. Shepard: "Glacial Troughs of the Continental Shelves", *Journ. of Geol.* Vol. 39, 1931, pp. 345-360.

(5) F. P. Shepard: "Detailed Surveys of Submarine Canyons", *Science*, Vol. 80 (N. S.) 1934, pp. 410-411.

(6) "The 'mean' of Table I is not the average of the head, center, and end, each of which represents short stretches.

(7) "A canyon recently surveyed in southern Bering Sea may represent the continuation of the Yukon. It has a gradient of 2.0 per cent.

(8) Daly, *op cit.*