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STATE OF ISRAEL

MINISTRY OF AGRICULTURE
DIVISION OF FISHERIES
The Sea Fisheries Research Station
BULLETIN No. 28

MINISTRY OF DEVELOPMENT
GEOLOGICAL SURVEY
BULLETIN No. 26

# 1. MEDITERRANEAN BEACHES OF ISRAEL

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# 2. THE CONTINENTAL SHELF OF ISRAEL

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JERUSALEM
JANUARY 1960

# MEDITERRANEAN BEACHES OF ISRAEL *

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## ABSTRACT

A northward decrease in grain size and a similarity in mineral composition indicate that beach sands of Israel are derived mainly from the Nile River but with some contribution from streams and sea cliffs of Sinai. The sands have been transported from Egypt by a fringe of the general Mediterranean current and by wave-induced currents. Off central and northern Israel the Mediterranean current continues its northerly transportation of sand, but curvature of the coast causes the wave-induced current to return some sand to the south-central part of the coast. Particularly in that region some of the beach sand is blown inland to form sand dunes. Similar distribution patterns of sand existed during the Pleistocene Epoch, as illustrated by the position and nature of eolianites.

## INTRODUCTION

The coast of Israel forms the southern part of the eastern end of the Mediterranean Sea, trending southsouthwest-northnortheast in a concave arc which is smoothly curved except for the projection of Mount Carmel and its associated indentation of Haifa Bay. On one side the shore is fringed by a coastal plain and on the other by a continental shelf.

Most of the shore, particularly of the southern two-thirds of Israel, consists of sand beaches. During hot summer days the beaches near population centers are crowded, and this use for recreation is likely to be greatly expanded in the future. Sands of the beaches also are extensively mined for use in building construction, but if mining should be faster than natural replenishment some beaches can be expected to disappear. Loss may locally be delayed by greater contribution of sandy debris from increased wave erosion of sea cliffs or dunes that are now protected by the beaches, but at the same time this erosion can undermine and destroy buildings and other shoreline structures. Local excesses of sand supply produce other problems, such as silting of harbours caused by trapping of sand from longshore drift. Many of the basic data needed for proper understanding and control of these problems are geological in nature: the source, movement, and fate of the beach sand. Inferences about them can come from shore topography, water movements, and composition of sands on the beaches and shallow sea floor. Existing data were supplemented by samples and observations collected from April 14 to 17, 1959, at beach stations spaced about five kilometres apart between the borders of Israel with Egypt and the Lebanon (Fig. 1).

## ACKNOWLEDGEMENTS

Appreciation is due the Guggenheim Foundation for providing a research fellowship for Emery during a sabbatical leave from the University of Southern California. All transportation and laboratory facilities were furnished by the Geological Survey of Israel. Special thanks are given M. Pomerancblum for making analyses of heavy minerals in the sand samples.

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* Manuscript Submitted August 1959.

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# TOPOGRAPHY

Information about the topography of the land behind, in front of, and beside a beach may be almost as useful as knowledge of the topography of the beach itself. Between the Israel-Egypt boundary and Bat Yam (Fig. 1) the beach is backed by dunes that lie against old sea cliffs or atop low deltaic plains. Active dunes in this area extend as far as five km inland from the shore, partly atop eolianite (calcareous cemented Pleistocene dune sand) ridges, often referred to as kurkar (Picard, 1943, pp. 131—137; Avnimelech, 1952). Uncut by wave erosion, the presence of active dunes indicates that this part of the shore is now depositional in nature and has been depositional for an unknown time, possibly for more than several hundred years. At only a few places (stations 3 and 9) are there small projecting points of eolianite that are being eroded.

Between Bat Yam and a point near Hadera (station 18) undercut sea cliffs of eolianite back most of the beaches, indicating that the beaches are too narrow at least seasonally to protect the shore and that erosion is dominant. Only off deltas (such as station 15) can deposition be considered important. North of Hadera the shore is irregular with rocky points and beachrock (calcareous cemented beach sand) alternating with short to long beaches; in this area erosional and depositional shores are approximately equal. Beachrock is exposed along most of the coast of Israel, but north of Bat Yam (stations 18, 19, 22, 30, 31, and 33) it locally forms barriers that stand between the waves and existing remnants of beach (Fig. 2B). At several stations (9, 18, 20, 22, 27, 30, 31, and 33) beachrock or eolianite ridges lie a few hundred metres offshore and constitute reefs (navigational sense) that also protect the shore from wave erosion. Many of the more prominent sea cliffs and projecting points once served as sites for Roman and Crusader fortifications; some of the same sites were used earlier by Phoenicians and later by Turks and others. Among them are Ascalon (station 3), Minat Isdud (station 5), Yavne-Yam (Minat Rubin) (station 9), Yafo (stations 11—12), Tel Arshaf (Apollonia) (stations 14—15), Caesarea (station 20), Athlit (station 24), Acre (station 30), and Akhziv (station 33). Wave erosion at nearly every site is indicated by fallen masonry. In summary, the shore south of Bat Yam is dominated by deposition, that between Bat Yam and Hadera—by erosion, and for that north of Hadera deposition and erosion are about equally important.

Soundings show that the sea floor along the entire coast south of Haifa is gently sloping from near the shore to a depth of about 20 metres at about one km seaward. In some areas the gentle slope extends deeper and farther from shore. Such smooth profiles are characteristic of sandy bottoms and this topographic indication is supported by existing sediment samples and by notations of bottom materials (Rosenan, 1937). North of Haifa the shallow sea floor is mostly irregular, in response to the presence of reefs of eolianite or beachrock.

Cross-sectional profiles of the beaches (Fig. 3) show that most have berms (flattenings or gentle backslopes at the top) and that most of the berms occur on depositional shores. Erosional shores containing only relatively small amounts of sand have narrow beaches with no berms (Figs. 1 and 3). Measured slopes of the foreshores range from 2° to 11° in the strip wetted by wave wash. As shown by Figure 1, the steeper slopes are usually those of coarsest grain size; however, a secondary factor that causes beaches to be steep is the effect of offshore reefs and barriers in preventing access of large waves (for example, at stations 18, 20, and 22). Probably both the width and steepness of the beaches undergo seasonal variations in response to high waves of winter storms, as they do elsewhere in the world (Shepard and LaFond, 1940). Lunar beach cycles are probably negligible owing to the small range of both spring and neap tides.

Superimposed on the gross topography of the beaches are many minor features that are typical of beaches in other regions. Among these features are cusps (as much as 30 metres from point to point), linguloid ripple marks, current and wind ripple marks on the berms, rills, swash marks, holes, sand domes, and excess porosity (Emery, 1945). Submarine parts of the beaches contain troughs that serve as feeder channels to the rip currents (see page 5) that were noted at nearly every station along the shore. Some of the feeder and main channels are more than a metre deep and similar in shape to those of California (Shepard, LaFond, and Emery, 1941) and elsewhere.

Throughout the entire shore, but best exposed north of Hadera, are outcrops of beachrock. This rock has the same general composition as the loose beach sand (clean sand, shells, and shell fragments), the same internal structure (laminae, gentle dips), and a trend usually parallel to that of the beach. It is evidently beach sand cemented by calcium carbonate and is similar to other beachrock in tropical and semi-tropical regions (Emery and Cox, 1956). It can be distinguished from the eolianite type of kurkar by its content of large shells (mostly of *Glycymeris glycymeris* (L.) and *G. violascens*) (Lmk.), gentler dips—generally seaward, harder and more uniform cementation, and absence of root-tubes. Locally, it contains fragments of earlier beachrock, showing that there have been several periods of cementation separated by periods of erosion. At least one of these periods of cementation occurred in post-Roman or even post-Crusader times, as revealed by the inclusion of brick, pottery, and marble fragments in beachrock at Caesarea (Fig. 2D) and Acre. In several areas, including Caesarea, it overlaps eolianite and at no place was eolianite noted atop beachrock; thus the beachrock is younger than the eolianite, at least along the present shoreline. However, as described by Avnimelech (1950), borings at Tel Aviv and elsewhere may have penetrated older layers of beachrock more than 40 metres below present sea level.

Once formed, the beachrock usually undergoes erosion, as exhibited by the presence of solution terraces, solution basins (Revelle and Emery, 1957), channels, and undercutting. Solution basins in the beachrock slabs used in Roman or Crusader construction at Caesarea, Arshaf, and Akhziv have diameters of 25 cm and depths of 10 cm, indicating a rate of formation comparable with that of solution basins in Cretaceous and Eocene sandstones of southern California (Emery, 1946). In some areas, notably below the walls of Acre, Yafo, Akhziv (Fig. 2C) and elsewhere, rimmed basins 5 metres or more in diameter cover the beachrock and were formed either by solution of the central areas or by growth of organic material on the rims.

## WATER

The most important currents influencing movement of beach sands are, of course, those that occur in shallow water in contact with the sands. In this region two different kinds of nearshore currents are important for sand movement. One is the inner fringe of the general offshore current, and the other is the wave-induced current inshore of the surf zone. These currents are independent and can move in the same or in opposite directions.

The main surface current in the eastern end of the Mediterranean Sea is directed northward, as part of the general counterclockwise circulation pattern (Sverdrup, Johnson, and Fleming, 1942, p. 649). Only a fringe of this current flows atop the shelf and, although its velocity must decrease markedly in shallow water near the beaches, it appears to be significant even here. The presence of the current is indicated by a northward set of ships (observed in May by the writers during an offshore topographic survey along the entire coast, as well as by others at various places and times), and by the presence of coconuts on many beaches of Israel, doubtlessly drifted from Egypt. Northward currents beyond the surf zone are also demonstrated by measurements by harbour engineers off Ashdod Yam and by observations by members of the Fishery School off Mikhmoret (about 6 km north of Netanya). The offshore current appears to be fastest in fall and winter when the parts of it nearest shore are also marked by low salinity, high nutrients, and high turbidity produced by a tongue of flooding Nile River water which is carried along the entire coast at least to Lebanon (Oren, 1952). Movement of the offshore current is aided at this time by the general presence of an atmospheric high pressure zone in the general area of the Nile Delta that produces winds from the southwest off most of Israel (Ashbel, 1948, p. 5). During the summer the low pressure zone is located farther northeast, so that winds off Israel are largely from the northwest. Although these summer winds are not strong, they are steady and appear to cause a decrease in velocity and even occasional reversals of the offshore current on the shelf.

Nearer shore than the general current is the longshore current produced by waves acting against gently shelving beaches. Data on waves were obtained by A. Doiban (personal communication) at Ashdod Yam between 1 April 1958 and 31 March 1959; during this period wave heights ranged up to nearly 6 metres with highest waves during February (35 per cent of February observations being more than 2.5 metres). Wave periods ranged from less than 4 seconds to about 12 seconds, with longer periods corresponding to higher waves. During the survey of 14 to 17 April the mean heights were 2.0 metres between Ascalon and Ashdod Yam, decreasing to 0.6 metre north of Netanya. The period averaged about 4.5 seconds. Data on direction of approach are scanty because of lack of high observation points; however, three trains of different direction and period were observed on many occasions from the heights of Mount Carmel, throughout a ship-board survey along the whole coast, and during two passenger airplane flights parallel to the coast between Yafo and Ascalon. All available observational data indicate that the largest and longest period waves come from approximately 280°. This is also the direction of longest possible fetch; fetches from other directions are restricted by nearness of the coasts of Cyprus, Greece, and Egypt. Waves from about 280° (azimuth of crest: 010) approach the curved southern coast of Israel in such a way that before refraction the apex of the angle between wave crests and shoreline points southwestward; thus a longshore current to the northeast should be produced by the waves (Shepard and Inman, 1950). The same waves approach the northern part of the coast parallel to the shoreline or with an angle in the opposite direction, so that longshore currents should be small and generally toward the south. In the northern half of Israel's shore only in areas of reversed trend of the shore, such as the south side of Haifa Bay, should the wave-induced current be northward and of high velocity. Another such area of reversed coastal trend north of the Lebanese border must also cause a northward current, away from Israel.

Local storms can also be expected to produce waves capable of considerable erosion and movement of beach sands. From compilations of wind data by the Israel Meteorological Service (Tel Aviv), computation was made of the average percentage of the number of observations (at 0800, 1400, and 2000 hours) during each month at Gaza, Tel Aviv, Netanya, and Acre which show winds in excess of Beaufort Wind Force 6 (44 km/hour). The results show that between January and April strong winds from the southwest and west are more common than those from the north and northwest at Gaza (20% vs. 0.2%) than at Tel Aviv (4.5% vs. 0.7%), Netanya (2.5% vs. 0.2%), and Acre (0.4% vs. 0.0%). During the rest of the year at all four places such strong winds are too rare to be significant. Thus the strongest winds in the coastal region are from the southwest and these winds are more frequent south of Bat Yam than north of it. Waves produced by such winds should form northward-flowing longshore currents capable of bringing more sand to beaches south of Bat Yam than they carry away to beaches farther north.

Observations at each of the collection stations of Fig. 1 showed that at least during the dates of the survey the longshore currents inshore of the surf zone were northward between Egypt and Bat Yam and southward between Bat Yam and the Lebanon, with velocities commonly of 25 to 40 metres per minute, or about 0.5 to 1.0 knot. Information on long-term longshore current direction is provided on many coasts by preferential accumulation of beach sand against one side of obstructions or in quiet water at their lee sides. At the narrow projecting point of Yavne Yam an accumulation against the south side shows that the longshore current must be prevailingly northward. The groins and breakwaters at Yafo and Tel Aviv show only a slight tendency for longshore sand movement there, again northward. Farther north at Tel Arshaf a map of 1871 (Vilnai, 1953) shows an accumulation of sand against the north side of a now destroyed Crusader jetty, indicating a longshore current from the north. Support for the latter indication is provided by observations of Mr. Burton B. Most (Dead Sea Works) during year-round swimming excursions that reveal an invariable southward drift, at least in good weather, about one km south of Tel Arshaf. At Haifa Bay the wave-induced currents move from each end of the bay toward its center back, as indicated by accumulations of sand east of the harbour jetty at Haifa and south of the Crusader fortifications at Acre.

The longshore transport of water locally causes it to accumulate, raising sea level several centimetres. When the hydrostatic head so produced is sufficiently high, the trapped water forces its way seaward through the lines of oncoming waves in the form of a rip current (Shepard, Emery, and LaFond, 1941). Feeder currents at the shore end of the rip current may temporarily reinforce or cancel the general longshore current during their periods of flow, making the measurement of the general longshore current somewhat difficult. When the hydrostatic head becomes sufficiently lowered, the rip current ceases for a time. The local rising and falling of sea level associated with the rip currents is known as surf beat (Munk, 1949). Its period is commonly about 2 minutes and its appearance on long-period wave recordings is similar to that of harbour seiches, except that the latter are usually of longer period, 8 to 16 minutes at Ashdod Yam and 15 to 25 minutes at Haifa. The abundance of rip currents along the entire coast of Israel warrants an understanding of them in order to prevent or reduce the number of drownings caused by them and to learn something of the degree to which they carry beach sand seaward to deeper water.

In summary, the fragmentary data indicate that the inshore or eastern fringe of the general Mediterranean current generally moves northward along the entire coast of Israel and that the wave-induced longshore currents near the shore generally move from both south and north toward the south-central part of the coast. Seasonal and shorter period reversals of direction occur for both currents. The velocity of each is sufficient to transport at least fine sand.

## SEDIMENTS

### a. Texture

Grain-size distributions of the untreated whole sand samples are typical of oceanic beaches with their sorting coefficients of between 1.07 and 1.49 (average is 1.18), indicating excellent sorting by wave wash. Median diameters of the whole samples range from 150 to 1500 microns with the finer sizes occurring mostly south of Athlit (station 24). In detail the sands exhibit a general decrease in median diameter from the Egyptian border to Athlit. Fine sands are also present at the back of Haifa Bay. Elsewhere north of Athlit the beach sands are coarse, chiefly in proportion to their contents of shell fragments. At Acre (station 30) abundant rock fragments have produced an especially coarse median diameter. Median diameters of dune sands are closely similar to those of the nearby beach sands (Fig. 1) A seafloor sample from 15 metres depth 0.5 km off station 26 near Cape Carmel is fine grained, unlike the sand of the nearby beach but similar to the beach sands farther south; the presence of this sand strongly suggests an offshore connection between the fine sands of Haifa Bay and those south of Athlit. Sediment still farther from shore—beyond two to five km, and deeper—below 30 to 50 metres, consists only of mud, according to the charts of the Fisheries Service (Rosenan, 1937) and thus is unrelated to the beach sands.

### b. Colour

Even to casual observation the beach sands of Israel are varied in colour. For precise colour classification use was made of the colour charts developed by Goddard et al(1951). According to this system the sands were assigned a notation based on three colour factors: hue, value, and saturation. An example is the notation 7YR7/4 for station 1 of Fig. 1, in which 7YR is hue (yellow-red with yellow slightly dominant over red), 7/ is value (on a scale from black—0 to white—10), and 4 is saturation (from 1—almost colourless to 6—bright). As shown by Fig. 1, the colour at stations between the Egyptian border and Athlit changes more or less progressively from 7YR7/4 to 10YR7/2: from reddish buff to yellowish gray. Most sands north of Athlit are yellow-red and darker than those south of it, corresponding with high contents of calcium carbonate. Irregularities in colour are present, with some due to admixture of white shell fragments as at Haifa (station 27) or of dark pebbles as at Acre (station 30). Most interesting, however, are the areas of gray sand at Tel Aviv (stations 12 and 13) and at the back of Haifa Bay (stations 28 and 29); in the former area the sands are similar in grain size and composition to those farther north and south. Sands from dunes near the shore are generally of the same colour as the beach sands, but those from dunes farther inland are brighter (more saturated) in colour. The range is 7 to 8 YR 5 to 7/ 3 to 6.

The reddish colour of most of the sands is due to a thin coating of ferric oxide. Treatment with reducing agents (stannous chloride, metallic zinc, or sodium hydrosulfide) caused an almost complete loss of colour, so that beach sand from station 1 (7YR7/4) and dune sand from inland of station 10 (8YR6.5/4) both changed to 5YR8/1. The gray beach sand from station 12 (1Y6.5/1) was little affected. This suggests that the original reddish colour of the beach sands is lost during longshore transportation, but especially at Tel Aviv where large quantities of sewage discharge from outfalls and from the Yarkon River reduces the iron to the ferrous state. The same reduction may occur in Haifa Bay where the Qishon River also discharges much industrial and domestic waste, although the fact that the sea floor sample from off station 26 has nearly the same colour (2Y6/2) suggests that most of the iron was reduced during travel of the sand around Cape Carmel in deep water. Sand blown inland becomes brighter yellow-red in response to greater oxidation of iron and perhaps to other forms of weathering on the dunes.

### c. Calcium Carbonate

Calcium carbonate is present in the fine-grained sands, in only minor amounts (mostly less than 7 per cent) but it reaches 97 per cent in the coarse sands of the northern third of the coast. A similar areal distribution of calcium carbonate was noted by Shalem (1928) in a study of 225 well spaced samples of beach sand along the Israel and Gaza coasts. Most of the calcareous grains are fragments of pelecypods and gastropods. A few foraminifera were found in many samples and large specimens of *Amphistegina* comprise about 10 per cent of the calcareous fraction of a coarse sand near Haifa (station 27). In this sample and in others of the coarse sands echinoid spines, coral, barnacles, and calcareous algae (*Jania* and *Halimeda*) make a minor (less than 5 per cent) contribution to the calcareous fraction. Dune sands contain calcareous grains in about the same proportion and of the same composition as the nearby beaches.

### d. Light Minerals

The acid-insoluble residue of the samples was separated into light and heavy fractions by floating or sinking in a heavy liquid, bromoform. The light minerals consist almost exclusively of quartz. An average of only 3 per cent of feldspar grains are present. Samples originally rich in calcium carbonate contain some large white and pinkish grains, at least some of which are siliceous replacements of organic materials. Fragments of echinoid spines and at least one specimen of *Elphidium*, a foraminifer, were noted.

### e. Heavy Minerals

Heavy minerals content supplements grain size in indicating that the sands are retained on the beaches and dunes of Israel for a relatively short time only. Studies by Shukri and Philip (1956a) show that sands of beaches near the western border of Egypt contain much zircon (39%), believed by them to indicate derivation mostly from the Nubian sandstone (Table 1). Sands of the west central beaches of Egypt are dominated by tourmaline (34%) and smaller percentages of zircon (13%), possibly indicating that the Mio-Pliocene marine sediments of Egypt are the chief source. Heavy minerals of the beaches near the western mouth of the Nile River have about 25 per cent augite and 40 per cent hornblende, being similar to sediments of the lower part of the Nile River for which Shukri (1950) reported

46 per cent augite and 42 per cent hornblende. The high concentration of augite is from the Atbara River, which enters the Nile 1,500 km upstream, after draining the volcanic area of Abyssinia. Analyses by Rim (1950—51) show that beach sands of Sinai between Port Said and Gaza contain somewhat lesser amounts of augite and hornblende and greater amounts of zircon, rutile, and garnet than the Nile or beaches near its mouth. These differences may be a result of loss of less resistant minerals during transportation and of admixture of additional sands from sea cliffs and streams of Sinai.

TABLE 1

Composition of Sands of Eastern Mediterranean Coasts

| | Number of Analyses | Per Cent of Total Heavy Minerals | | | | | | | | Calcium Carbonate | Median Diameter of whole Sand |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Augite | Hornblende | Epidote | Garnet | Staurolite | Tourmaline | Rutile | Zircon | | |
| LIBYA[1] | 3 | 2 | 21 | 19 | 3 | 3 | 10 | 3 | 39 | 30 | 240 |
| EGYPT | | | | | | | | | | | |
| West[1] | 18 | 8 | 22 | 16 | 2 | 1 | 34 | 3 | 13 | 97 | 400 |
| Central[1] | 17 | 25 | 40 | 24 | 3 | 1 | 2 | tr | 3 | 60 | 370 |
| Nile[2] | 10 | 46 | 42 | 7 | 3 | | | | 2 | | |
| East[3] | 21 | 24 | 26 | 23 | 8 | 1 | 1 | 8 | 6 | 2 | 190 |
| ISRAEL | | | | | | | | | | | |
| South Beaches | 24 | 11 | 65 | 13 | 2 | 1 | 4 | 1 | 2 | 8 | 200 |
| North Beaches | 10 | 9 | 65 | 13 | 1 | 2 | 2 | 2 | 3 | 59 | 320 |
| South Dunes | 6 | 5 | 55 | 23 | 4 | 4 | 5 | 1 | 3 | 8 | 210 |
| North Dunes | 2 | 7 | 55 | 21 | 2 | 2 | 6 | 1 | 5 | 55 | 230 |
| Kurkar | | | | | | | | | | | |
| Kurkar[5] | 30 | 13 | 44 | 25 | 4 | 1 | 2 | 3 | 7 | | |
| Hamra[5] | 18 | tr | 36 | 31 | 4 | 3 | 4 | 6 | 15 | | |
| Rivers[4] | 8 | 2 | 35 | 22 | 4 | 6 | 7 | 8 | 14 | | |

1. Shukri and Philip (1956 a)
2. Shukri (1950)
3. Rim (1950—51)
4. Pomerancblum
5. Slatkine and Pomerancblum (1958) and Files of Geological Survey of Israel

Minerals in the sands of Israel's beaches exhibit a continuation of the trend of decreasing percentage of augite (Table 1). Hornblende is very abundant, 65 per cent, on both southern and northern beaches. Epidote is more abundant than at the mouth of the Nile River, perhaps in response to additions contributed along the Sinai coast. Tourmaline and zircon are far less abundant off Israel than off Libya, indicating the Nile as a source of beach sands that is so important as to outweight contributions from the North African coast west of the Nile.

Heavy minerals of the eolianite phase of the kurkar in Israel resemble those of the present beaches and dunes in their high content of hornblende, but epidote and zircon are more concentrated (Table 1). As shown by Slatkine and Pomerancblum (1958) and by additional analyses from the files of the Geological Survey of Israel, the same is true of the heavy mineral assemblages of the red soil-like hamra, which overlies and is interbedded with the kurkar. Clearly, the sequence is one of progressive loss during weathering of unstable minerals, such as augite and horn-blende, and the resultant concentration of resistant ones, such as zircon and rutile. A similar sequence was noted in Pleistocene terrace sediments of California by Bradley (1957), who also found stages of progressively deeper etching of augite grains into cockscomb-like shapes. The same decrease of augite and increase of stable minerals was noted in Egyptian coastal eolianites by Shukri and Philip (1956b), but they attributed the difference in mineralogy to drainage changes in the Nile River basin. Extending the weathering sequence even further back in time for Israel, Vroman (1944) reported a progressive decrease of augite, hornblende and epidote in strata of greater age and a resultant increase of the resistate minerals zircon, rutile, and tourmaline. Sediments collected from rivers of Israel (Fig. 1, Table 1) also exhibit a concentration of resistate minerals, probably a reflection of the mineral species present in the limestones of the region. One sample (H) from the Qishon River contained 54 per cent of augite because of its nearness to basalt flows; data from this unusual river sample were omitted from the averages of Table 1. Comparison of their mineralogy with that of the beaches supports the view that rivers make little contribution to the beaches of Israel except possibly locally along the northern coast (Fig. 1).

### f. Miscellaneous Materials

Among the interesting exotic materials on the beaches are many pieces of gray pumice, all well rounded and as much as 15 cm in diameter. These were noted earlier in Israel by Shalem (1928) and on Egyptian beaches by Shukri and Philip (1956a). Pumice also occurs in a layer within a sub-Recent terrace deposit at the shore near Acre and near the base of a sea cliff at Tel Aviv (Blake, 1935). Most probably the pumice floated to these coasts from volcanoes of Greece. Several pieces of dark gray to black scoria were found; their origin is unknown, but possibly archaeological.

All the beaches are littered with flat fragments of tar, mostly between 0.5 and 5 cm diameter and concentrated in swash marks near the upper limit of storm and ordinary waves (Fig. 2A). Similar fragments were observed floating at many places on the sea at least as far as 5 km from shore. A rough method of estimation showed that the largest amounts probably occur between the Egyptian border and Caesarea, the smallest amounts are near Haifa, and a second peak of abundance is in the north near Nahariya. The total amount probably does not exceed 25 tons. Locally, particularly in the south, many of the tar fragments liquify in the sun's heat and sink slightly into the sand. On all beaches the tar appears to be concentrated at the sand surface; on erosion of the beaches the tar becomes rolled about and mixed with sand to form more or less spherical balls as much as 25 cm in diameter. In contrast to the flat fragments, many of the balls are so dense (because of evaporation of lighter fractions and the inclusion of sand grains) that they cannot float in sea water. Possibly these balls eventually become transported seaward and deposited mostly beyond the surf zone. The source of the tar could be either natural seeps or washings from ships. A ship source is suggested by the probable increase in the abundance of beach tar during the past 30 years (according to local reports) corresponding to the increased use of tanker shipping in the Mediterranean Sea with the probable accumulation of most of their debris at the eastern (leeward) end of the sea. Further substantiation is given by the similarity in composition of a sample from Tel Aviv (station 12) to bunker oil according to tests made by Consolidated Refineries at Haifa.

### g. Roundness

The roundness of the detrital grains that make up the insoluble residue of the beach sands was estimated visually, using the comparison charts of Krumbein (1941). As shown by Fig. 1, the mean roundness is between 0.2 and 0.4. In general, the roundness decreases northward from Egypt to Haifa, farther north it increases again. This directional trend of roundness is believed to be a reflection of the regional trend of grain size, rather than an indication of the distance or direction of transportation. For comparison, the roundness of the coarser grains composed of shell fragments was found to lie between 0.4 and 0.5, representing a continuation of the tendency toward increased roundness with increased grain size, as well as a result of easier rounding of the softer material. The carbonate grains are also noteworthy for the high degree of polish of their surface, a feature also common for carbonate sands of beaches on coral atolls. Although the grains of quartz and feldspar are less well polished, few of them have the matt surface that indicates wind abrasion, as noted earlier by Cailleux (1949) in a brief study of Palestine sands.

## CONCLUSIONS

Data on topography, water currents, and sand texture and composition form a basis for inferences about the source, movement, and fate of the beach sands of Israel.

The bulk by far of the beach sand comes to Israel from the southwest by longshore transportation provided by both wave-induced and general offshore Mediterranean currents (Fig. 4). Contribution of calcareous organic debris is important north of Athlit on open sea beaches, where the bulk of the sand consists of broken shells. Elsewhere, in Haifa Bay and south of Athlit, sand of organic origin is minor in quantity. Sand provided by local erosion of sea cliffs could not be detected south of Bat Yam and it must be negligible at all but a few small parts of the northern beaches. Important concentrations were noted only at station 30 near Acre. Contributions of sand by rivers draining to the shores of Israel are probably also relatively unimportant, owing to the small number of rivers and to the fact that at least the larger ones have such low gradients near their mouths that they can transport little sand. Contribution of sand by wind is also insignificant, because of a prevailingly onshore wind direction. Both the grain size and composition of the detrital fraction of the sand on Israel's beaches resemble those properties of sands from the Nile River with allowances for changes en route. The Nile is the only large river that is competent to carry large quantities of sandy sediments to the sea along the northern coast of Africa; moreover, the sands of beaches west of the Nile Delta are of somewhat different composition. Therefore, it is believed that the Nile is the chief source of the detrital and main fraction of the beach sands of Israel, although probably there is some supplemental contributions from sea cliffs and seasonal streams of Sinai.

When the sand from Egypt reaches Israel its movement continues to be controlled by the same currents that brought it. The general offshore Mediterranean current that moves chiefly northward carries some of the sand with it, probably even past the northern border of Israel (Fig. 4). Some sand is washed shoreward by both wave and current action, adding to the beaches along the whole coast. By this action fine-grained detrital sand is able to reach the back of Haifa Bay, by-passing the coarse organic sands on the beaches between Athlit and Haifa. This deep-water movement around Cape Carmel is similar to deep-water movement around projecting points of the California coast. Once on the beach, the sands are moved across the beach by wave action and along it by longshore wave-induced currents. The largest waves approach Israel from about 280° so that their crests usually trend a little east of north, or 010°. Owing to the concave shape of Israel's shore, these waves produce a longshore transport of sand that is directed from both south and north toward the middle of the coast. South of Bat Yam this wave-induced current supplements the offshore one in carrying sand north-eastward. North of Bat Yam the currents are opposed, so that the sands brought to the northern beaches by the offshore current are transported back to the south by the wave-induced current. Still farther north, at the Lebanese border, another reversal of the wave-induced current causes sand to be lost to the north from Israel and no contribution can be made from the Lebanese coast. Some recycling of the sands occurs through seaward transportation in rip currents which carry sand beyond reach of the wave-induced current and back to the offshore current. In general, therefore, the source and movement of beach sand is such that the fine-grained detrital sands tend to accumulate on beaches in the southern middle part of Israel. The organic sands, on the other hand, remain near their sources on the northern beaches because of their coarseness and because locally they are protected from waves and currents by offshore reefs and irregular rocky shores.

Eventually sand must be lost from the beaches, in order that steady-state conditions be maintained and the beaches neither widen nor narrow. Some sand is dissolved or comminuted and carried seaward to be deposited with the muds that cover the outer half of the continental shelf. The rest is lost to the land by wind transportation and deposition in the form of dunes (Fig. 4). Wind losses also have occurred during the past, as indicated by the presence of consolidated Pleistocene coastal dunes. In recent years losses of sand by mining operations have probably exceeded those caused by natural processes. At present too few data exist to permit estimation of the quantities of sand annually brought to the beaches of Israel and annually lost from them. However, one can estimate the total volume of beach sand on the basis of 180 km of coast having beaches with an average width of 50 metres, an average thickness of 2 metres, and an equal amount of sand on the adjoining shallow sea floor. This estimated volume is 36 million cubic metres. Mining of the sand, according to estimates by A. Braunfeld (personal communication), amounted to about 800,000 cubic metres in 1958, 650,000 in 1957, and 450,000 in 1956. During these three years about 5 per cent of the total amount of sand must have been removed. Good estimates of the rate of contribution of sand from Egypt and of its rate of movement along Israel's beaches can be formed only by measurements of the rate of accumulation against experimental groins or harbour beakwaters, which in the future may be built across the beaches.

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## EXPLANATION OF FIG. 1

Location and characteristics of beach sands along Mediterranean coast of Israel. From left to right: (1) Positions of samples from beaches (composite samples from wave-washed zone), dunes, shallow sea floor, and rivers. Stippled areas show distribution of modern active dunes. Numbers around margin of map are coordinate system of Israel in kilometres. (2) Dominance of Recent coastal erosion or deposition at the site of samples as estimated from nature of coastal topography. (3) Distribution of beachrock as judged from field observations supplemented by aerial photographs. (4) Areas protected by offshore reefs are shown by circles. (5) Portions of the beach where mining of sand has been extensive, indicated by black lines, are based on field observations plus unpublished data supplied by A. Braunfeld, Geological Survey of Israel. (6) Longshore wave-induced currents during the dates of the survey were measured as the distance traveled in one minute by oranges or pieces of tar cast into the water (both are so dense that they float with little surface exposed to wind). (7) Slope of wave-washed zone was taken from beach profiles of Fig. 3. (8) Median diameters of whole samples and of acid-insoluble residues are from cumulative grain-size curves constructed from measurements at $\sqrt{2}$ grain-size progressions measured by settling tube of Emery (1938). Points for beach sands are connected by lines; those for nearby dune and sea-floor sands are unconnected. (9) Grain-size distribution cumulated to 100 per cent is for insoluble residue only (detrital grains). (10) Percentages of calcium carbonate were determined by weight loss on treatment with cold dilute hydrochloric acid. (11) The amount of tar on the beaches is shown by semi-quantitative estimates of the number of 100 square centimetre squares that are covered by tar in a typical strip one metre wide across the beach. (12) Colour of whole untreated beach sands is from the colour chart of Goddard et al (1951). (13) Heavy minerals of the 62 to 500 micron size fraction are cumulated to 100 per cent (measurements by M. Pomerancblum) and arranged from left to right in order of increasing stability — augite, hornblende, epidote, garnet, staurolite, tourmaline, rutile, and zircon. (14) Roundness of 20 detrital grains in each sample is based on Krumbein's (1941) chart for visual estimation.

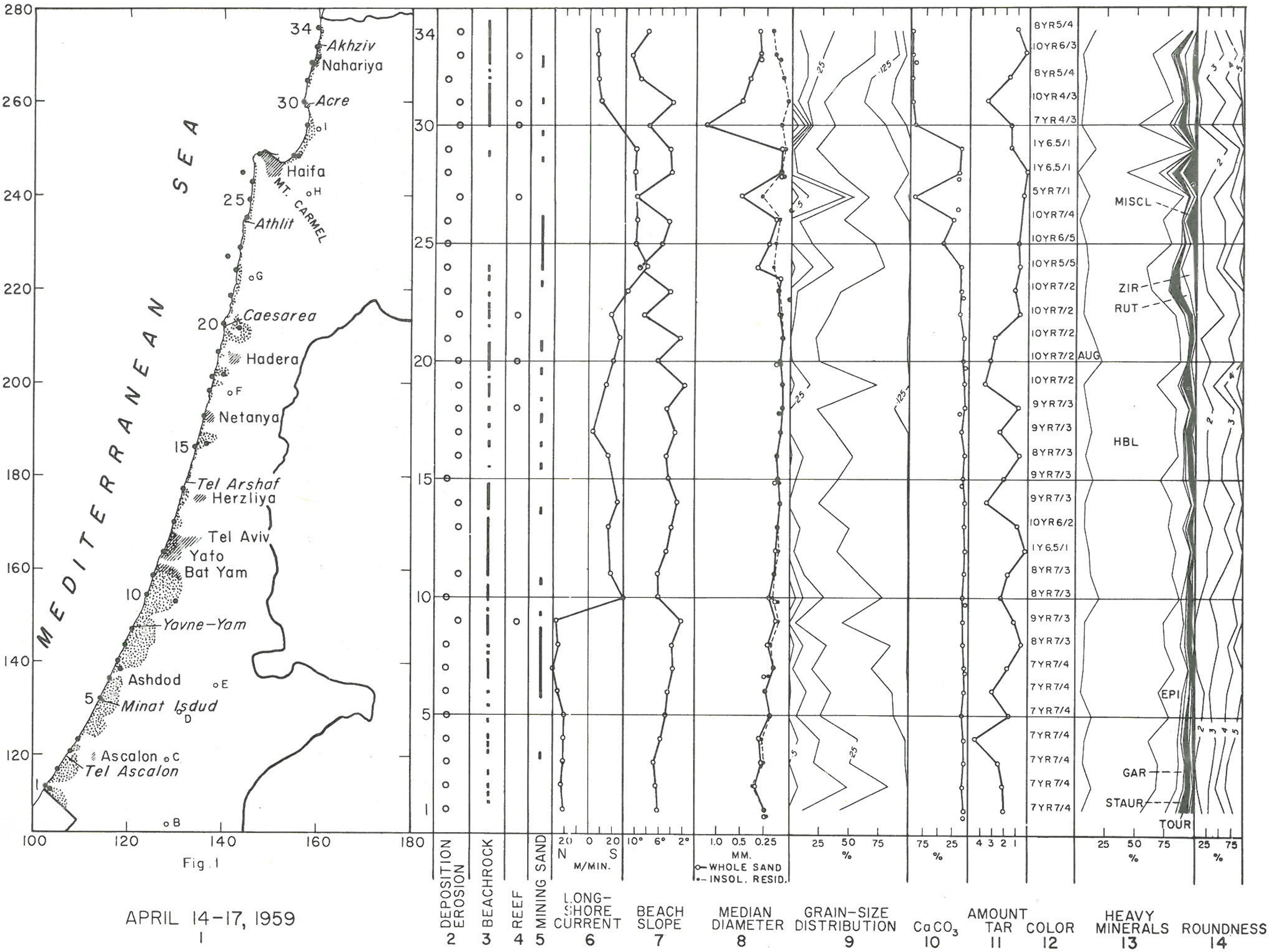


Fig. 1

APRIL 14-17, 1959
1

## EXPLANATION OF FIG. 2

Photographs of beaches and beachrock.

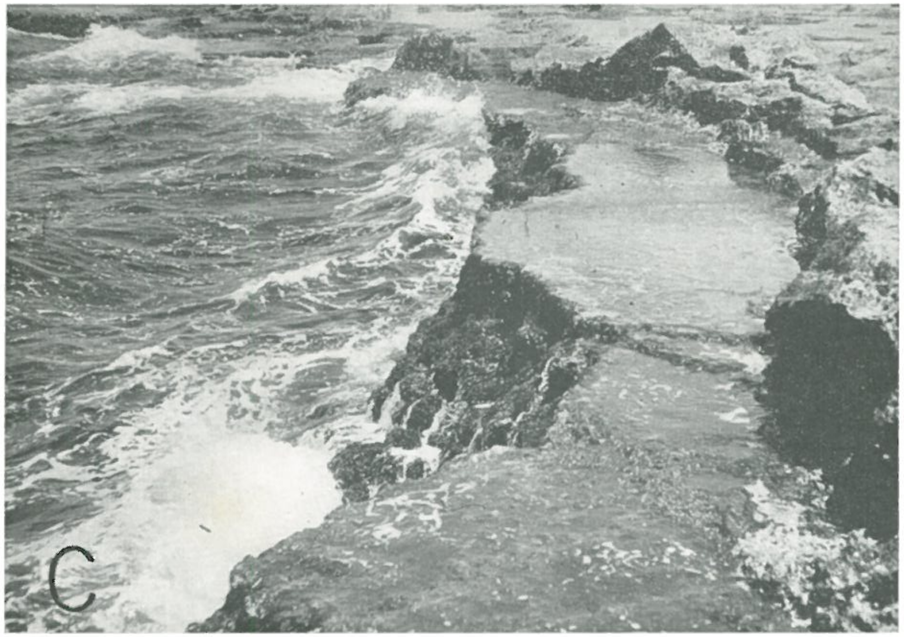
A. Abundant tar near high tide zone of beach near Ashdod (station 6).

B. Barrier of beachrock with seaward-dipping layers at Tantura (station 22).

C. Rimmed terraces in beachrock at Akhziv (station 33).

D. Shelly beachrock containing fragments of Roman or Crusader pottery at Caesarea (station 20).


A

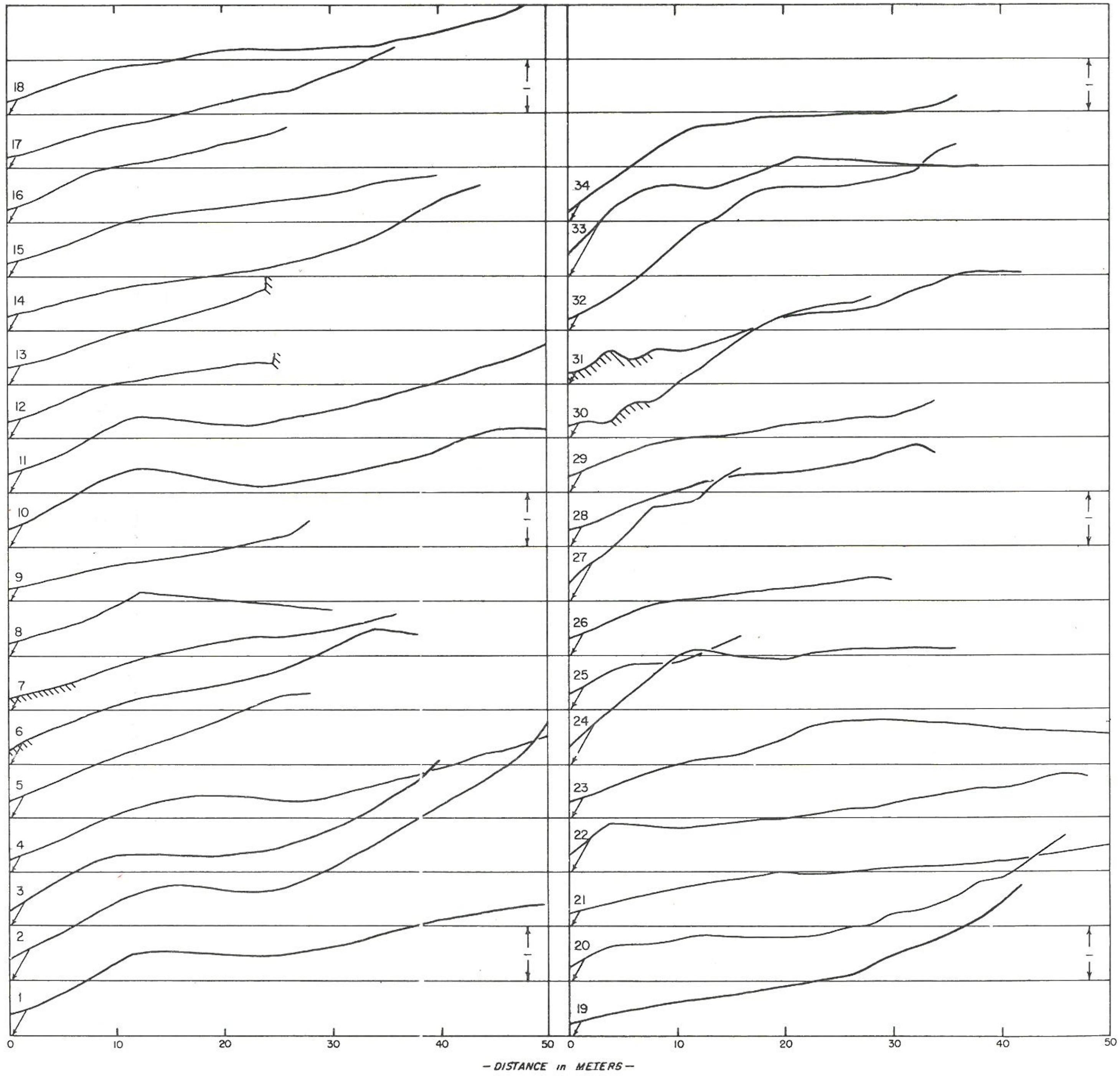

C


B


D

## EXPLANATION OF FIG. 3

Profiles of beaches adjusted to approximate hydrographic zero according to sea levels read from tide curves of Ashdod for the time at which each profile was made. Israel Land Survey Datum is 0.329 metres above hydrographic zero and mean sea level is 0.397 metres above it, according to data supplied by Eng. A. Doiban, Ministry of Transport and Communications.



18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
1
0
10
20
30
40
50
- DISTANCE in METERS -

## EXPLANATION OF FIG. 4

Diagram illustrating source, movement, and fate of sand on Mediterranean beaches of Israel.

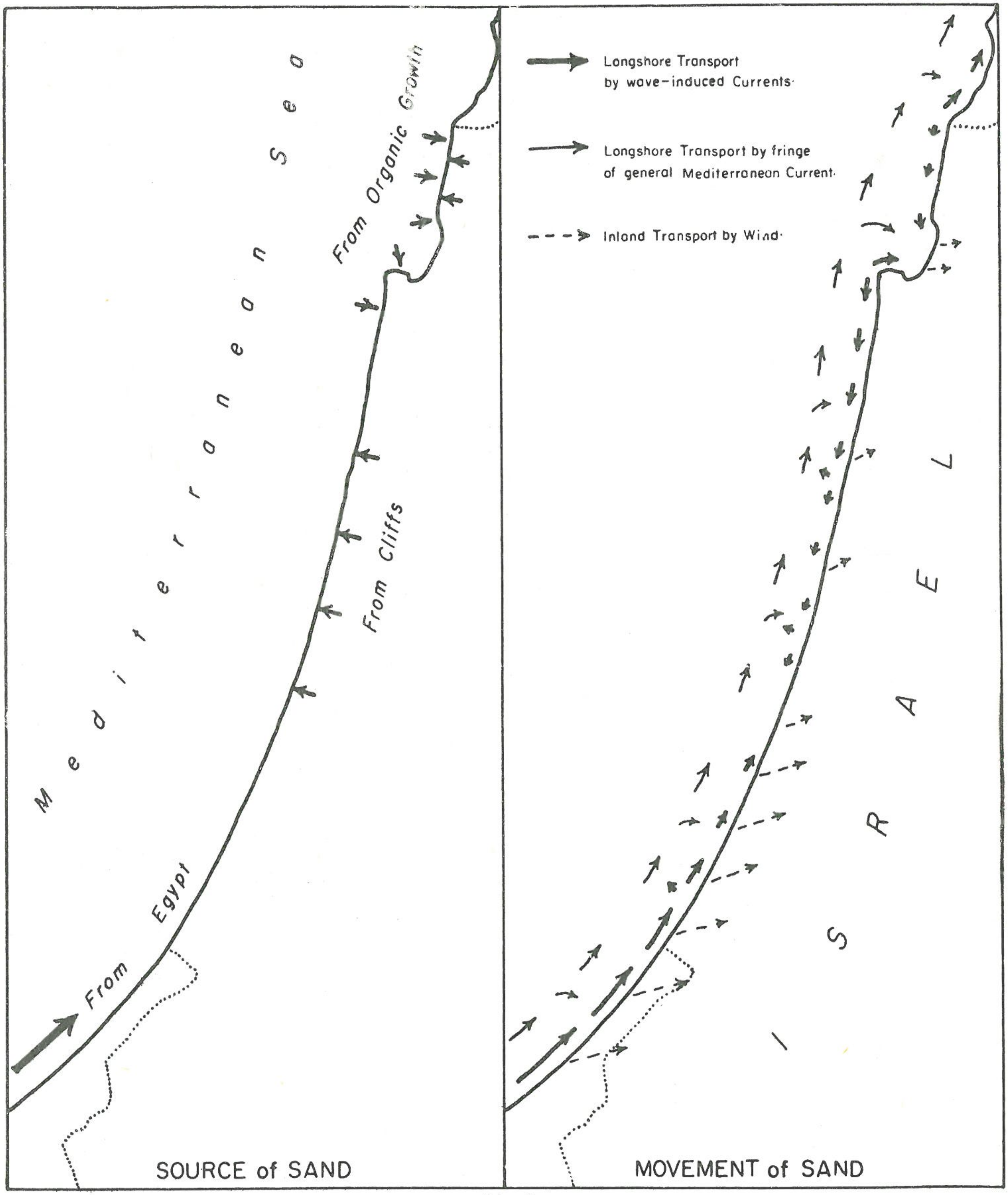

Mediterranean Sea
From Organic Growth
From Cliffs
From Egypt
SOURCE of SAND
Longshore Transport by wave-induced Currents.
Longshore Transport by fringe of general Mediterranean Current.
Inland Transport by Wind.
ISRAEL
MOVEMENT of SAND

Fig.4

# APPENDIX

| Sample | East | North | Per Cent of Total Heavy Minerals | | | | | | | | | Calcium Carbonate | Median Diameter (microns) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Augite | Hornblende | Epidote | Garnet | Staurolite | Kyanite | Tourmaline | Rutile | Zircon | | whole sand | residue insoluble |
| BEACHES | | | | | | | | | | | | | | |
| 1 | 103 | 112 | 6 | 50 | 20 | 9 | 3 | 2 | 7 | 1 | 2 | 5.9 | 240 | 240 |
| 2 | 105 | 116 | 14 | 54 | 17 | 6 | 2 | 0 | 4 | 2 | 1 | 8.8 | 335 | 355 |
| 3 | 108 | 121 | 7 | 63 | 17 | 5 | 1 | 0 | 4 | 1 | 2 | 5.8 | 280 | 270 |
| 4 | 109 | 123 | 8 | 54 | 24 | 3 | 2 | 1 | 4 | 1 | 3 | 6.8 | 290 | 270 |
| 5 | 113 | 132 | 14 | 65 | 9 | 3 | 2 | 1 | 2 | 6 | 2 | 10.2 | 210 | 225 |
| 6 | 116 | 137 | 5 | 65 | 20 | 3 | 3 | 0 | 2 | 0 | 2 | 6.4 | 240 | 235 |
| 7 | 118 | 140 | 7 | 76 | 12 | 0 | 1 | 1 | 2 | 0 | 0 | 6.2 | 205 | 200 |
| 8 | 119 | 144 | 8 | 67 | 13 | 4 | 2 | 0 | 4 | 2 | 0 | 8.4 | 235 | 225 |
| 9 | 121 | 147 | 8 | 66 | 15 | 2 | 1 | 0 | 5 | 0 | 2 | 9.6 | 180 | 175 |
| 10 | 123 | 155 | 21 | 67 | 1 | 4 | 1 | 1 | 4 | 0 | 1 | 8.1 | 230 | 210 |
| 11 | 125 | 158 | 13 | 68 | 12 | 2 | 0 | 0 | 1 | 2 | 2 | 7.0 | 200 | 195 |
| 12 | 127 | 164 | 12 | 72 | 13 | 0 | 1 | 1 | 1 | 0 | 0 | 6.1 | 185 | 175 |
| 13 | 130 | 171 | 8 | 70 | 12 | 2 | 1 | 0 | 5 | 4 | 1 | 6.5 | 180 | 180 |
| 14 | 132 | 177 | 8 | 73 | 16 | 0 | 2 | 1 | 0 | 0 | 0 | 5.8 | 165 | 165 |
| 15 | 134 | 187 | 19 | 56 | 19 | 2 | 3 | 0 | 3 | 1 | 0 | 8.8 | 175 | 175 |
| 16 | 135 | 193 | 9 | 77 | 5 | 1 | 2 | 1 | 5 | 0 | 0 | 6.1 | 185 | 185 |
| 17 | 135 | 198 | 14 | 69 | 7 | 1 | 1 | 3 | 3 | 1 | 1 | 9.9 | 175 | 165 |
| 18 | 137 | 202 | 11 | 73 | 11 | 0 | 2 | 0 | 2 | 0 | 1 | 7.4 | 155 | 155 |
| 19 | 138 | 207 | 7 | 61 | 18 | 1 | 2 | 2 | 8 | 0 | 1 | 5.7 | 160 | 205 |
| 20 | 140 | 213 | 23 | 65 | 6 | 0 | 0 | 0 | 1 | 1 | 4 | 10.2 | 165 | 165 |
| 21 | 142 | 218 | 16 | 71 | 8 | 0 | 1 | 1 | 2 | 0 | 0 | 8.4 | 160 | 160 |
| 22 | 143 | 224 | 7 | 76 | 8 | 0 | 2 | 0 | 4 | 1 | 2 | 15.0 | 175 | 175 |
| 23 | 144 | 229 | 8 | 58 | 13 | 1 | 1 | 1 | 8 | 6 | 4 | 13.6 | 185 | 180 |
| 24 | 145 | 235 | 11 | 48 | 21 | 0 | 1 | 0 | 4 | 2 | 12 | 12.4 | 165 | 225 |
| 25 | 145 | 239 | 9 | 70 | 9 | 0 | 2 | 1 | 2 | 3 | 3 | 42.6 | 335 | 200 |
| 26 | 146 | 244 | 3 | 69 | 16 | 0 | 1 | 0 | 0 | 1 | 2 | 26.6 | 200 | 180 |
| 27 | 148 | 249 | 11 | 78 | 5 | 0 | 0 | 0 | 1 | 3 | 2 | 93.4 | 540 | 300 |
| 28 | 154 | 248 | 1 | 41 | 27 | 6 | 4 | 0 | 6 | 0 | 3 | 15.8 | 175 | 175 |
| 29 | 157 | 255 | 16 | 81 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 15.3 | 165 | 150 |
| 30 | 157 | 260 | 4 | 47 | 26 | 3 | 3 | 3 | 6 | 2 | 6 | 94.0 | 1500 | 165 |
| 31 | 158 | 265 | 6 | 74 | 8 | 2 | 0 | 1 | 2 | 1 | 6 | 97.7 | 520 | 145 |
| 32 | 159 | 269 | 8 | 64 | 13 | 1 | 2 | 0 | 2 | 1 | 5 | 97.6 | 420 | 160 |
| 33 | 160 | 272 | 5 | 58 | 15 | 2 | 1 | 0 | 3 | 5 | 7 | 96.7 | 300 | 205 |
| 34 | 160 | 277 | 16 | 73 | 6 | 0 | 2 | 0 | 0 | 2 | 1 | 96.8 | 320 | 225 |
| DUNES | | | | | | | | | | | | | | |
| 1 | 104 | 112 | 3 | 31 | 38 | 5 | 6 | 1 | 10 | 0 | 6 | 5.3 | 250 | 240 |
| 7 | 118 | 136 | 2 | 47 | 31 | 6 | 4 | 0 | 3 | 2 | 5 | 5.6 | 265 | 235 |
| 10 | 130 | 153 | 9 | 77 | 6 | 0 | 2 | 0 | 5 | 0 | 0 | 4.6 | 185 | 180 |
| 15 | 136 | 187 | 6 | 53 | 29 | 4 | 5 | 0 | 1 | 0 | 2 | 9.6 | 195 | 180 |
| 18 | 140 | 202 | 2 | 62 | 18 | 3 | 4 | 0 | 7 | 1 | 3 | 16.3 | 185 | 180 |
| 20 | 144 | 211 | 9 | 60 | 16 | 0 | 4 | 1 | 5 | 2 | 3 | 7.4 | 175 | 175 |
| 28 | 155 | 248 | 6 | 57 | 28 | 1 | 2 | 3 | 6 | 0 | 0 | 19.1 | 165 | 160 |
| 33 | 160 | 270 | 8 | 53 | 16 | 2 | 3 | 0 | 5 | 2 | 10 | 91.1 | 320 | 180 |
| SEA FLOOR | | | | | | | | | | | | | | |
| 3 | 140 | 227 | 14 | 69 | 9 | 0 | 4 | 0 | 3 | 1 | 0 | 9.9 | 135 | 130 |
| 12 | 145 | 245 | 15 | 81 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 19.1 | 130 | 120 |
| RIVERS | | | | | | | | | | | | | | |
| A | 123 | 079 | 3 | 39 | 23 | 4 | 8 | 0 | 8 | 5 | 10 | | | |
| B | 127 | 115 | 7 | 51 | 16 | 5 | 2 | 3 | 3 | 6 | 7 | | | |
| C | 128 | 119 | 0 | 30 | 25 | 5 | 9 | 0 | 2 | 13 | 16 | | | |
| D | 131 | 129 | 1 | 10 | 27 | 4 | 14 | 3 | 21 | 9 | 12 | | | |
| E | 138 | 135 | 2 | 51 | 18 | 4 | 3 | 1 | 2 | 3 | 15 | | | |
| F | 142 | 198 | 0 | 17 | 39 | 3 | 8 | 3 | 15 | 8 | 7 | | | |
| G | 146 | 222 | 2 | 38 | 14 | 3 | 2 | 1 | 0 | 11 | 29 | | | |
| H | 157 | 240 | 54 | 20 | 11 | 2 | 0 | 0 | 1 | 0 | 12 | | | |
| I | 159 | 254 | 2 | 36 | 17 | 5 | 3 | 1 | 6 | 10 | 19 | | | |