THE CONTINENTAL SHELF OF ISRAEL *

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ABSTRACT

Detailed sounding profiles made across the Mediterranean continental shelf of Israel show the presence of sand, mud, and rock bottom. Some of the rocks are in the form of submerged kurkar ridges which have served as dams to cause the deposition of mud and sand on their shoreward sides. That these sediments have been derived mostly from the Nile River is indicated by a southward shoaling of the flat areas of the shelf. In contrast, the shelf edge, believed to have been eroded across rock bottom, deepens to the south, probably in response to downwarping of the earth's crust under the weight of the Nile Delta off Egypt.

INTRODUCTION

The Mediterranean Sea is probably the area in which maritime sciences were first developed by the ancients for their trading and fishing industries. During the second millenium these sea-peoples, the Mycenaeans and Phoenicians, had several ports along the coast of Canaan from Byblos in the north to Gaza in the south. Most of the sites were later occupied by larger harbours constructed by Romans, Crusaders, and others. In spite of the long and more or less continuous commercial and military use of the sea bordering Israel, however, neither these waters nor the sea floor beneath them are well known.

The first comprehensive survey of the topography of the sea floor off Israel was made in 1862 by the British Admiralty. A new survey in 1932—1933 aboard H.M. Surveying Ship ENDEAVOUR provided new soundings for the continental shelf. Navigational charts now in use are based on both these surveys. Data from these charts, supplemented by later soundings and bottom samples, were incorporated by Rosenan (1937) into a series of four 1:100,000-scale charts for fishermen, published by the Palestine Fisheries Service in 1938. Subsequently, some additional information about the topography (Fig. 1) and bottom materials was gathered incidental to studies of water characteristics and organisms, largely by personnel of the Sea Fisheries Research Station at Haifa (Oren, 1952; Wirszubski, 1953; Gottlieb, 1959). However, as pointed out by Shalem (1955), the composition, history, and origin of the shelf are still imperfectly known, and more geological research is needed.

Knowledge of the continental shelf off Israel is warranted, if only because its area is nearly 8 per cent of the total area of Israel. In particular, more precise information about the sea floor—its topography and composition—should prove of value to the fishing industry by outlining areas where bottom topography permits trawling, and to coastal engineering by indicating paths likely to be followed by sand moving along the shore; scientifically, a study of the physiography and lithology of the shelf may provide a better insight into the geological history of the country, especially during the Pleistocene.

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SURVEY METHODS

Between May 7 and 12, 1959 some topographic characteristics of the continental shelf were investigated by a survey aboard the research and training ship MEVUOT YAM, kindly provided for the purpose by the Department of Fisheries, Ministry of Agriculture, at the initiative of O. H. Oren of the Sea Fisheries Research Station. This 18-metre 60-ton steel trawler was capable of making a speed of 6 to 8 knots.

Echo soundings were continuously recorded with an Elac model Arcturus LAZ 17 AV. Most of the work was within the range of the shallowest scale in which the recording paper moves at 3/4 inch per minute, and its recording width of 7.2 inches corresponds to 42 fathoms. For greater depths the paper speed and depth range was 3/8 inch per minute and 84 fathoms, or 3/16 inch and 168 fathoms. In addition to the automatic record, soundings were read from the instrument at 5- to 30-second intervals for later plotting; during the making of these readings the depth variations caused by waves were averaged out. The 5-second soundings are spaced about 20 metres apart. About 16,000 soundings taken during the 27 hours of active sounding work form the basis for the accompanying profiles. A few wire casts were made to correct the soundings empirically for the velocity of sound in the sea water; they showed only small and erratic differences from the echo soundings. A better method of correcting the soundings is that of adjusting them for the computed velocity of sound in the water at the observed temperature of 20° C and salinity of 39 parts per thousand. This velocity is 1525 metres per second, about 1.7 per cent greater than the 1500 m/sec for which the instrument was calibrated. Accordingly, depths of the original soundings were increased by 1.7 per cent to yield true depths. In order to bring the depth units into line with the metric system used on the adjacent land, all depths are expressed in metres. During the period of the survey tide corrections for adjustment relative to mean sea level were negligible, less than 0.2 metre. With the velocity correction the soundings are probably accurate to within 1 metre, but along the profiles the relative accuracy should be within about 0.5 metre.

Positions during the survey were established by double horizontal sextant angles made usually at 5-minute intervals between three known points on land. Most were prominent buildings or water towers, but some were steep cliffs. Positions are probably accurate to within about 0.2 km near shore and usually 1 km at the seaward ends of profiles. A few of the latter positions may be of lower accuracy, owing to occasional necessary use of dead reckoning required by poor visibility in early mornings. After the cruise the positions provided horizontal, and the soundings vertical control for profiles. Of the 27 profiles, 25 are at right angles to the shore and cross the shelf at 5- to 8-km spacings, one is across a submarine canyon, and one is across the seaward extension of Mount Carmel.

BOTTOM MATERIAL

The charts compiled by Rosenan (1937) give a general picture of the distribution of sediments and rocks on the sea bottom. The areal distribution of materials is patchy, as on continental shelves of most other parts of the world, but the general pattern, particularly south of Cape Carmel, is one of sand on the inner third or quarter of the shelf and mud on the outer part. Between the belts of sand and mud is an irregular zone typically 1 to 3 km wide and mostly at depths of between 30 and 50 metres consisting predominantly of shells, rock, or coral. Some of it is unmarked and at the time of chart construction was of unknown composition.

Sonic soundings taken during the course of the present survey provide additional information on the composition of the bottom. It is well known from surveys made in many areas of the world that the three chief kinds of bottom material, rock, sand, and mud, are characterized by different kinds of echograms. Rock is an excellent reflector of sound, but because rock bottom is nearly always very irregular most of the sound which strikes it is scattered. As a result echograms of rock generally show an irregular thin dark trace. Sand, because of its excellent reflectivity, also presents a thin dark trace; but its surface is smooth and flat or sloping except where large undersea sand waves cause the surface to be more or less regularly undulating. Mud bottom is usually flatter than sand bottom but, because mud is a much poorer reflector of sound, echograms show mud bottom in a mushy wide band. This width indicates considerable penetration of sound into the bottom before reflection. Where good reflecting horizons, such as sand layers or bedrock, are buried under only a few metres of mud, echoes from them may also occur on the recordings.

Echograms along the profiles made during the present survey exhibit characteristics of all three kinds of material (Fig. 2). Rock is most clearly shown by highly irregular narrow zones in the inner half of the shelf. These occur on adjacent profiles, indicating the presence of narrow elongate ridges parallel to the coast. Widths of the ridges are typically about 400 metres and heights range up to about 15 metres above surroundings. On profiles 4, 10, 11, 14, and 21 (Figs. 3 and 4) reflections at depth in the sediment indicate that the base of the ridges is buried by muddy sediments, and in profiles 17 and 23, and less certainly in several others, the mud has completely buried a ridge. The position, linearity, and size of the features make it probable that they are submerged kurkar ridges similar to those known on the adjacent land (Fig. 5B). Attempts to sample one of them off Athlit during the survey resulted only in the recovery of organic debris consisting of shells, sponges, calcareous algae, corals, and bryozoans, all of which are usually restricted to rocky areas. The now submerged position of probable kurkar ridges of eolian origin agrees well with the presence of kurkar in drill holes to a depth of 50 metres below sea level at sites on land near Gaza (Picard, 1943, p. 133) and near Tel Aviv and Netanya (Avnimelech, 1950, 1952). These and other areas of kurkar on land with their interbedded soils (hamra) have yielded flint artifacts, showing a late Pleistocene to Holocene age and deposition during a time of relatively lower sea level.

Another area believed to be rocky but possibly mantled with sediment occupies the outer part of the continental shelf, particularly south of Caesarea, where it occupies about one-fifth the total width of the shelf (Fig. 5B). The bottom is regular but with hillocks less sharp (Fig. 2G) than in those areas nearer shore which are believed to be kurkar. Correlation of hillocks from profile to profile cannot be made, at least not at the present spacing of profiles. Widths of individual hillocks reach about 400 metres and heights about 10 metres, but most are much narrower and lower. Although the undulating nature of this bottom is somewhat suggestive of sand waves, the great variation even in a given profile of the widths and heights of hillocks is more characteristic of rock bottom than of sand waves. A structural contour map (Bentor and Vroman, 1954), supplemented by later data from borings, indicates that Cretaceous strata are many hundreds of metres below sea level along most of the shore of Israel. Seaward projection of the Cretaceous surface suggests that at the outer edge of the continental shelf these rocks probably deepen to depths of more than 1500 metres below sea level. Only off Cape Carmel, where the geological structure projects seaward, is it reasonable to suppose that Cretaceous strata crop out on the shelf. The rocks most likely to form outcrops in the area of probable rocky bottom near the shelf edge may belong to the Sakie Formation of late Eocene to Pliocene age, or to unnamed chalks and limestones of lower to middle Eocene age. Further speculation is useless in the absence of samples from the sea floor.

A third kind of bottom irregularity is represented on Figure 5B by isolated points less than 70 metres wide and 2 metres high (Fig. 2C) on profiles 13, 14, and 15. Since these features rise above an otherwise flat bottom and are all near the ancient seaport of Caesarea, they may actually be old shipwrecks covered by sediment, rather than rock bottom. Their depth is 50 to 70 metres.

Sand bottom is indicated near the shore ends of most profiles by smoothness of the bottom and by inability of sound to penetrate it. Much more extensive, however, are the areas considered to be mud bottom. On most profiles these areas occupy the middle half of the shelf and locally they are present also on the smooth sloping surface beyond the outer belt of rock bottom. Echograms of many profiles (Figs. 2 and 4) show sub-bottom reflections from as much as 15 metres below the mud surface. Some of them appear to be extensions at depth of the hillocks believed to consist of rock, whereas others are smooth continuous surfaces that probably represent buried sand layers. The latter are present in as many as three superposed parallel layers. Other layers diverge seaward, indicating that mud in the intervening layer was deposited faster on the seaward part of the shelf, or that part of the mud was eroded away on the inner part of the shelf before being buried under a new sand layer. Internal reflections are not as abundant in profiles 1 to 10 as in the others, but in these first profiles the echo-sounder was not properly adjusted.

TOPOGRAPHY

The continental slope beyond the continental shelf of Israel is unusually gentle, measuring 2.0° in the south, but steepening to about 8.5° in the north (Fig. 1). Farther south off the Nile River delta of Egypt the slope is even gentler and farther north it is steeper. Evidently the continental slope off Israel is only a short section of the transition between a deltaic slope and a true (tectonic?) continental slope. At its base the continental slope appears to merge gradually into the deep sea floor of the eastern part of the Mediterranean Basin, though detailed soundings are lacking here. Certainly, at least the depth of the base of the slope is less off the southern than off the northern parts of Israel, again probably in response to shoaling of the Mediterranean Basin in the south by the growth of the Nile Delta (Fig. 1). Because of the greater rate of deposition of sediments in the south, this section of the continental slope has reached physiographic maturity, while the northern section has remained in about middle youth, according to the cycle outlined by Dietz (1952).

Two indentations of the continental slope occur off Israel. The more prominent one is just south of the Lebanese border, where an apparently true but as yet poorly sounded submarine canyon extends to within two km of the shore. Its walls are steep, 14°, as shown by the single sonic profile that was made (profile 1 of Fig. 4). No information is available on the topography of its mouth or on the material of its walls. Farther south, off Yavne-Yam (Minat Rubin), the continental slope is broadly indented, possibly for structural reasons that are not evident on land. A sounding profile made across the feature at about 60 metres depth revealed little evidence of a submarine canyon in the broad sag. Many other sounding lines were run along the slope connecting the outer ends of the various profiles. Most connecting lines were only about 5 km long, but one was about 30 km. None showed irregularities greater than those of the main profiles so that there is little likelihood of other submarine valleys extending across the shelf and down the slope between sounding lines.

The top of the continental shelf is flat compared with the continental slope and the adjacent land (Fig. 3), but it still exhibits irregularities. Some of these have the form of sharp narrow ridges probably composed of rock, possibly of kurkar (Fig. 5B). On both landward and seaward sides the ridges are bordered by flat areas clearly underlain by sediments (Fig. 5C). Similar flat areas elsewhere are separated only by a step or simple slope. The widest flat area occupies a strip down the middle of the shelf south of Haifa. In few places is its outer edge sharp and definite; mostly the flat area gradually steepens in a seaward direction until at some point it either suddenly becomes much steeper, or more commonly it joins the belt of rocky bottom on the outer part of the shelf. Accordingly, two points can be taken on each profile as indicating the seaward edge of the shelf, either the place where steepening begins or the place where the slope becomes markedly steeper or changes to rock bottom. Mostly the place of greatest steepening on the profiles is within the belt of rocky bottom. This steepening fits the accepted definition of the edge of the continental shelf (Wiseman and Ovey, 1953). The depth of the shelf edge becomes gradually shallower from about 110 metres in the south to about 80 metres in the north.

An attempt was made to systematize and compare the flat areas of the various profiles in the manner used by Emery (1958) for similar profiles off southern California. Flat sections were marked off on each profile of Figure 4 by brackets (┌ ┐) to indicate the seaward and landward (or deeper and shallower) edges, respectively. Since the selection of flat areas is subjective, the use of these brackets allows the reader to determine for himself the degree of acceptability of choice. The position of each flat section on the profiles was plotted in map form on Figure 5C, and connections were drawn between adjacent profiles. The resulting map shows that the shelf edge lies mostly between 10 and 20 km from shore. Inshore of it is a gradual slope that leads inward to the western edge of the broadest flat area. Throughout about half of its length this flat area is limited in the east by a ridge or a short upward slope (Fig. 4, profiles 15 and 20); elsewhere it grades into the next flat area (Fig. 4, profiles 16 and 24). Thus two flat areas lie parallel and adjacent to each other; locally they are separate and elsewhere they merge. South of Caesarea the second flat area is bordered by a narrow discontinuous third one that was detected in only three profiles (18, 20, 25). North of Caesarea, however, this third flat area is slightly broader and appears to be continuous as far as the Lebanese border (Fig. 5C). Still a fourth flat area appears in Haifa Bay extending from Cape Carmel to the Lebanon border and partly joined and partly separated from the third one in much the same manner as the first and second flat areas are related to each other south of Caesarea. A small fifth flat area occurs inshore of the fourth one near the Lebanon border. Thus in plan there are five flat areas on the continental shelf arranged roughly in echelon with only three present in any given profile, but with flat areas disappearing on the seaward side and new ones appearing on the landward side from south to north.

The same flat areas can be correlated according to depth. With this method the degree of certainty of identification of the edge of flat areas is indicated by the breadth of a bar that shows the depth span of each area. Corresponding flat sections of each profile are connected by lines in much the same manner as they were connected in map form. The resulting chart (Fig. 5A) represents the flat areas as though they were visible to a viewer looking toward the coast from the sea. According to this interpretation, each of the flat areas becomes deeper toward the north, just as they diverge seaward from the shore.

ORIGIN OF SHELF TOPOGRAPHY

On most of the profiles the shelf edge is located in an irregular and presumably rocky area which occupies an outer belt along almost the whole length of the continental shelf off Israel. A shelf edge in rock must be erosional in origin and was eroded probably during a stage of glacially lowered sea level during the Pleistocene Epoch, as discussed by Dietz and Menard (1951) and Emery (1958). Originally, the shelf edge would have been nearly the same depth along the whole coast, but at present it deepens from about 80 metres at the northern border of Israel to 110 metres at the southern border. The southward deepening may reasonably be attributed to downwarping of the region by the great weight of the Nile Delta. The bottommost beds of the delta appear to have prograded across the floor of the Eastern Mediterranean Basin, building a gentle slope from south to north (Fig. 1) so that the deepest area of more than 2500 metres lies just south of Cyprus rather than off Egypt. The area of probable thickest deltaic sediments, near the shore of Egypt, is one of some seismic activity (Shalem, 1959), a result to be expected from isostatic loading of the earth's crust. The same downwarping is reflected in eastward sloping tops of the kurkar ridges in Egypt west of the delta (Sandford and Arkell, 1939; Shukri, Philip and Said, 1956).

Downwarping must have begun long ago, when the delta reached a critical size. The slowest downwarping should occur in the northern part of the Israel coast far from the delta, and, as shown by Rim (1950—51), the present gradient (1:10,000) of a Roman aqueduct draining southeasterly to Caesarea indicates that downwarping to the south or west has been negligible there during the past 2000 years. Only the downwarping since the shelf was eroded across the rocks now exposed at the edge of the shelf is recorded by the variation in depth of the shelf edge. Radiocarbon dating indicates that the shelf edge in southern California was eroded about 20,000 years ago (Emery, 1958). Such a date may correspond to the pre-Flandrian regression of the sea to a position west of the present coast of Israel, as inferred by Avnimelech (1950) from well borings. However, speculation about the rate of subsidence from these data alone seems unwarranted.

The flat areas atop the shelf off Israel are mostly underlain by sediments, as shown by their smooth surface and by the presence of sound-reflecting layers as deep as 15 metres below the sea floor. Mostly the outer edge of each flat area is bordered by a long narrow ridge believed to be a submerged kurkar ridge identical with those that parallel the cost on land. Damming of the sediment by the ridges serves to cause a shoaling similar to that of stream deposits behind dams. Conceivably, some of this deposition occurred subaerially in the form of swamp deposits like those now accumulating behind the kurkar ridges of the land. In most places the ridge still projects above the bottom on either side; elsewhere, sediments have built up to its crest and have begun to spill over it to form a simple slope or step down to the next deeper flat area. In still other areas the ridge has become buried, so that the two parallel flat areas have coalesced along their length. In some profiles (Nos. 17 and 23) the buried ridge is indicated by sub-bottom echoes.

It is evident that the control of deposition exerted by the ridges means that at least most flat areas do not represent former stages of erosion or deposition at lowered sea levels of the Pleistocene glacial stages. Instead, the flat areas are probably more or less contemporaneous, and their deposition is still continuing. Again the influence of the Nile River can be detected, in the faster rate of deposition of sediments atop the continental shelf in the south than the north. That the Nile River is capable of such a contribution is indicated by its average annual discharge of 57,000,000 tons of suspended sediments (Shukri, 1950) and by the eastward movement of the offshore Mediterranean current past the delta and toward Israel (Oren, 1952; Anonymous, 1958, p. 32). The main flat area is about 30 metres shallower in the south than in the north (Fig, 5A) even though the shelf edge there is about 30 metres deeper; thus the sediments atop the original eroded surface of the southern part of the continental shelf are considerably thicker than those in the north, possibly more than 60 metres thick. Unquestionably, the collection and examination of core samples from the sediment-covered areas of the shelf will provide interesting information on the late geological history of the coastal region of Israel.

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EXPLANATION OF FIG. 1

Topography of the deep-sea floor and continental slope of the eastern Mediterranean Sea. Generalized contours are based on soundings given on U.S. Navy Hydrographic Office Chart No. 3924 (British Admiralty Chart No. 2634). Profiles A to G were supplied by O.H. Oren, Sea Fisheries Research Station, Haifa; profile H is from Dietz and Menard (1951, fig. 8).

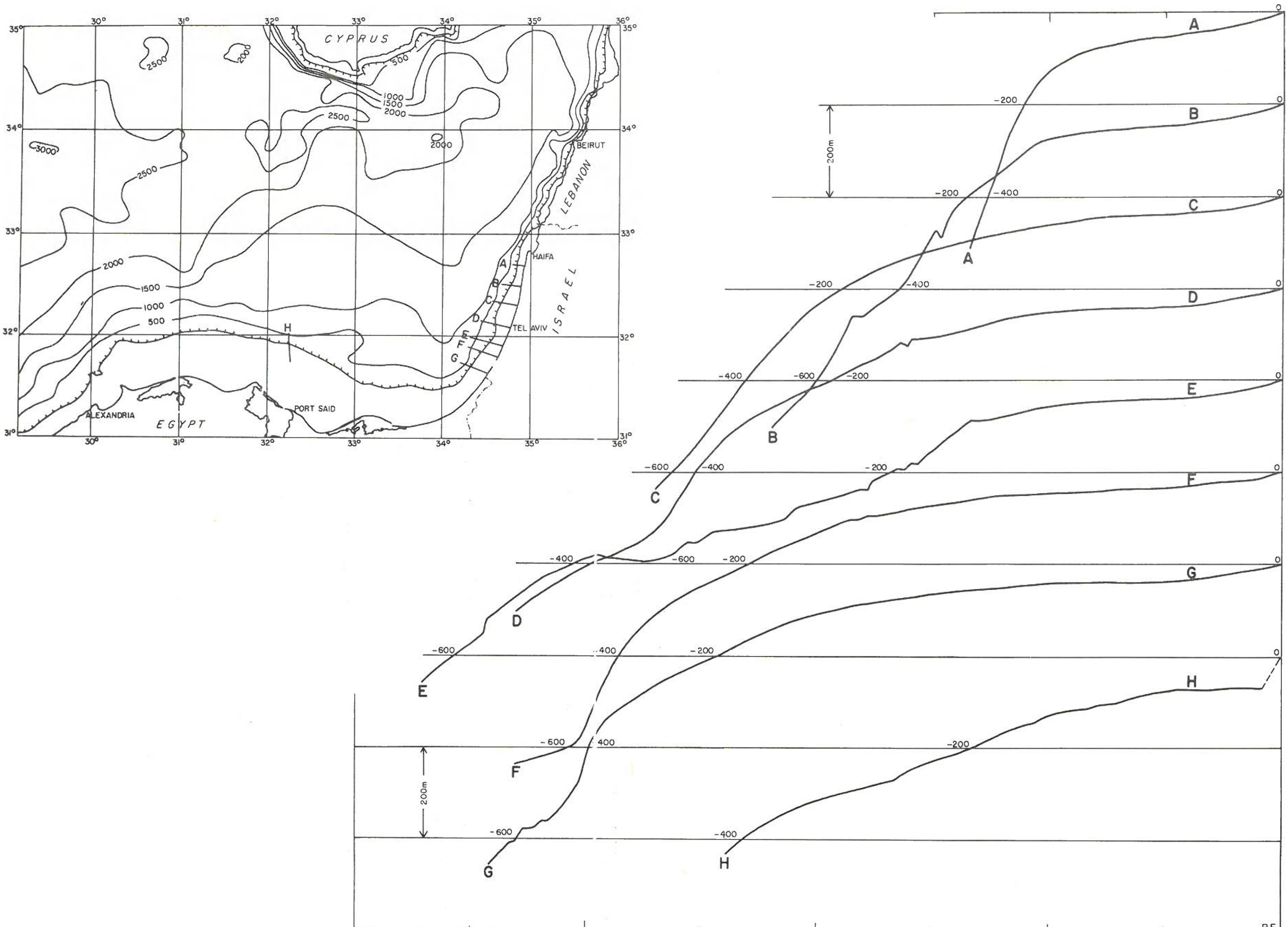
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Fig. 1

Explanation of fig. 2

Typical sections of echograms.

A. Profile 13; 10 to 40 m.; east at right, Sand bottom; echo at lower right is double reflection from sands, not a sub-bottom echo.

B. Profile 23; 40 to 70 m.; west at right.
Mud bottom; sub-bottom echoes are from two diverging sand (?) layers beneath mud.

C. Profile 14; 40 to 70 m.; west at right.
Shipwreck (?) on mud bottom off Caesarea.

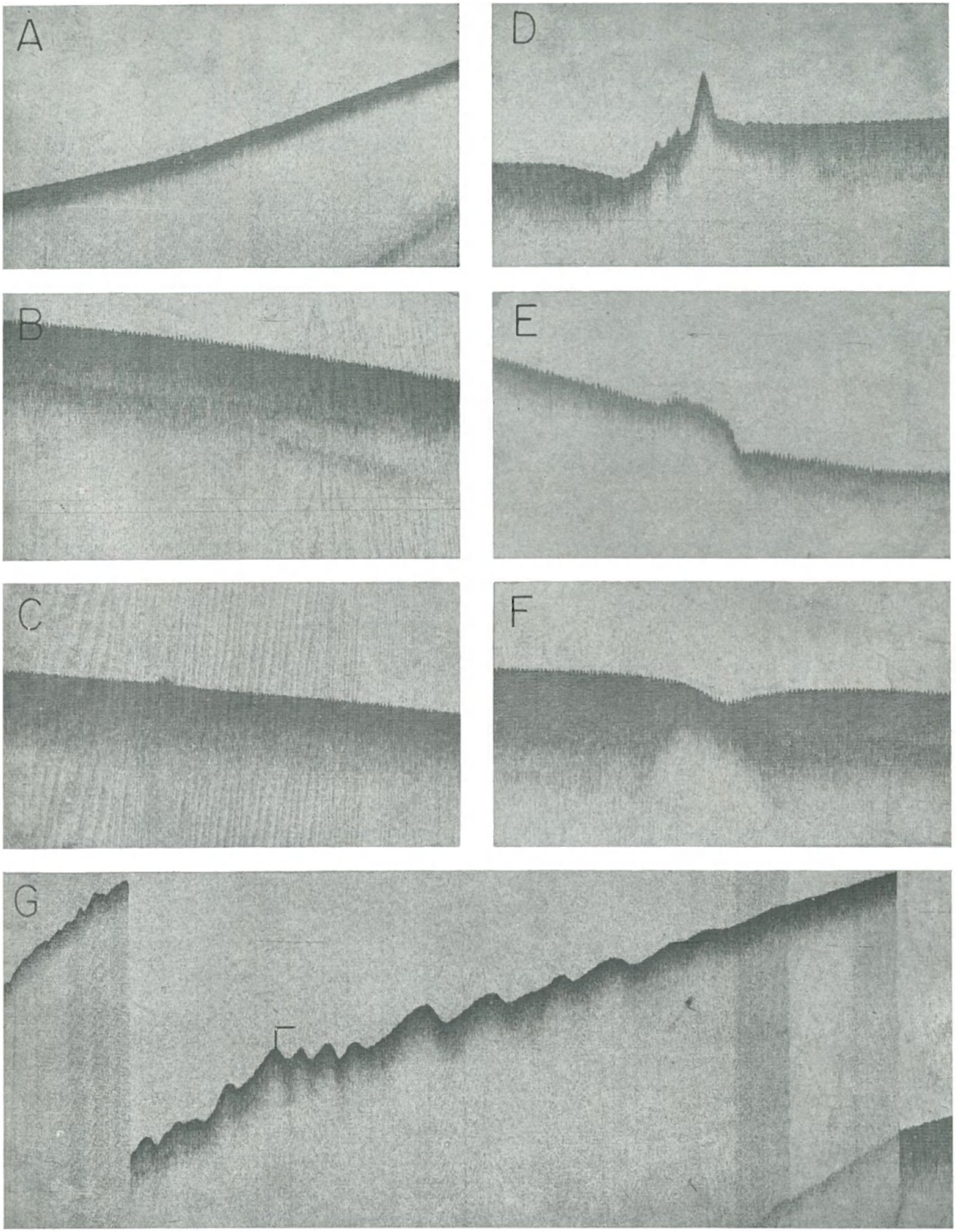
D. Profile 15; 30 to 60 m.; east at right.
Kurkar ridge; note sub-bottom echoes at right of ridge.

E. Profile 11; 40 to 70 m.; west at right.
Kurkar ridge serving as dam to sediment from left; note sub-bottom echoes at right.

F. Profile 23; 30 to 60 m.; west at right.
Kurkar ridge nearly completely buried under sediments; note sub-bottom echoes from ridge and from sand (?) layers under mud of both sides of ridge.

G. Profile 21; left 120 to 280 m, middle 60 to 140 m, right 30 to 70 m; east at right.
Rock bottom at outer edge of shelf; bracket indicates assumed shelf edge.

FIG. 2



EXPLANATION OF FIG. 3

Topography of continental shelf and adjacent land area of Israel. The 20-metre interval contours are based on soundings along the indicated profiles made May 7—12, 1959 aboard MEVUOT YAM. Contours of land area are from topographic maps of the Palestine Survey.

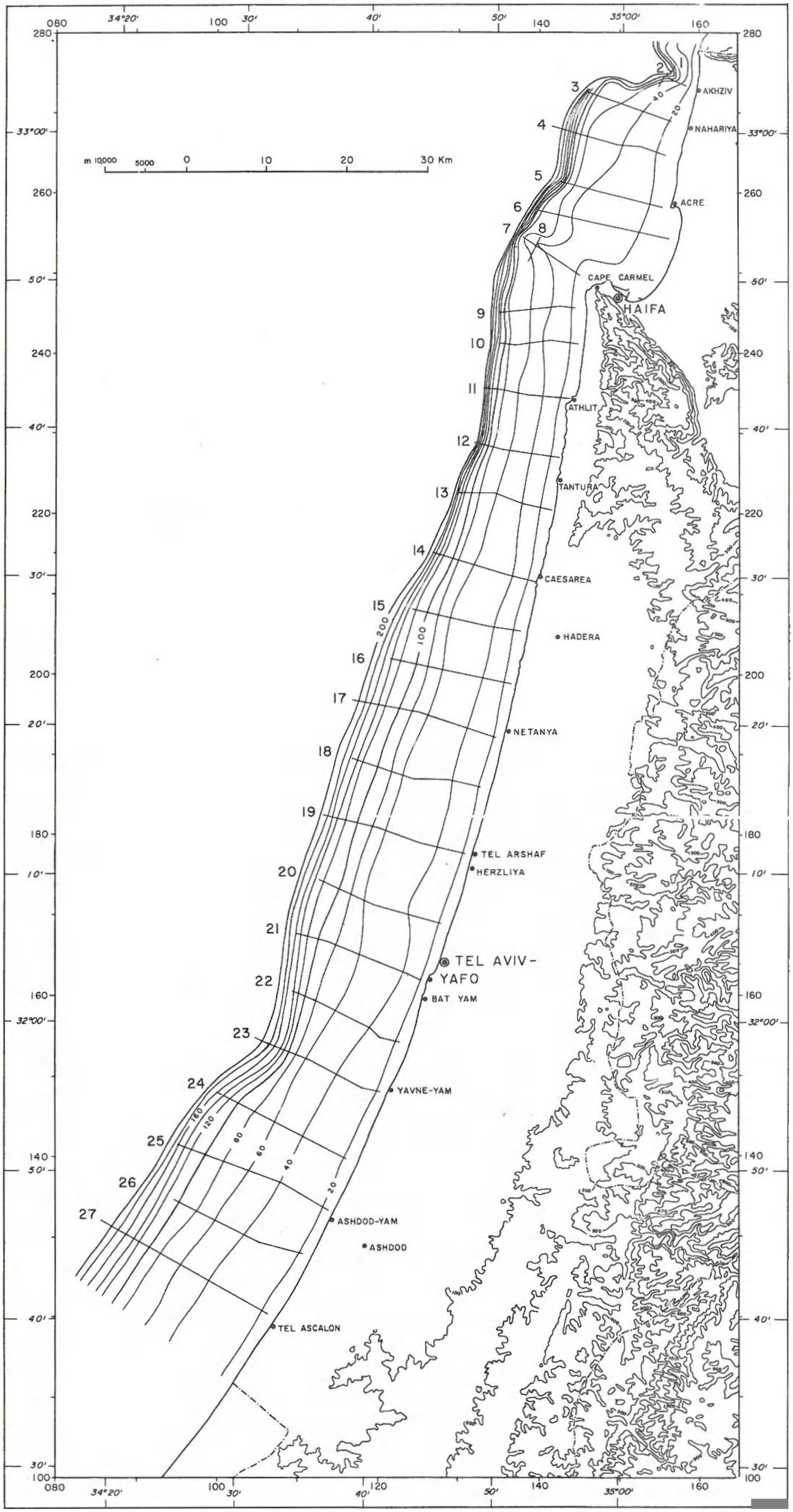

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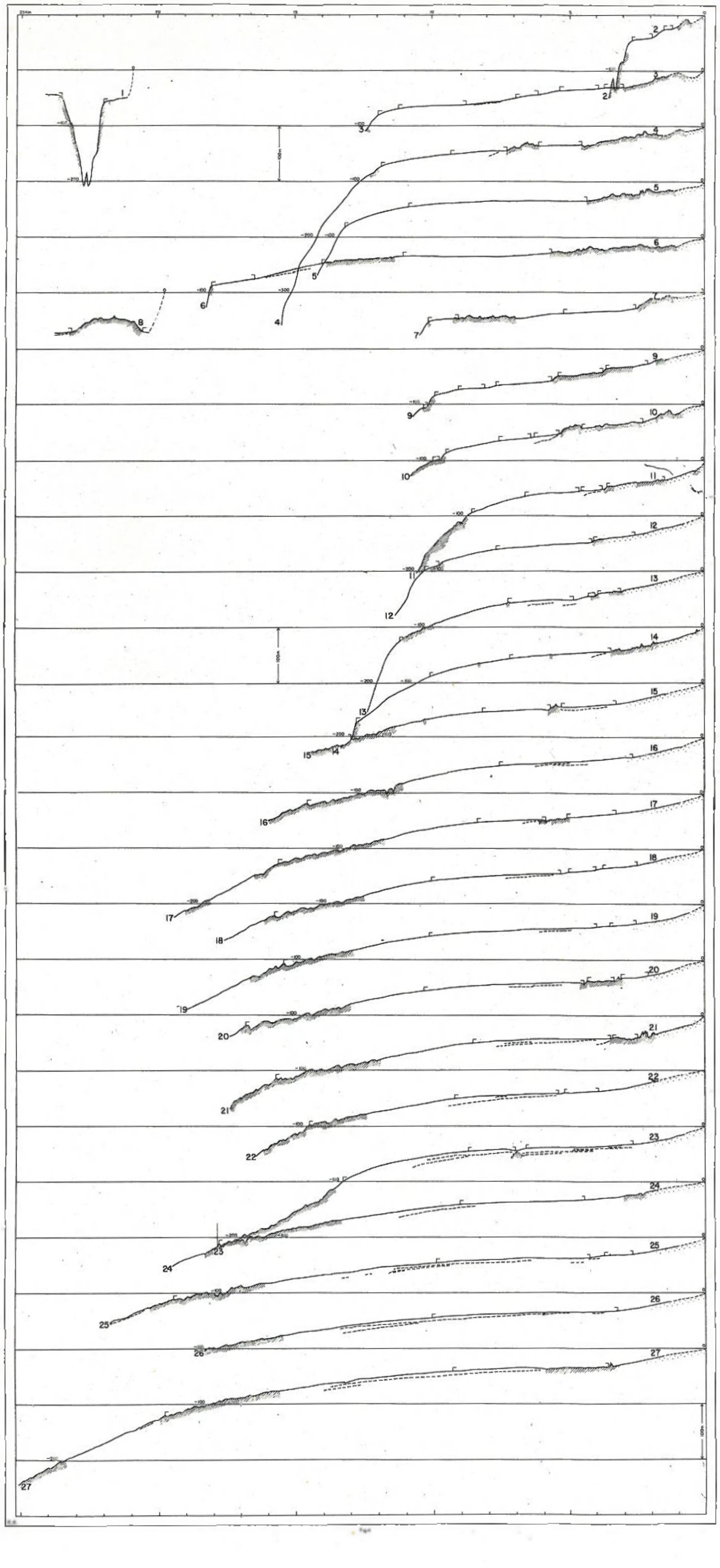
Fig 3

Explanation of fig. 4

Profiles across the continental shelf at positions given by Figure 3. Each profile is based on soundings read at about 20-metre spacing as read on echo-sounder (not corrected for sound velocity) checked by references to an automatically recorded echogram. The shallow nearshore portion, shown by dashed line, is estimated from soundings on published charts. Dashed lines below the bottom are reflections visible on echogram; some are from rock and others from sand layers buried beneath mud. Vertical exaggeration is 20. Brackets (⌈ and ⌉) indicate positions of flat sections of each profile. Shading indicates rock-bottom, dots sandy bottom.



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Explanation of Fig. 5

Details of shelf topography.

A. Depth distribution of flat areas based on Figure 4 but with depths corrected for sound velocity. Narrow vertical lines indicate depth range of sounding profiles. Wider portions indicate depth range of each flat area with widest portions representing the most definite evidence of depth of edge of flat area. Shelf edge is indicated by small isosceles triangles.

B. Areas of rock bottom based on characteristics of echograms. The outer area is a broad belt of numerous hillocks. The inner narrow areas are believed to represent kurkar ridges, the probable trends of which are indicated by dashed lines. For comparison, the positions of kurkar ridges on the adjacent land are given from data on aerial photographs, topographic maps, and field observations.

C. Areal distribution of flat areas based on correlation of sections of profiles of Figure 4 that are marked off by brackets. Positions of profiles are also shown.

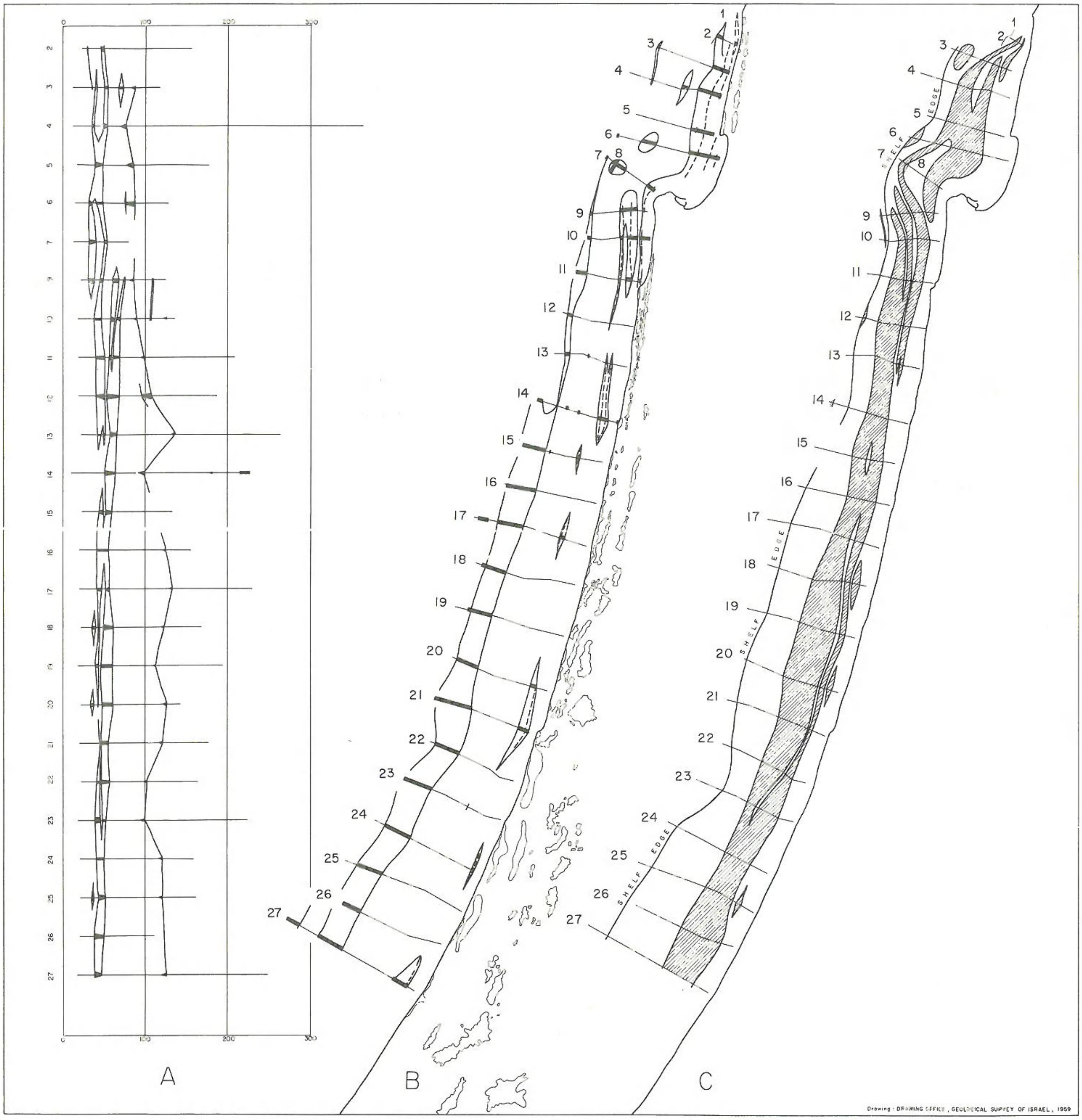
A
B
C
SHELF EDGE
Drawing: DRAWING OFFICE, GEOLOGICAL SURVEY OF ISRAEL, 1959

Fig 5

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