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Submarine Physiography of the U.S. Continental Margins

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Submarine Physiography of the U.S. Continental Margins

G. F. JORDAN, Oceanographer

U.S. Coast and Geodetic Survey

A CONTINENT is more frequently thought of as the vast mass of land extending inward and upward between the coasts, as portrayed on most maps. In reality, the continents do not end at the coastline, but spread out under the ocean to great depths usually at considerable distance from shore. The marginal submarine surface adjacent to the coast, the continental shelf, generally remains relatively flat at comparatively shallow depths for a considerable distance seaward; it eventually steepens on the continental slope and then grades into the abyssal floor of the ocean. The continental margin can be visualized, therefore, as a band around the continent between the continental shelf and the abyssal ocean floor.

For the United States this invisible margin ranges from depths of about 20 fathoms where the shelf is practically nonexistent to 3,900 fathoms where the Alaska slope terminates in the Aleutian Trench. Although this range of depths is not visible to the eye as one perceives the elevations of lofty mountainsides it is reflected graphically by the sounding profiles which are the basis of bathymetric and navigation charts.

With the inception of submarine warfare during World War I and the resulting development of under-water sound detectors, it naturally followed that echo-sounders were devised to replace deep-sea leadlines used for surveying and charting the deeper waters of the continental margin and adjacent ocean floor. Knowledge of the marginal areas adjacent to the United States, its territories, and possessions, has gradually accumulated as a result of the basic survey and charting activities of the U. S. Coast and Geodetic Survey and of the specialized explorations conducted by various other organizations. The survey information provides basic knowledge for surface and subsurface navigation, for the pursuit of fishery and mineral resources, and for scientific studies related to all aspects of the marine environment. Comparable knowledge of the broad ocean basins will become available when a national and international oceanographic survey program becomes fully effective.

The continental margins of the United States have not been surveyed in their entirety, some areas have been explored only with widely spaced reconnaissance sounding lines, while other areas lack the detailed accurate sounding data now provided with the use of modern sounding and electronic ship-positioning instrumentation. Although this instrumentation has been used mostly in coastal areas it has been used also in many far offshore areas such as the broad shelves and deep basins in the Gulf of Mexico and in the Bering Sea. In the northern and western Gulf of Mexico, on the Atlantic margin between the Gulf of Maine and Chesapeake Bay, and on the California margin, the available soundings were read at intervals on the dial of an echo-sounder not equipped with a graphic recorder; and they were positioned by timing sound impulses sent through the water from the ship to the shore or to anchored electronic receivers and responders. Although this system was a major improvement over earlier dead-reckoning surveys along the southeastern margin, it did not provide the accuracy and fine detail of modern instrumentation. Nevertheless, the abundance of sounding data provided adequate material for bottom studies and for the compilation of extensive bathymetric charts of some areas by A. C. Veatch and P. A. Smith (1939), F. P. Shepard and K. O. Emery (1941), and B. L. Gealy (1955). There is now sufficient information of the general character of the margins as a whole to warrant comparative studies.

The purpose of this bulletin is to present a general picture with representative and contrasting details of the submarine physiography of the Atlantic, Gulf, and Pacific margins of the continental United States. For further and more detailed information of specific areas or features the student of submarine physiography is referred to numerous scientific papers and books, only a very few of which are cited in this bulletin.

The physiography is presented in geographical order from north to south along the Atlantic margin west across the Gulf of Mexico, and north to south along the Pacific margin for the comparative studies in figures 1-4. The same order is used in the regional studies that follow except for the Pacific margin.

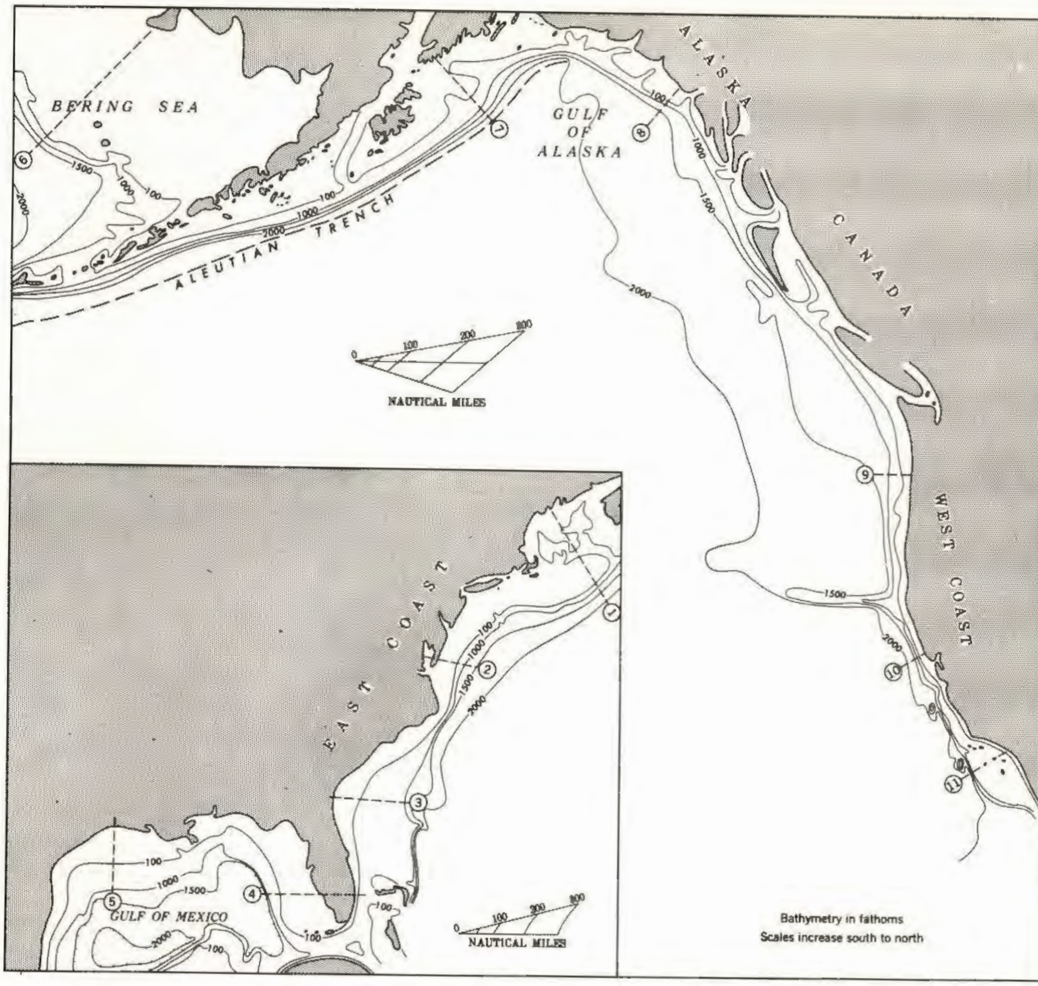

FIG. 1.—Bathymetry of the continental margins and the locations of profiles (fig. 2).

Variations in the seaward extent of the continental margins and some indications of their characteristics are indicated by the generalized bathymetry of figure 1 which includes an inset of the Atlantic and Gulf of Mexico. The inset is at the same scale and it places the Atlantic coast margin in a proper north-south relationship with the Pacific coast. The Mercator chart projection on which the maps were constructed engenders an increasing scale from south to north; the horizontal lines in the mileage scales indicate distances at the respective latitudes of the two scales.

Although the continental shelf is not delimited by the 100-fathom contour this line is readily available on nautical charts and it indicates at small scale the approximate limit of the relatively shallow continental shelf and the variations in distance from the coastline. Actually, the shelf terminates in depths varying from 20 to more than 100 fathoms. This point, the shelf edge, is marked by an abrupt change in slope in many areas, and the graphic sounding profiles portray an edge generally because of contracted horizontal scales, or exaggerations of the vertical scales; but a definite single shelf edge is not apparent in many areas where there is a gradual transition from shelf to upper continental slope, or where there is a series of abrupt changes in gradient on the outer shelf and in the zone of transition.

Continental shelves of the world average 40-50 miles in width, but an average value has little meaning because of wide variations. The width at any point relates directly to the geomorphology of a particular region. The geologically mature margin of the eastern United States borders a broad coastal plain the outer part of which is now submerged. On the southeast, the margin is modified by calcareous growth of the youthful and tropical Bahamas platform. The geological history of the eastern Gulf of Mexico is different from that of the western part; and the northern rim has been modified by a shifting Mississippi River Delta and by the great quantities of sediment transported into the Gulf.

In contrast to the eastern margin the Pacific is quite youthful. The coasts are rugged and in part mountainous; they are still affected by earth movements; and broad coastal plains have not developed from sediments eroded from elevated lands. The shelves are narrow. The shelf broadens in the Gulf of Alaska where the coast was modified by erosive glaciers and where great quantities of sediments were bulldozed or carried from interior valleys and deposited at the continental margins. Uplifted islands have modified the shelf topography on the eastern rim of the Gulf of Alaska and the mountainous terrain and frequency of earthquakes around the entire rim testify to a young continental region. Extending southwestward from the Gulf is the volcanic peninsula and island chain and its fronting deep trench, the most youthful physiographic features in continent building.

In contrast to this marginal trench, the continental slope off the eastern United States terminates in a continental rise which forms a gently graded surface, an apron, between abyssal depths and the steep continental slope. Farther south, however, east of Florida and the Bahama Islands, there is neither rise nor trench; the continental slope is an escarpment which deepens precipitously to the smooth plain of the abyssal ocean floor. West of Florida, a similar escarpment rises from the Gulf floor to half the height of the continental slope. A similar but minor escarpment rises from the Pacific floor in one area off Oregon, yet not far distant from this area there is the familiar continental rise above which the steepest gradient of the continental slope is at mid-slope. This latter characteristic is more pronounced in the northeastern Gulf of Alaska where a 30° escarpment separates a generally convex upper slope and the gentle concave continental rise.

The general character of the continental margin in some areas is modified by terraces, ridges, knolls, and seamounts. The margin is also interrupted by borderlands such as the extensive island-dotted basin area off southern California.

All of these variations affect the seaward extent of the continental margins of the United States. For example, the shelf is essentially nonexistent near Miami; it is 150 miles wide off the Florida west coast; and in the Bering Sea the shelf extends more than 300 miles from the Alaskan coastline. The continental margin is a steep band only 20 miles wide in the eastern Gulf of Mexico, whereas it spreads out 200 miles wide in the northwestern Gulf.

These variations are exemplified in part by the bathymetric contours of figure 1. On the northeast, in the inset, is an extensive bulge southeast of Cape Cod and an extensive embayment into the Gulf of Maine where the shelf is drowned to depths of nearly 200 fathoms. Southward, the 100-fathom contour generally follows the coastline except where Cape Hatteras projects seaward and also where there is a near convergence with the tip of the Florida peninsula. The same convergence exists in the Gulf of Mexico at the Mississippi River Delta, in contrast with the broad shelf west of the delta and also west of the Florida peninsula. East of Florida the spread between the 100-fathom and 1,000-fathom contours highlights the extensiveness of a continental terrace, the Blake Plateau, in depths of 400-500 fathoms. Its outer margin is marked by a major escarpment descending to depths of 2,600 fathoms. A similar escarpment west of Florida extends to the floor of the Gulf of Mexico in depths of 1,850 fathoms.

The broad bulges in the 1,500- and 2,000-fathom contours north of the Bahamas Islands at the position of Profile 3 mark a deep topographic ridge aligned with Cape Fear, N. C., and collinear with a deep structural ridge (J. B. Hersey, et al, 1959, p. 461) extending inland from the coast. A comparable bulge in the Gulf of Mexico reflects an extensive fan formed by sediments discharged from the Mississippi River. This fan can be delineated on the hydrographic survey sheets for more than 300 miles from the shelf at the delta to the western approaches to the Straits of Florida. It has also been traced from the presence of alluvial sediments (M. Ewing, D. B. Ericson, and B. C. Heezen, 1958).

In the Pacific, the continental shelf is characterized by its narrowness along the California coast; by inclusion of the Alexander Archipelago off the mainland of Canada and southeast Alaska; by the glacial troughs cutting across the rim of the Gulf of Alaska; and by the very extensive and smooth surface in the Bering Sea off western Alaska.

The slope off southern California is interrupted by an extensive area of islands, banks, ridges, and basins comprising a continental borderland beneath the waters of a continental sea. Off the northern California coast at Cape Mendocino there is a major spur and escarpment continuing as a transverse ridge south of which the ocean floor is 700 fathoms deeper than on the north. The spur and north-facing escarpment mark the continental end of a crustal fault which has been traced 1,400 miles out into the Pacific Ocean (H. W. Menard, 1955, p. 1162).

Although the continental slope and rise north of Cape Mendocino to the head of the Gulf of Alaska is relatively subdued in depth, due in large measure to heavy sedimentation from large outflows from glaciated areas, the southern margin of western Alaska descends to depths of 3,900 fathoms where it terminates in one of the great ocean trenches, the Aleutian Trench.

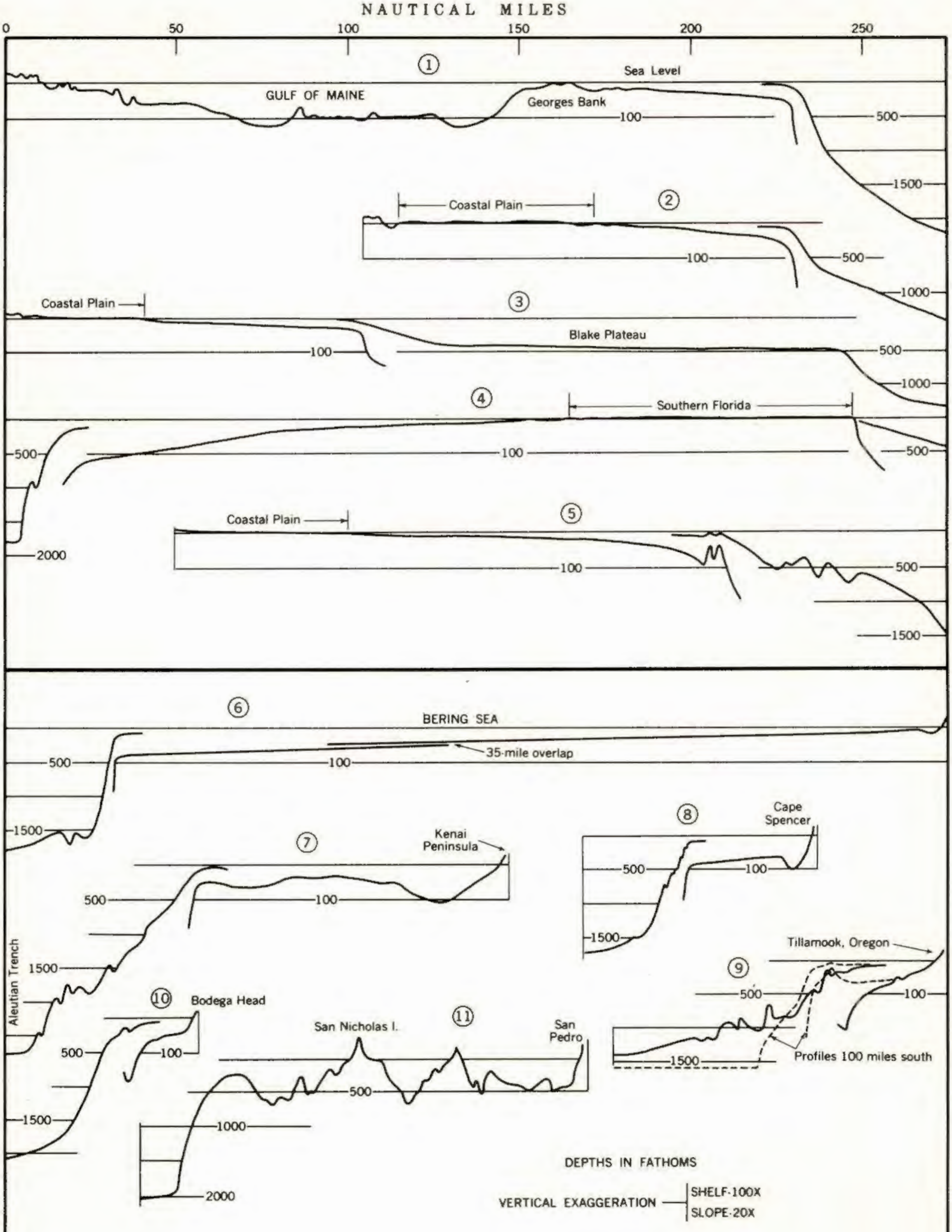

FIG. 2.—Profiles of the shelf and continental margin.

The profiles in figure 2 extend great distances from the coast and it is necessary to greatly exaggerate the vertical scale on the continental shelf in order to illustrate minor relief. Then, in order to contain the slope and as much of the continental rise as possible the vertical exaggeration is reduced for the outer section of the profiles.

The deeply drowned and irregular nature of the shelf in the Gulf of Maine is illustrated in Profile 1. This glaciated area is pocketed with numerous basins and is dotted with innumerable banks, knolls, and ridges. Basin depths of 150-180 fathoms are considerably below marginal shelf depths on the ocean side of Georges Bank. This immense bank, actually a continuation of the outer shelf, rises nearly to sea level on several shoals.

Profile 2 extends inland from the coast across the coastal plain to uplands on the western shore of Chesapeake Bay. As in Profile 1 the seaward end of this profile emphasizes the existence of a gentle continental rise below the steeper continental slope.

Profile 3 illustrates a continental terrace, the Blake Plateau, which spreads seaward for more than 100 miles at depths of 400-500 fathoms.

Profile 4 extends fully across the peninsula of southern Florida. On the east, the shelf is relatively nonexistent and the upper continental slope grades gently into the Straits of Florida. On the west, the shelf is very broad, the outer third in this section having more of a dip and its margin twice the depth of most shelves. The slope profile on the left includes a major escarpment rising abruptly from the Gulf floor.

Shelf Profile 5 off western Louisiana reveals a very gentle gradient which can be projected 40 miles inland under the present low coastal plain. On the outer shelf the gradual transition with the continental slope is interrupted here and elsewhere along the northern Gulf margin by topographic rises many of which might reflect salt domes (F. P. Shepard, 1937). The continental slope here has the distinctive irregular characteristics of a deeply sedimented delta-front slope subjected to erosion and differential subsidence.

The broadest and smoothest shelf of our continent is off northwestern Alaska where it is contiguous with the Siberian shelf, uninterrupted by ocean basins or troughs. There is, however, an ocean basin between this former land bridge and the Aleutian Islands. Profile 6, north of the Pribilof Islands, illustrates the smooth extensive shelf which ends abruptly 275 miles from an island lying 50 miles off the general coastline. The profile is broken and overlapped for 35 miles because of the common-scale limitations. The continental slope is very steep and smooth here.

On the northwestern rim of the Gulf of Alaska, Profile 7 crosses a glaciated and deformed shelf and a continental slope which was also deformed by forces which created a major structural depression, the Aleutian Trench. Both shelf and slope, and even the trench, are marked by major topographic rises. The shelf is dotted with innumerable islands, mountains, pinnacle rocks including volcanic plugs, banks, and craters. Several seamounts and numerous knolls have been discovered in mid-slope; and south of Profile 7 a seamount rises more than 10,000 feet from the floor of the Aleutian Trench.

On the northeastern rim of the Gulf of Alaska the shelf is crossed by Profile 8 between two of the several glacial channels which dissect the shelf in this region to depths as great as 1,000 feet below general shelf depths. Near the coast, Profile 8 crosses a trough which parallels the coast and which has counterparts elsewhere in glaciated regions. It is included in the illustrations and discussion of structural troughs which parallel uplifted glaciated coasts in a paper by Hans Holtedahl (1958). The outer limits of the shelf terminate at a definite shelf edge from which the continental slope drops steeply to 1,300 fathoms. There is a gentle transition with a broad continental rise.

Considerably to the south at the Oregon margin off Tillamook we find in the solid-line Profile 9 a rapidly deepening narrow shelf with an apparently faulted margin. Deformation continues down the full depth of the slope and rise which are marked by knolls, banks, and an elongated depression. Only a 100 miles southward the dash-line profile crosses an outer bank rising to depths of only 25 fathoms at an abrupt transition from shelf to slope. The bottom of the slope is an escarpment which rises from a smooth plain of the ocean floor; there is no continental rise here.

Profile 10 shows a transverse section of the margin 40 miles northwest of San Francisco. The shelf is only 13 miles wide here, half the width 25 miles nearer the entrance to San Francisco Bay. The continental margin has a smooth transition with the ocean floor.

Profile 11 cuts across the continental borderland off southern California, from San Pedro to the outer slope 100 miles distant. The shelf profile is omitted as the shelf is relatively nonexistent, the width of 1-2 miles not being discernible at the scale of this illustration.

Although Profile 11 vividly illustrates the anomalous topography of a continental margin, it can be observed from the other profiles that considerable variations exist elsewhere. Monotonous conformity is not found in the delineations of the continental margins of the United States.

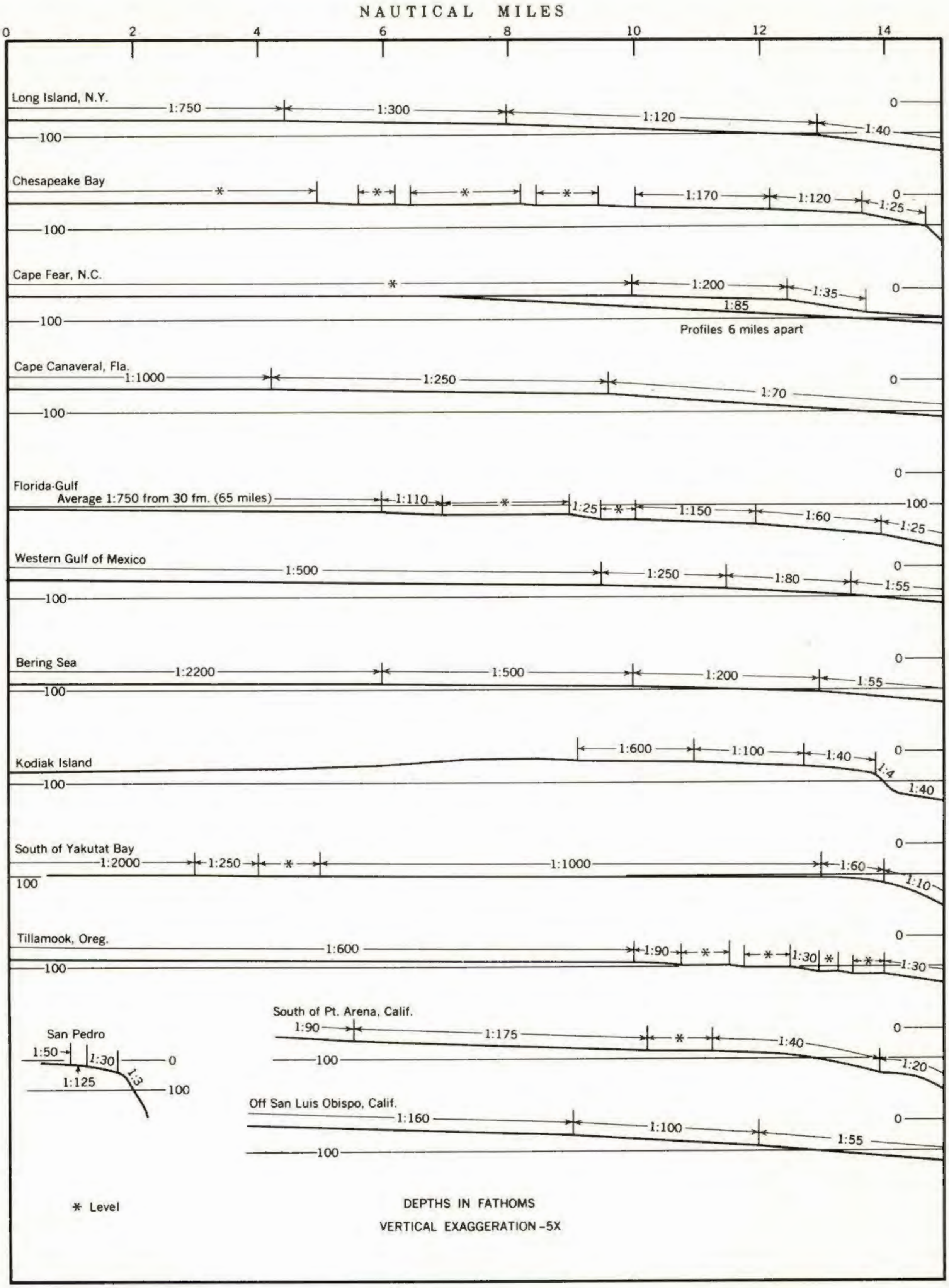

FIG. 3.—Profiles and gradients of the outer shelf and upper continental slope.

Profiles of the continental shelf are usually illustrated with scales so grossly distorted that it is difficult to visualize the natural physiography. This is true of fathograms whose vertical scales are generally 20-70 times horizontal scales at normal ships' speeds. It is also true of most constructed profiles, as in figure 2 where the horizontal distance is necessarily great in respect to elevations. A compromise is effected in figure 3 where the profiles can be visualized five times longer without difficulty.

The 13 profiles were selected at random and do not intentionally represent average conditions in the respective areas. Variations occur over short distances, as illustrated in the third profile.

The first profile begins more than 50 miles offshore from Long Island in depths of 45 fathoms where the gradient has steepened slightly to 1:750. A significant change occurs slightly below the 100-fathom line where the gradient becomes 1:40 on the upper slope. On the profile beginning in 16-18 fathoms off Chesapeake Bay there is a series of level (*) terraces separated by short gradients of approximately 1:70. The first appreciable change occurs in 58 fathoms below which the gradient is 1:25.

The shelf off Cape Fear is nearly level in 22-24 fathoms for more than 10 miles in the upper profile, beyond which a gradient of 1:200 abruptly changes to 1:35 for a distance of more than 1 mile. An outer gradient of 1:85 is paralleled on the lower profile which is only 6 miles to the south. Off Cape Canaveral in the next profile the steeper 1:70 gradient begins in about 50 fathoms.

The profile off the mid-southern Florida Gulf coast shows the first appreciable change in gradient to 1:110 at the end of a 65-mile stretch of relatively smooth gradient averaging 1:750 in depths of 30-118 fathoms. In the western Gulf of Mexico the 1:80 gradient begins in 70 fathoms and ends in 94 fathoms. Actually, the changes in gradient on this profile are not abrupt as in some of the previous profiles.

The Bering Sea profile is comparable in smoothness to the profile above, and it coincidentally shows a noticeable change to the common gradient of 1:55. The profile off Kodiak Island, 130 miles southwest of Profile 7 of figure 2, crosses an outer bank which rises to depths of 16 fathoms. The edge of the bank terminates on a 1:4 escarpment which separates gradients of 1:40.

The shelf at the head of the Gulf of Alaska, south of Yakutat Bay, is 50 miles wide and smooth. In the outer zone a low gradient of 1:1000 extends to the shelf edge. Except for the short interruption where the gradient is 1:250 this profile might be considered to represent an ideal, nearly level shelf which terminates definitely at the beginning of the 1:60 gradient which shortly steepens to 1:10.

The profile off the Oregon coast is only a few miles away from Profile 9 of figure 2 which shows several rises on the shelf. The smoother profile of the present illustration terminates in a series of level terraces separated by gradients of 1:30 to 1:40.

The last three profiles, off California, are relatively short as indicated in figure 1; the gradients are comparatively steep. In northern California south of Point Arena the profile begins in 25 fathoms on a gradient of 1:90 which lessens to 1:175 and then to a level terrace at 72 fathoms before bowing downslope on average gradients of 1:40 and 1:20. Much farther down the coast, off San Luis Obispo, the profile begins in 18 fathoms on a gradient of 1:160, comparable to the 1:175 gradient near Point Arena. There is a gradual steepening to 1:55 on the upper slope. The last profile, off San Pedro, begins in 10 fathoms and ends on the continental slope 2 miles from the coastline. There is an absence of gentle gradients.

These 13 profiles are too small a number for the determination of an average or an abnormal continental-shelf profile. They do however enable comparisons over extensive geographical areas, from which tentative conclusions can be made. The first conclusion is that it is difficult to determine for many areas just where the shelf ends and the continental slope begins. There is no question that the gradients of 1:2000 and 1:1000 are on the shelf, and that those greater than 1:40 are on the slope, as stated by B. C. Heezen, M. Tharp, and M. Ewing (1959). Bearing in mind the distortion in scales of the profiles it does appear that the shelf off Long Island does not end on gradients of 1:750 or 1:300, but terminates where the gradient abruptly steepens to 1:40. The Yakutat Bay profile is more definitive where there is a change from 1:1000 to 1:60. It is suggested that the continental slope begins generally on gradients steeper than 1:100, approximately 50 feet per mile, and that the transition from shelf to slope is more frequently marked by changes to gradients of 1:60 to 1:30.

A consequent conclusion is that if it is difficult to determine the outer shelf limits in so many areas then there is for these areas no physiographic evidence of a shelf edge, the generally accepted term for the shelf margin. The term is generally a cartographic one in that it relates to the shelf-slope boundary on the distorted scales of fathograms, diagrams, and charts.

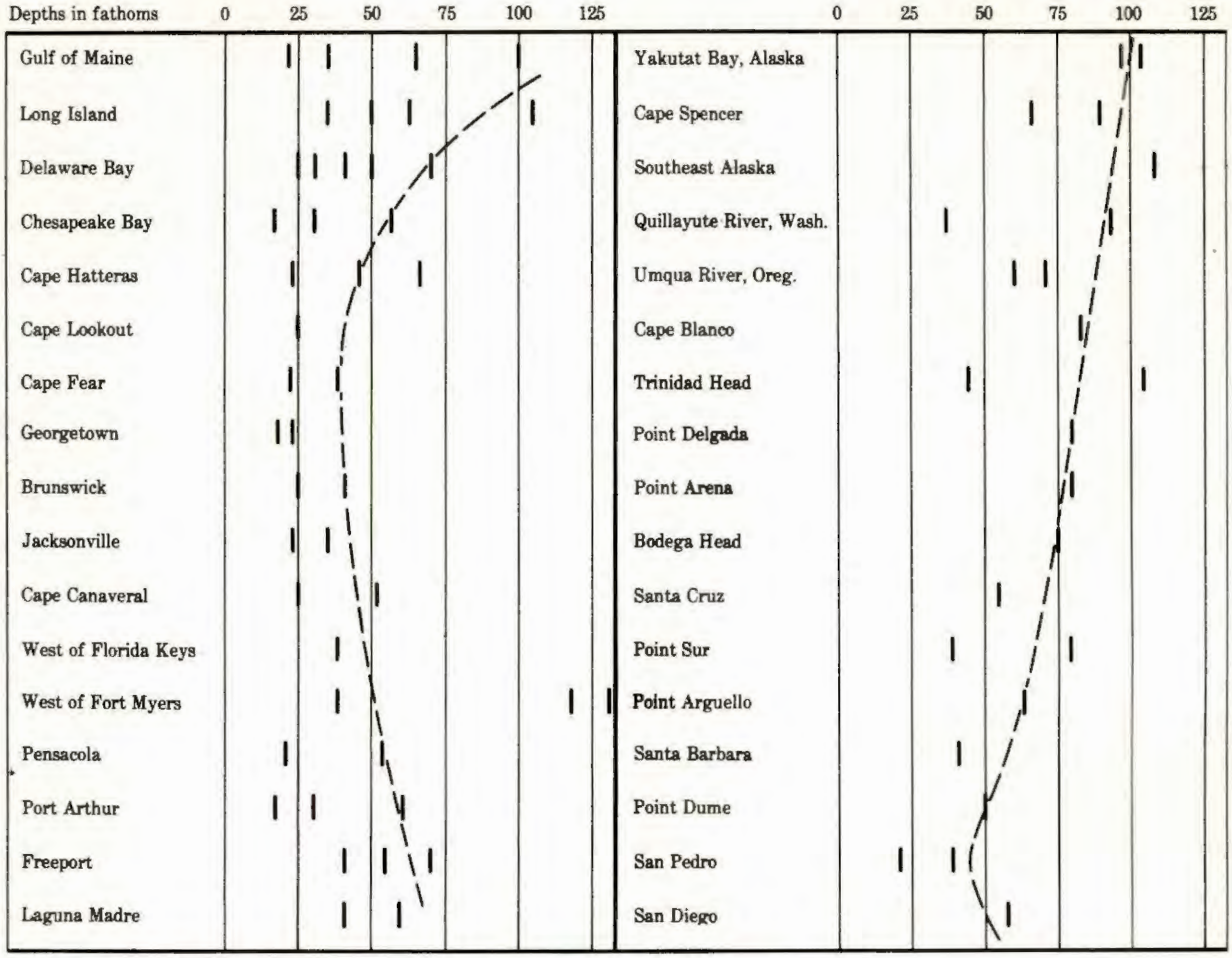

FIG. 4.—Changes in gradient on the outer continental shelf.

The depths at which the changes in gradient occur on the outer shelf are indicated by the tabulation in figure 4. The 34 profiles represented by the tabulation are divided for each coast and arranged in geographical order north to south. The profiles do not necessarily include the ones of figure 3. Most of the profiles reveal several points at which there are abrupt or noticeable changes in gradient.

An interesting deduction might be made from the variations in depth of the deeper points of change. General trends are suggested by the dash lines. On the eastern margin the line bows in to shoalest depths off South Carolina. Anomalously deeper depths are indicated at the limits of the broad shelf west of Fort Myers. On the Pacific margin the trend of the line southward is along progressively shoaler depths.

Although it might appear that the trends indicate general changes in the relationship between sea level and the continental surface, the limited number of profiles precludes drawing definite conclusions. Along the limited stretch of the southern California margin it has been shown in the 33 profiles presented by K. O. Emery (1958) that although the average depth at the edge of the shelf is 40-50 fathoms these depths range from 15 to 60 fathoms.

The tabulation of figure 4 does however illustrate the variations in depth at the shelf edge, just as there are variations in other characteristics of the continental margins.

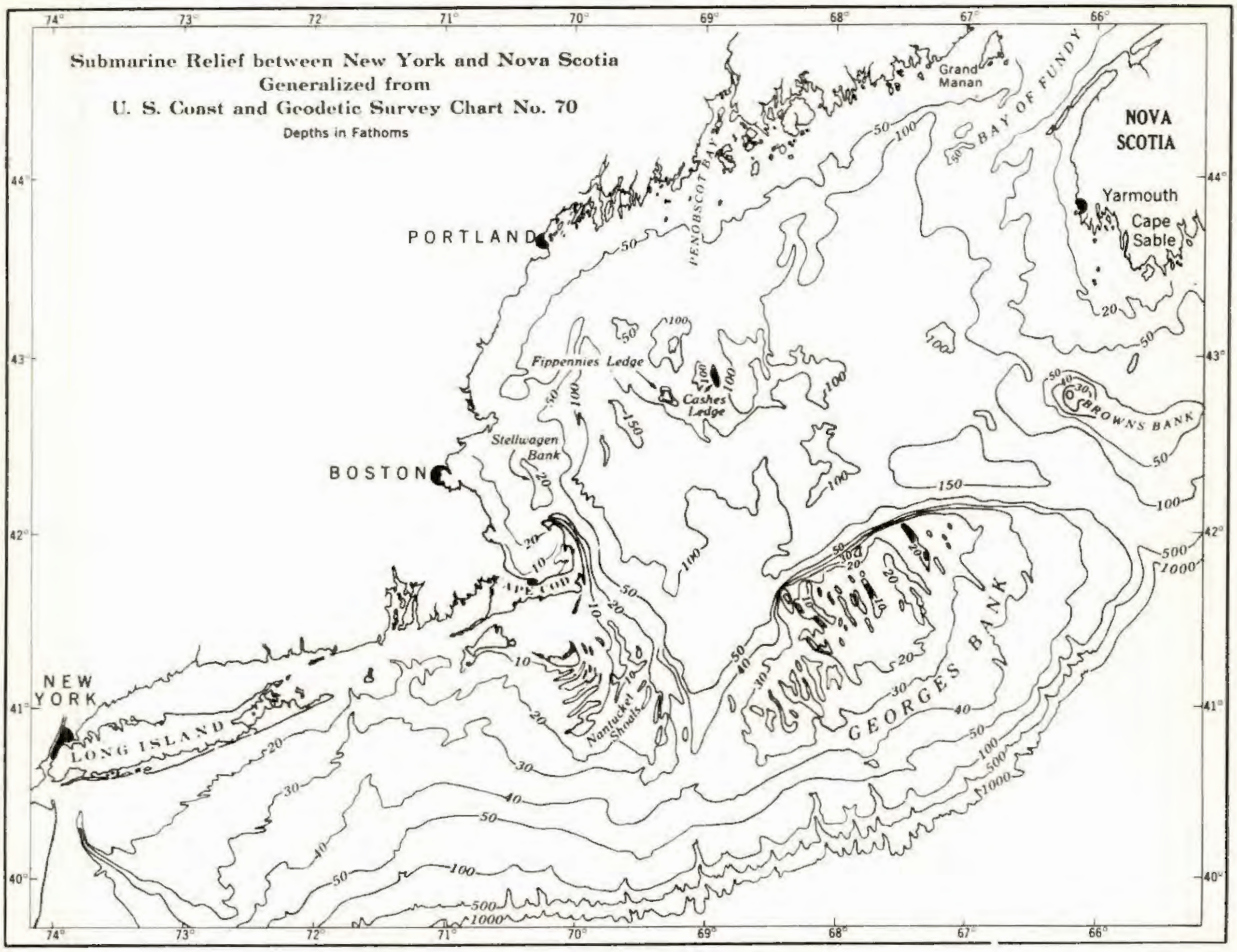

FIG. 5.—Continental sea of the northeast margin.

The northeastern limits of the U. S. continental margin nearly encloses a continental sea, the Gulf of Maine, where a large area of the shelf is submerged to depths of 130-160 fathoms. The submarine topography is complex, having innumerable basins, knolls, ridges, and banks which are only partially indicated by the large-interval depth contours of figure 5 and by Profile 1 of figure 2. In the western area the 150-fathom contour outlines the deepest portion of a large elongated basin bounded on the northwest by an extensive and high submarine ridge. This ridge, actually a spur projecting 30 miles northeastward, is outlined by the 50-fathom contour. The spur is truncated generally at depths of 27-29 fathoms and rises 400-700 feet from the bottoms of the bordering basins. Other ridges and knolls rise as high as 500 feet. A rocky reef, Cashes Ledge, is only 25 feet below mean low water.

The floors of the deeper basins are blocked by sills which rise generally 90-150 feet. At the eastern limits of the Gulf the basin depths of 200 fathoms are discontinuous seaward because of a sill rising about 200 feet above the basin floor. This sill forms a gap or outlet between Georges and Browns Banks.

The floors of the basins are covered with a layer of soft mud which is at least 90 feet thick in some places, as revealed by sub-bottom profiles on the echo-sounding fathograms (H. W. Murray, 1947). The surface of the rises is composed of rock, gravel, and sand. Glacial erosion and deposition have undoubtedly had a significant role in molding the surficial submarine topography, but faulting is indicated by alignment of some scarp slopes; and subsidence is suggested by the deeper submergence of this large area of the continental shelf.

Georges Bank resembles a mammoth submerged cuesta rising as a bulwark between the Gulf of Maine and the continental slope. Its inner edge is higher and steeper. The crest is capped with numerous transversely elongated shoals.

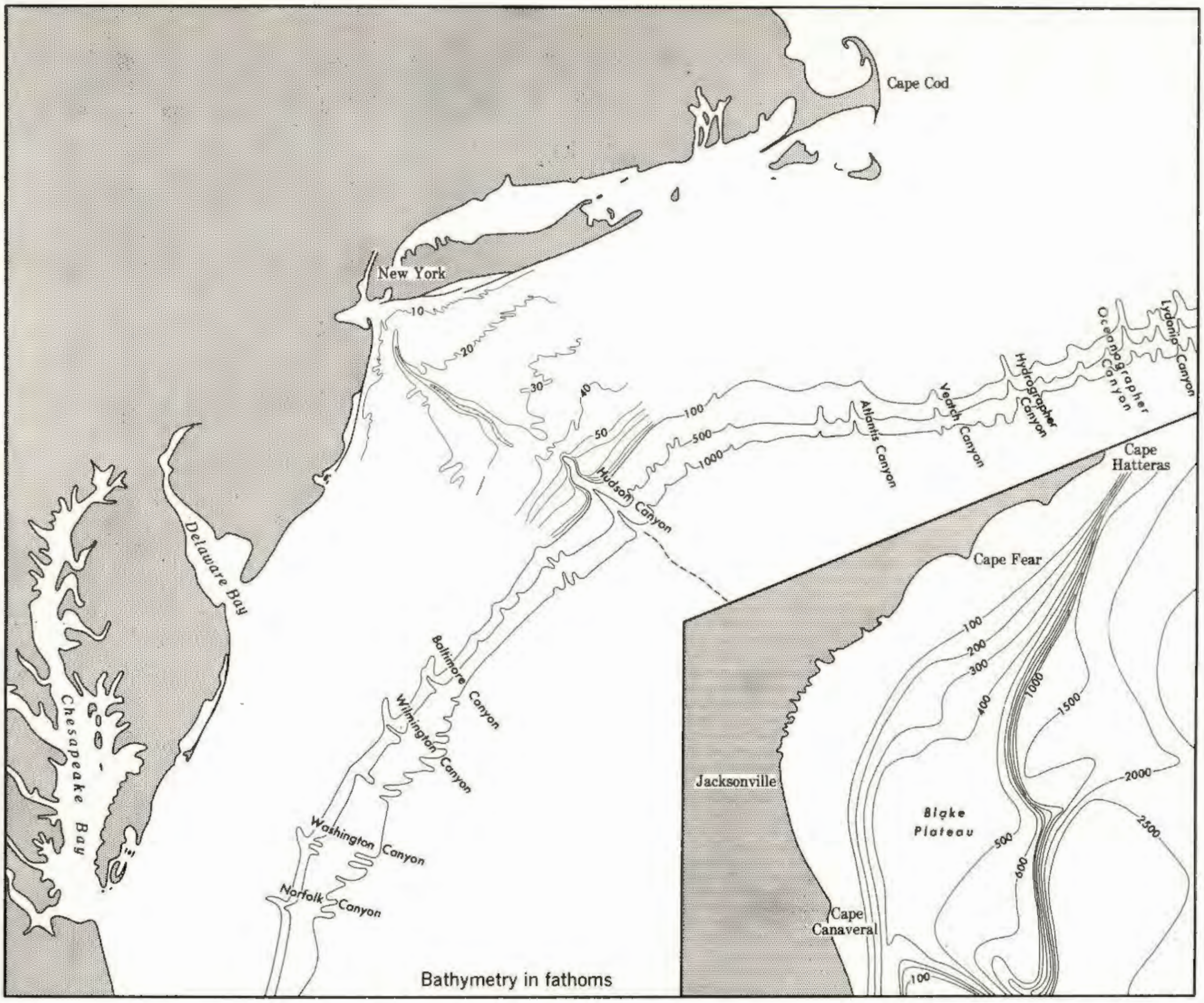

FIG. 6.—Atlantic-slope canyons, escarpment, and terrace.

The continental slope of the Atlantic margin is prominently marked by three types of features--an extensive continental terrace, a major escarpment, and numerous canyons. These are delineated in figure 6.

CANYONS

The northeastern margin surveyed during the period of 1930-39 revealed that this stretch of continental slope has a rugged topography conspicuously marked by large numbers of valleys most of which are of canyon proportions. They are relatively narrow in relation to the great depth to which they cut into the upper slope and shelf.

The Hudson Canyon is the most prominent of the series. It cuts back into the shelf a distance of 15 miles where it is aligned with a discontinuous channel extending toward the Hudson River. The floor of the canyon is cut as much as 3,700 feet below the rim. In the lower reaches across the continental rise a seachannel continues out across the ocean floor for at least 200 miles (B. C. Heezen, M. Tharp, and M. Ewing, 1959).

It is this latter aspect which lends support to the theory that turbidity currents engendered by mass flows of sediment-laden waters had carved out the canyons, as the seachannels of the deep floor of the ocean could not have been carved out by subaerial rivers.

It had been postulated in the original study of these canyons by A. C. Veatch and P. A. Smith (1939) that they were eroded when the sea was at a much lower level, approximately at the present 1,200-fathom level. There have been severe objections to this suggestion because it is calculated that the extent of the glaciers spreading out from the polar cap during the latest glacial epoch was far less than would be required to contain the volume of water represented by such a lowering of sea level. For that reason it was considered that the canyons were carved below sea level, probably by density currents induced by frigid glacial melt-waters. Subsequently it has been found that turbidity currents have transported sediments far out on the ocean floor. They have therefore been considered to be the erosive agent responsible for the canyons as well as the seachannels.

There are still some objections to this theory because fine sediments remain on the canyon floors and because the postulated high velocity of the currents necessary for erosion of rocky canyons is questioned. It is recognized that submarine landslides or slumping forms valleys in unconsolidated sediments, but still unexplained is the cutting of V-shape canyons deeply into the rock layers of the upper slope.

If the canyons were cut subaerially then it might be expected that all canyons would be submarine continuations of land valleys. This is the case for many canyons such as the Hudson Canyon and others on the south in figure 6. But in many areas the submarine canyons and valleys are not aligned with land valleys. Quite the contrary, some are transverse to coastal ranges or are off points of land.

Perhaps all of the canyons and valleys do not have a common origin. Some are considered to be rift valleys. Only a few have been dredged or cored to determine the composition of their surfaces. It is still postulated by some scientists that sinuous V-shape canyons were cut subaerially and preserved under the sea after subsidence and downwarping of the continental margins rather than from a rise of sea level after a great lowering. Support for this contention comes from the fact that sedimentary layers deposited in shallow seas are now thousands of feet below sea level. Downwarping of these layers is reported in several areas. In one area the seaward dip is 1:120 which corresponds approximately with the average gradient at the outer limits of the present shelf.

In the event that it is determined that the rock-sided canyons are many millions of years old, predating the last glacial epoch, then they might be largely kept open and free from burial by sediment because of density currents, slumping, and turbidity currents.

MARGINAL TERRACE

The continental slope off Georgia and Florida, north of the Bahama Islands, is interrupted by an extensive terrace in depths of 400-500 fathoms. Named the Blake Plateau when it was traversed with sounding leads in the last century this continental terrace is more than 150 miles wide and covers an area of 15,000 square nautical miles.

The terrace is in general a grossly smooth plain, but it is not completely devoid of topographic irregularities. An east-west profile in figure 2 shows a gradient of 1:2000. The origin of this great plain has not been definitely established. It appears as a northern extension of the Bahama Islands platform, on which calcareous growth was possibly halted by cold-water intrusion, by subsidence, or both (N. D. Newell, 1959). The strong currents of the present Gulf Stream probably inhibited further deposition.

MARGINAL ESCARPMENT

Eastward of the Blake Plateau and southward along the edge of the Bahama Islands platform the continental margin is marked by a major escarpment beginning in midslope and deepening precipitously to abyssal depths greater than 2,500 fathoms. Unlike the margin on the north there is no continental rise. Quite the contrary, the abyssal floor deepens toward the bottom of the escarpment.

Although precipitous escarpments are generally considered to indicate faulting, it has been suggested (N. D. Newell, 1959) that the Blake-Bahama Escarpment resulted from the vertical growth of marginal reef corals in accompaniment with a subsiding platform. Borings on elevated portions of the platform reveal limestone rock 2-3 miles thick, which began forming in shallow lagoon waters.

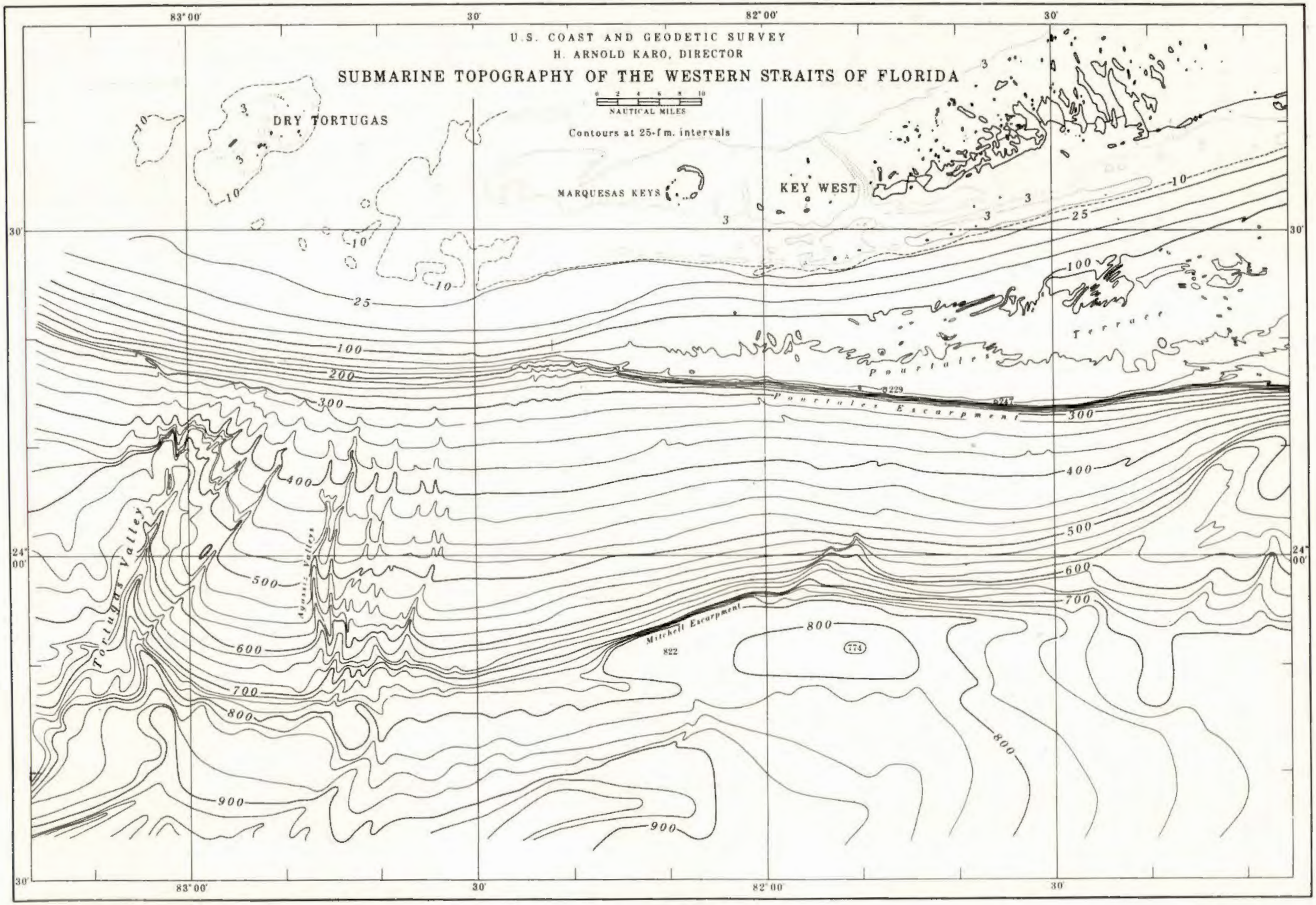

FIG. 7.—Marginal features in the Straits of Florida.

Comprehensive surveys on the southern margin of the submerged platform of the Florida Peninsula reveal valleys, an extensive karst terrace, and three escarpments which are largely but not completely indicated by the bathymetry of figure 7.

VALLEYS

The valleys are grouped in a band 30 miles wide and they head in 300-fathom depths 20 miles south of a shallow pass east of Dry Tortugas. Several valleys converge to form the major Tortugas Valley whose floor is in part 1,000 feet deeper than general depths along the slope. It has an average gradient of 1:75 which is comparable to gradients of the lower reaches of Hudson Canyon and the other canyons to the south in figure 6. Tortugas Valley is 10-15 miles wide and is joined by a singular tributary which runs a straight course for 30 miles to depths of 750 fathoms.

The easterly group of valleys converge at 800 fathoms where there is a pronounced fan. There are two main valleys which have a combined width of 1 1/2-3 miles midway in their parallel courses. These valleys and the Tortugas Valley curve eastward in the lower reaches and then reverse direction below the deflecting influence of sedimentary banks and fans.

A complete history of these valleys can only be conjectured. One condition appears obvious--their former heads lie buried under a mask of sediments on the upper slope and shelf. If the erosional forces were presently active then the valleys could only begin from slumping of sediments on the steeper slope in 150-250 fathoms. But this slope is grossly smooth and free from landslide scars, and it appears to be a broad fan of recent sediments carried through the wide passage east of Dry Tortugas from the shallow waters north of the Florida Keys. These waters become white with bottom sediments when stirred up by strong northeasterly storms during winter months. The broad Tortugas Valley probably lies buried beneath the shelf east of Dry Tortugas. It may have coursed straight outward through the pass and downward to a point where the margin of figure 7 cuts the 825-fathom contour. Gradual deposition on the "right bank" caused the valley axis to curve eastward. Subsequent to original erosion of the main valley a straight and narrow valley intersecting in present depths of 750 fathoms was possibly cut by turbidity currents which accelerated the deposition of sediments along the old axis of the main valley.

CONTINENTAL TERRACE

The Pourtales Terrace begins in depths of 90-100 fathoms and covers a band of gently sloping bottom widening to 10 miles, which extends over a distance of more than 100 miles along the continental slope. Although the average gradient is about 1:200, the terrace is nearly flat in a 5-mile-wide band in depths of 105-110 fathoms, east of the area of figure 7.

The irregular surface of the terrace is in sharp contrast with the smooth slope above and below it. It is severely scarred by elongate and circular depressions. It is also marked with topographic rises. The fathograms and 5-fathom-interval bathymetry (G. F. Jordan, 1954) reveal a typical karst topography. Many of the depressions are 150-200 feet deeper than general surroundings. Many bottom-out at common depths of 140-145 fathoms in the western portion and in 155-165 fathoms on the east. Three prominent sink holes were found near the edge of the terrace. Their rims are about a half mile in diameter and the holes are approximately 500 feet deep. The bottom depths of two are indicated in figure 7. The deepest part of many depressions occurs adjacent to rises, the total relief amounting to 400-600 feet in many areas. The tops of the rises are in general at common depths of 85-95 fathoms, but several are at about 70 fathoms. They relate to a lower stand of sealevel, as does the karst terrace.

ESCARPMENTS

Pourtales Terrace is bordered by an escarpment 600 feet high, with gradients as steep as 1:2. It merges with the slope at the western limits of the terrace. The escarpment lies on the north slope of the trough between Florida and Cuba, and it is considered to mark a zone of faulting. A less extensive escarpment is delineated in 700-800 fathoms, south of the Pourtales Escarpment.

A third escarpment located above the head of Tortugas Valley is not apparent in the bathymetry of figure 7. It is in depths of 250-300 fathoms and is aligned with the Pourtales Escarpment. Several fathogram profiles transverse to the slope show an escarpment 180 feet high on a gradient of 1:3. This escarpment gradually diminishes eastward, where it is aligned with an abrupt change in gradient.

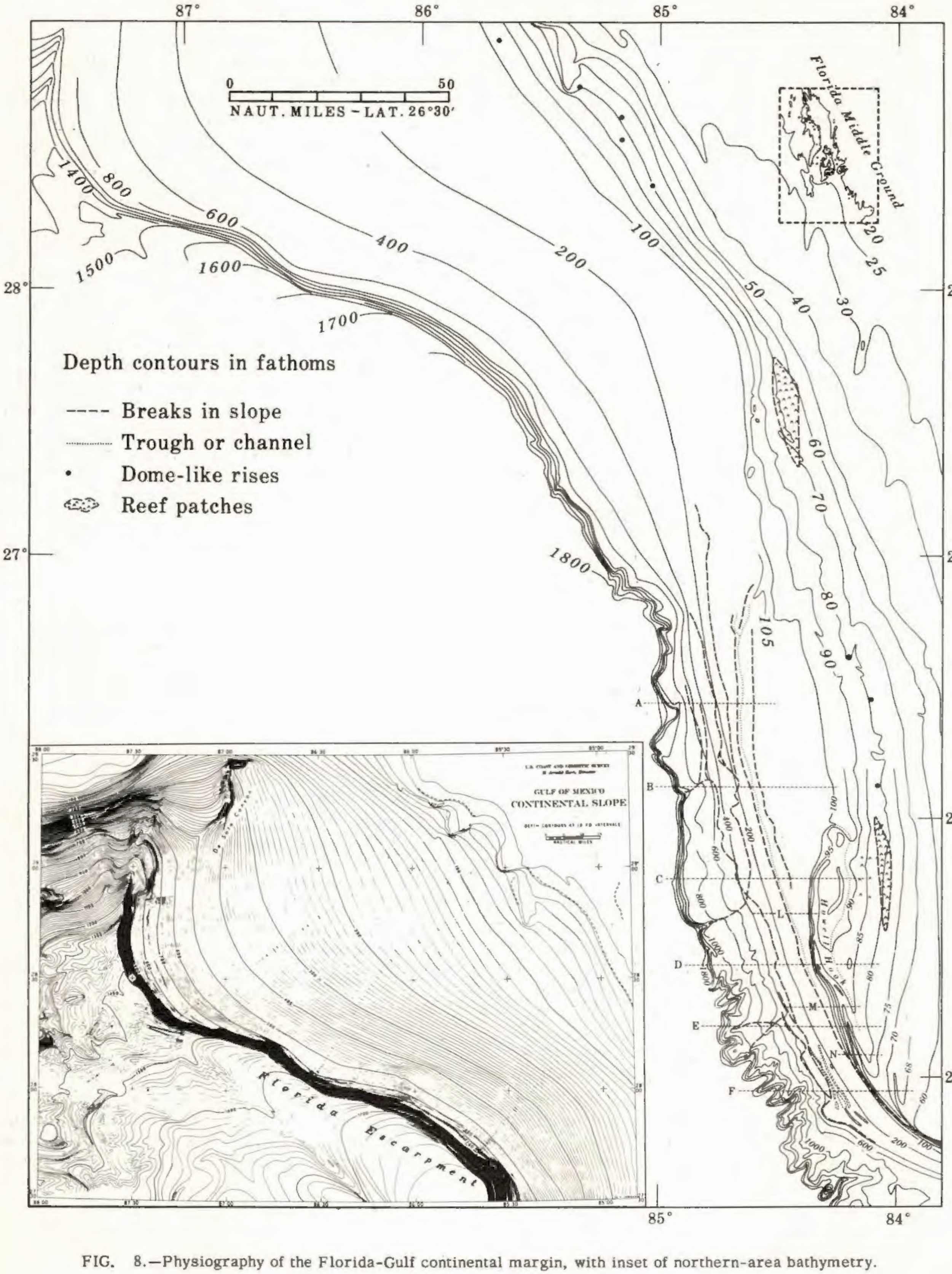

FIG. 8.—Physiography of the Florida-Gulf continental margin, with inset of northern-area bathymetry.

The continental margin lying 100-150 miles off Florida's west coast in the Gulf of Mexico presents a study as equally interesting as the southern area of figure 7. The area in the lower right corner of figure 8 is about 55 miles west of Dry Tortugas, and the upper corner is 40 miles from the coast at Cape San Blas represented by a bulge in the shoreline of figure 1.

The most prominent feature is the major escarpment delineated in the inset covering the northern portion of the area. The inset is greatly reduced from the original compilation of the area by the author (G. F. Jordan, 1951). The partial bathymetry and physiography in the main portion of the illustration are from a later study (G.F. Jordan and H. B. Stewart, Jr., 1959).

ESCARPMENT

The Florida Escarpment emerges from a cover of sediment on the lower slope south of Pensacola, in 1,000 fathoms, and it extends 400 miles eastward and southward to the axis of the Straits of Florida. Its course is interrupted by a series of arcuate and straight trends, the latter being broken in the southern half by offsets and a series of canyons which incise the slope to distances of 10-15 miles. The escarpment deepens on its southward course. In the lower right area of the inset the top of the escarpment is in 700 fathoms, and in the lower portion of the main illustration it is at 1,200 fathoms. The escarpment is more than a mile high in part and has gradients as steep as 50° (fig.9). It makes a shear emergence from the deepest part of the floor in the eastern Gulf of Mexico, and there is no continental rise.

A pronounced easterly offset of the escarpment at the labelled 1,800-fathom contour marks a change from a simple trend to the north to a very irregular course to the south. Lesser offsets occur in the southern section which is severely incised by canyons, some of which have floors deeper than depths along the bottom of the escarpment. The canyons incise only the lower slope.

UPPER-SLOPE LINEATIONS

The continuity of scarps, troughs, terraces, ridges, and abrupt changes in gradient are traced by the dash lines of figures 8-10. Although an upper lineation closely parallels the very smooth 200-fathom contour, the line begins in less than 40 fathoms eastward of the lower right corner of figure 8. It deepens gradually to 138 fathoms and then trends upward to lesser depths at its northern extremity (fig. 10). This lineation is characterized generally by a 100-150 foot scarp which has in part a 10° gradient. The bottom of the scarp terminates in a trough 55 feet deep.

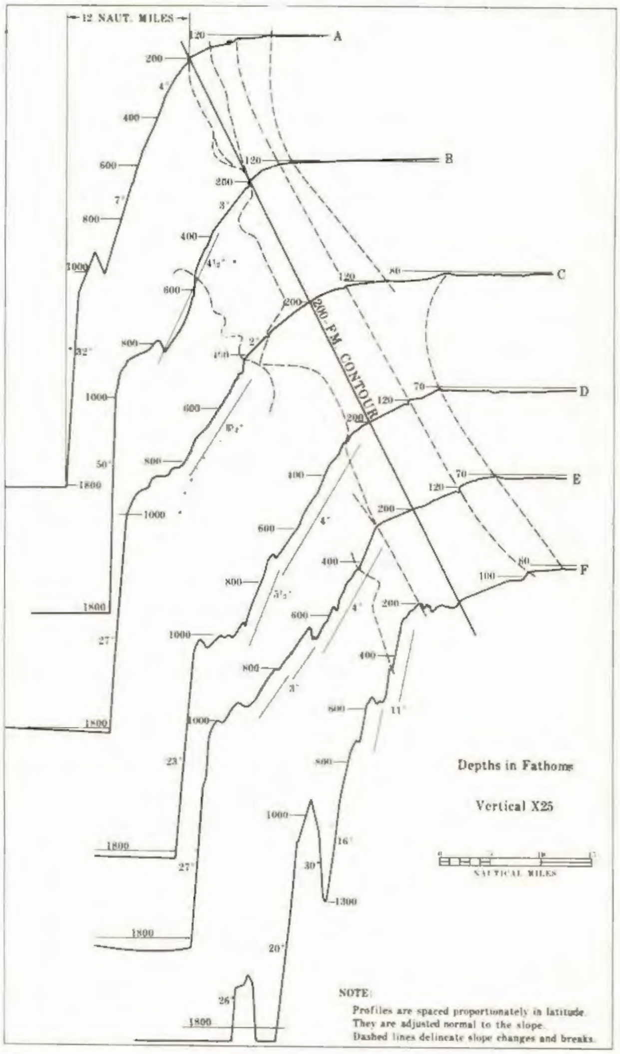

FIG. 9.—Profiles of the Florida-Gulf continental margin.

Back of the scarp is a terrace and a shallow trough which is traced by a dotted line in figure 8. The deeper lineations are more erratic in their trends, crossing and recrossing the contours and trending downslope. Although the more shallow and smoother lineations may represent a warped former shoreline, it is believed that the deeper ones mark faulting along the upper slope.

BARRIER SPIT AND LAGOON

The submerged barrier spit named Howell Hook begins in 72 fathoms and deepens to 90 fathoms, 65 miles north. The spit is a broad rise of 25-50 feet above the floor of the "lagoon." The lagoon has a channel which is narrow and 30 feet deep at its entrance. A similar but comparatively minor spit is delineated by a 68-fathom contour. The formation and preservation of these spits bear witness to a former relative

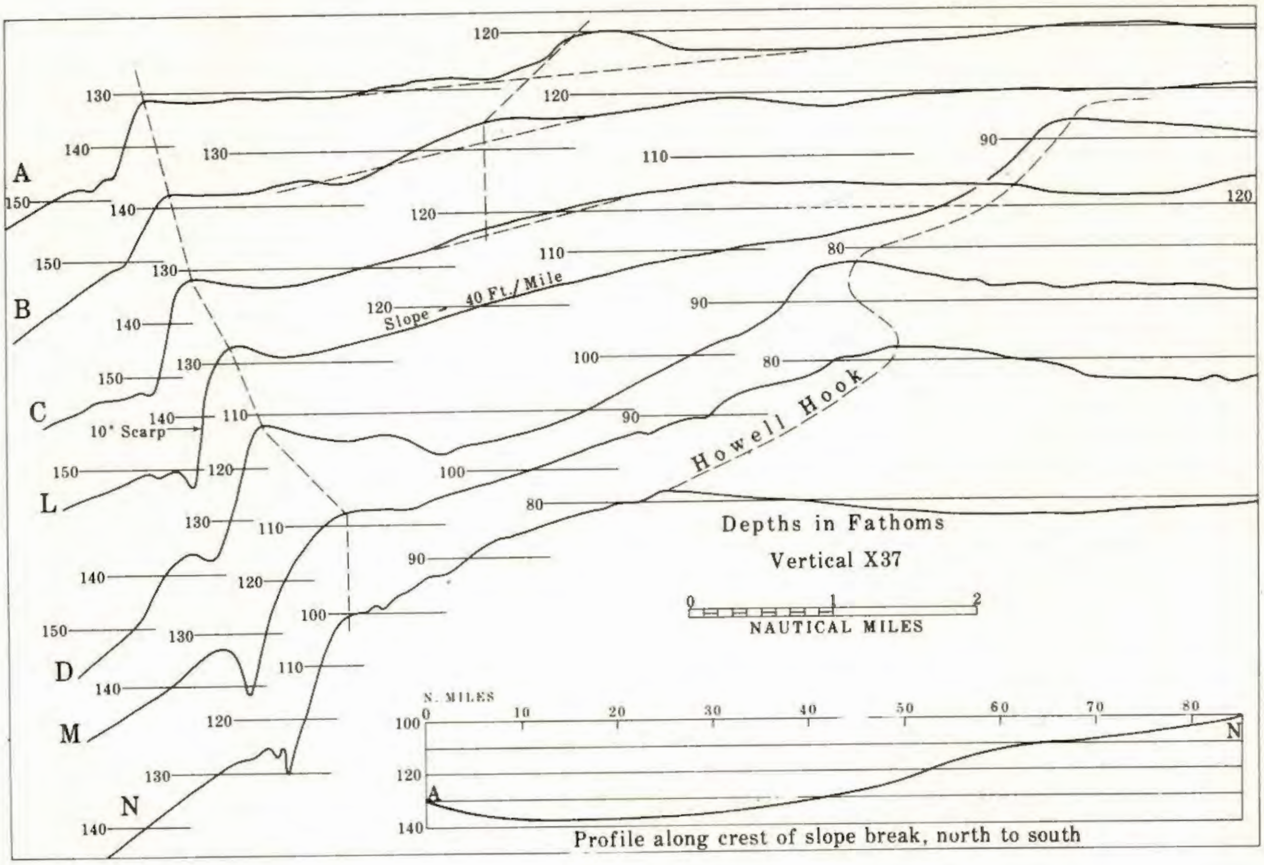

FIG. 10.—Profiles of the Florida-Gulf outer shelf and upper slope.

stand of a receding sea and subaerial cementation of the sediments of which they are composed. The present depths of these features correspond with depths of the numerous elevations above the Pourtales Terrace mentioned with figure 7.

REEF PATCHES, MOUNDS, AND SPURS

The bottom east of the drowned lagoon, in depths of 75-85 fathoms, is in part very irregular with patches of micro-relief. The patches are quite dense in the outlined area, and the relief amounts to 10-15 feet. Another extensive area of similar relief is indicated 85 miles northward in depths 15 fathoms shoaler. These drowned, dead reefs were presumably constructed of coralline algae at lower sea levels, as determined in the vicinity by H. R. Gould and R. H. Stewart (1955).

The mounds are dome-like rises found generally in 70-80 fathoms, north to south. The average mound rises 20-30 feet and covers an area of about 500 acres. The origin of the mounds is conjectural. Topographically, they are comparable to the salt domes of the Louisiana and Texas coastal plain and shelf, and to mounds and hills along the margin of the continental shelf in that region (fig. 12). The mounds probably resulted from reef growth or from calcareous incrustation or cementation of the points of former spits which were subsequently severed by erosion of unindurated necks.

Numerous spurs, some of major proportions, are delineated by the bathymetry along the outer shelf. A series of prominent spurs or former spits are outlined by the 30-fathom contour in the northern area. One of them projects 12 miles and rises 50 feet above the embayed bottom. Others are in depths of 60-105 fathoms. All of the spurs in the northern area point southward to southwestward in striking contrast with Howell Hook and its small counterpart in 68 fathoms, which were formed by currents of opposite direction.

FLORIDA MIDDLE GROUND

The area outlined in the upper right corner of figure 8 covers 300 square miles of submarine topography which has sharp irregularities and distinctive form. From the overall bathymetry published by G. F. Jordan (1952) and profiles (fig. 11) it was originally suggested that the topographic form resembled a river delta. The

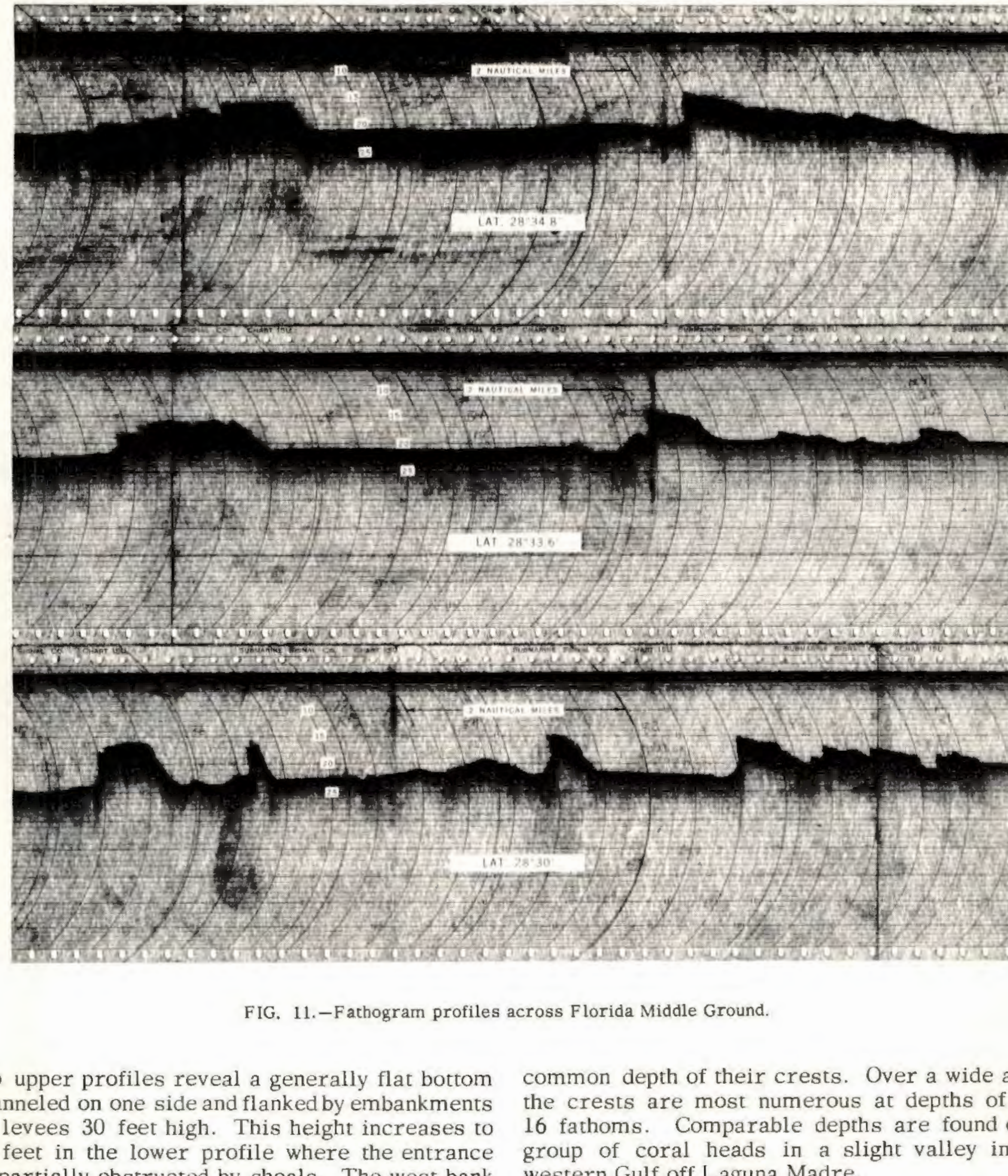

FIG. 11.—Fathogram profiles across Florida Middle Ground.

two upper profiles reveal a generally flat bottom channeled on one side and flanked by embankments or levees 30 feet high. This height increases to 40 feet in the lower profile where the entrance is partially obstructed by shoals. The west bank continues for 15 miles south of the entrance and is outlined by the spur in the 30-fathom contour in figure 8. The smoothness of the bottom on the spur and east to the 25-fathom contour is in sharp contrast with the irregularities on the north.

Irregularities comparable to the narrowest rise in the lower profile are profuse. They are partially indicated by the small dots in figure 8. One significant aspect of these features is the common depth of their crests. Over a wide area the crests are most numerous at depths of 13-16 fathoms. Comparable depths are found on a group of coral heads in a slight valley in the western Gulf off Laguna Madre.

The origin of the overall topography can only be conjectured at this time. It might appear from the description that Florida Middle Ground was once the confluence and mouth of the major rivers on the north where figure 1 shows a broad deltaic bulge in the coastline. But it has been suggested that the irregularities were caused by faulting. Regardless of the origin the Florida Middle Ground is a unique formation unparalleled on the shelf of the northern Gulf of Mexico.

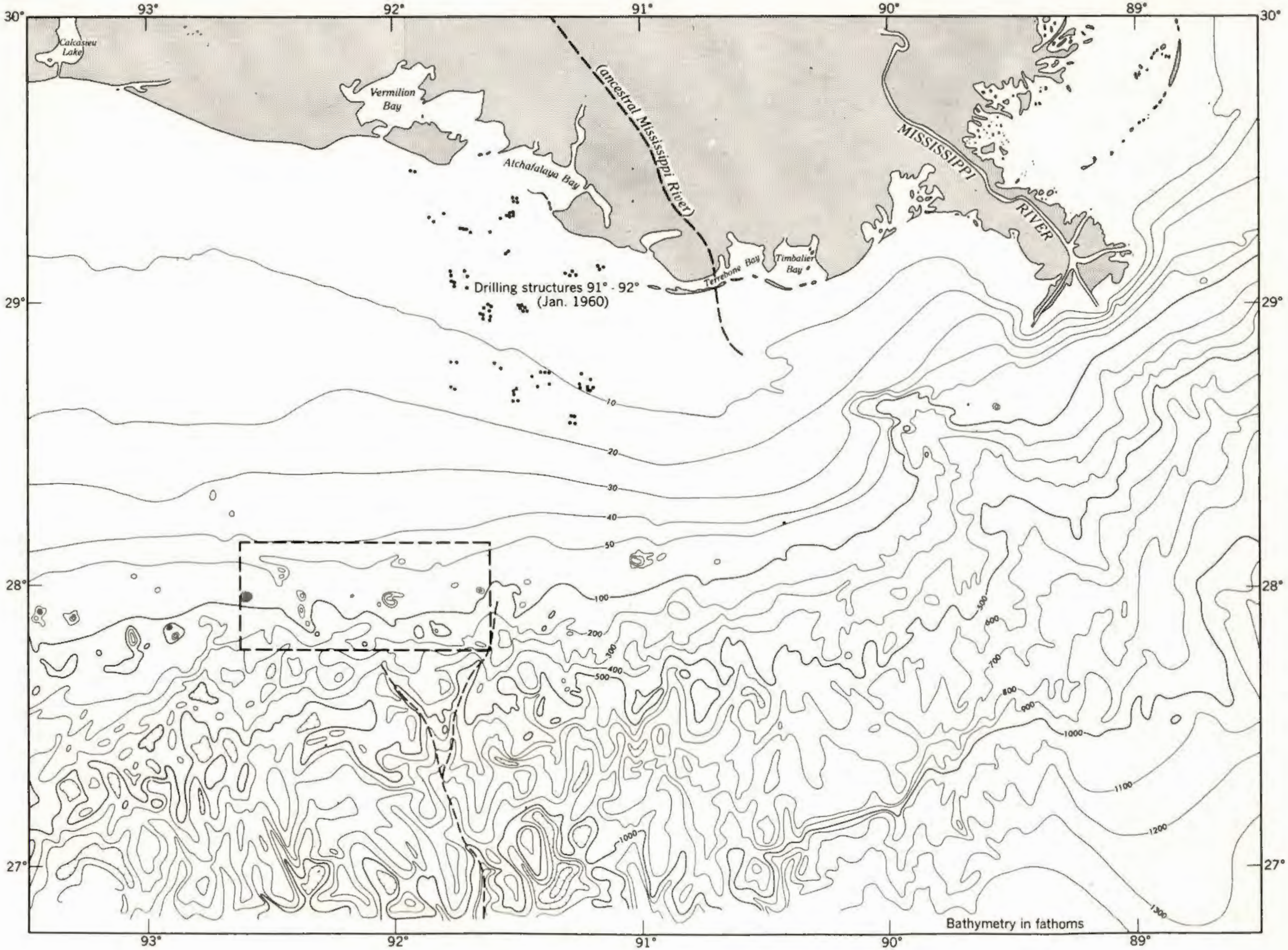

FIG. 12.—Shelf and continental margin off Louisiana, with outline of figure 13.

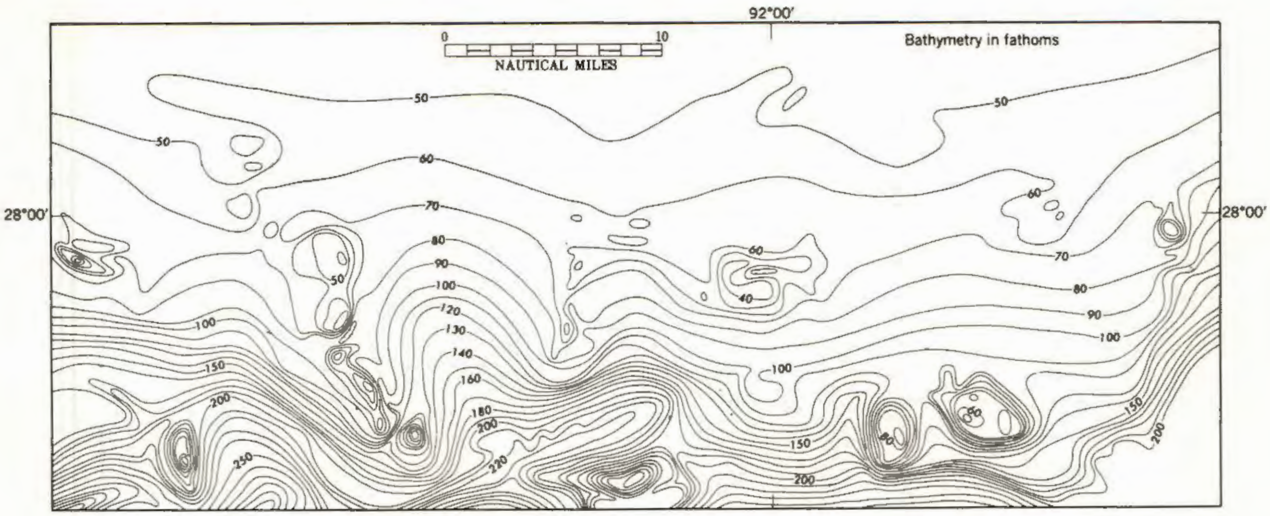

FIG. 13.—Knolls and other features of the shelf margin off Louisiana.

The Louisiana margin is closely approached by the bird-foot delta of the present Mississippi River which has meandered considerably westward and eastward in past geologic time. Here, the shelf is practically nonexistent where there is a 40-mile projection of the coastline from the larger deltaic area. On the west, however, the shelf widens to 100 miles. There is an immense amount of petroleum exploration on this shelf, which is partially indicated by the dots which represent clusters of derricks and related structures in a representative 50-mile-wide band extending offshore from Atchafalaya Bay.

The marginal topography of figure 12, which is largely taken from a previous compilation by B. L. Gealy (1955) is made complex by the innumerable knolls, basins, and valleys. One of the most obvious valleys, marked by a dash line, appears to be a confluence of two valleys outlined by embayments in the 100-fathom contour. The westerly one is included in figure 13 which shows a northwesterly alignment of knolls and mounds. The alignment might also represent a former river embankment or natural levee which was partially preserved by coralline incrustation or by cementation during a low stand of the sea.

Figure 13 shows at larger scale several of the mounds and knolls which dot a marginal band all along the outer shelf and upper slope. The dome-like form of many, originally discovered during surveys of 1933-37, gave rise then to the suggestion that they might be salt domes comparable to the numerous ones on land in shallow waters, which have been successfully drilled for petroleum (F. P. Shepard, 1937). However, the presence along the shelf margin of dome-like rises in the eastern Gulf (fig. 8), of calcareous fossil reefs in the northeast off Alabama and Florida, and of a chain of coral heads in the western Gulf suggests and origin related to a lower sea level for many of these features.

Although it has been suggested that some of the knolls in mid-slope might also be salt domes, it is generally believed that most of the deeper knolls are formed from slope failures and faulting of thick sediments under stress of gravity. Landslides, sediment flows, and faulting have apparently modified a warped and subsided margin which was earlier carved by subaerial river erosion.

Major erosion of this type is indicated by the now submerged major valley of the ancestral Mississippi River. It is topographically delineated for a distance of 80 miles from 30 to 900 fathoms. The dash line on the delta indicates approximately where coring has traced the valley now buried about 400 feet below sea level (H. N. Fisk, 1944). In 300-600 fathoms the broad floor of the valley is 1,000-1,500 feet deeper than marginal depths, and the valley is 25-30 miles wide.

Extending southeastward from the valley is a huge fan which spreads out more than 250 miles to the western approaches of the Straits of Florida. At the limits of figure 12 the fan is made obvious by a 30-mile bulge in the 1,300-fathom contour. Extensive sampling of the surface and subsurface of the fan has revealed the alluvial nature of the sediments which are identified with the Mississippi River system (M. Ewing, D. B. Ericson, and B. C. Heezen, 1958).

FIG. 14.—Unique features of the margin off southern and northern California.

The continental margin off California is distinctive because (1) an extensive, unusual borderland separates the outer continental slope from the inner initial slope and shelf beneath the waters of a continental sea, (2) a major transverse escarpment and fault zone extends seaward from the coastline; (3) the slope and shelf are severely incised by large numbers of canyons and valleys; and (4) because several seamounts rise from or adjacent to the lower continental slope.

CONTINENTAL BORDERLAND

The main bathymetric chart of figure 14, taken from more detailed bathymetry compiled by F. P. Shepard and K. O. Emery (1941), delineates the continental borderland off southern California. It includes eight islands, one of which rises 2,500 feet above sea level, and several basins 600-1,100 fathoms deep. Total relief amounts to as much as 8,800 feet.

The complex topography is composed of basins, ridges, and banks elongated generally in a direction parallel to the coastline. In the northern area the coastline and chain of offlying islands cut across the general trend. The topographic trends are accentuated in figure 14 by shading of the 300- to 600-fathom band which outlines and separates most of the rises and depressions.

A half-dozen major lineations having a northwest-southeast trend are shown by K. O. Emery (1960, fig. 68), which are ascribed to faulting. Lesser lineations with more easterly trends cut the borderland area into blocks, as along the south slope of the San Nicolas Island platform. Considering the magnitude and sharpness of the topographic relief in the region it is obvious that crustal faulting has created this continental borderland. Concrete evidence is given by the several marine terraces on San Clemente Island, elevated by uplifting to heights of more than 1,500 feet above sea level. Similar series of terraces exist at various heights on the other islands and on the coastal land.

Submarine terraces on the shelves and upper slopes have been exhaustively studied by K. O. Emery (1958). More than 100 profiles reveal a series of five terraces which in coastal waters range from 5 to nearly 50 fathoms; but in offshore island waters and on the outer banks the comparable terraces are progressively deeper. It is therefore inferred that warping to the extent of about 1 1/2 feet per mile for the deepest of these terraces had occurred since the lowest stillstand of the sea in the last glacial epoch.

ESCARPMENT OFF CAPE MENDOCINO

A major transverse fracture in the earth's crust offsets the continental margin at Cape Mendocino, the westernmost point of land along the California coast, 190 miles northwest of San Francisco. The fracture is manifested here by a northfacing escarpment which rises about a mile above the ocean floor. It was originally named the Gorda Escarpment because it closely approaches the coast at Punta Gorda. About 75 miles from the coast the escarpment continues on the north side of a spur projecting out from the continental slope. Farther seaward the south side of the spur becomes an escarpment of greater proportions where the ocean floor is deeper than on the north side of the spur or ridge. At a distance of 150 miles from the coast the ocean floor on the south side of the ridge is in 2,400 fathoms, 700 fathoms deeper than on the north, and 1,700 fathoms below the top of the ridge. A fathogram recording of a transverse crossing of the ridge at this point is reproduced in the inset of figure 14. This ridge and the escarpments have a greater significance in that they are part of the more extensive Mendocino Fracture Zone which has been traced for a distance of 1,400 miles across the floor of the Pacific Ocean (H. W. Menard, 1955).

CANYONS

Another impressive aspect of the California margin is the large number of valleys having canyon characteristics of relatively steep sides and narrow widths. The ratio of width to depth is generally 10:1 or less for most of them. In contrast, the Tortugas Valley of figure 7 has a ratio of 50:1, and for the submarine valley of the ancestral Mississippi River (fig. 12) the ratio is 20:1.

One significant aspect of the California canyons is the proximity of their heads to the shoreline. This condition is due largely to the relatively narrow shelf, but in localities where the shelf widens the canyons cut deeply across it. Inshore from the heads of some canyons their sediment-buried continuities have been traced by analyses of core samples (K. O. Emery, 1960), as in the case of the ancestral Mississippi River.

SEAMOUNTS

Several seamounts fringe the California margin southward from the approaches to San Francisco Bay. A major one, San Juan Seamount, is included in the limits of figure 14. This seamount rises more than 10,000 feet above the ocean floor to a depth of 302 fathoms, and it spreads out about 25 miles along the longest dimension of its base. The other seamounts adjoin or rise from the continental slope. They are 3,500-6,500 feet high.

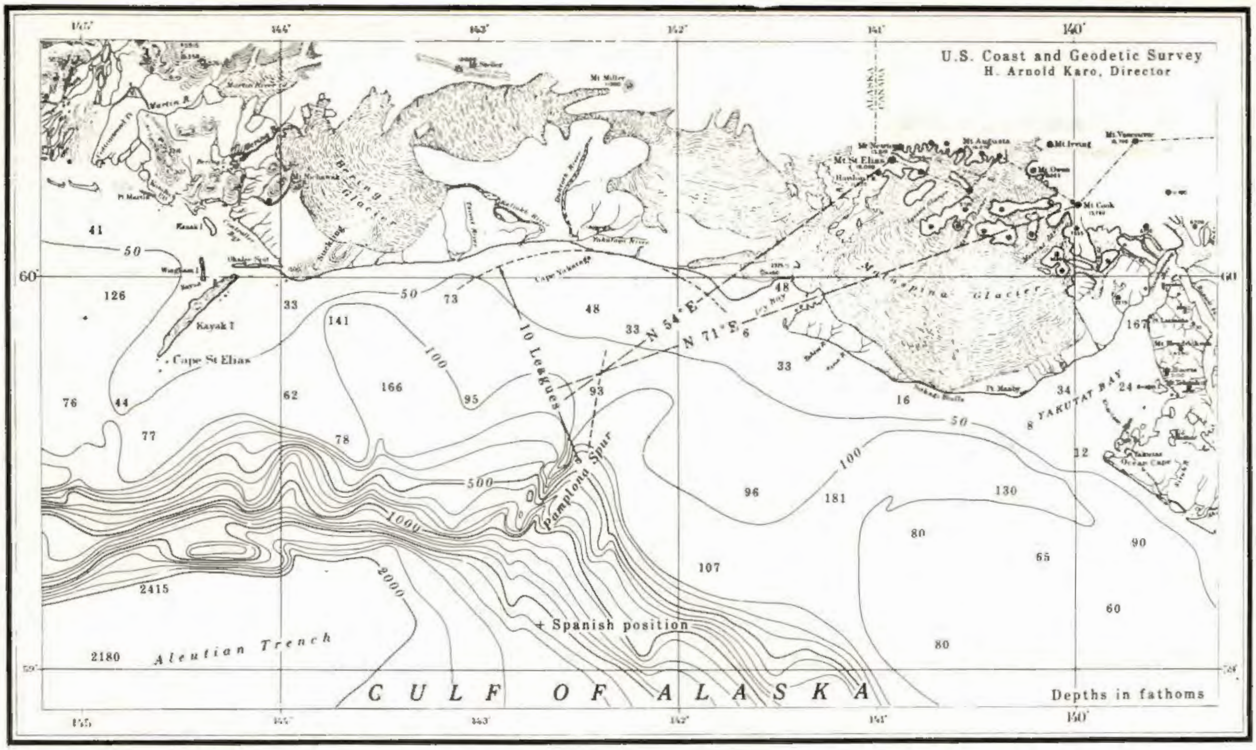

FIG. 15.—Bathymetry of the northern rim of the Gulf of Alaska.

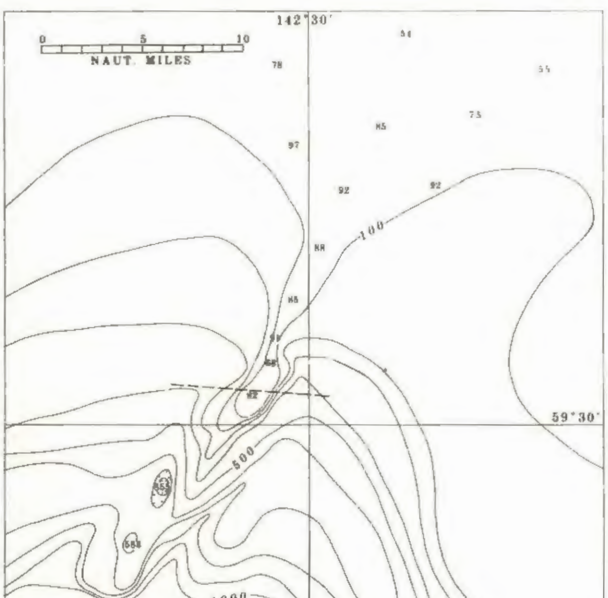

FIG. 16.—Pamplona Spur and position of profile (fig. 17).

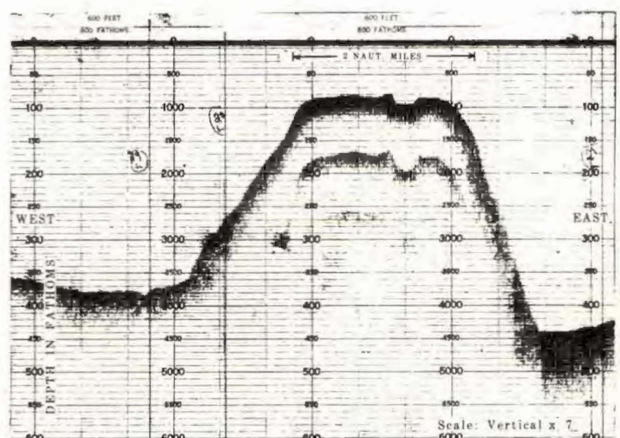

FIG. 17.—Fathogram profile across Pamplona Spur.

Referring to figure 1 it can be seen from the general bathymetry of the Gulf of Alaska that the 100-fathom contour delineates several valleys which cut deeply into the continental shelf. This is a glaciated region in which glacial tongues and great outpourings of melt-water have left their mark in the form of channels and valleys. It is the only area of the United States where a glacier now encroaches on the coastline (fig. 15).

This region has also been subjected to major earthquake activity. The rugged topography inland from the coast gives ample evidence of crustal upheaval and mountain building. Mt. St. Elias and other mountains in a group marking the zigzag boundary with Canada rise to majestic elevations of 13,000-18,000 feet above sea level. Here was considered to be the alps of North America. Numerous expeditions sailed into Yakutat Bay before the turn of the century to explore the ice and snow-covered mountains. A mecca was envisioned comparable to major resorts of the Swiss Alps.

Perhaps the major earthquake in Yakutat Bay which lasted for 17 days in 1899 might have been a deterrent. For during this period the lands rose and fell. The shoreline was elevated to heights of 47 feet. It was in the preceding 13 years that reports of several expeditions had caused attention to be drawn to this area. The last private expedition was only three months before the series of earth shocks which were felt around the world. Government agencies have of course continued exploration and mapping.

In fact the severe earthquake of 1958 extending southeastward from Yakutat Bay and centered near Lituya Bay, 100 miles distant, immediately attracted scientists and surveyors who traced the course of events and measured vertical and horizontal displacements of the land. This was the largest earthquake in this region since the one of 1899.

Considering the occurrence of these major shocks and the considerable evidence of land deformations in this region, including subsidence of marginal areas below sea level, the hydrographic surveyor's attention is drawn to an anomalous phenomenon of the continental slope at the head of the Gulf of Alaska.

A submarine spur or ridge discovered at depths of 400-500 feet coincides in position with a shallow rocky ridge originally reported by early Spanish mariners 178 years before (G. F. Jordan, 1958). It was sufficiently shallow to have caused the wreck of a Russian galiot. No further reports of its existence were made in the last century, nor until Coast and Geodetic Survey ships recently rediscovered and surveyed this feature.

Pamplona Spur, named after the original Bajo Pamplona, is 30 miles from shore (fig. 15). Although the original Spanish position is farther out into the Gulf the original observations recorded in the ship's log and now related to modern maps place the position adjacent to Pamplona Spur. The spur projects seaward 15 miles, a dimension stated by a Russian hunter of sea otters to the British explorer Vancouver in 1792.

Pamplona Spur is delineated at larger scale in figure 16 and a fathogram showing a transverse profile is illustrated in figure 17. The profile shows the spur rising 2,160 feet from depths of 440 fathoms on the east side, largely on a gradient of 1:2.4, or 22°. The extremity of the spur is cut longitudinally by a channel-like depression which is 1,400 feet wide and 80 feet deep, shown in figure 17.

Two questions arise with the rediscovery of this feature. The first one is how to explain the much greater depth over the crest. The second question concerns the nature of such a relatively sharp feature rising transverse to the continental slope. Both questions are related, but the answers must of necessity be based on assumptions.

It must be assumed that a once very dangerous rocky bank or shoal disappeared well below very shallow depths. Its existence as a near-surface feature cannot be denied after considering the several separate reports. The originally reported position must be in error, as no other comparable feature could be found other than the present Pamplona Spur. Furthermore, the originally observed positioning data--the distance from land and the loci of the angle between compass bearings--place the shoal in close proximity to the present spur. The 400 to 500-foot increase in depth could not be due to wave erosion, as this action could account for about only one-tenth this amount. Therefore, the increased depth is considered to be due to subsidence or foundering which occurred in the first half of the last century before renewed search was conducted after Alaska became a territory of the United States. Some of this subsidence might have occurred during a severe earthquake around the rim of the Gulf of Alaska in 1847.

The spur is considered to be a bedrock structure uplifted similarly to nearby elevated ridges. Kayak Island, 60 miles west, is 17 miles long and rises to heights of 1,665 feet at its southern end. Close by this end is a pinnacle rock, a volcanic cone which rises 494 feet above sea level. Kayak Island and several other ridges inland have the same north-northeasterly trends as Pamplona Spur.

Inasmuch as the spur is located near the north end of the Aleutian Trench and along its extended axis then perhaps a crustal weakness extends into the continental margin here.

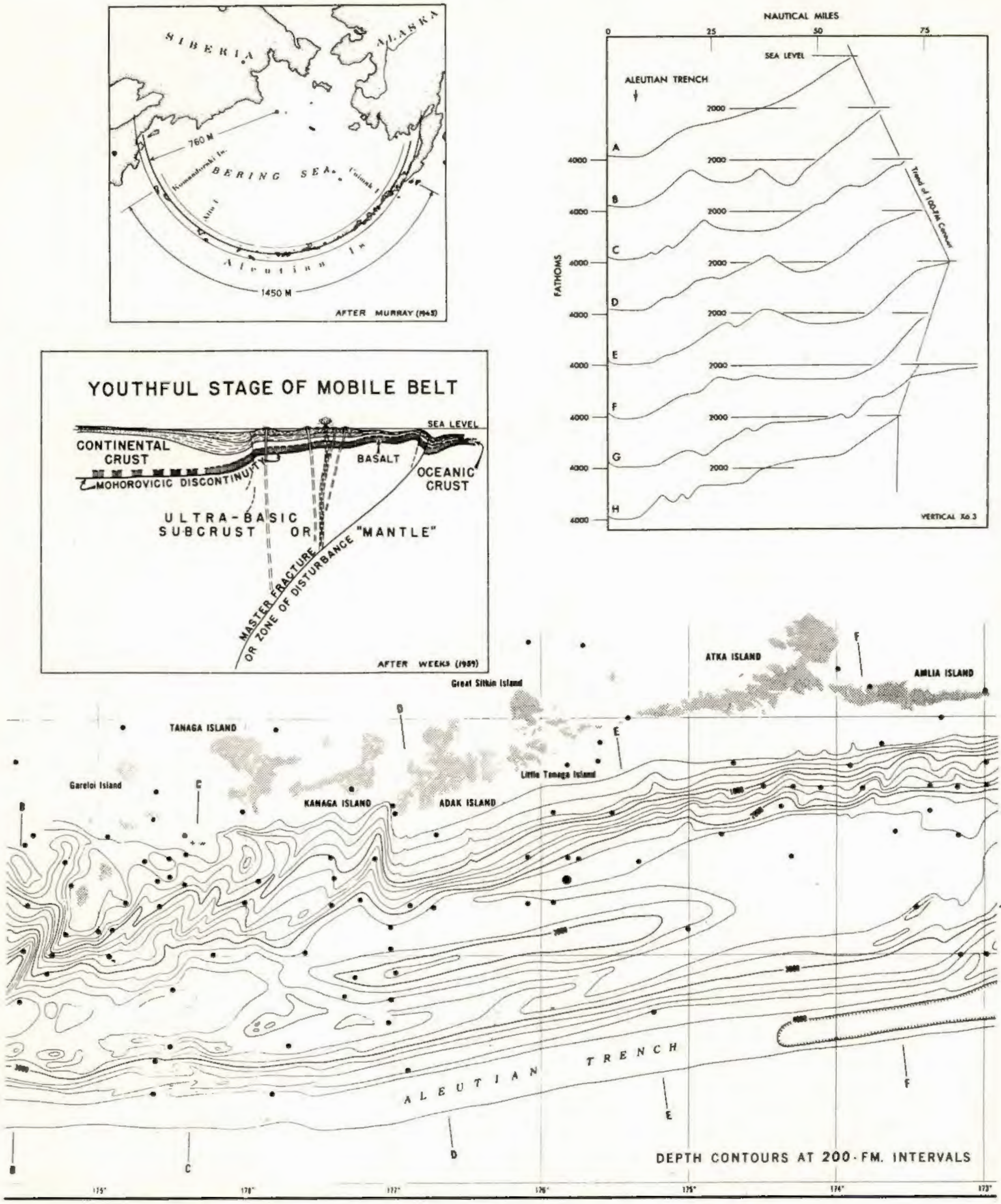

FIG. 18.—Aleutian arcuate ridge and foredeep and a series of earthquake epicenters.

A major arcuate island archipelago, the Aleutian Islands, extends across the northern Pacific Ocean from the Alaska Peninsula for a distance of 1,000 miles to Attu Island. By including the Soviet Komandorski Islands and the Alaska Peninsula the arc assumes even greater proportions. An arc with radius of 760 miles centered in the Bering Sea forms the axis of the island chain. The east end of the submerged islands platform or ridge is at Unimak Island which intercepts the southeasterly trend of the continental margin in the Bering Sea (fig. 1). Yet, there is no interruption in the arcuate continuity of mountainous volcanic cones northward along the Alaska Peninsula into the mainland, where many are 7,000-10,000 feet high.

Paralleling the arcuate ridge is one of the major foredeeps of the North Pacific Ocean. The Aleutian Trench begins along the northern rim of the Gulf of Alaska (fig. 15) and continues westward to the Komandorski Islands. It maintains a distance of 60-90 miles concentric with the islands ridge westward from the Alaska Peninsula. The eastern section of the axis (fig. 1) veers out into the Gulf of Alaska for a distance of more than 200 miles from the peninsula, where a second arc manifested by Kodiak Island and the Kenai Peninsula intervenes.

The trench reaches a depth of nearly 1 1/2 miles below the abyssal ocean floor south of Unimak Island. Depths greater than 4,00 fathoms have been obtained westward at various places along the axis. Midway in the islands arc the floor of the trench is 30,000 feet below a mountainous peak on Tanaga Island.

Between the submerged ridge of the Aleutian Islands and the Aleutian Trench the island slope is interrupted by a terracelike feature which was originally named the Aleutian Bench (H. W. Murray, 1945). The terrace does not have a simple form throughout and it does not have an unbroken continuity. There is, however, a general flattening of the slope over a wide band in midslope. This condition is illustrated in figure 18 which is a composite of illustrations used in previous studies.

The bathymetry is composed of depth contours at 200-fathom intervals and includes the floor of the trench. Locations of Profiles B-F are shown. Other profiles are located beyond the limits of this section of a larger unpublished bathymetric chart.

The profiles were drawn facing west. They begin on the floor of the trench and trace the slope upward to the 100-fathom contour. Profile F shows a simple terrace for a width of more than 30 miles. This profile is near the eastern limits of an extensive depression on the terrace, which is more pronounced in Profiles E and D and continues in Profiles C and B. The depression results from entrapment by a ridge which in some places rises 3,500 feet high.

The occurrence of this ridge on the inner, concave side of the trench provides substance to a hypothetical diagram included in figure 18. This diagram was presented by L. G. Weeks (1959) in a discussion of geotectonics and the progressive seaward growth of continents. It appears to apply to the Aleutian Islands and Trench as viewed from the west, opposite to Profiles A-H. The Aleutian Trench foredeep is the surface expression of a master fracture. The mountainous island chain has built up from innumerable vents branching from the main fracture. The ridge adjacent to the trench appears as the inner fold depicted in the diagram.

That a zone of disturbance underlies the convex side of the Aleutian Islands ridge is well manifested by the continual occurrence of earth shocks year after year. Every few years a swarm of shocks reach major proportions. This happened during the months of March and April of 1957 when more than 200 large shocks were recorded in a belt 500 miles long. Epicenters of the larger shocks occurring during this period within the limits of figure 18 are indicated by dots. Many hundreds more having numerical ratings less than 5 on the Richter scale probably occurred without detection and location by distant seismographs. The initial major shock rated at 8.5 is indicated by the larger dot. The focal points of these shocks were generally at depths of 25-100 miles below the earth's surface.

These deep-seated earthquakes on the rim of the ocean sometimes result in deformations of the submarine surface, thereby generating sea waves. These are a special type of waves called seismic sea waves which have inflicted great damage on distant shores. On reaching shallow waters they have pushed up waves reported to be 20-50 feet high, which have inundated coastal areas, wrecked structures, and in 1946 resulted in the loss of 173 lives on the Hawaiian Islands. The waves speed across the ocean at speed velocities to 500 miles an hour and they formerly struck without warning. Now, however, a Seismic Sea-Wave Warning System maintained by the Coast and Geodetic Survey spreads the alarm around the rim of the Pacific Ocean. Automatic alarm systems installed at numerous seismographs inform observers of major shocks. The observers report to a central observatory on the Hawaiian Islands, which locates and evaluates the initial shock and then flashes the warning.

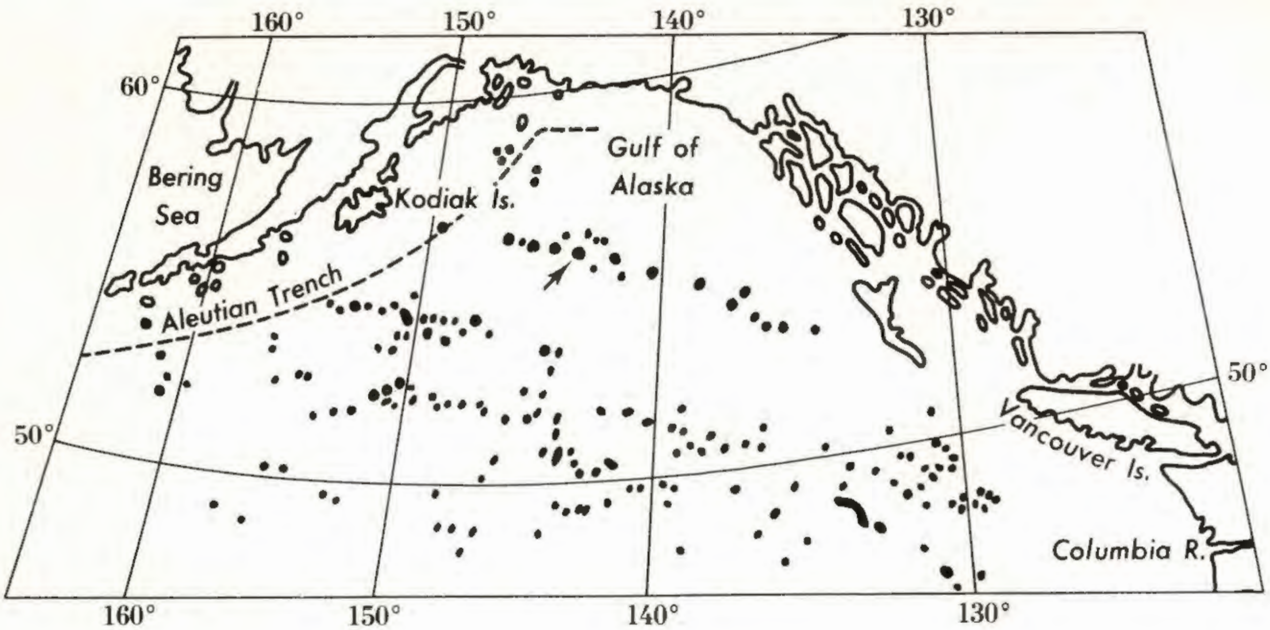

FIG. 19.—Seamounts in the Gulf of Alaska and approaches.

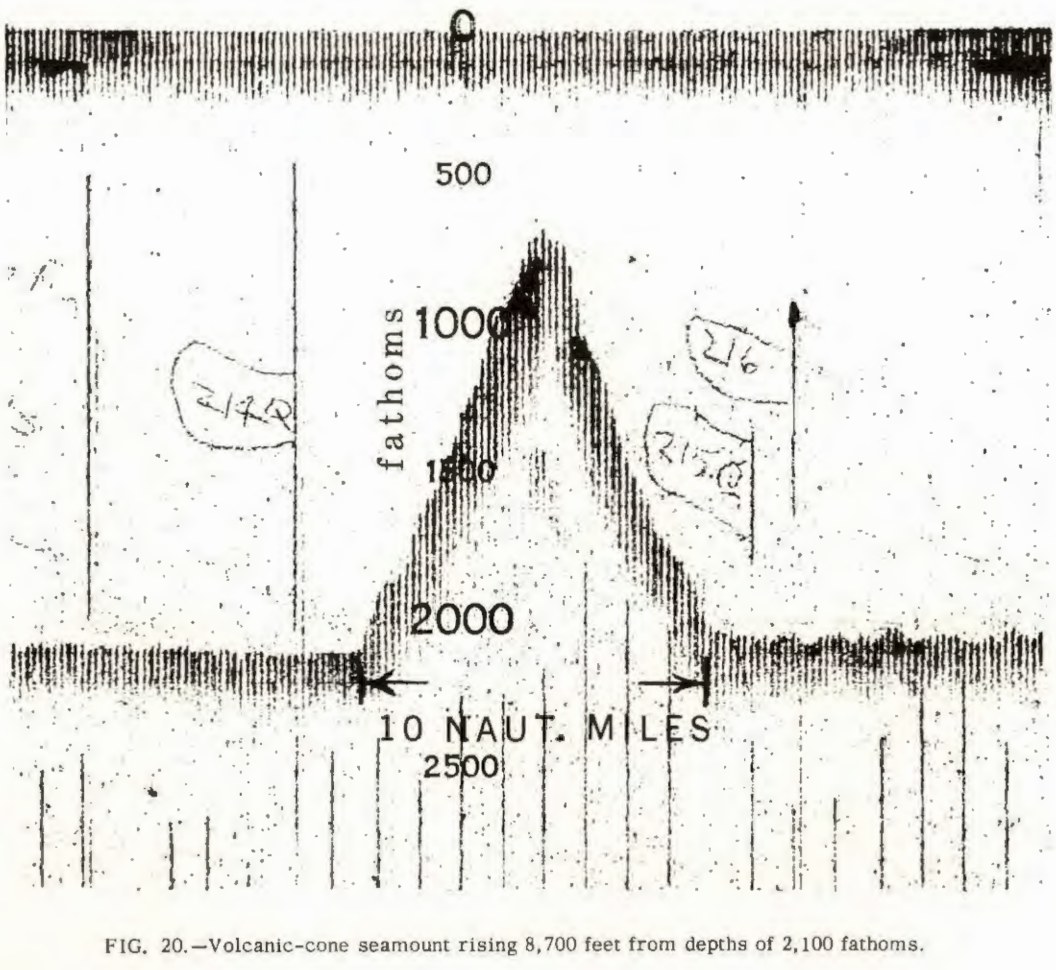

FIG. 20.—Volcanic-cone seamount rising 8,700 feet from depths of 2,100 fathoms.

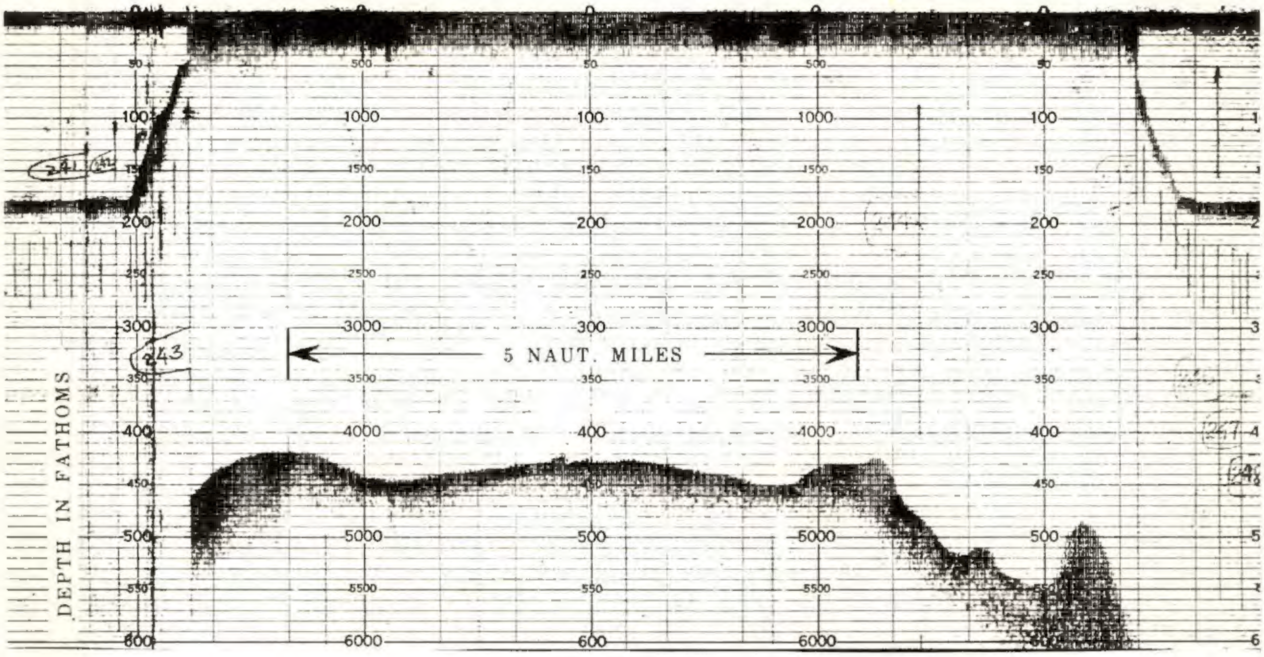

FIG. 21.—Profile on deep scale interrupted to record crest of tablemount at 420 fathoms on expanded shoal scale.

The western margin of the North American continent partially encircles a large region of the Northeast Pacific Ocean, the most northern portion of which is the Gulf of Alaska (fig. 19). This region is an immense waterway for commerce between ports of the West Coast, Western Alaska, Bering Sea, and the Northwest Pacific. Survey ships of the Coast and Geodetic Survey have continually run deep-sea sounding lines across this region since the development of echo-sounding instruments more than 35 years ago. In recent years the lines have been interrupted for detached surveys of seamounts.

The floor of the Gulf of Alaska and approaches is in general a gently sloping plain which is profusely dotted with seamounts, knolls, and ridges. The seamounts rise 3,000 feet and more, frequently rising to heights of 1 1/2-2 miles. One rises 12,000 feet to a depth of 124 fathoms below sea level. More than 160 seamounts have been discovered in the area of figure 19. It is not feasible to include a bathymetric chart of the region in this bulletin, and the reader is referred to one recently published by W. M. Gibson (1960). For additional geological discussion, reference should be made to papers by H. W. Menard and R. S. Dietz (1951), H. W. Menard (1955), and R. J. Hurley (1960).

A typical volcanic-cone seamount (arrow-marked) is illustrated by the fathogram profile of figure 20. Because of recorded exaggeration of the vertical scale the slope is not as steep as it appears. The seamount base is 10 miles in diameter, and the 1 1/4-mile-diameter crest maintains a depth of 700 fathoms except for a central peak rising 200 feet above the platform.

A profile of another seamount in the chain is shown in figure 21, the crest being recorded at a scale 10 times larger than the slope recording. The printed 600-fathom scale applies to the crest. The seamount rises nearly 8,300 feet from depths of 1,800 fathoms shown at both sides of the profile. The profile is over the longer 24-mile axis of the elliptical-shape seamount.

This truncated seamount is one of a large number of tablemounts discovered in this region and elsewhere in the Pacific. The truncation is indicative of wave planation, yet the truncated crests of large numbers are 1/2-1 mile below sea level. A full explanation of this phenomenon has not been presented for unanimous acceptance by scientists. It is generally considered that submergence has resulted from local and regional subsidence. There is evidence of local subsidence at many seamounts which rise from circular depressions called moats. Greater subsidence is indicated for the most westerly seamount of the northern chain (fig. 19), which rises from the Aleutian Trench floor. The crest of this tablemount would be at the approximate depth of other nearby tablemounts of the chain if the floor of the trench was raised 6,000 feet to the level of the abyssal plain.

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