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EVIDENCE OF WORLD-WIDE SUBMERGENCE¹

BY

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INTRODUCTION

At the beginning of the century geologists were discussing the idea that the glacial period was the result of enormous vertical movements of the continents. Uplifts were said to have cooled the climates, bringing on glaciation, and subsequent submergence caused the glaciers to melt. This hypothesis was supported by the finding of deep canyons on the sea floor which indicated the former elevated condition of the continents. The idea was later abandoned, partly because of the very limited amount of information concerning submarine canyons but largely because the glacial period was found to have a series of ice stages or epochs with intervening times of relatively warm climate. The alternate elevation and depression of the continents to a degree sufficient to produce widespread glaciation, all during about one million years, appeared to be completely out of accord with the history which geologists had been building from their accumulating evidence.

The abandonment of the diastrophic hypothesis seems to have resulted in shelving the subject of submarine canyons, so that for a quarter of a century there was almost no mention of them in the literature. This neglect terminated when the amazing advances of hydrographic surveys of the past two decades revealed the presence of abundant submarine canyons of huge dimensions off many coasts of the world. While many geologists have considered these canyons as having been cut by running water, and therefore being indicative of great changes of level, others have developed hypotheses by which they attempted to explain the canyons as having been formed under the ocean. These explanations have proved satisfactory to many geologists, but as oceanographic research has progressed it has become increasingly evident that the submarine canyons are remarkably like the river-cut canyons of the land. During the same time, an abundance of field observations has supplied independent evidence that

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there has been a very general submergence of continental borders, oceanic islands, and perhaps even of the deep sea bottom.

SUBMARINE CANYONS

Nature of Canyons. Because of the implications of enormous changes of level resulting from the world-wide distribution of the canyons, if they prove to be submerged stream valleys, some assurance should be provided that they are truly stream-eroded rather than the product of processes which can operate on the sea floor. If one considers the number of illustrious scientists who have offered hypotheses attempting to prove a submarine origin, skepticism of the stream origin would be natural. However, if one studies the detailed charts of the canyons and examines the evidence which has come from canyon exploration by dredging, coring, bottom photography, current measurements, and diving, the skepticism should not be as great. In fact, a study of the field data leaves one with the impression that the various authors of hypotheses of submarine origin were describing somewhat imaginary undersea valleys.

Submarine canyons have been described from many parts of the world (Fig. 1). Canyons have been discovered on virtually all well-explored continental slopes except where there are indications of relatively recent faulting or where the slopes are very gentle. Further exceptions may exist off coasts which now have very slight precipitation.

Some writers have been inclined to consider that the canyons were entirely different in character in different areas. For example, they have been quite willing to concede that the California canyons were the result of stream erosion, while they considered that the canyons in most other areas were of a different nature. In the present article the canyons can not be discussed adequately, so that reference should be made to a recent comparison of canyons from all parts of the world (Shepard, 1948: 210-229). So far as evidence is now available, the conclusion from this work is that the canyons are essentially the same the world over. They cut the submarine slopes as deep notches with V-shaped transverse profiles. They have narrow floors sloping almost continuously away from the lands. They have twisting courses and tributaries entering with the dendritic pattern characteristic of land canyons. The walls are precipitous and have proved to contain rock exposures in almost all of the areas from which samples are available. Many of the rocks are of a type resistant to erosion. The majority of the canyons extend shoreward across most of the continental shelf and many of them enter estuaries. Others, however, have their heads on

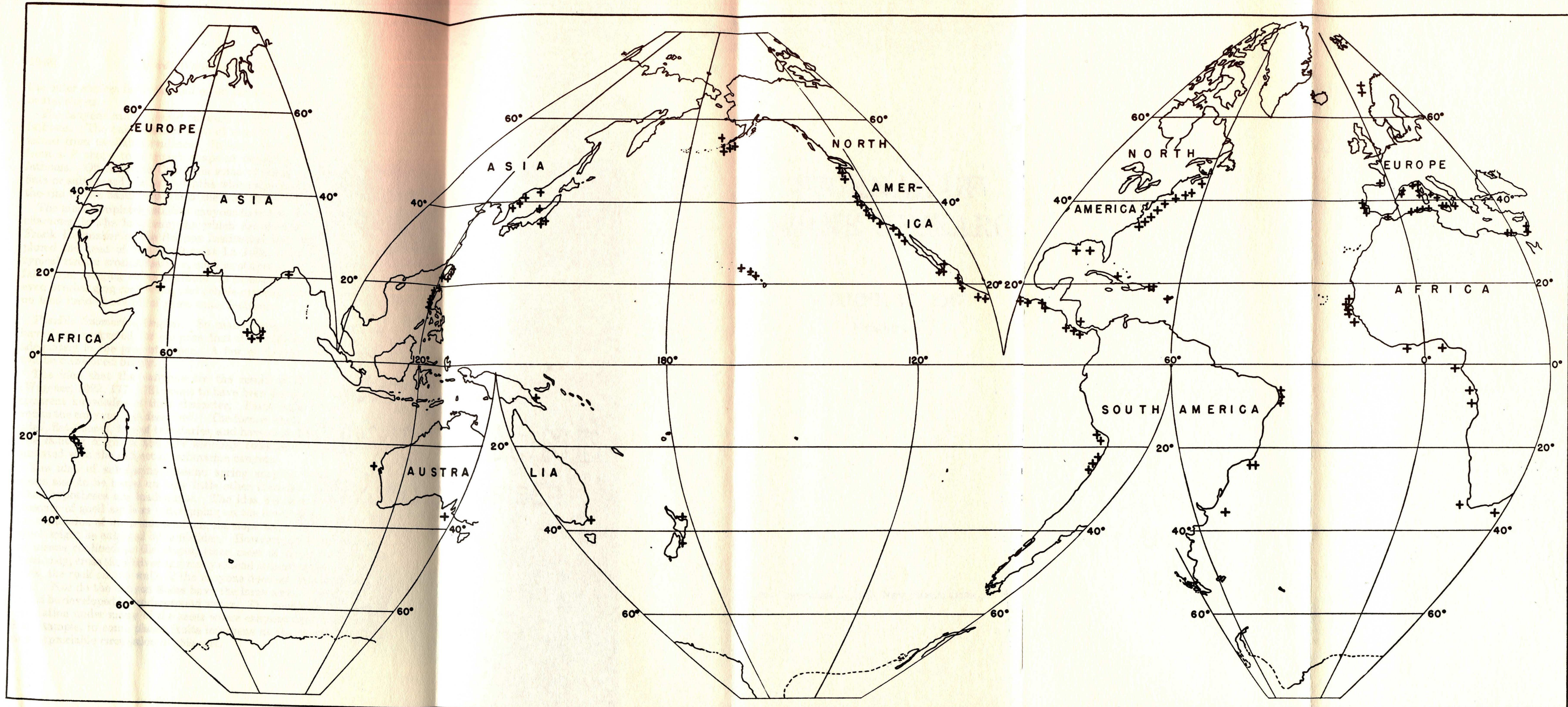


Figure 1. The world distribution of submarine canyons. Each cross indicates one or a group of canyons. Many areas lack adequate soundings for the determination of canyons.

the outer shelves far from land or on the upper portions of the continental slopes.

The canyons can be traced outward to depths of many hundreds of fathoms. The outer terminations of most canyons can not be ascertained from available evidence. In some cases they show a change from a V shape to a trough shape at depths of the order of 1,000 fathoms. Off southern California some of them appear to end with flats or submerged deltas at depths which are approximately those of the rim of the basin into which the canyon has been cut.

The most completely studied canyons have proved to be identical in character to the land canyons which are directly inside (Fig. 2). Frank Haymaker of the Scripps Institution has dived into and explored the head of two canyons at La Jolla, California. He found typical stream erosion features, such as staircase canyons with waterfall drops, hanging valleys, tributaries entering at grade, vertical and even overhanging rock walls, and cobble covered floors. The canyons on land inside have all of these same features.

Possible Submarine Origins. So many types of submarine origin have been suggested for canyons that it is difficult to discuss each adequately in the present paper. A few of the principal hypotheses will be mentioned briefly.

The idea that the canyons are the result of faulting or rifting (Wegener, 1922: 177, 178) seems to have been developed without any apparent knowledge of their character. Fault valleys are obviously unlike the canyons just described. The former are in general straight-sided, flat-floored, free of tributaries, and have deep basin depressions. The faulting origin is not now seriously considered by any one acquainted with the subject of submarine canyons.

The idea of submarine artesian spring sapping (Johnson, 1939) seems also to be based on very little other than the conviction that other hypotheses are inadequate. The idea depends largely on the presence of good aquifers outcropping on the continental slopes, with the circulation of water undermining the slope and thus forming gullies which might be enlarged by landslides. However, the canyons are by no means confined to the slopes, since most of them, as explained previously, cross the shelves and many extend into estuaries. Furthermore, the rock on the walls of the canyons does not favor the aquifer idea. Nor do the canyon floors have the large sinks or basins which would be developed by underground water. The possibility for artesian circulation under many of the areas where canyons exist is negligible. For example, in some places faults intervene at the coast preventing any appreciable circulation of this sort.

The conception of origin by tsunamis (tidal waves) (Bucher, 1940) seems to be equally unfortunate. The great waves, set up rarely by submarine faulting, are virtually confined in their effects to the shore and coast. Although the tsunamis develop strong currents in shallow water along the shore, their effectiveness decreases rapidly with depth. In long waves of the Stokes type, the horizontal bottom velocity under the crests of the waves where it reaches a maximum of short duration, is given by the formula: $Q = CH/(2h)$, where Q is the velocity of the bottom current, C is the wave velocity, H is the wave height and h is the depth of water. To obtain the wave velocity, use is made of the formula $C = \sqrt{gh}$, where g is the acceleration of gravity. Using these formulae and considering a very large tsunami, we find that the maximum currents would have values approximately as follows:

<i>Fathoms</i>	<i>Cm/sec</i>
5	95
10	62
100	11
300	4.5
500	3

These figures indicate how powerless tidal waves are in producing erosion in deep areas. Furthermore, several areas which have an abundance of tsunamis have no canyons, as for example the Sanriku Coast of Japan.

The only hypothesis which has been supported in print by more than one geologist is that of cutting by density currents (Daly, 1936). According to this idea heavy muddy water moves down slopes, thereby excavating the canyons. The hypothesis has some appealing features, since these density currents are actually known to exist, at least in lakes. Model studies show how the currents produced by heavily weighted liquids could cut gullies into soft materials. Beyond this point the hypothesis has been built on highly hypothetical claims. It has been said that density currents flow along the bottom of Lake Mead at the rate of four miles an hour. Actually, the basis for this rate has been shown by the U. S. Reclamation Service to be groundless, and the present studies of Lake Mead by the U. S. Geological Survey show that the density currents are so feeble that they are allowing the rapid deposition of clay at the front of the delta of the Colorado River where the currents are best developed. In fact, at the places where density currents should be at their best, deposition is going on rapidly. This being the case, one should hesitate to believe that canyons thousands of feet deep cut into hard rocks could be due to such currents.

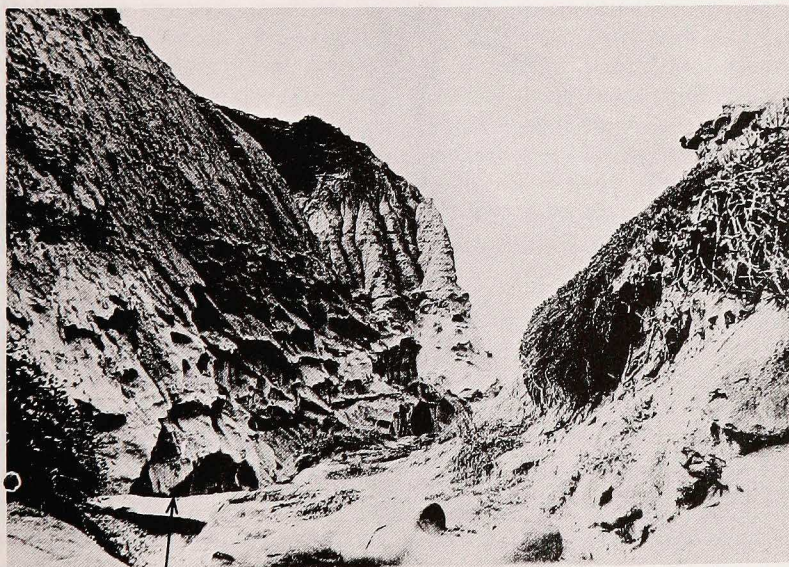
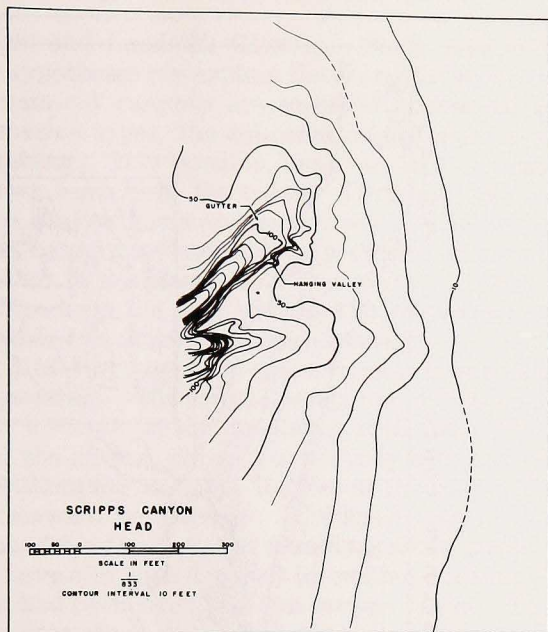


Figure 2. Comparison between the submarine canyon head (upper) and an adjacent land canyon (lower) at La Jolla, California. Both canyons have hanging valleys and precipitous walls. The arrow in lower illustration indicates the edge of a 40 foot vertical cliff.

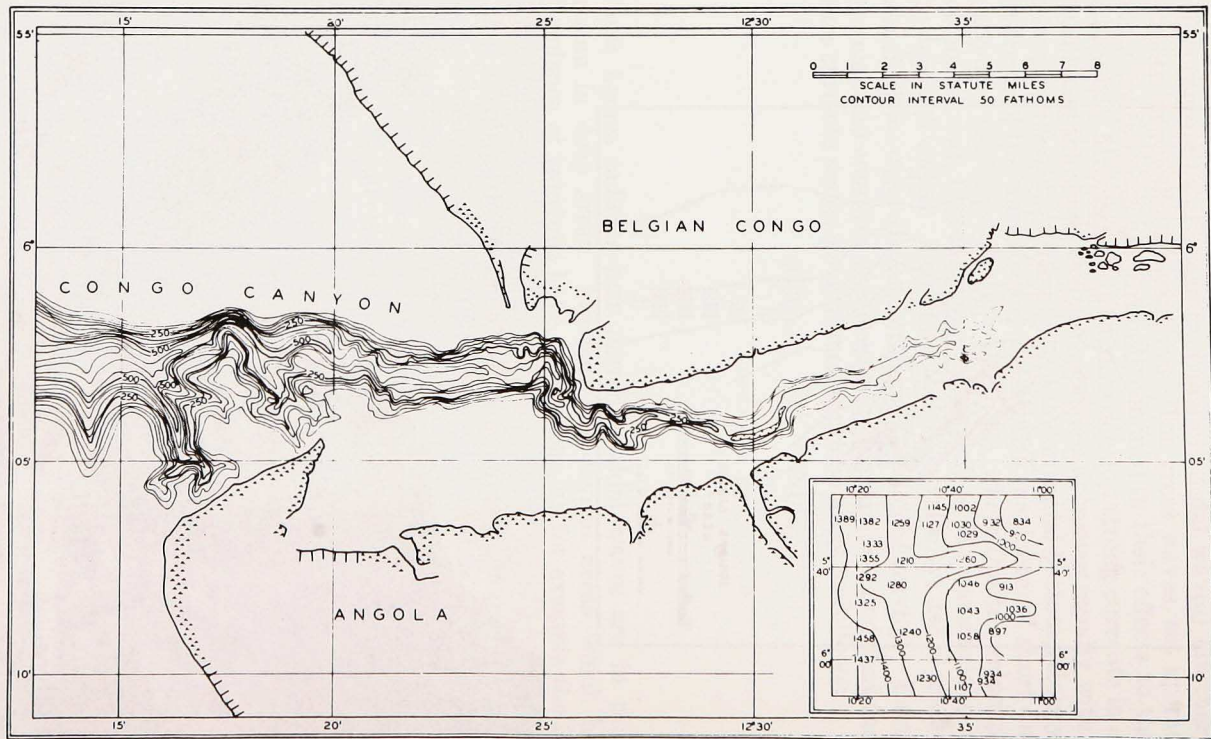


Figure 3. The deep estuary at the head of Congo Canyon. The inset shows the outer canyon terminus.

Stream Origin and Landslide Clearing. Since none of the existing marine origin hypotheses can explain the characteristics of the canyons and since stream-cut canyons are essentially identical in character with the submarine types, the subaerial origin appears to be by far the most promising. It is possible, however, that currents now completely unknown have been the cause. Certainly, the currents now existing on the canyon floors are far too weak to be held responsible. These currents have been determined by current meter observations, and their nature is confirmed by diver reports. They are barely strong enough to keep the finer sediment in suspension except under unusual circumstances when they cease entirely.

Deposition is in progress in the canyons, as is now well known from the California studies. The canyon heads would soon be filled by this deposition if it were not for the instability of the fill. The mud in the sediments and the organic debris, particularly kelp and eel grass, apparently favor slumping along the inclines at the canyon heads so that the fill slides seaward periodically. Evidence both of the fill and of the slides comes from the repeated soundings along carefully surveyed lines. Slides have also been detected by sudden deepening at the ends of piers which had been built into the canyon heads. To date, there is no evidence that these slides do more than remove sediment from the canyon floors. It is possible that some enlargements may occur, particularly in the nature of widening, but it seems almost impossible that the huge canyons could have been cut thousands of feet into the solid rocks underlying the continental slopes by landsliding alone. The extension of a canyon 50 miles across the continental shelf and up into an estuary (Fig. 3) by landsliding is obviously out of the question. The shapes of the canyons are by no means those of landslide scars. The latter are for the most part cirque-like and have greater width than length. Also, landslide scars have irregular floors with many basins along their courses. The sliding associated with the canyons must be preservative and not formative.

Implications of the Stream Origin Hypothesis. Almost all objection to the subaerial origin of the canyons has come from concern over the implications which such an origin would have. If the canyons were found only off certain unstable coasts such as California or Japan, it might be easy to convince geologists that the canyons were submerged by regional earth movements, but the finding of these canyons off supposedly stable coasts as well as unstable coasts without indication of any preference for the one or the other has caused considerable uncertainty. It is not only necessary to account for the submergence of the continental margins by a mile or more, but also for the deep

drowning of insular canyons. We find, for example, that the canyons are well developed in the mid-Pacific Hawaiian Islands (Fig. 4). Here they are found off the deeply eroded windward coasts of the older islands, but so far as is known they are not present off the coasts where there have been recent lava flows.

It might be argued that the canyons have been submerged from time to time in the remote geological past, but most of the evidence which we now possess favors relatively recent submergence. The existence of narrow gorges with vertical and overhanging walls is not indicative of very great age, since the burrowing and boring of organisms on the ocean bottom should be capable of reducing these slopes to moderate inclinations over the course of millions of years. Furthermore, some canyon walls are definitely known to contain Tertiary formations, ranging from Eocene to Pliocene. This suggests that at least the inner parts of many of the canyons were cut during the Pleistocene or Recent. The Tertiary formations incidentally are found off both the east and west coasts of the United States, so that the implications of recency are not confined to unstable coasts. A valley has been found to extend to a depth of 350 feet below sea level in the delta of the Mississippi. This valley was traced to a depth of 1,000 feet at the coast by an oil company using geophysical methods of exploration and later was traced across the shelf nearly to the point where the head of Mississippi submarine canyon appears on the charts. The age of the excavation of the filled head within the delta has been definitely determined by Fisk (1944: 11) to be late Pleistocene. By implication, the canyons which are cut into the edge of Georges Bank off the New England Coast are contemporary with the stand of the glaciers on these banks, since otherwise it would be difficult to imagine sufficient drainage from the small water sheds of the banks to cut canyons that are comparable in size with the canyons off the large river valleys from the Hudson to Chesapeake Bay. On the other hand, there is no evidence at present which would prove that more than the inner portions of the canyons down to depths of about 1,000 feet were cut during this late geological epoch. The deep outer portions may have been excavated at various times during the past and their filled heads reopened by excavation during the glacial period.

Conclusions Concerning Submarine Canyons. At the present stage of our canyon investigations we have found substantial evidence that the canyons are river-eroded whereas we have so far failed to find indications of submarine origin. The canyons are apparently present on both insular and continental slopes except where recent faulting or vulcanism has interfered, or where the slopes are so gentle that valleys

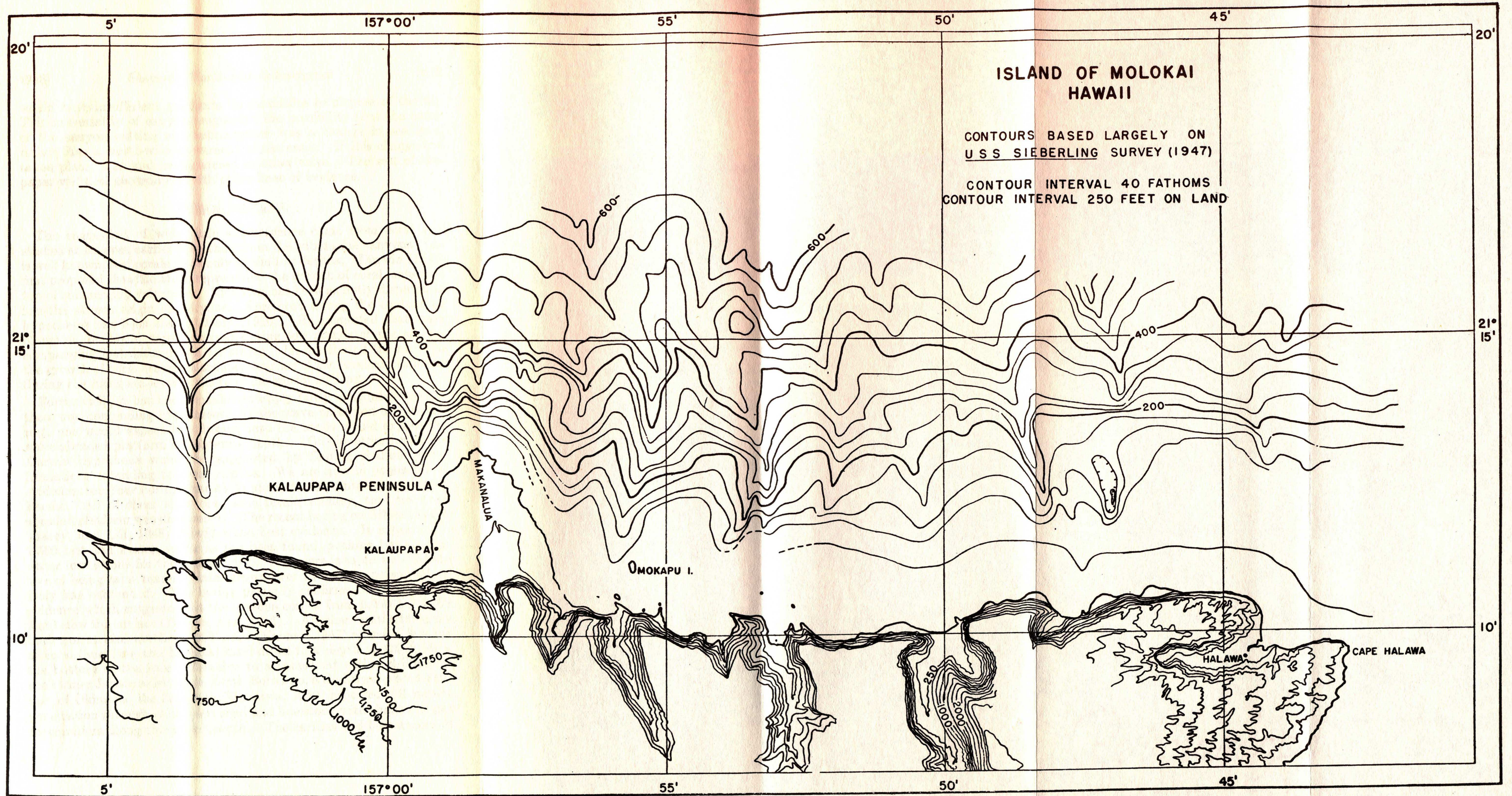


Figure 4. The submarine canyons north of Molokai, Hawaiian Islands. Note relation of sea and land canyons.

would have insufficient gradients for landslides to dispose of the fill. This universality of canyons suggested the possibility that the cause of the canyon cutting and submergence was a change in sea level rather than a world-wide movement of the crust. If this change has taken place, it should be registered in other ways. The rest of this paper will deal accordingly with other lines of evidence.

CORAL REEFS

The suggestion of wide scale submergence came from coral reef studies at an even earlier date than from the submarine canyons. As is well known, reef corals grow only at shallow depths. Darwin (1842) first proposed that the atolls represented the growth of coral masses on top of submerging volcanoes. This idea has been as hotly disputed as has the stream origin of canyons. Foremost among the contending hypotheses has been that of Daly (1910). He suggested that wave planation of island tops occurred during low stands of the sea accompanying high latitude glacial stages. He attributed the atolls to the growth of coral crescents around the rims of the levelled platforms during the rising sea level accompanying glacial melting.

Fortunately, it has been possible to apply fairly conclusive tests to these two contending hypotheses. If the wave planation idea is correct, one would expect that boring into the atolls would expose the wave abraded platform at moderate depths. On the other hand, the Darwin hypothesis would be supported by finding shallow water formations extending to great depths. We are now in possession of evidence from four borings into atolls at scattered points in the western Pacific. All of them show the same result, namely, that no wave abraded platform was discovered. The recent boring on Bikini (Ladd, Tracey, and Lill, 1948) provides the best evidence. It extended to 2,500 feet and shows, so far as has been found, nothing but shallow water formations for the entire depth. The core is in no way indicative of being talus material later grown over by an advancing reef, as Daly has contended. The boring partially confirms the geophysical evidence which suggests that the igneous core is from 6,000 to 13,000 feet below the surface (Dobrin, *et al.*, 1946). Another relatively recent boring on an atoll northeast of Borneo (Kuenen, 1947) revealed deposits of coral limestone and lagoonal marl down to a depth of 429 meters, the bottom of the hole. Relative to a somewhat earlier drilling on the former Japanese island of North Borodino, a slightly elevated atoll east of Okinawa, the Japanese (Hanzawa, 1940) reported 431 meters penetration through calcareous sand and limestone with shallow water foraminifera along the entire length. The earliest and best known of

the cores was from the atoll of Funafuti. According to what is known of this core, the entire 1,114 feet is indicative of shallow water origin and of materials like those of the present reef or of the lagoon. The investigation of the core was made so long ago that the results are now questioned. Some of the core is to be restudied in the near future to bring the data into line with what is now known about ecology of organisms.

Indications of submergence are less pronounced in the case of the borings of the Queensland Reef off the Australian coast (Richards and Hill, 1942). Here the reef proves to have a thickness of only about 400 feet. It does not overlie a wave-abraded platform but rests on a coarse grit formation suggestive of shallow water deposition. At Bermuda the borings revealed weathered rock at 245 feet, sand and gravel at greater depths, and finally volcanic material at 560 feet, but no definite wave-cut platform. The results of the deep borings in the Bahamas by oil companies are not yet published, but it is known that they have penetrated some 14,000 feet of limestone, all apparently of shallow water origin.

According to Kuenen (1933), evidence of submergence of the coral islands comes from the steep slopes which surround some of them. These slopes are considered too steep for talus and are interpreted as due to upgrowth as the reefs submerged. Also, Kuenen has called attention to the existence of atolls rising from deep platforms which have no evidence of vulcanism, so that the atolls have evidently grown up as the platforms submerged. Davis (1928) introduced various other lines of evidence, too numerous to list, suggesting submergence of the coral islands. Perhaps the most impressive of these is the wide distribution of atolls in the central Pacific in areas where remnants of volcanic islands are not found (Fig. 5). It would be most surprising if volcanic islands, many of which must have been as large as the Hawaiian group, have been so completely bevelled by the waves as to leave nothing but platforms. Obviously, this abrasion could not be accomplished during short glacial epochs. Furthermore, if reefs have simply grown on the tops of shallow banks, it is difficult to account for the absence of an equal number of shallow reefless banks in the zones north and south of the coral seas.

Age of Submergence. The time of submergence of the coral islands may not be the same as that of the submarine canyons. The Bikini boring has shown definitely that there are Tertiary formations at depths of 900 feet or less. Pliocene is underlain in turn by Miocene. Similarly, the deep Bahama boring passes down through most of the Tertiary. These borings suggest a gradual submergence and by them-

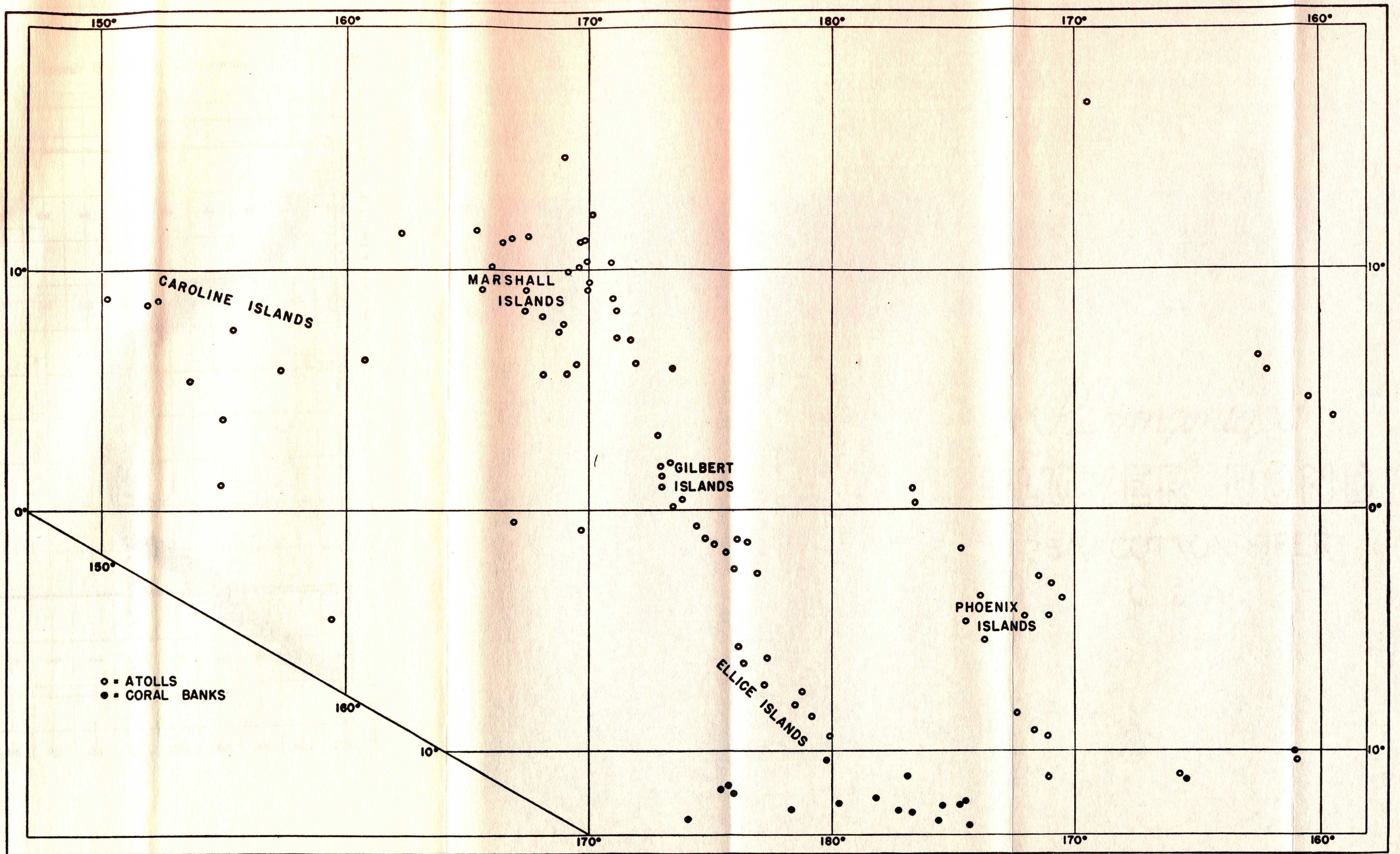


Figure 5. The distribution of atolls and coral banks in the Southwest Pacific. All of these islands lack volcanic rocks so far as is known, and except in the Caroline Islands volcanic islands are missing from these groups.

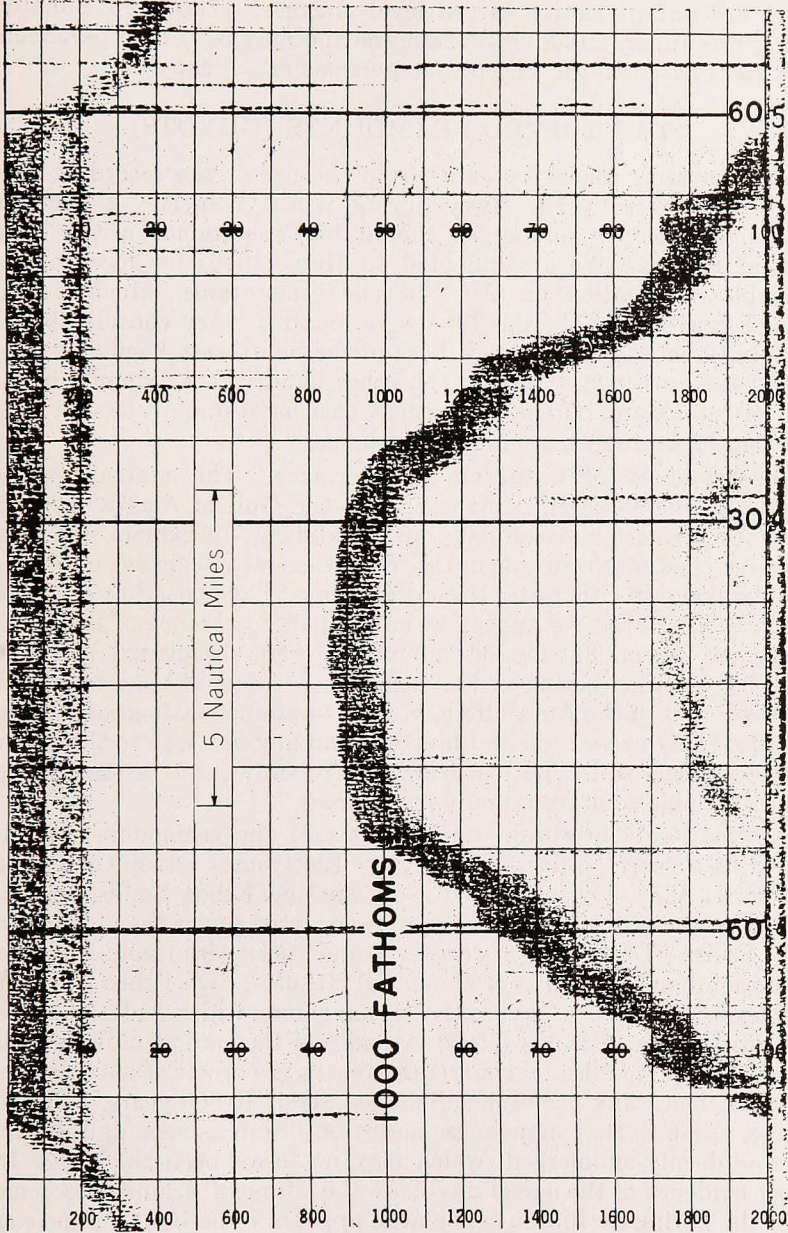


Figure 6. A bathogram of a seamount with terraces in the Gulf of Alaska. Center of seamount is at Lat. 52° 34' N, Long. 151° 19' W.

selves are not indicative of sea level changes. The deep Funafuti boring was apparently all in Pleistocene and may be contemporaneous with and related to the Pleistocene portions of the canyons.

FLAT-TOPPED SEAMOUNTS (GUYOTS)

An interesting discovery came from the use of the recording echo sounding devices by the Navy during World War II. A series of flat-topped, deeply submerged mountains was found in the West Central Pacific. We are indebted to Hess (1946) for most of the available information on these bevelled mountains, which he has termed "guyots." The flat tops were found to vary considerably in level, but about 50 per cent of those in the Southwest Pacific lie close to 800 fathoms in depth. On the other hand, the seamounts in the Gulf of Alaska and off the California Coast have summit flats at variable depths averaging around 400 fathoms.

The seamounts off California have terraces. The same appears to be true of the submerged mountains in the Gulf of Alaska (Fig. 6). Both the terraces and the flat tops are difficult to explain except as wave-bevelled platforms, or in the West Central Pacific as submerged coral banks. In either case the surfaces must have been brought close to sea level so that we appear to have further evidence of large submergence. Some flat-topped mountains were discovered in recent work by Maurice Ewing in the Atlantic. It should be pointed out, however, that in the Antarctic R. S. Dietz obtained fathograms during the 1946-1947 expedition and failed to find any flat tops to the mountains or ridges which he discovered. Probably information will become available soon from many other areas.

Information concerning the materials of the seamounts was obtained in a recent cruise of the Navy Electronics Laboratory vessel EPCE(R) 857. During this cruise Twin and Erben Banks, 580 and 860 miles off southern California, were explored under the direction of R. S. Dietz. Dredgings procured volcanic rocks with rounded cobbles from each bank at depths of about 350 fathoms. On Erben Bank the cobbles were embedded in a crust of manganese which had a thickness of 4 cm. If Pettersson's (1945) estimate of the rate of radial growth of manganese nodules of 1 mm/1,000 years is correct, the suggestion is that Erben Bank has been submerged about 40,000 years. This, of course, assumes that manganese accretion began as soon as the bank became deeply submerged, which may not have been the case. Indirect evidence of the age of guyots in the Marshall Island area comes from the boring at Bikini. The atoll appears to be built on one edge of a guyot platform, so that the flat top of the seamount could be con-

sidered as older than the formations which cover it. Since the 2,500 foot drilling has penetrated to Lower Miocene, the guyot surface is apparently pre-Miocene. Hess (1946) suggested that the guyots of the Southwest Pacific were bevelled in the pre-Cambrian and that they have been sinking slowly ever since due to oceanic sedimentation which has weighed down the floor of the ocean. This is an interesting suggestion, but seems rather unlikely in view of other evidence of what must be much more recent submergence.

COARSE SEDIMENTS AND SHALLOW WATER FORMS OBTAINED FROM GREAT DEPTHS

Geologists have generally assumed that coarse detrital sediments could be deposited only in shallow water, although it was recognized that some coarse material could be transported to a deep water environment by rafting or even by landsliding. Rafted sediment dropped into deep water can usually be distinguished by the finding of coarse debris mixed with typical deep-water deposits. Landslide deposits are largely confined to the base of relatively steep slopes, but they are otherwise not easy to distinguish in bottom samples. In general, one might expect to find coarse debris mixed with sediments in the vicinity of great glaciers discharging into the oceans, as, for example, around Antarctica and Greenland. Such finds have been numerous and the deposits are called "glacial marine." However, the finding of coarse sediment in deep water at considerable distance from the ice fronts should be rare because of the limited amount of transporting facilities other than icebergs. The debris drifted by vegetation mats, tree trunks, and kelp must constitute an insignificant proportion of the deep sea sediment which is contributed by marine life and colloidal material carried from land by currents. Therefore, it is interesting to find that coarse sediments are not uncommon among the few ocean cores now available. Sand layers have been obtained in cores from the deep Atlantic far from any shoal areas, according to H. C. Stetson and Maurice Ewing. Cross-bedded sand was found in the Gulf of Mexico at over 2,000 fathoms according to Trask, Phleger and Stetson (1947). According to R. Revelle, cores obtained by Scripps Institution in the deep basins off California and Lower California have also shown sand layers. Gravel was found in the Dutch East Indies at 20 out of 385 stations, in depths ranging from 192 to 1,400 fathoms (Neeb, 1943: table 2 on pp. 72-85, also 225-227). It is possible that this coarse material was deposited at great depth, but the alternative of submergence must be considered.

Other evidence comes from the rounded nature of the rocks dredged

from ridges and seamounts. Since the violent turbulence of shallow water conditions is necessary to produce rounding, rocks formed on the deep ocean floor by vulcanism would rarely, if ever, be rounded. Some of the rounded rock obtained in the North Atlantic may have been introduced by ice, but the cobbles on banks and seamounts off California (Shepard, 1941: 1869, pl. I) are in all probability an indication of submergence. It is unfortunate that so few of the marine highs have been sampled, but it is probably significant that a large per cent of those which have been explored have yielded rounded rocks. If the percentage holds good for future exploration, this source of information will add substantial evidence to the other lines. Possible confirmation of the rounded rocks in dredgings comes from the numerous chart notations of gravel in deep water.

The coring operations under the direction of Pettersson (1946) in the Mediterranean yielded evidence that the deep parts of that sea may have been shallow at not too remote a period. The cores contained layers with abundant molluscs, the latter being almost entirely confined to a shallow water habitat. Dangeard (1928) reported the discovery of lamellibranch shells with gastropod borings in 660 fathoms west of the Strait of Gibraltar. Beebe (1932: 39) reported a dredging of shallow water shells along with rounded gravel at 1,200 fathoms on a ridge off Bermuda. Kuenen (1933) referred to the dredging of recent coral reef material in 550 fathoms in the Ceram Sea. Of possible less significance was the discovery of littoral shells at depths of 1,420 fathoms off the Norwegian Coast (Hull, 1912). Much more exploration is required before the faunal evidence can be properly evaluated.

INSULAR FAUNAS AND FLORAS

The submergences indicated by the preceding lines of evidence should be reflected also in the faunas and floras of islands, provided that the submergences had been of sufficient extent to destroy former land bridges to the mainland or to adjacent islands. The literature relative to island connections is large and some of it contradictory. Some extremists claim former connections of many of the true oceanic islands with the mainland, but the general consensus of opinion seems to be that islands separated from the mainland by deep and wide channels, that is, channels over 1,000 fathoms deep and 100 miles or more in width, have waif faunas and floras, either rafted to or blown onto the islands. On the other hand, the life forms of islands on the continental shelves are for the most part clearly related to the adjacent continents and require land bridges.

Between the extremes of true oceanic islands and continental shelf islands are the cases where there are channels of depths between 100 and 1,000 fathoms. Among the best known of this group are the islands of the "continental borderland"² off southern California. Here the sills of the channels range from 150 to 450 fathoms. The faunas of all of the larger of these islands include endemic species which are difficult to explain without land bridges. The presence of endemic foxes is particularly impressive, since it seems impossible that these animals could drift on a log for the forty miles or more required for transportation to the outer islands. The Pleistocene elephants of Santa Cruz Island are undoubted evidence of a former land connection at this place.

The fringing islands of the West and East Indies and of such groups as Madeira and Cape Verde Islands of the Atlantic have separations of intermediate depths, and like the California islands have faunal evidence of former connections. Extensive bibliographies cover this subject but the evidence is not entirely conclusive.

SUMMARY AND CONCLUSIONS

An examination of available information from the sea floor around the continents and around oceanic islands provides abundant evidence of large scale submergence. The investigation of submarine canyons has now yielded so much indication of subaerial origin that the world-wide distribution of these features constitutes the most conclusive evidence that the continental margins and even some of the oceanic islands once stood thousands of feet higher in relation to sea level than they do at the present time. Widespread submergence of oceanic islands in the coral island areas, long ago advocated by Darwin, has now been well confirmed by recent borings in widely separated places. This evidence indicates that extensive tracts of the ocean floor have been considerably depressed. The recent discoveries of flat platforms on the tops of deep seamounts suggest a former elevated condition during which waves bevelled the platforms to sea level, or that the flat surface was developed at sea level by calcareous reef builders. Evidence from bottom samples is somewhat less conclusive than that of the canyons and coral islands, but the limited dredgings and corings available from deep water contain a large per cent which have evidence of former shallow-water conditions. Insular faunas in general are also of a character which favors considerable submergence, particularly along the continental margins. The deep fills in many of the mouths

² A term referring to broad submerged areas seaward of and deeper than the continental shelves but landward of the principal continental slope.

of river valleys, not discussed here, are still further evidence in the same direction.

The significance of all of these converging lines of evidence in the unravelling of the late geological history should be profound. Unless further exploration provides very different evidence from that which is now available, we shall be forced to conclude that the continental margins and the islands have undergone great submergence alike in areas where stability was supposed to have long prevailed and in areas where other lines of evidence indicate either great crustal rising (as along much of the California Coast) or long-continued crustal submergence (as at the delta of the Mississippi). The world-wide nature of the evidence suggests a change of sea level, and the indication of Pleistocene origin of at least some of the submarine canyons could be used as an indication that the changing sea level resulted from the extraction of water during glaciation. However, the extent to which the sea could be lowered by this means is most difficult to determine. The common estimates of 40 fathoms may be far too small (Shepard and Emery, 1941: 146-155), since the ice could have been much thicker on the continents than generally assumed and may have covered much more territory than is considered in the usual estimates, particularly in the Arctic and along the continental margins. On the other hand, some of the recent evidence indicates that the submergence, at least of the coral reef islands, was going on all through the Tertiary. Possibly the same may be true of the submarine canyons, and the evidence of Pleistocene origin now available may apply only to the upper near-shore portions where glacially-controlled sea levels may have been important factors. However, the failure to find breaks in the canyons between any apparent Pleistocene excavation and canyons of earlier age is disconcerting. None of the well-explored canyons which can be traced into shallow water show a change in character at a depth of the order of 40 fathoms (the supposed glacial low sea level), nor has any other depth down to about 1,000 fathoms shown any indication of such a change.

In conclusion we are confronted with abundant evidence of world-wide submergence, some of it Pleistocene and some Tertiary or even earlier. It is time that these facts be faced by those geologists who have been trying to hold back the tide. More exploration is badly needed, but new hypotheses should utilize the wealth of oceanographic data now available.

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