OFFSHORE ARTIFICIAL STRUCTURES AND THEIR INFLUENCE ON THE ISRAEL AND SINAI MEDITERRANEAN BEACHES

by
Yaacov Nir
Geological Survey of Israel,
Marine Geology and Geomathematics Division,
30, Malkhei Israel St., Jerusalem 95501, ISRAEL.

INTRODUCTION

The Israel Mediterranean shore forms a gentle curve from an almost easterly direction in north Sinai to an almost northerly direction in Israel. This shore forms the southeastern corner of the Levantine Basin which itself forms the extreme eastern part of the Mediterranean Sea. The length of the Israel shoreline from Rosh Haniqra near the Lebanese border to northern Sinai in the south is about 230 km, while the Sinai coast from Rafah to Port Said (Fig. 1), is almost 200 km long. The coastline region consists largely of Quaternary carbonate cemented quartz sandstone, known by local name "kurkar". Recent faulting is responsible for the shape and, to a certain extent, for the morphology of large parts of the central coastline, which is characterized by kurkar cliffs (Neev et al., 1973 & 1978). Wide sandy beaches are found in the southern parts, while an abraded rocky platforms occur mainly in the central and northern parts, where the beaches are narrow having kurkar cliffs at their backshore side.

Four different morphological sections can be found in the Israel Mediterranean shore, (Nir, 1982). These differ in their beach and inland morphology on one hand, and in their sedimentological properties on the other. The four different sections from north to south are:

1) Rosh Haniqra to Akko. A sedimentologically isolated region, bounded on both the south and north. Beach sediments are mostly of local calcareous material of marine origin. Akko promontory is the most northern limit of Nile derived sands and plays as the recent edge of the Nile sedimentary cell (Nir, 1980). 2) Haifa Bay. Wide sandy beaches, bounded on the north by the Akko promontory, and by the Carmel "nose" on the south. 3) Mount Carmel coastal plain, is sedimentologically somewhat isolated region with relatively narrow beaches and small kurkar cliffs. Sediments consist of both local and imported components. 4) The kurkar cliffs and sandy beaches from Caesarea to Rafah. Beaches of differing width having quite uniform petrographic components, mostly quartz grains originating from the Nile river and transported along the Sinai beaches to the Israeli beaches. Some of the present beach components are derivated from the abraded kurkar cliff.
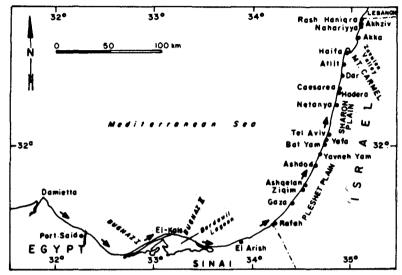
Fig. 1.　Northern Sinai and Israel　Mediterranean　beaches,
location map.

THE BEACHES

　　　The Israel Mediterranean beaches　are　mostly　sandy,
with　a　few　exceptions　where　local kurkar or limestone
pebbles are found.　The sands are light in　colour,　white
to light yellow, and are mostly composed of quartz grains.
The beaches between Rosh Haniqra and Akko and　some　parts
of　the　Carmel　Coastal Plain are exceptional in that the
sands are of local origin and mostly composed of　skeletal
material,　mostly　algae　and　molluskal　debris.　Kurkar
cliffs constitute a very　distinct　morphological　feature
along the shores.　Most of the cliffs are 20-40 m high and
are very strongly abraded by the sea at the　foot　of　the
cliff, and by rainwater along its slopes (Fig. 2).

　　　The following scheme shows the qualitative budget　of
sand　along　the　North　Sinai　and　Israel　Mediterranean
beaches, showing both onshore and　offshore　sand　sources
and　sinks:　1)　Offshore Losses　—　by　sand mining and
dredging in harbours, accumulation of sand in　and　around
harbours　and artificial objects.　2) Seaside contribution
— Nile sands transported along the beaches, destruction of
beaches　in the Nile delta and northern Sinai, and organic
production mostly of pelecypod shells.　3) Onshore　losses
—　sand　mining　(up to 1964), use of beach and artificial
tombolo areas, wind blown sand　and　dune　formation.　4)
Landside contribution — erosion and abrasion of the kurkar
cliffs, river alluvium, and sand dunes.

Quartz sand dunes cover relatively large areas of the
nearshore regions of the Coastal Plain of Israel. The
majority of the dunes are located in the southern part,
connected with the north Sinai enormous sand dune sea.
The origin of their quartz grains, which make up the
primary component of the beach, has been investigated
mineralogically (Shukri and Philip, 1960; Pomerancblum,
1966; and Nir, 1973 & 1982). Certain conclusions can be
drawn: 1) Nile-derived sediments are transported along
the beaches of the Nile Delta, Sinai and Israel by waves
and wave generated longshore currents and the
counterclockwise East Mediterranean current. 2) A
relatively minor amount of sandy sediments are also
introduced by local rivers (wadis), which are active only
during winter floods.

Fig. 2b. Kurkar cliff near Hadera.
Most of the cliff is composed of
soft friable red loam ("Hamra")
and sand. Landslides are typical
on these cliffs, causing talus
of huge blocks at their base.

Fig. 2a. Steep kurkar cliff south of Netanya. The beaches
are narrow, but show maximum development in this photo.

In the cliff regions, beaches are very narrow,
reaching a width of only 10-20 m and much less during
winter time (Fig. 2a). The sandy beaches are relatively
wide in regions where kurkar cliffs are absent, in some
parts reaching widths of 60-80 meters.

Large quantities of beach-sand were quarried until
1964, at an estimated annual rate some 10 to 20 times
larger than the naturally occuring annual sand
replenishment. This quarrying produced a sand deficit
along many beaches, causing an accelerated erosion of the
beaches and nearby cliffs.

SEDIMENT TRANSPORT ALONG THE BEACHES

        Artificial constructions such as groins, breakwaters,
barges, etc. found along the Sinai and Israeli shores
trap some of the longshore sand drift, causing damage
downstream and sometimes enabling us to ascertain the
qualitative and even quantitative net sand drift at a
certain point.

        These shores on a whole belong to the large
sedimentary cell which starts at the two Nile Delta
outlets at Rosetta and Damietta, and extends along the
Sinai shores as far north as Akko in Israel (Nir,
1980). Zenkovich (1971) shows a very clear easterly
directed sediment transport along most of the Nile Delta
beaches.

        Two channels ("Bughaz") were dug in the outer
Bardawil bar in order to maintain its water connection
with the open sea. Groins were constructed to keep the
channels from silting up. As a result, sand accumulated
on the western side of these groins and Inman and Harris
(1970) estimated the yearly net easterly sand transport at
the western outlet (Boughaz 1) to be on the order of
300-800,000 m3/year.

        The El Kals temporary harbour and sand mining close
and west of El Arish caused severe erosion to nearby dunes
and summer houses respectivelly (Fig.3).

        Wadi El Arish drains practically all of northern and
central Sinai. The beach near the outlet of this ephermal
wadi is straight and usually conforms with the regular
shoreline. In a very short period of time, at the end of
February 1975, a voluminous flood transported several
hundred million cubic meters of water and sediment to the
sea. These clastic sediments formed a large new delta
more than 400 m offshore with a large submarine extention.
This new delta partially dammed the sand drift, resulting
in a sediment accumulation on the delta's western flank,
on the one hand and a very effective abrasion on the
down-drift shores east of the outlet on the other (Fig.4).
The sediments of this delta were transported eastwards
quite quickly and the delta changed shape, reaching an
almost straight and regular shoreline (Fig.5).

        All the obstacles east of El Arish up to Rafah show a
clear net easterly drift, while those northwards almost up
to Tel Aviv show a northern drift. These obstacles are:
a barge east of El Arish (Fig.6), two groins and the wreck
between them in Gaza Harbour (Fig.7), a harbour with two
groins on its southern and northern sides at Ziqim
(Fig.8), and the huge Ashdod Harbour, whose main
breakwater reaches 18 m water depth. This last structure
impedes sand transport and accumulates sand in large

quantities   in   the   offshore   at relatively great depths
(Dornhelm, 1972;   Kran, 1980;   and Finkelstein, 1981).

Fig. 3. Summer houses at El Arish,
N. Sinai. The collapse was a
result of the sand deficit caused
by quarrying of beach sand
("Zifzif") nearby.

Fig. 4.   Roots of palm groves were exposed to wave
action   east of El Arish as a result of the provisional
damming of the regular eastward sand transport by the
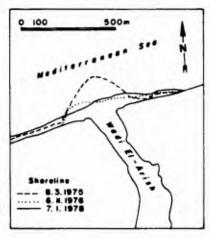delta of Wadi El Arish in Feb. 1975.

Fig. 6. A barge at N. Sinai
beach east of El Arish
accumulates sand on its
western side, thus
clearly illustrating the
easterly sand transport.

Fig. 5. Schematic map of Wadi El-Arish Delta , drawn
from   aerial   photographs,   showing   its different
development and disapearing stages.

         Dornhelm (1972),   and Kran (1980) who reanalysed
Dornhelm's charts show that the Ashdod Harbour's main
breakwater interrupted about 80% of the annual northward
transport of sand.   Finkelstein (1981) also shows a

tremendous offshore sand accumulation during 13 years
which reaches perhaps 4 million cubic meters at the main
breakwater and westwards.   Northwards   he   shaws
accumulation close to the lee breakwater and a large area
of erosion farther north. By and large this agrees with
the main trend of northerly drift. He also estimated the
net annual northerly transport at Ashdod to be on the
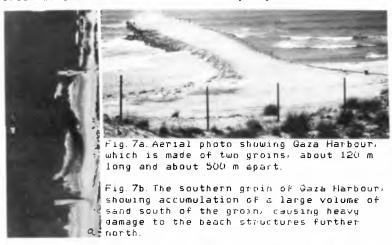order of 560,000 m3, which is a very high value.

Fig. 7a. Aerial photo showing Gaza Harbour,
which is made of two groins, about 120 m
long and about 500 m apart.

Fig. 7b. The southern groin of Gaza Harbour,
showing accumulation of a large volume of
sand south of the groin, causing heavy
damage to the beach structures further
north.

Fig. 8. A map of Ziqim Harbour, drawn from an aerial
photograph   Note the extreme widening of the beaches
to the north. These are now almost totally exposed of
their sand cover yearround.   Prior to harbour
construction beaches to the north had normal sand
quantities and normal widths even during severe winter
storms.

      The old site of Yavneh Yam show northerly drift in
the form of a large retreat of the seashore which has
caused damage to the old site (Fig. 9).

      Northwards from Tel Aviv the net transport decreases
significantly, and at the Carmel Head transport is to the
east and to the south, and the region between here and
Atlit is to a certain extent isolated.

Fig. 9. The beach north of Tel
Yavneh-Yam ("Minnet Rubin"),
suffers from heavy abrasion
due to the sand deficit and
the protruding promontory of
the Tel. Beaches here have
withdrawn about 50 m during
the last 50 years. In Early
British Mandatory topogra-
phic maps almost no
promontory was shown here.

Emery and Neev (1960), assumed a northerly sand
transport for the southern Israel beaches and a southerly
one for the central and northern beaches.   A northerly
directed offshore current and sediment transport of mostly
fine grained sediments was also suggested.   This transport
is responsible for most of the present influx of fine sand
to Haifa Bay.

On the basis of theoretical studies Migniot (1974),
Sauzy et al., (1974) and Manoujian and Migniot (1975) show
that the annual resultant sediment transport is always
directed to the north and reaches about 400,000 m3 at
Gaza, 215,000 m3 at Ashdod, 100-150,000 m3 at Hadera and
only 80,000 m3 at Atlit.

Goldsmith and Golik (1978) summarized the Israel
Mediterranean wave climate and constructed a longshore
sediment transport model for these beaches.   In general
they support the conclusions of the earlier studies
regarding sediment transport.

OFFSHORE STRUCTURES OF THE ISRAEL MEDITERRANEAN SHORELINE

Prior to 1960 with the exception of a few ancient
harbour sites such as Akko, Haifa, Caesarea and Yafo
(Jaffa), the Israel Mediterranean shore did not have any
large offshore structures (Kravitsky, 1966).

The main stage of offshore construction for
recreational purposes took place in the late sixties and
the early seventies when 25 structures (15 breakwaters and
10 groins) were built along the beaches from Gaza in the
south to Akhziv in the north (Fig. 1).   The environmental
impact of these structures were studied in the field, by
succesive aerial photos, and by bathymetric and
topographic maps of the sites and their vicinity.   They
were also studied with regard to their engineering
characteristics (Fried, 1975 & 1976; Tauman, 1975 &
1976).   Vajda (1975) investigated their sedimentological
development in the laboratory in order to limit as much as
possible their erosional effect.   Nir (1976) gives a

detailed   description of the different offshore structures
with   their   sedimentological   characteristics   and   their
relationships   to   the   nearby   beaches.   Spar (1976), and
Sofer and Sass (1982) studied in detail the   sedimentology
of the Netanya twin breakwaters.

Most of the structures have developed   a   tombolo   at
their   "shaded"   landward   side.   These tombolos typically
have a trapezoidal shape (Figs. 10 & 11).   They   reach   a
mature   stage   (at   which   significant size changes cease)
about 5 years after the end of construction (Fig. 12).   The
sand   accumulated   in these tombolos comes mostly from the
nearby beaches and   shallow   sea.   In   most   cases   these
beaches   have therefore suffered severe erosion during the
first 3-4 years after   the   construction,   while   in   some
cases this erosion even continues beyond maturity.

Many of the   detached   breakwaters   and   groins   were
built   in   very   populated   areas in order to increase the
amount of beachfront and to calm the relatively rough seas
occuring   during   the   bathing   season in July and August.
These problems were partially solved by the tombolo   which
was formed in the shaded area of the breakwater and by the
attendent of areas of quiet water.

These breakwaters were mostly constructed about 200 m
offshore   of the original shoreline, mostly on a submarine
exposed rocky strip in about   3-4   m   water   depth.   This
rocky   strip (Fig. 13) was chosen for the practical economic
purpose of reducing foundation costs.   As   their   length
almost   equals   their   distance   offshore,   huge   tombolos
started to grow out from shore which later joined with the
breakwater.   Figure   12   and the following table show the
aerial development with time of these tombolos,   following
their   completion.   Most of these tombolos reached almost
one half of their final size within a period of one or two
years.   There is a sharp decrease in the rate of expasion
of the sand area in the second year after the end   of   the
construction.

Site	Time (years) for tombolo volume to go from		Total years
	0-50%	50-100%	
Carmel Beach	3.23	2.60	5.83
Netanya (south)	1.06	3.52	4.58
Netanya (north)	1.56	2.10	3.66
Tel Aviv 1	1.50	4.07	5.57
Tel Aviv 2	3.15	2.66	5.81

Table 1. Time needed (yrs) for tombolo volume to develop
from 0-50% and from 50-100%. The averages show that the
tombolo reaches its half volume in about two years and
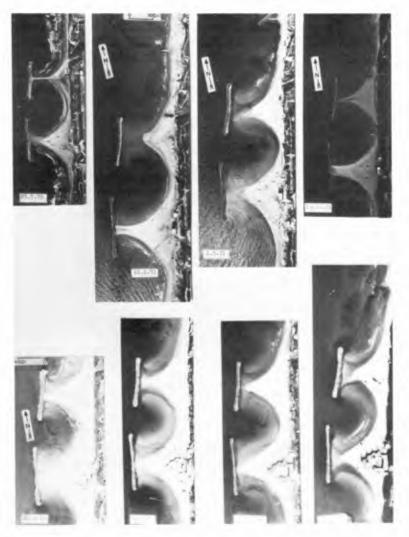that it takes another 3 years to reach the mature stage.

Fig. 10. The twelve year history of the twin tombolos off the Netanya beaches. The tombolos reached their first maximal stage at the end of 1973, and since then they show seasonal fluctuations. Winter storms usually open a channel between the tombolo and the breakwater.

This slowing in sand accumulation is primarily because the nearby beaches, which are the main suppliers of sand to the tombolos, have already suffered an enormous sand deficit due to sand capture by the newly built structure, and also because of the increase in water depth around the tombolo. In sites where two structures were built, the tombolo of the most recently built structure reached its 50% sand volume in a much longer time than the first structure. In Netanya, this time difference is about 50% while in Tel Aviv it required more than twice as long to reach the 50% sand volume stage, this probably due to the general deficit of sand in the Tel Aviv beaches. The Netanya case on the other hand, at the second stage of its development, shows faster accumulation at the northern structure which is the younger, with probably preferred southerly directed longshore transport.

Most tombolos reached their mature size between the 5th and the 6th year after construction. Thereafter the only changes are seasonal with maximum tombolo size at the end of summer, or more precisely just before the first storm at the end of autumn. Some decrease in size occurs during winter and early spring (Fig. 10). This fits very well with the regular winter to summer variations in beach width. In his study of the shallow Ma'agan Mikhael beach Eitam (1975) also found that the accretion period extends over the autumn.

Aerial photographs of the different sites where one or more detached breakwaters were constructed, taken before, during, and after construction, show the different stages of tombolo growth on the one hand and the fast erosion of the nearby beaches on the other (Fig. 15). At the Carmel Beach site the nearby beaches were almost totally stripped of their sands. A large beach area, just next to and south of the tombolo, disappeared 12 years ago and has not been rebuilt (Fig. 14). The Carmel Beach structure was chosen to represent a single breakwater tombolo while the Netanya structures typify twin tombolos. Fig. 10 illustrates the different stages of tombolo growth as they attain their mature stage in 4-5 years time.

In Netanya tombolos began to grow during the construction activities, and about 70,000 m3 of sand were attracted from the nearby beaches and shallow sea in 3-4 years time. Prior to construction, Netanya's beaches were already in very bad shape and waves were reaching the base of the steep kurkar cliffs. This was among other morphological and stratigraphic reasons due to the enormous quantities of sand being quarried all along Israel's Mediterranean beaches up to 1964; for example, Emery (1963) estimated that about 1/3 of the beach sand reserves had by that time already been quarried. Following formation of these tombolos, abrasion in the

nearby kurkar cliffs was accelerated, so that measures had
to be taken to protect the cliff. Recently Ron (1982) has
proved enormous cliff retreat in the region of Netanya
during the last 35 years.

     Table 2 summarizes the sand quantities that
accumulated in the aerial parts of the seven first built
tombolos at the different sites. These account for about
270,000 m3 of sand. It is assumed that about the same
quantity or more of sand was deposited underwater in the
vicinity of the tombolos. Therefore, altogether these
offshore structures (with the exception of the huge
quantity deposited near Ashdod Harbour), captured about
600,000 m3 of sand in a period of 4-5 years. This volume
is much larger than the actual sand available from the
annual import from the Sinai beaches. The volume of sand
at each separate site was calculated using the following
formula (derived by John K. Hall):
     volume of sand V = dc(2a+b)/3; where:
2a - is the length (in m) of the tombolo's offshore edge
     (taken parallel to the shoreline).
b - is 1/2 of the length of the base of tombolo (in m).
c - is the distance between the base and the seaward edge
     of the tombolo(in m).
d - water depth (m) at the seaside edge of tombolo.

Site	Quantity of accumulated sand (in m3)
Nahariyya	20,000*
Shavey Zion	5,000-18,000
Carmel Beach	55,000
Netanya (north)	34,000
Netanya (south)	38,000
Tel Baruch	15,000
Tel Aviv 1	45,000
Tel Aviv 2	20,000
Bat Yam	26,000
Total	258,000-271,000 m3

Table 2. Sand quantities which were accumulated at the
different offshore structures along the Mediterranean
coasts of Israel (including only the subaerial sand
bodies within the tombolos).
* Some sand was quarried from the tombolo.

     Figures 10, 12 and 14 show the developments that
occurred around the twin detached breakwaters in Netanya.
The different shorelines were drawn from aerial photos of
the site, taken at various time intervals. Comparison
between the areas of the successive tombolos and the
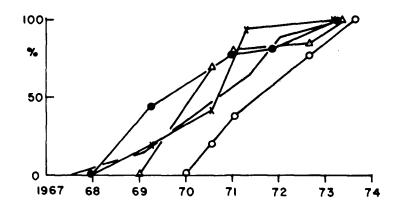quantities of accumulated sand shows that one of the main

Fig. 11. The different stages of tombolo development
for the Carmel beach structure, from the very early
stages of construction(11a), to the formation of an
enormous tombolo (11d) some 5 years later.

factors affecting the sand quantity is the ratio between
the length of the breakwater and its distance from the
original shoreline. The smaller the ratio — the smaller
the tombolo that develops.

Empirical study shows that there is a direct
relationship between a structure's distance from shore and
its length (or its projection onto the shoreline): the
larger this ratio the smaller the sand volume accumulated
in the tombolo. Accretion is very little, or does not
occur at all, if this ratio has a value of 2 or more (Fig.
16) This value is somewhat smaller than that of Inman
and Frautschy (1966), who studied the Californian beaches
showing that non-depositional conditions prevail only when
this ratio reaches a value of 3: "pronounced accretion
does not occur if the structure is situated offshore a
distance equal to or greater than 3 to 6 times the length
of the detached breakwater". Although there are no
structures in Israel with these high ratios, it is
apparent that no accretion occurs here if the ratio is
smaller.

The area of the mature tombolo ranges between 40 and
75% of the rectangular area between the breakwater and the
original shoreline. Beach area for that particular
section of shoreline has been increased, but on the other
hand the protected bathing area has been commensurately
decreased; among other reasons are dead algae
accumulations at the protected areas. The regions of
turbulent water around the edges of the breakwater are
dangerous for bathers and present another major problem
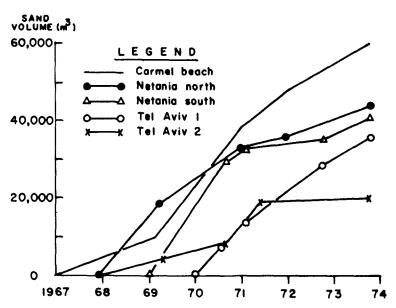resulting from the construction.

Fig. 12. Tombolo development at the different sites:
Carmel beach, Netanya and Tel Aviv. The upper graph
shows the cumulative percentage of the tombolo's area
while the lower one shows cumulativesand volume both
show the relatively quick sand accumulation at the
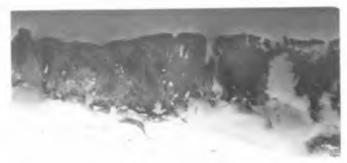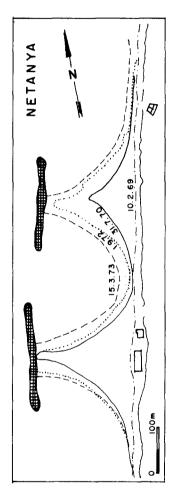early life stages of the structures.

Fig. 13. Central Israel — underwater relicts of kurkar strata showing the clear outlines of two submerged ridges and a wadi (dry creek) between them.

Fig. 15. Severe beach erosion near offshore structures. Fig. 15a. Heavy destruction on the beaches south of Tel Baruch structure (16/6/80). Fig. 15b. Shore buildings north of the Gaza Harbour groins have suffered heavy damage. Small nearshore structures parallel to the beach were erected here to prevent further collapses. Fig. 15c. Exposed beach basement at Bat Yam, after a severe storm (19/4/71). Damage was greater here because marine construction on a half closed pool in shallow water caused buildup of water during storms. Fig. 15d. Small bay north of King Herod's ancient harbour in Caesarea. While in operation this now submerged harbour caused heavy damage to the Roman aquaduct and therefore measures should have been taken to protect the aquaduct whose broken remnants appear in the foreground.
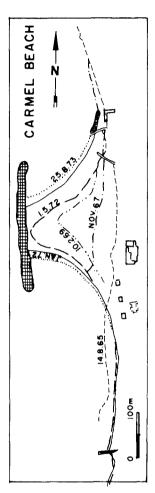
Fig. 14a. A map of Netanya's twin breakwaters and tombolos, showing the "step by step" growth of the twin tombolos and the formation in the internal of a new small bay between them. In the first few years the cliff at the backshore by the space between the tombolos suffered serious abrasion.
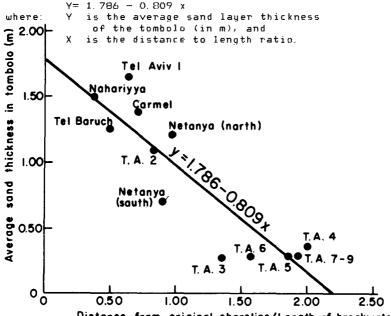
Fig. 14b. Map of Carmel Beach tombolo development from its early stages to mautrity. Note the original shoreline of August 1965, south of the tombolo, which shows the missing beach which has not since recovered.

Site	Distance from shore (m)	Length of breakwater (m)	Distance --------- Length
Nahariyya	70	180	0.38
Carmel Beach	200	280	0.71
Netanya (north)	200	207	0.97
Netanya (south)	216	240	0.90
Tel Baruch	100	200	0.50
Tel Aviv 1	200	310	0.64
Tel Aviv 2	200	240	0.83

Table 3. Dimensions, distance to length ratio, and the average sand layer thickness for the different sites.

The data given in Table 3 above was used to determine the relationship between the distance to the length ratio and the average tombolo sand layer thickness. The graph in Fig.16 shows that the sand layer equals zero (i.e. that there is no sand accumulation at all) when the distance to length ratio is somewhat larger than 2.

The equation for the least squares straight line through the data in Fig.16 is:

$$Y = 1.786 - 0.809 \, x$$

where: Y is the average sand layer thickness of the tombolo (in m), and
         X is the distance to length ratio.

Fig. 16. A graph showing the relationship between length of the breakwater, its distance from the original shoreline and sand accumulation in the different tombolos.

This empirical formula is supported by the latest measurements of the size and quantity of sand accumulated in the tombolos developed in the more recently built breakwaters (Nos. 3-9) in Tel Aviv. These new breakwaters' dimenstions and distance offshore came from laboratory model studies by Vajda (1975). The ratio of distance from shore to breakwater length was enlarged to 1.85 and more, with the result that tombolo sizes were much smaller than the ones developed on the original structures (Fig. 17). Extrapolating the sand quantities accumulated in the modeled structures, excellent agreement was found with the above formula. It should be noted that the model studies hypothesized an unlimited sand supply to the sites, which perhaps is not the case at present in the Tel Aviv beaches.

Fig. 17. Offshore structures at the Tel Aviv beaches. The northern (right) are long and relatively close to the shoreline, so that huge tombolos developed. The chain of 7 breakwaters south of the marina (left) have shorter lengths than the northern ones, and are found at somewhat larger distances offshore so that the sand accumulation in their "shadows" is much smaller.

SUMMARY AND CONCLUSIONS

A very large number of detached breakwaters, groins, harbours and other marine structures were constructed along the Israeli Mediterranean shore during the late sixties and up to the mid-seventies.

Sand accumulated rapidly in the "shaded" areas and up-current, causing heavy damage to the nearby and downcurrent beaches. This erosional sand deficit was in addition to the large deficit caused by the heavy mining of sand for construction purposes up to 1964.

As most of the detached breakwaters were constructed relatively close to the shoreline, large tombolos have developed. It was found here that accretion is very small or negligible when the distance of the breakwater from the original shoreline is more than twice the breakwater length.

The southern beaches provide an excellent
demonstration of downcurrent erosion; beaches north of
structures were heavily damaged, with their sand cover
almost totally removed and the backshore cliff starting to
collapse (Fig. 8).

As there was almost no distinctive sand accumulation
south of the main breakwater of Ashdod harbour, it
appeared as if this gigantic structure did not interfere
with the longshore sand transport. Recently Finkelstein
(1981) showed that huge amounts of sand are being
accumulated next to and off the deep parts of the main
breakwater. This accumulation is equal to the transport
of many years which is removed from the cycle, and the
beaches north of Ashdod thereby suffer from increased
erosion.

Due to the heavy damage and other environmental
problems that these structures create, measures should be
taken to minimize downcurrent erosion as much as possible,
mainly by a continuing artificial replenishment to the
affected beaches. On the other hand, if beach conditions
are bad then offshore structures should be either improved
or not permitted.

REFERENCES

Dornhelm, R. B., 1972. Determination of the longshore sand
    transport rate in the vicinity of Ashdod Port. GSI
    Marine Geology Div. Rep., 45p. unpub.
Eitam, Y., 1974. Morphological and grain size seasonal
    changes in the Ma'agan Mikhael coast and shallow sea.
    M. Sc. thesis, Hebrew Univ. Jerusalem, 89 p. (in Hebrew).
Emery, K. O., 1963. Some remarks on the sediments of the
    Israel Mediterranean Beaches. "Zifzif Co." Rep.
    Appendix 2, 2 p., Min of Dev. Report (in Hebrew).

Emery, K. O.   & D. Neev, 1960.   Mediterranean beaches of
    Israel. Bull. GSI No.   26, 24 p.
Finkelstein, A., 1981.   Sedimentological developments around
    Ashdod Harbour 2nd Symposium on Beach Problems, Tel
    Aviv, May 25, 1981, Unpub. Manus. 6p.
Fried, I., 1975. Foreshore and beach development of Tel
    Aviv and Natanya.   Symposium on "Foreshore and beach
    development from the Coastal Engineering aspect".
    Assoc. of Eng. & Archit. in Israel, 9 p (in Hebrew).
Fried, I., 1976. Coastal protection by means of off- shore
    breakwaters, Proc.   of the 15th Coastal Engineering
    Conference, Honolulu, Hawaii, 10 p.
Goldsmith, V. and A. Golik, 1978. The Israeli Wave Climate
    and Longshore sediment transport model. Israel Ocean.
    and Lim. Res. Rep. 79/1, 56 p.
Inman, D. L. and J. D. Frautschy, 1966. Littoral processes and
    the development of shorelines. Chap. 22 in Coastal
    Engineering. Am. Soc. Civ. Engrs., pp. 511-536.
Inman, D. L. and R. W. Harris, 1970. Preliminary report on the
    inlets of the Bardawil Lagoon. Report submitted to the
    Nat. Coun. for Res. and Development, Haifa, 13 p.
Kravitsky, A., 1966. Inventory of offshore structures in
    Israel shoreline. Min. of Transport, Haifa, 8 p. mim.
Kran, N., 1980.   Analysis of bathymetric data and
    sedimentation near Ashdod Harbour (1964-1971). Marine
    Geol. Div., GSI, Rep. No. MG/6/80, 9 p.
Manoujian, S. and C. Migniot, 1975. Sedimentological study in
    three dimensional Model. Lab. Cent. Hydrol. France,
    Report, 57 p.
Migniot, C., 1974.   Creation of a New Power Station north of
    Hadera cooling water basin, Natural Phenomena Study and
    Sediment   Movement Study with radioactive and
    fluoroscent tracers. Int. Atomic Energy Agency,
    Report. 34 p. with appendix.
Neev, D., Y. Nir and M. Pomeranchblum, 1963. Problems regarding
    sand quarrying along the Mediterranean beaches of
    Israel. GSI Unpub. Rep., 19 p. (in Hebrew).
Neev, D., N. Bakler, S. Moshkovitz, A. Kaufman, M. Magaritz and
    R. Gofna, 1973.   Recent faulting along the Mediterranean
    coast of Israel. Nature, v. 245, pp. 254-256.
Neev, D., E. Schahnai, J. K. Hall, N. Bakler and Z   Ben-Avraham,
    1978. The young (Post Lower Pliocene) Geological
    History of the Caesarea Structure. Israel Jour.
    Earth-Sci., v. 27, pp. 43-64.
Nir, Y., 1973.   Geological History of the Recent and
    Subrecent sediments of the Israel Mediterranean shelf
    and slope. GSI, Unpub. Rep., 179 p.
Nir, Y., 1976.   Detached breakwaters and groins and their
    influence on the Israel Mediterranean beaches. GSI,
    Unpub. Rep., 33 p., (in Hebrew).
Nir, Y., 1980.   Recent sediments of Haifa Bay. Report
    Marine Geology Div. GSI, MG/11/80, 8 p.

Nir, Y., 1982. Israel and Sinai Coastal Morphology. in:
    The Encyclopedia of Beaches and Coastal Environments.
    M. L. Schwartz Ed., Hutchinson Ross Pub.
    Co., Stroudsburg, Pennsylvania, pp. 86-98.

Pomerancblum, M., 1966. The distribution of the heavy
    minerals and their hydraulic equivalents in sediments
    of the Mediterranean Continental Shelf of Israel.
    Jour. Sed. Pet., vol. 36, pp. 162-174

Ron, Z. Y. D., 1982. Destruction and withdrawal of Netanya's
    Sea Cliff. A. Shemueli and M. Braver eds., Netanya
    Book, Am Oved, pp. 45-67 (in Hebrew).

Sauzay, G., Ch. Gilat, M. Meltzer, G. Courtois, I. Frenkel, A. Levin
    and S. Blit, 1974. Study of sediment transport on the
    bed and on the beach at the site of the Hadera Power
    Plant Israel Atom. Energy Com. Rep., 40 p.

Shukri, N. M. and G. Philip, 1960. The mineralogy of some
    recent deposits in the El-Arish-Gaza area. Bull.
    Faculty of Sci., Cairo Univ. vol. 35, pp. 73-85.

Sofer (Spar), S. and E. Sass, 1982. Sedimentological and
    morphological characteristics of seashore sands at
    Netanya's twin breakwaters. Netanya Book, A. Shemueli
    and M. Braver, eds. Am Oved, pp. 69-79 (in Hebrew).

Spar, S. M., 1976. Sedimentological behavior of the beach sand
    in the vicinity of the Netanya Breakwaters. Unpub.
    M. Sc. thesis, Hebrew Univ., Jerusalem, pp. 56.

Tauman, J., 1975. Foreshore and Beach development of Bat-
    Yam (Bathing Beach Development with enclosing
    structure). Symp. on "Foreshore and Coastal
    Eng. Aspect". Assoc. Eng. & Archit. in Israel; 8p.

Tauman, J., 1976. Enclosing scheme for bathing beach
    development. Amer. Soc. Civ. Eng. 15 Coastal Eng. Conf.
    Honolulu, Hawaii, Chap. 84. pp 1425-1438.

Vajda, M., 1975. Tel Aviv Shore Development Model Study,
    Hydrodynamics and Hydraulic Eng. Lab., Technion
    Research and Development Foundation, Haifa.

Zenkovich, V. P., 1971. Dynamic elements of Nile Delta
    shoreline. in: New studies of shore processes,
    Akad. Nauk. SSSR, "Nauka", Moscow, pp. 35-49. (In Russian).