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TECTONIC AND EUSTATIC CHANGES ON THE MEDITERRANEAN COAST OF ISRAEL IN THE LAST 9000 YEARS

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ABSTRACT

Archaeological sites on the Mediterranean Coast of Israel were studied in order to identify the original relation of each occupation level to its contemporary sea level. Sites were classified by age into 14 different time zones from Neolithic (starting 9000 years ago) up to Crusader (ending 700 years ago). Thirty-five coastal sites were visited and surveyed from the shore and by divers, while data from the literature were obtained on a further 23. Several sites produced information on sea levels from more than one archaeological period. Tide-gauge and meteorological readings were obtained from the Port of Haifa throughout the period of observation, and temporary tide-staffs were installed at sites where work continued for more than a few hours.

A few Neolithic and Chalcolithic sites were found to be submerged by several metres, due to the Flandrian glacio-eustatic rise in sea level. From the Middle Bronze Age (4000 years ago) onwards, the vast majority of sites correlate to within ± 1.0m of present sea level, indicating minimal eustatic sea level change and tectonic activity. A significant region of tectonic activity, with multiple movements and net submergence, is revealed within 40km north and south of the Haifa-Qishon Graben. Caesarea shows differential submergence within the site area, suggesting local slumping or faulting. There is no evidence for exceptional vertical movements anywhere on the coast which might be associated with a continuous coastal fault system.

INTRODUCTION

The geological structure and recent tectonic processes in the eastern Mediterranean have aroused a great deal of controversy and speculation. Simple divisions of regions into oceanic and continental crust are difficult, and the various models for the origin of the basin in terms of geosynclines (Aubouin, 1958, 1965) or plate tectonics (Mackenzie, 1970, 1972; Dewey and Bird, 1970a, 1970b; Dewey et al., 1973) are faced with severe problems. Data relevant to resolving these problems include recent and historical earthquake seismicity (Ambraseys, 1962, 1970, 1971, 1975; Arieh, 1967), reflection profiling (Ryan, 1969; Rabinowitz and Ryan, 1970; Lort and Gray, 1974; Wong et al., 1971; Hall and Nathan-Bakler, 1975; Neev et al., 1976), gravity measurements (Harrison, 1955; Woodside and Bowin, 1970), fault plain solutions (Mackenzie, 1970, 1972; Ben Menahem et al., 1976), the analysis of recent fault movements on land, especially along the Dead Sea rift valley (Freund, 1965, 1970; Freund and Garfunkel, 1970; Ben Menahem et al., 1976) and the Anatolian fault (Ambraseys, 1970), repeated geodetic levelling (Kafri, 1969; Garcz and Kafri, 1971, 1973, 1975), and bathymetric and side-scan sonar surveys of the sea floor (Emergy et al., 1966; Stride et al., 1977).

An indication of the scale and rate of tectonic processes responsible for the evolution of the eastern Mediterranean can be gained from study of the horizontal and vertical earth movements which are detectable in the coastal regions. Previous studies (Flemming, 1968a, 1968b, 1968c, 1969, 1972, 1978 in press; Flemming et al., 1973a, 1973b) have shown from archaeological evidence that the north-east Mediterranean and southern Aegean can be divided into lithospheric regions classified as stable relative to present sea level, submerging or uplifting, tilting, or distorting in an irregular fashion. Blocks vary in size from a scale of about 100km to 500km, and rates of vertical movement reach a maximum of 5m per 1000 years, while rates of tilt may be up to 10 seconds of arc per 1000 years.

The Mediterranean Coast of Israel (Fig. 1), with its associated coastal plain and continental shelf, occupies a critical and highly problematical place in any model of the eastern Mediterranean. While the Dead Sea- Red Sea rift system is proposed as a plate boundary by most authors (eg Mackenzie, 1972; Dewey et al., 1973), the western and northern boundaries of the plate of which Israel is supposed to be a part have not been found and indeed, may not exist. This problem is closely related to the question of the relative movements of Cyprus and the Eratosthenes Seamount in relation to the adjacent sea floor and land masses (Ben-Avraham and Ginzburg, 1976). Any model of the relative movements in this area must account for the linearity of the Mediterranean Coast of Israel, the low seismicity of the Israel continental shelf, and the lack of

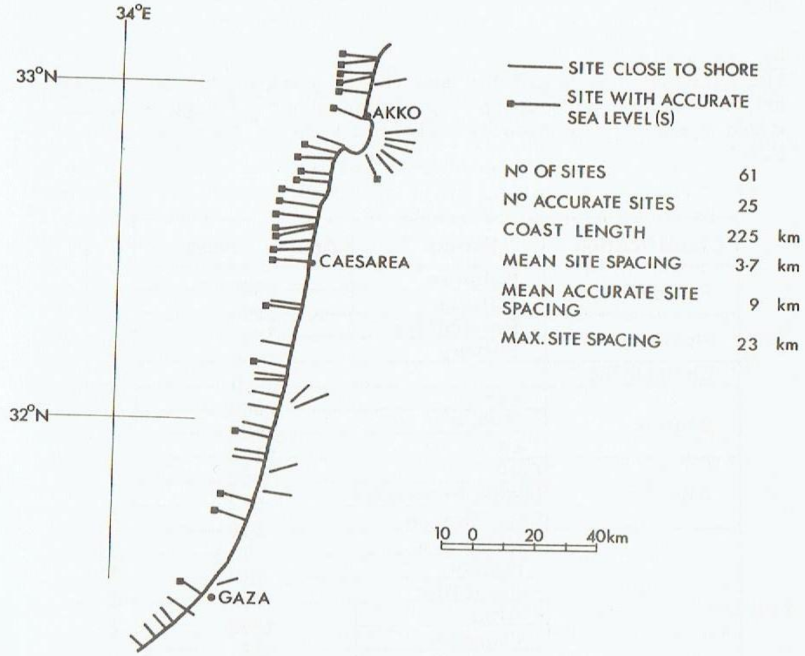


Figure 1. Sketch map of the Mediterranean Coast of Israel, showing location of sites studied. Solid squares indicate sites for which an estimate of relative sea level was obtained. Other sites are potential sources of data on sea levels.

evidence for "plate boundaries" extending the northerly trend of the Gulf of Suez, or around southern Cyprus. One such model is that proposed by Neev et al., (1976), which includes the supposition that the present coastline of Israel is determined by a highly active fault line which has shown vertical movements of the order of 10 to 20m in the last 1000 years (Neev et al., 1973).

The purpose of the present paper is to apply the methods developed previously for the estimation of relative changes of level at archaeological sites (Blackman, 1971; Schmeidt, 1972; Flemming, 1969, and in press) in order to establish the magnitude and distribution of tectonic activity on the Mediterranean coast of Israel, as a contribution towards the solution of these problems. It is assumed that there may be a component of eustatic sea level change, and the field data

will be analysed to separate the eustatic and tectonic components.

METHODS

Dating scale

The dates of the beginning and end of each of the principal archaeological periods in Israel are shown in Figure 2, in round numbers, (Archaeological Institute of America, 1967, p.XV).

Classification	Period	Approx Dates	
Paleolithic	Kebaran	9000	
	Natufian	7000	
Neolithic	Pre-pottery	5000	B
	Pottery	4000	C
Chalcolithic		3000	E
Bronze	Early	2000	
	Middle	1500	
	Late	1200	
Iron	Early	900	
	Middle: Phoenician	587	
	Late: Persian	330	
	Hellenistic	63	↕
	Roman	330	
	Byzantine	638	C
	Arab	1099	E
	Crusader	1291	

Figure 2. Beginning and end dates, in round numbers, of the principle archaeological periods of the Near and Middle East (after American Institute of Archaeology, 1967).

From the Middle Bronze Age onwards, the periods have an average length of 332 years with a maximum length of 500, and a minimum of 192 years. Thus, to a quick mental approximation, the time-scale can be thought of as linear in terms of successive archaeological periods. Although certain buildings or items of pottery at given sites may be dated much more accurately within a period, eg Middle Bronze IIa, etc, no attempt is made to date sites in this way in the present study. Such accuracy would only be possible at a few sites, and the implications would be misleading. An occupied site is usually occupied for several hundred years, sometimes several thousand years, and its structures are adjusted to tolerate small sea level changes over several hundred years. Thus, to date a particular building and relate it to the sea level, only indicates that the sea level was within a certain vertical

range for 100 years or so on either side of that date. At this stage of the study of the Israel coast it therefore seems better only to allocate sites or occupation levels to the broad archaeological periods.

Archaeological sea level indicators

Structures in coastal cities, slipways, quays, mooring bollards, salt tanks, fish tanks, breakwaters, jetties, causeways, etc, were built in a precise relation to the sea level at their time of use. These relationships have been analysed by Flemming (1969, and in press), Schmeidt (1972), Blackman (1973), and Pirazzoli (1976a, 1976b). In addition, the discovery of normal terrestrial remains such as houses, tombs, roads, etc, in the water, is an obvious indication of relative change of level.

The earliest known man-made artificial breakwater at a marine site is that at Atlit, in Israel, probably dating from about 900BC (2900 Before Present: BP). Thus, all sites of the Bronze Age lack the definitive features which have hitherto been used as sea level indicators.

Previous studies of harbours have been almost entirely concerned with the remains of the classical Greek period or later (later than 2600 BP), with the exception of Evans & Renfrew (1968) and Harding et al., (1969). Very few habitation sites of earlier dates have been studied with sufficient emphasis on the shore areas to identify even approximate relative levels. Furthermore, although it is manifestly obvious from the presence of trade goods at coastal sites, and from writings and inscriptions, that there were many harbours in the 3rd and 2nd millennia BC, no built construction obviously designed as a harbour wall, jetty, slipway, or quay, has yet been identified at a marine site. The glacio-eustatic rise of sea level from about 17000 BP to 5000 BP produced an in-flooding of river valleys so that there would have been many deep inlets and rias at the start of the 3rd millennium BC. It can only be assumed that these inlets provided the Egyptians and other sea-traders with so many natural harbours that no masonry constructions were needed. Additionally, offshore islands, reefs, and suitably shaped headlands were probably used. This picture is far from satisfactory, and it is difficult to imagine that large trading ventures and military expeditions were supported entirely by ships which relied on natural shelter, or being dragged up on beaches. In effect, it appears that there was a 2000 year lag between the development of efficient sailing and rowed sea-going ships, and the construction of artificial harbours. The frescoes from Thira (Marinatos, 1974) show ships approaching coastal cities, but there is no sign of harbour works of either wood or stone.

During work on the Mediterranean coast of Israel from October 1975 to February 1976, every effort was made to locate Bronze Age sites which might have been harbours, or which might reveal artificial harbour constructions. This search was based on the long experience of one of us (AR) working on this coast, and on the experience of Dr. E. Linder, Director of the Department of the History of Maritime Civilization at the University of Haifa. All Bronze Age tells within 1km of the coast were identified from the archaeological literature, plotted on a map at a scale of 1:50,000 and a bibliography of archaeological literature was compiled by Chava Magon. The principal English language references from this bibliography are cited in the data sections below, but many of the references are in Hebrew, and these are not quoted. Copies of the Hebrew references can be provided on request to the authors.

A total of 35 Bronze Age sites were listed, and the locations were examined for closeness to streams, swamps, lagoons, headlands, or reefs and islands, which might have been used originally as harbours. Before commencement of this study, Tell Nami had already been selected by Dr. Linder as a probable site for a harbour, since the Tell was on a promontory rock, joined to the mainland by a low spit of sand. This site was surveyed intensively for a week during the present study, and trial excavation trenches were dug. A full report of this survey is being published elsewhere.

The examination of excavation reports, combined with visits to many of the tells, and the survey and excavation at Tell Nami, failed to reveal any evidence for built harbours in the Bronze Age. However, the topographic plans of the excavated sites, the positions of houses and tombs, enabled an approximate estimate of relative sea level change to be made at some sites to within an error of about $\pm$ 1.0 to 2.0m.

No new data were observed from the Neolithic or Chalcolithic periods during this study, but reports and photographs were provided by Ernst Wreschner, and Avner Raban. The finds described included house walls, burials, and pottery, none of which bore any precise relationship to the original sea level. All that can be said is that since these remains were found below mean sea level (MSL), there must have been a relative change of sea level sufficient to submerge them from their original position on dry land.

Sea level corrections

As explained above, sites from the Bronze Age and earlier only provided data for approximate estimates of the ancient relative sea levels. However, sites of the Iron Age and later periods provided a mass of useful indicators, and an attempt was made to increase the accuracy of derivation of sea levels significantly over previous studies.

Early investigations of archaeological evidence for sea levels are reviewed by Flemming (1969, p.3-10). The accuracy of such observations was about $\pm$ 2.0m, due to lack of careful interpretation of the functions of structures and their original relation to sea level. Flemming (1969) studied data from 179 sites in the western Mediterranean, and concluded that the accuracy of the method had been improved to $\pm$ 0.5m (Ibid, p.81). The sources of observational errors are:- inaccuracy of vertical measurements due to wave action; uncertainty about the state of the tide; variations in sea level due to changes in atmospheric pressure and winds; and variations in the height of structures above sea level arising from varying exposure to wind and waves.

In calm sheltered water a measuring tape or pole can be read to an accuracy of 5cm or better. Tide tables with times of high and low water do not exist for most parts of the Mediterranean, although the amplitude of spring and neap tides are published for principal ports. If the state of the tide is not known, this introduces an error of the order of 20cm. A 1 millibar change of atmospheric pressure produces a 1cm change in sea level, other things being equal, and since the pressure drops over the eastern Mediterranean by 4 millibars relative to the central Mediterranean during the period of May to August (Warners, 1957, p.14-19), one would expect the sea level to rise in summer. Striem (1974, p.62) records that the average sea level on the Mediterranean coast of Israel is 6cm higher for the 6 months May-October than for the 6 months November-April, with a peak rise of 17cm between May and August. Wind and wave set-up can also cause short-term sea level changes. For example, on the 4th of December 1975, during excavations at Tell Nami, there was a strong offshore wind, and the sea level at the site was measured as being 20cm lower than usual. Finally, estimates based on the position of structures such as breakwaters and quays, depend upon assumptions about the exposure of the original structure to waves. Uncertainties inherent in these assumptions introduce an error of the order of 20cm in the estimate.

The root sum square from all these causes, waves (5cm), tides (20cm), atmospheric pressure variations (10cm), and variation in exposure (20cm), is thus about 30cm. If a further error of the order of 20cm is allowed for the possible changes of level during an occupation period of several hundred years, the total root sum square error is 37cm. This is the probable error of previous work by Flemming in the north-east Mediterranean and Aegean (Flemming, 1978, in press). However, if the tidal-plus-atmospheric component can be eliminated by use of tide-tables, tide recorders or tide-staffs, and meteorological records, then the root sum square error can be reduced. If this source of error is reduced to 5cm, then the root sum square error is 28cm. This can only be improved upon in exceptional cases.

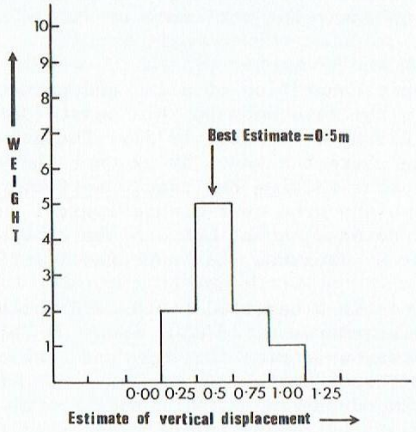
Accordingly, copies of the maregraph record and daily meteorological observations were obtained at the end of each month from the Port Authority of Haifa, and the times of all field observations of relative levels of structures to sea level were recorded to the nearest 5 minutes. Observations of level were made with a Wild NAK-1 surveyor's level, and a graduated surveyor's pole, and then corrected to MSL from the tide record. Since the maregraph record was itself uncorrected, it included the changes of sea level due to atmospheric effects. As a further check, at Dor, Caesarea, and Tell Nami, graduated poles marked in centimetres were fixed in sheltered water so as to plot the local sea-level curve during surveying. The tidal range and times of high and low water could then be correlated with the Haifa record, and corrected to annual MSL. Although these corrections could only be applied with certainty to sites where there were good sea level indicators, and work was conducted for a whole day or more, the increased accuracy at these particular sites amply justified the effort.

Probabilities of estimates

The evidence at a given site may not give a symmetrical probability of error on either side of the best estimate of original sea level. It is common to find evidence, such as house foundations, which place a clear limit on the possible range of sea levels in the upward direction, while finding no clear limit in the downward. Alternatively, the foundations of a mole or jetty must have been in the water, although, in the absence of the upper surface, one cannot place a limit on their maximum depth. In these asymmetric, or skewed, conditions it is not reasonable to estimate errors in terms of a standard error distributed normally on either side of the mean. The technique used (Flemming, 1972,p.195) is to allocate a weight of 10 points to each dated occupation level, and to distribute the weighting onto 25cm classes around the best estimate (see Figure 3). Thus, a very clear-cut estimate has all 10 points loaded onto the best estimate; an asymmetric one shows a zero probability that the magnitude of submergence could be to one side of the best estimate, and a non-zero probability that it could be to the other side. Symmetrical poor estimates are shown by abroad normal distribution of probabilities. The weightings are listed in Table II after the best estimate in each case.

Geomorphological indicators

Abrasion terraces The dominant wind direction and maximum fetch are both from the west. Thus, the coast is exposed to an almost continuous wave attack (Emery and Neev, 1960). The form of the coastline is largely controlled by the longitudinal calcified Pleistocene dune ridges known as Kurkar (Farrand & Ronen, 1974; Ronen, 1975; Raban, 1973, p.32, Figure 2). Where a low ridge is partially broken through, as between Caesarea and Atlit the coast consists of numerous small bays, headlands, reefs, and tombolos. Where the waves have cut into a high ridge, as between Mikhmoret and Tel Aviv, there are cliffs. Where the present shore lies between the Kurkar ridges one finds a submerged offshore reef, and a low coast. South of Tel Aviv there is an ample supply of unconsolidated sand, and mobile



Figures 3. Distribution of weighting of estimates around the best estimate for a site. See text for explanation.

dunes extend to the coast in many places. Where the wave action cuts rapidly into the Kurkar a flat abrasion terrace is produced, usually between 10 and 30m wide, but sometimes reaching 50m. The outer rim is protected by an organic growth of Vermetus (see below). The terraces are common from Caesarea to Haifa, and almost continuous from Acco to Rosh Ha Niqra, on the border with Lebanon.

The terraces and the residual rocks standing upon them were frequently quarried for building stone, and cut in to for the construction of fish tanks and salt tanks (salinas). For many kms north of Acco, the terrace is covered continuously by quarry marks.

Levelling of the outer edges and surfaces of several terraces showed that the organic rim was usually 20-30cm above mean sea level, while the terrace behind was irregular and pitted, but generally lower than the rim. Waves break over the rim in all but the calmest weather, producing a raised pool on the terrace, with streams of water running back through gaps in the rim. The landward junction between the terrace and the residual rock or low cliff is consistently 20-50cm higher than MSL, due to the raised level of the pool, and the run-up of large waves.

The abrasion terrace should form an excellent indicator of change of sea level, but in no case was it found significantly displaced from its relation to present sea level. In the neighbourhood of Acco the quarries seem a bit low in the water, about 20-30cm, but elsewhere the terrace indicates an almost constant relative level. No raised or submerged terraces were identified, although searches were made by divers at several sites.

Vermetus An organic concretion of algae and vermetid worms grows profusely in the wave zone on this coast (Safriel, 1966, 1974, 1975; Ben Eliahu & Safriel, 1975). The growth is most active in the zone where the waves break over the edge of the abrasion terrace, thus raising the edge, and forming a raised pool. The vermetus can grow over archaeological cuttings or encase blocks and columns, as at Dor. A search was made for submerged vermetus at Caesarea, but none was identified.

Beachrock Beachrock is a cemented beach sand which forms near the water-line (Alexandersson, 1972). South of Tel Aviv it has formed in continuous strips for many kms, and occurs on most beaches from there, southwards to Gaza. The beachrock is often exposed and depleted of its natural cover of loose sand, probably due to the quarrying of beach sand for modern concrete construction (Emery & Neev, 1960). Beachrock occurs less frequently further north, but there are large sheets of it at Shavei Zion, north of Acco.

At almost all sites where beachrock was observed it exhibited a close correlation with present sea level.

Marine solution notches Sea-water dissolves notches in calcareous rocks even in the absence of wave action. On exposed coasts the small tide in the Mediterranean, combined with wave action, results in a notch 30-50cm high, and cut the same depth into the rock horizontally. In sheltered waters, or within caves or rock-cut tanks, two notches may be cut, one at mean high (MHW) water and one at mean low water (MLW). Double notches have been observed previously by NCF at Gibraltar and Lambousa, Cyprus. For the coast of Israel the data on tidal range were combined by Israel Levit with the data on the monthly variation of sea level throughout the year (Striem, 1974) to produce a curve indicating the total time which the sea level spends in each 1cm vertical range during the year. This double-peaked curve fits exactly to the form of the solution notches found in sheltered rock cuttings at Dor. Vertical displacement of these notches cut into channel and tank walls was used to measure relative changes of level at several sites.

FIELD OBSERVATIONS

Introduction

Table I is a list of sites from north to south with archaeological periods represented. In the following sections the sites are listed from north to south, with brief descriptions and deduction of sea level where possible. For each site the following information is given:- name, latitude and longitude, references to site descriptions and excavation reports, followed by discussion of evidence for ancient sea levels. As explained above, references in Hebrew are not cited. A summary of all the estimated levels is shown in table II (Appendix).

Sites

1. ROSH HANNIQRA, SHORE $35^{o}5.2$'E. $33^{o}5.5$'N.

Paleolithic and Neolithic flint implements have been found on the slopes of the hill immediately above the derelict railway cutting (Ernst Wreschner, personal communication). These show occupation near the shore, but no relative sea levels. The abrasion terrace immediately seaward of the railway cutting is deeply incised with quarries and tanks believed by Wreschner to be late Roman or Byzantine. They indicate submergence of about 0.5m.

2. ROSH HANNIQRA, TELL $35^{o}5.2$'E. $33^{o}5.5$'N.

Tadmor and Prausnitz (1959).
The Tell, which is believed to be the site of the biblical Misrephoth-Maim, is located between 40 and 45m above the sea, and excavations there have revealed house foundations, city fortifications, and pottery from the Early Bronze to the Late Bronze Age. The location of the site is clearly strategically related to the sea, but there is no natural harbour.

3. ROSH HANNIQRA, ISLANDS $35^{o}5$ 'E. $33^{o}4.2$'N.

Three small islands lie 1km off Rosh Hanniqra, just south of the border with Lebanon. They are part of the submerged Kurkar Ridge which extends all the way from Rosh Hanniqra to several kms offshore from Acco. In winter storms the waves break along the entire length of this ridge. The islands are called Trelet, Shakhaf and Nachlieli. Trelet is very low, never rising as much as 1.0m from the water; Shakhaf is composed of residual blocks from extensive quarrying; Nachlieli consists of quarry residuals rising 4.0m, 3.0m and 2.0m above the water, interspersed with rectangular quarries and stepped depressions, cut to a depth of 20cm below MSL. Near the northern end of the island is a stratum of red earth, of the kind known as Hamra, about 30-40cm thick. Similar earth layers on land have frequently contained Stone Age implements and artifacts.

The quarrying has been carefully conducted so as to leave an almost continuous rampart against the waves

TABLE 1

Site list giving summary of sites for which dateable remains were identified. Pal = Paleolithic; Neo = Neolithic; Ch = Chalcolithic. EB, MB, LB, EI, MI, and LI, as in text. Hel = Hellenistic; Rom = Roman; Ar = Arab; Cru = Crusader. A cross with a circle indicates that sufficient evidence was found from that period to give a reasonable estimate of the original relative sea level. Estimates and errors are shown in Table II (appendix).

	DATED SITE ×							ACCURATE LEVEL ⊗						
	PAL	NEO	CH	EB	MB	LB	EI	MI	LI	HEL	ROM	BYZ	AR	CRU
ROSH HANIQRA	×	×										⊗		
MISREPHOTH					×	×								
ROSH/NACHLIELI								(⊗)	(⊗)	- - -	- - -	(⊗)		
AKHZIB		(⊗)	- (⊗)		×	×		×	×	×	⊗			×
AKHZIB/SIGORION								(⊗)	- - -	- - -	- - -	(⊗)		
NAHARIYA					×	×		×						
SHAVEI ZION N											⊗	⊗		
SHAVEI ZION S									- - -	- - -	⊗			
YASSIF RIVER									- - -	- - -	⊗			
AKKO					×	×	×?	⊗	×	(⊗)	×	×	×	⊗
TELL ZIVDA									×	×				
KHIRBET GEDORA									×	×				
TELL ZARAT									×	×				
TELL EL IAHAM									×	×				
TELL NAHAL									×					
TELL ABU HAWAM						⊗	×	×	×	×				
RAMBAM									×	×				
BAT GALIM											⊗			
TELL SHIKMONA						×			×	⊗	⊗	⊗		
MEGADIM						(×)			×					
ATLIT			⊗		⊗	⊗		⊗	×	×	⊗			⊗
BEIT EL MILH									×					
NEVE YAM			⊗						×					
TELL NAMI					⊗	⊗			×					
TELL NAMI		×												
TELL NAMI														⊗
DOR. NORTH									×					
DOR						×			×	⊗	×	×		
NAHAL DALIA		⊗	⊗											
MAGAN MIKHAEL														
CROCODILOPLIS									×	⊗	×?			
CAESAREA									×	⊗	⊗	×	×	⊗
TELL GIRITH						×								
MIKHMORET						×		⊗		×				
TELL POLEG					×									
APOLLONIA											⊗			⊗
TELL MAKMISH					×	×				×	×			
TELL MICHAL					×	×								
TELL AVIV														
TELL QASILE					×	×								
TELL GARISHA				×	×	×								
YAFFO				×	×	×				×	×			
TELL YONA														
PALMACHIM				×	×	×		⊗	×	×	⊗	⊗		
TELL HASHAVYA								×						
TELL MOR					×	×								
ASHDOD YAM	×							×			×		⊗	
ASKELON		×		×	⊗	×		×	×	×	×	×	×	⊗
ANTHEDON						×				×				
GAZA MAIUMAS												⊗		
TELL EL AJJUL					×									
TELL EL QATIFA														
TELL EL RIDAN					×	×								
TELL EL JINAN						×								
TELL RAFIA					×									

approaching from the west, while the eastern side of the island has been quarried away entirely. Such a technique was used by the Phoenicians when quarrying on headlands, which would date the work to the Middle Iron Age. But it would not really require much ingenuity to see the value of this method, and the quarries might date as late as Roman or Byzantine. There has been submergence of 30cm, possibly more.

4. ACHZIB 35°6'E. 33°2.5'N.

Prausnitz (1959, 1964, 1969, 1970, 1975b)
Artifacts of Neolithic to Chalcolithic period were found in the neighbourhood of Achzib by Ernst Wrescher & Prausnitz, (Prausnitz, 1969), but with no precise relation to the seashore. The site which was occupied in the Middle Bronze (MB) is on a low hill rising steeply from the shore, and flanked on the northern side by the Chezib River. A ditch was cut round the landward (eastern) side of the hill, rejoining the sea through a rock-cut channel to the south. The channel shows up clearly on aerial photographs. Prausnitz (1975b, p.26) states that this channel was cut during the MB to isolate the "port and city". The southern curve of the channel is at present blocked by sand, but the mouth opening into the sea is cut in rock, and seems well adjusted to the present sea level, to within a margin of ± 0.5m. Probing through the sand to the floor of the channel would reveal the exact cross-section, and relation of the floor and the lip of the side-walls to the sea level.

Achzib flourished during the Middle and Late Iron Age (MI, LI), but the tombs and foundations of these periods cannot be related to the sea level. The Hellenistic and Roman cities have not left remains of harbours or jetties, but quarrying and cut pools which probably originated in the Roman times relate very closely to present sea level. The most probable estimate is that there has been no change of relative sea level, though it is just possible that there may have been submergence by as much as 0.5m.

The Crusader walls and fortifications along the shore have foundations which disappear into the sand at a height of 1.5-2.0m above sea level, but these do not give any clear evidence, and could in any case have been built with their footings in the water.

The reefs and ridges which protect the beach have, at first sight, the appearance of harbour works, but the aerial photograph indicates only the broken remnants of a submerged ridge of Kurkar. Inspection of the ridge close to the shore reveals no harbour works, and only a few quarry marks and rectangular pools. The only possible harbour would have been in the mouth of the Chezib River, partly sheltered by the Kurkar reef.

5. ACHZIB, ISLANDS $35^{o}5'$E. $33^{o}2.5'$N.

Four small islands lie 3km offshore from Achzib, being high points on the Kurkar Ridge which extends more or less parallel to the shore all the way to Acco. The largest island is called Sigorion. The northern and smallest island is merely a network of broken vermetus reefs, with one rocky residual rising 1.0m above the water. Quarries were observed there by AR some years ago, but these have now been eroded away. The two small southern islands are also quarried relics, with no part rising more than 50cm above the raised pools enclosed by the vermetus rim.

Sigorion is a larger massif with outcrops rising to 2.3m, 1.8m, and several blocks to about 1.0m. The island is surrounded by a vermetus rim which retains the water within, at a height of about 40cm above MSL. The quarrying within the island is cut down to 30cm below MSL so that the central pool is 70cm deep. The quarrying has been conducted so as to leave the highest ramparts on the seaward side, protecting the work from wave action whenever possible.

The dating of the quarries is highly uncertain. The technique of leaving protective residuals is typically Phoenician, that is, Middle Iron Age, but could be as late as Roman or even Byzantine. Submergence of the order of 40-50cm has occurred, since quarrying would not have been conducted below sea level.

6. NAHARIYA $35^{o}5.4'$E. $33^{o}0.8'$N

Ben Dor (1950), Dothan (1956a, 1956b).
Tell Nahariya lies on the south side of the Ga-athan River, and the port was presumably in the river mouth. The foundations of a Middle Bronze Age temple lie 800m north of the river, approximately 100m back from the water line, at the back of a broad beach. The floor of the temple is laid at 5.5m above MSL, on virgin soil at 4.7m. There is no evidence of a change of relative sea level, since the site is rather far from the water, and the margin of error is so broad as to leave the possibility of either submergence or uplift.

7. SHAVEI ZION, (north) $35^{o}4.8'$E. $32^{o}58.8'$N

Guide Bleu (1972, p. 207).
One hundred metres north of the modern jetty a stream flows into the sea across wide accumulations of beachrock. On the south side of the stream is a well-preserved 4th century A.D. mosaic, and on the north side a mound rises to 15m, covered with Roman and Byzantine remains. On the seaward side of the mound, walls and quarries extend down as low as 1.6m above sea level, although exposed to the sea and protected only by a narrow terrace.

The enormous width of beachrock between the jetty and the stream is composed of gently dipping strata each from 15 to 25cm thick, although the whole assemblage appears level, and consequently must have been formed by successive accumulations under constant sea level conditions. The stream has not cut down through the beachrock, indicating lack of uplift. Old people say that the beach used to be sandy, and that the beachrock is now permanently exposed because of removal of sand for construction projects. Examination by divers showed that the beach rock extended intact to a depth of only 40cm at its upper surface, and then broke off into large blocks, and progressively to smaller blocks at a depth of 1.5m. If the beachrock had extended to a depth of, say, 2 or 3m, there would have been evidence for submergence. However, every indication, both above and below the present water line, suggests a constant sea level for a prolonged period.

8. SHAVEI ZION (south) $35^{o}4.7'$E $32^{o}58.2'$N.

One kilometre south of Shavei Zion a series of quarries and rectangular pools are cut into the abrasion terrace on the shore. The outer edge of vermetus is 30cm above MSL, and the cuttings do not extend below sea level, although they are filled by the waves. The cuttings most probably date to the Roman period, and indicate no change of sea level, with an error of about $\pm$ 0.5m.

9. YASSIF RIVER $35^{o}4.5'$E. $32^{o}57.5'$N.

Between Shavei Zion and Acco the Yassif River flows into the sea across a bed of beachrock. Pottery from a small settlement on the bank dates from the 1st to the 5th century A.D., and there are quarries and cuttings almost to the water line. The adjustment of the beachrock to present sea level, the abrasion terrace, the height of the vermetus rim, the quarries, and the absence of stream down-cutting into the beachrock, all indicate constancy of relative sea level.

10. ACCO (see Figure 4) $35^{o}5.5'$E. $32^{o}55'$N.

Makhouly and Johns (1946), Linder and Raban (1964), Dichter(1973), Goldmann (1975).
The Tell of the Bronze Age City lies on the north bank of the river Na-aman, and the excavations are currently continuing under the direction of Professor M. Dothan. The earliest remains are of the period MB1, and throughout the Middle and Late Bronze Age pottery from Greece and Cyprus is found. The river mouth could have been used as a harbour, but extensive searches by divers in the bay over many years have not revealed any Bronze Age pottery or evidence of harbour construction of the Bronze Age.

The Tell was occupied throughout the Iron Age, but during

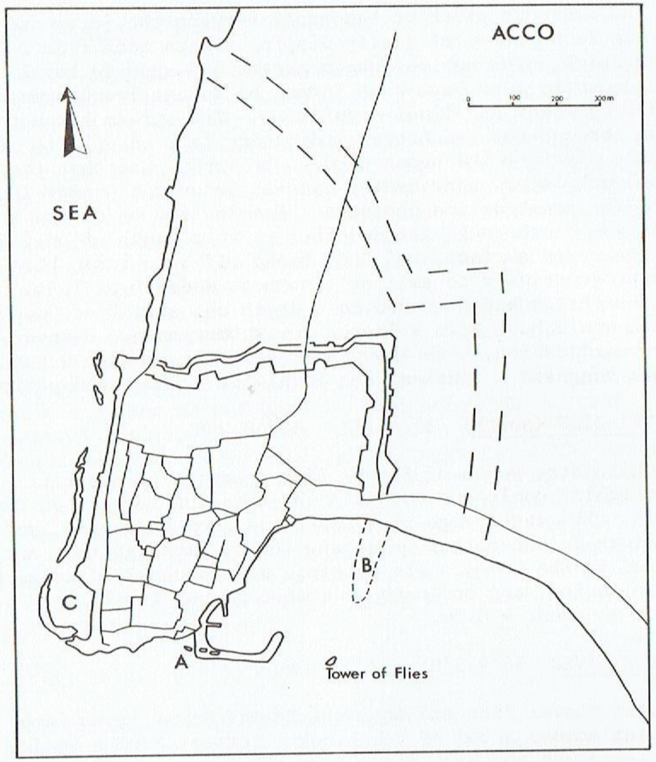


Figure 4. Acco, after Dichter (1973). A = area of remains of Phoenician breakwater still visible, and submerged Crusader wall; B = supposed position of second breakwater; C = breach of city wall made in 1840 by bombardment of Church of St. Andrew.

the Late Iron Age the city spread north and westwards to occupy the headland which forms the northern limit of Haifa Bay, and which is the location of the modern city. The harbour flourished under Greek and Roman rule, and during the latter period it was used as the port for disembarkment of the legions. In 636-A.D. Acco was conquered by the Arabs, and in 1104 by the Crusaders. In 1291 the city was destroyed by the Mamelukes, and only reached prosperity again under the Turkish rule in the 18th century.

The changes in perimeter of the defences and the harbour walls during successive occupations, destruction, and re-fortification, are such that many years of field work would be needed to elucidate

the whole story. Some idea of the complexity of the problem can be gained from the numerous historic maps of the city from 1250-A.D. onwards, collected by Dichter (1973). In general, the maps show one or two inner harbour basins which are in areas now covered by buildings, and two outer basins protected by breakwaters. The outermost point of the harbour is guarded by a tower built on a small rock, and known as the Tower of Flies.

The historical records, descriptions, and maps, contain a mass of circumstantial and occasionally conflicting evidence, and will not be discussed here. The principal items of archaeological evidence presently available are quite few. The southern harbour wall of the Phoenician harbour was described by Linder and Raban (1964) after detailed diving surveys. It consists of large header blocks laid in several metres of water, stretching in a straight line towards the Tower of Flies. Most of this ancient breakwater was covered by the construction of the modern fishing jetty in the late 1960's, but parts of it can still be seen from the surface at the point marked "A" in Figure 4. It has frequently been assumed that there was a second breakwater at the point marked "B", and this area has been extensively searched by divers of the Israel Undersea Exploration Society. A shallow area of scattered blocks has been found, with some squared stones, but no evidence of header construction. Nearer the Tower of Flies there are some squared blocks in situ, as if the tower foundation extended towards the land. The Tower itself has been surveyed in detail by divers, and shows Phoenician header construction down to a depth of 7.0m on the seaward side. The upper part, above present sea level, is Crusader.

As already mentioned, there is a great deal of quarrying on the abrasion terrace outside the walls of Acco, and for several kms to the north, which appears to be slightly submerged. Thus there is evidence for a constructed harbour of the Iron Age, and for submergence of about 30-50cm.

Although there are archaeological remains of all subsequent periods on land, some of which might give relative sea levels, the only one for which there are firm data at present is the Crusader period. In the area marked "A", near the Cafe Abu Christo a section of Crusader wall stands isolated in the sea. On the mainland nearby are various broken arches and cut-off walls, all indicating that a large roofed structure used to exist in the intervening area which is now flooded. Although the upper parts of most of these walls were built in the 18th century, they are founded on the original Crusader sea wall (Dichter, 1973, p.182). In the free-standing isolated segment of wall there is the upper curve of a vaulted arch, rising only 0.5m above the water. If this arch is part of a door, then the floor would be about 1.5m below sea level. However, it is more probably a large drain, though this cannot be checked because of the large quantities of fallen masonry. Linder (oral communication) states that floor levels in nearby Crusader buildings line up approximately with present sea level, and so there does not appear to have been marked subsidence.

Along the western margin of the city the 18th century defensive walls rise directly from the abrasion terrace, and are beaten heavily by the waves in almost all weather conditions. In general, the walls seem low in the water, but they withstand storms even in winter, so it is just possible that the foundations were laid at the present level. However, at the southern corner, marked "C" on Figure 5, the defensive wall was breached by the naval bombardment of 1840-A.D. (Dichter, p.116-117), destroying the area which, in Crusader times, contained the Church of St. Andrew, the Temple, and the hall of the Knights Templar. Within a few years of the breach the winter storms brought down the surrounding masses of masonry, and the gap in the city perimeter still exists. The area where the wall has been broken has been swept by the waves, and the foundations of the destroyed buildings can be seen cut into the rocks to a depth of about 0.5m below mean sea level.

Thus the Crusader remains of Acco appear to be submerged by about the same amount as the Phoenician remains, of the order of 50cms, suggesting a single movement after about 1300 AD.

11-16. TELL ZIVDA, KHIRBET GEDORA, TELLS ZARAT, EL IAHAM, NAHAL, AND ABU HAWAM.

$35^{o}5.5'$E.	$32^{o}49.8'$N;	$35^{o}5.2'$E.	$32^{o}49.3'$N;
$35^{o}5.1'$E.	$32^{o}48.8'$N;	$35^{o}4.5'$E.	$32^{o}48.3'$N;
$35^{o}4'$E.	$32^{o}48'$N;	$35^{o}1'$E.	$32^{o}48'$N.

Hamilton (1934), Anati (1959, 1975, p.9-12). Avnimelech (1959), Olami (1975), Prausnitz (1975a, p.23-25).

Olami (1975, personal written communication) has compiled working maps of distributions of sites in the Haifa area for the Israel Department of Antiquities. These show 5 Bronze Age Tells and 1 Khirbet in an arc across the alluvial plain of the Qishon between Tell Acco and Haifa. The line of the settlements curves back from the present shore line, and is set some 3km from the sea at the mid point between Acco and Haifa. Since no Tells occur seaward of this line, while many more occur inland on the plain of the Qishon valley (Prausnitz, 1975a, p.24), it is clear that the line approximates to the shore in the Bronze Age. Prausnitz (1975a, p.24) shows in a map that the Roman road followed a similar trend, and in fact the modern road from Haifa to Acco also follows a course well back from the shore. The area between the line of ancient

settlements and the present shore is an extremely flat plain of alluvium and beach sand. There is evidence from drilling and offshore seismic profiling (Kafri, 1970) that the valley of the Qishon is a graben which has been sinking at least since the tertiary relative to Mount Carmel to the south and the hills of Galilee to the north. In the present context it is important to establish whether the archaeological evidence confirms this subsidence through the last 3-4000 years. Avnimelech (1959, p.103) considers that the floor of the Qishon valley within 5-10km of the sea has subsided rapidly, and is still subsiding. At the same time the river Qishon has changed course many times, and presumably the river Na'aman on the north side of the plain has also altered course. Avnimelech (1959, p.104) considers that during the Neolithic the sea extended several km inland relative to the present shore line, and that the river Qishon flowed close to the foot of Mount Carmel.

If the line of Tells was built close to the water, and if the subsidence of the area was continuing to the present day, then we would expect the Tells to show signs of submergence, to have foundations below sea level, or below ground water. No detailed evidence has been obtained from any of the Tells except Abu Hawam, but there are no reports of submergence, and the Roman road also has not been waterlogged. At Tell Abu Hawam, Hamilton (1934) found remains dating from the Late Bronze Age to Hellenistic. There was Cypriot pottery from the LB, indicating sea trade, and walls and foundations extending to within 1.5m of MSL. Anati (1959, p.89, 1975, p.9) is categoric that Abu Hawam was a Bronze Age port, and states that in 1963 a thick wall built of large, rough stones, was found 20m west of LB city wall, on the side facing the sea. In the layer of sand at the foot of this wall shards of pottery were found covered with a concretion of sea shells. The function of this wall, whether it was a land structure or part of a harbour, is not explained. Nevertheless, the wall was clearly built very close to sea level, probably within 0.5-1.0m, and is not submerged now, so that there can have been no significant submergence in the last 3000 years.

17. RAMBAM $34^{o}59'$E. $32^{o}50'$N.

Construction workers reported finds of Roman remains during enlargement of the Port of Haifa in the suburb of Rambam. This has not been substantiated, but the area is a very likely one since it would be the most natural sheltered region for a small harbour.

18. BAT GALIM $34^{o}59'$E. $32^{o}50'$N.

Fifty metres south-west from the derelict Casino there is an area of quarrying with precise block marks cut into the rock.

The block sizes are typically 35 x 80cm. The outer part of the quarry was flooded to a depth of 28cm on the 12th of December, 1975, equivalent to 30cm below MSL. The quarries are probably Roman, and indicate submergence of 30cm or slightly more.

19.TELL SHIKMONA $34^{o}57.3'E.$ $32^{o}49.2'N.$

Elgavish (1968, 1974).
Excavations have revealed structures close to the shore from LB to Byzantine. There are historical records referring to a harbour, but no signs of artificial harbour-works on the shore, or underwater, and no natural shelter. The prolongation of Mount Carmel forms a broad shelving reef extending north-west from the shore, but this is more likely to be a danger to shipping than a shelter. Levelling from the mosaic floors within the ruins over the coast road and down to the beach, showed the floors to be 1.66m above sea level. Allowing for the thickness of the floors and footings of walls, this is still comfortably above the sea. There has probably been no relative change of sea level, but the margin of error is about 0.75m.

There is an unusual pool cut into the Carmel limestone on the foreshore between the Tell and the oceanic laboratory. It is of approximately hexagonal form, with slightly curved sides, and a mean diameter of 4.6m. The rock surface around the edge of the pool has been cut into shallow recesses as if to support the foundation blocks of a wall. Two channels open through the rock into the sea, and the pool itself is partly blocked with sand and gravel. The pool does not conform to common designs of either fishtanks or salt tanks, but could have been used for either. Schmeidt (1972, p.42, 77,85) shows maps and photographs of Roman fishtanks in Italy with round pools of about 10-15m in diameter, but in all cases, as part of a larger complex of pools.

The most probable date for the pool is Roman, and it does not indicate a change of relative level, although there could possibly have been submergence of up to 50cm.

20.MEGADIM $34^{o}56.3'E.$ $32^{o}43.1'N.$

Hebrew references document the discovery of pottery from EB and LB at this site within 500m of the shore. Bronze Age pottery is reputed to have been found offshore, but no details are available.

21.ATLIT (see Figure 5) $34^{o}56'E.$ $32^{o}42.5'N.$

Johns (1932, 1933, 1934, 1935, 1975), Linder (1967)
During the late 1960's wave erosion in the north bay at Atlit cut into a Chalcolithic cemetery, and tombs and pottery were found to extend about 2.5m underwater by

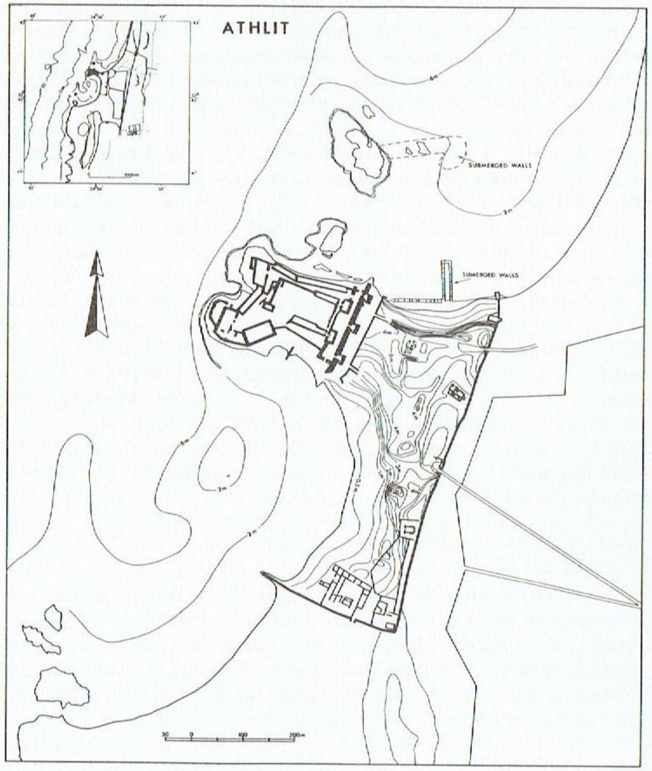


Figure 5. Atlit, after Johns (1932, 1933, 1934). Isobaths from Admiralty Chart. The inset location map shows the indented coastline at Atlit, and southwards, caused by erosion of the Kurkar ridge.

divers from the Israel Undersea Exploration Society.

The settlement at Atlit shows remains in every period from MB to Crusader. Johns (1934, p. 147-149) describes MB jar burials in earth, 75m from the present waterline, and cut down to a level only 1.0m above present sea level. Johns (1934, p. 149-150) describes a LB gateway with a sill 2.0m above MSL, and 25m back from the present waterline. Both these features indicate reasonable adjustment to present sea level, within a margin of ± 1.0m.

An extensive Phoenician (MI) cemetery was found by Johns (1933, p. 41 et seq.) and Linder and Raban have mapped the Phoenician harbour walls (Linder, 1967). This harbour is the oldest known fully constructed artificial harbour on the Mediterranean Coast. The breakwaters consist of two faces of headers, laid 6.0m apart, and filled with rubble. The walls survive on the seafloor to a height of two courses in many places, and four courses in some places. The water depth within the harbour varies from 1.5-4.0m over most of its area, but there is much fallen masonry and broken beach-rock. The sea walls are well adjusted to present sea level, to within a margin of ± 0.5m.

The LI and Hellenistic periods do not provide evidence for sea level, although house walls of these periods occur within 3.0m of sea level (Johns, 1934, p.149). Ronen (oral communication) reports that Roman pottery was found 1m above sea level in eroded low cliffs on the north side of Atlit, but these have now been completely eroded away.

The dominant visible structures at Atlit are the colossal Crusader walls and towers. These are built right up to the water line on all sides, but do not descend into the water. They appear individually to be structurally related to the present sea level, while the over all pattern of defences is logical in relation to present sea level. From Johns (1934, p. 145, Fig. 1) it appears that the floors of stables in the sheltered southern part of the site are only 0.75m above present sea level.

22. NEVE YAM 34°55'E. 32°35'N.

In January 1968 a severe storm temporarily depleted many Israeli beaches of sand, and at Neve Yam neolithic walls and pottery were exposed extending below sea level. These were photographed by Ernst Wreschner (personal verbal communication and photographs). There is probable submergence of the order of 2m, with an error of ± 1m.

23. TELL NAMI 34°55.2'E. 32°39.8'N.

Hebrew references only.
The Tell is on a sharp promotory headland joined to the mainland by a low sand isthmus. The foundations on the headland were first reported by Olami (unpublished report) and were investigated in some detail by a team from the University of Haifa in November-December 1975. A full report will be published separately. The sand spit and rocky headland were levelled and surveyed to an accuracy of ± 5cm relative to a tide staff, against which the tidal curve was measured each day, and this was correlated with the recorded tide at the Port of Haifa. The beach profiles were plotted, and the form of the sand bars related to storm conditions. Aerial photographs showed that the headland was almost cut off from the mainland in 1944, while the present distribution of drift-wood showed that storm waves can carry right across the spit. The highest point of the saddle of the spit during the present survey period was 1.74m above MSL. Three small areas of ruins were excavated on the headland, and pottery of MB and LB periods was found.

A major purpose of the survey was to find whether there had been any harbour construction at the site, since the location was ideal for both marine trade and marine warfare. Cypriot pottery was found on the Tell, confirming sea trade with Cyprus. A search by divers around the headland failed to find any signs of construction in the sea, and no concentrations of pottery. Three trenches were dug with a mechanical excavator through the unconsolidated sand where it abutted against the landward side of the Tell. These trenches were intended to find out whether there was always sand against the Tell, whether it was sometimes surrounded by deep water (thus becoming an island), and whether any walls, quays, or other structures had been built along the landward side where ships would have berthed in sheltered water.

The trenches showed varying combinations of clean, fresh sand layers, alternating with thin layers of shells, typical of scattered shells visible on the present surface of the spit. The rocky side of the Tell sloped down to the present water level, at which point it was covered by fallen stones intermingled with pottery and shells. The stones were similar to those in walls higher up the slope. The deepest part of any trench was 1.15m below MSL, and the rocky slope was still descending. Water-jet probes sunk into the sand in the middle of the spit descended 3 to 4m without striking definite hard-rock bottom.

The results of the archaeological excavations on the Tell will be published elsewhere. The data regarding sea levels are not conclusive, but are circumstantial. There is no good shelter for even small boats now, and, if the sand spit were not present, there would definitely be sheltered water of several metres depth in the lee of the Tell, which would then be on an island. Tumbled rocks and pottery of MB Age suggest that there may have been large structures, a landing stage or quay, on the sheltered side of the island, but there is no evidence for any kind of constructed harbour. The island could have been inhabited, and the roadstead could have been used as a harbour, with sea level at its present position. However, the inhabitable area of the Tell is very small, and although no buildings or storage pits are actually located lower than 1.5m above sea level (except right in the lee of the rock), waves and spray go over the ruins even in mild storms. The sheltered roadstead would still be usable with a slightly lower sea level, and in fact the area of shelter would be larger. It therefore seems probable, with a broad margin for error, that there has been slight submergence of the order of 0.5m.

24. TELL NAMI, MAINLAND 34° 55.3'E. 32° 39.8'N.

On the mainland opposite the Tell AR has found Neolithic materials which cannot be related at the moment to sea levels.

25. TELL NAMI, 1KM SOUTH

Crusader rock cuttings have been studied by AR, both from aerial photographs and on the shore 1km south of Tell Nami. The channels and tanks have not been measured and surveyed in detail, but seem to indicate a slight submergence, of the order of 0.5m.

26. DOR, NORTH

Extending 1km or more along the shore north of the remains of Dor, there are cut quarries, natural arches, embayments, and caves in the Kurkar. Large slabs of beachrock are present in the sandy bays. Notches are dissolved into cut quarry faces to a height of 0.5-1.0m in some places, though this may be partly due wave run-up. There is a slight indication of uplift.

27. DOR, Tantura 34°54.7'E. 32°36.5'N. (see Figure 6).

Garstand (1924a, 1924b), Albright (1925), Foerster (1975). This is a site of enormous extent and complexity, and no attempt will be made to describe it in detail. Several days work were devoted to the shoreline features, and to analysis of aerial photographs of structures near the sea. The city was probably founded in LB, and shows remains in addition of LI and Hellenistic periods. During the first few centuries AD it appears to have been almost derelict, although there was a Jewish synagogue in the 1st Century AD, and bishops resided at Dor until the 7th Century. There is also a Crusader fortress.

The dominant architectural feature of the site is a large rectangular structure at the south end, which has been partially excavated (Garstang, 1924a, 1924b). The lower strata contain Iron Age materials but the largest walls are Hellenistic and Roman, and these walls are exposed to the sea on the west side with their footings in the water. A rectangular foundation extends further seaward with the base of the stones in about 40cm of water. However, this water level is formed by the pool retained upon the reef flat by the vermetus rim, which is itself raised. This structure does not seem to be related to any harbour as the coast is very exposed, but could have been a simple landing stage if we assume the reef grown forward organically.

From this Temple Podium northward the shore is bordered by rock cuttings and channels, and a group of three slipways for boats. The slipways seem to be correctly related to sea level, although their lower ends are obscured by trottoir and beachrock. The channels and cuttings are probably related to several different functions: 1)wave traps to prevent erosion or wave run-up exposed

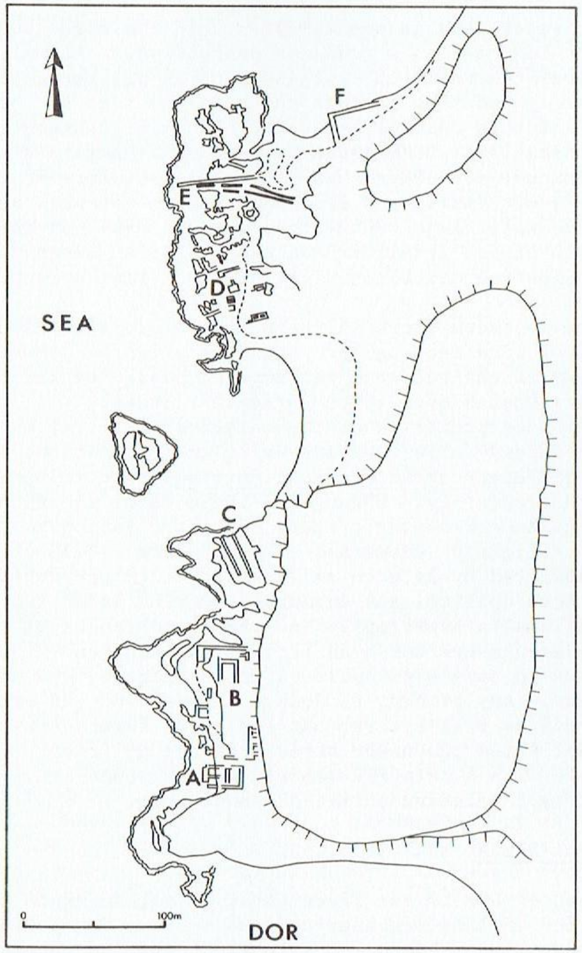


Figure 6. Sketch map of Dor. A = rectangular foundations based in shallow water. B = Temple Podium, after Garstang (1924a). C = slipways. D = area of tanks, channels, quarries and rock cuttings. E = canals, wave-channel, and cuttings. F = submerged rectangular masonry structure.

promontories; 2) water channels to promote circulation in the northern bay and prevent silting; 3) salinas for salt collection; 4) storage tanks for water, oil, dyes, etc. Detailed maps and drawings are being prepared. One channel is still active in circulating water into the northern bay, and this has its rock-cut floor at a depth of 60cm below MSL. The seaward end of this channel stops several metres short of the open water, and is square-cut. This indicates that it was never intended as a road, or navigational channel. Waves run up over the vermetus reef and erosion platform, spill into the channel, and flow through the headland into the bay. In the wall of this channel are solution notches suggesting a relative sea level 30cm above present MSL. Adjacent to the active channel are other channel-like depressions above present sea level, with walls and incised solution notches suggesting a relative water level 90cm above present MSL. On the island just south of Dor itself is a network of fish tanks measured by AR indicating relative uplift of the island by approximately 1.0m.

On the southern shore of the northern bay there are masonry foundations of a rectangular structure slightly submerged, while many of the recessed rectangular pools, tanks, and quarry floors are washed over by the slightest storm.

A full interpretation of the relative sea level cycle at Dor must depend on further surveying and excavation, since all the different structures and cuttings need to be dated much more accurately. Throughout the area of the site, some structures appear close to their correct relation to sea level, or slightly submerged by about 25cm, while others appear uplifted by as much as 1m relative to present sea level. Both uplifted and submerged remains occur interspersed and occasionally superimposed so that synchronous differential earth movements are not a sufficient explanation. The whole site seems to have been uplifted in one period, and submerged in another. Any attempt to deduce the sequence of events must be regarded as speculative, but the older features seem to be submerged, while the newer structures are uplifted. This is compatible with a relative submergence of about 1.25m, followed by a relative uplift of about 1.0m.

28. NAHAL DALIA 34^{o} 55'E. 32^{o}35'N.

South of Dor is the river Nahal Dalia, and from there a series of long rectangular fish cultivation pools extend about 1km southwards to a look-out station observing the coast. AR reports that during excavation of the pools Neolithic and Chalcolithic pottery was found over the whole area. Exploration of the shore indicated that remains extended to a depth of 3-4m, though this may be due to erosion and scattering. With rather low reliability there is indication of a relative submergence of the order of 3-4m.

29. MAGAN MIKHAEL Hammam Island 34^{o} 54.1'E. 32^{o} 33.2'N.

The low rocky island off Kibbutz Magan Mikhael contains Roman quarries and a fish pool all of which are fairly well related to present sea level. The quarry floors are at 20-40cm above MSL, except for one isolated pit at -30cm. There has been no relative change on the island

to within an accuracy of ± 25cm.

30. CROCODILOPOLIS, Tell Taninim 35^{o}54.1'E. 32^{o}32.3'N.

The Tell stands on the south side of the Crocodile river, and shows remains from LI, Hellenistic, and Roman periods. The river was trained by walls in Roman times, but the bridge near the mouth is modern. It may be constructed on older foundations. The headland is eroded Kurkar, but quarries on the south side extend down to water level, and just below, to a depth of 15cm below MSL.

31. CAESAREA (Fig. 7). 34^{o}53.5'E. 32^{o}30.5'N.

Josephus Flavius BkI , Link and Link (1961), Fritsch and Ben-Dor (1961), Frova et al. (1965), Neev et al. (1973), Levine (1975), Negev (1975), Raban (1976). Flinder (1976) This is a vast site with huge monuments and architectural structures as well as an enormous harbour. The underwater area was surveyed by Link and Link (1961) in a provisional manner, and parts of the site were subsequently visited by researchers from the University of Haifa and the Israel Undersea Exploration Society. However, no serious attempt of underwater mapping was made until a commission was received from the Israel Electric Company in early 1976 to conduct a complete survey and report on the evidence for or against major earthquake displacements. A report was submitted (Raban, 1976). The arrangement of the site is shown in Figure 7. The site shows remains from LI, Hellenistic, Roman, Byzantine, Arab and Crusader periods. Prior to 1975 a number of different investigators had concluded that there was evidence for no relative sea level change, or, in contrast, submergence by as much as 10m (Neev et al., 1973). The following analysis is based on several periods of observation and survey by the present authors in the winter of 1975-1976, and the survey conducted for the Israel Electric Company in spring 1976.

The piscina (Figure 8, Figure 7:1) at the south end of the site indicates a very close correlation with present sea level. Due to tidal and seasonal cycles of local sea level, two solution notches are likely to be dissolved into vertical rock surfaces approximately 15cm above and below MSL (Figure 9). There are groups of notches around the piscina up to a height of 40cm above MSL, suggesting possible uplift of 15-25cm since Roman times, or small eustatic fluctuations.

The large sluice-gate (2) cut into the rock correlates with modern sea level to within ± 50cm, also indicating an almost unchanged relative sea level since Roman times. The excavation of the Roman wall on land (3), Crusader mole, the Roman mole to the north of the site, the sloping drain, and the aqueduct, all indicate minimal change of sea level

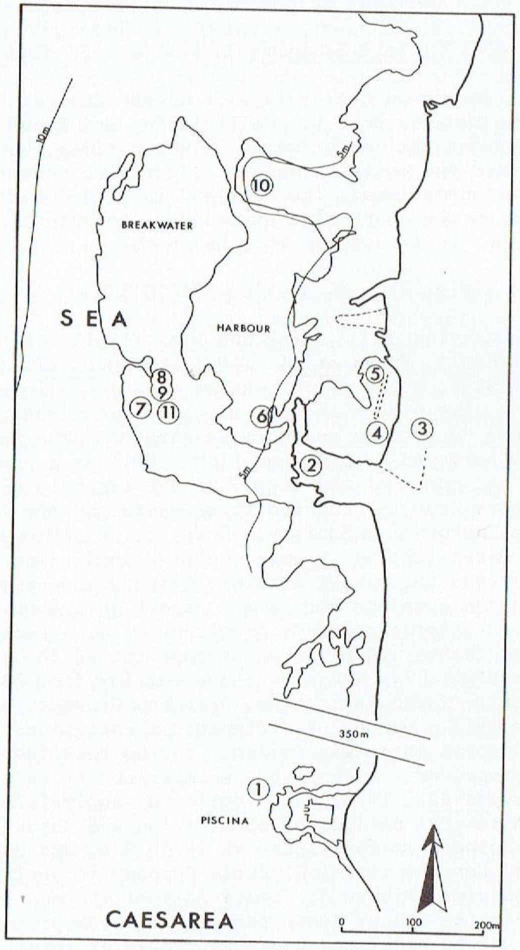


Figure 7. Sketch map of Caesarea, based on survey by Raban (1976). The numbers indicate structures discussed in the text.

to within ± 0.5m. The precise date of construction of the aqueducts is discussed by Levine (1975, p.-30-36), with the conclusion that the high-level aqueduct was probably built in two sections, the eastern section under Herod, and the western section in the 2nd or 3rd Century AD. In spite of the frequent repairs to the aqueducts, their precise gradients indicate no net change of the shore-line relative to the water sources since their construction. The only discrepancy from indicators of stability on the shore-line

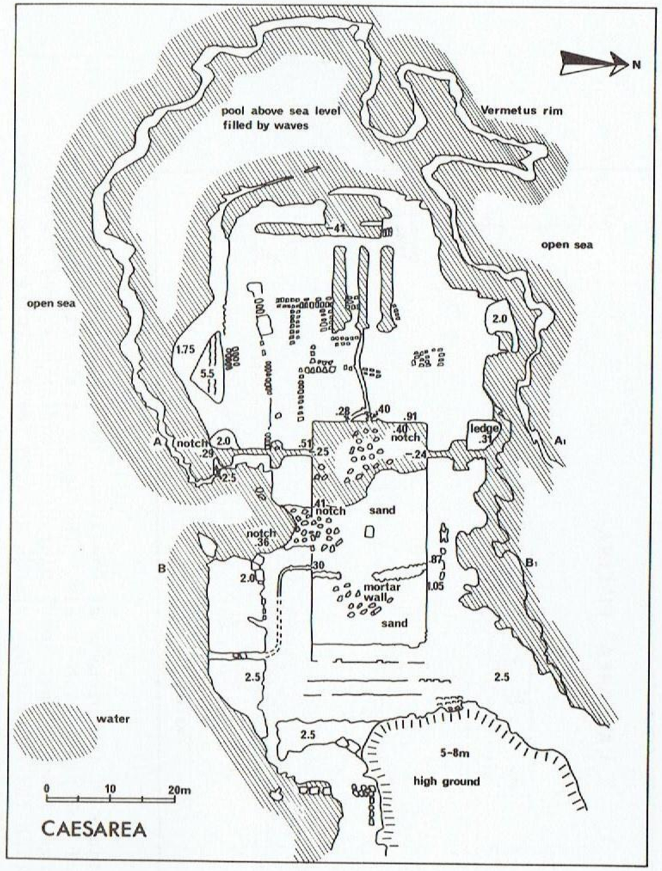


Figure 8. Plan of the piscina at Caesarea, after Flinder (1976). Numbers indicate altitude in metres, measured during the present survey. The cross-sections A-A- and B-B- are shown in Figure 9.

is the parallel-sided double wall (4-5, and Figure 10) of Crusader date, lying on 1-2m of water in the back of the modern harbour basin. This wall was examined very briefly by NCF in July 1974, and at that time it was suggested that interpretation of the site must depend upon multiple earth movements. Recent investigation by AR shows that this wall slopes from a depth of about 60-70cm in the northern part to about 1.5m at the southern part. The

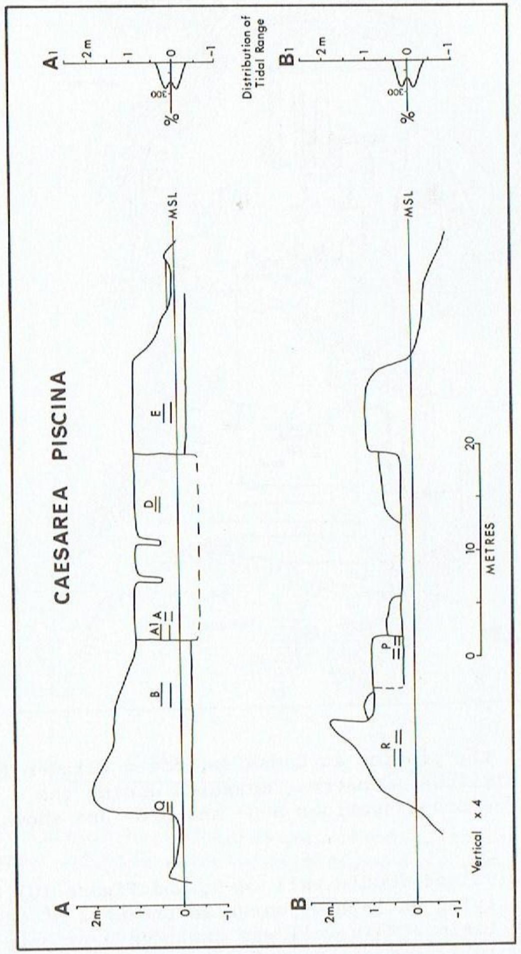


Figure 9. Cross-sections of the piscina at Caesarea. The code letters refer to unpublished analyses of solution notch levels. The scale at the right-hand side shows the vertical range of annual sea level plus tidal variations, and the proportion of the time which the sea surface spends at each level. Pairs of notches occur in several places at the upper range of present variation, suggesting uplift of about 25 cm, or eustatic fluctuation.

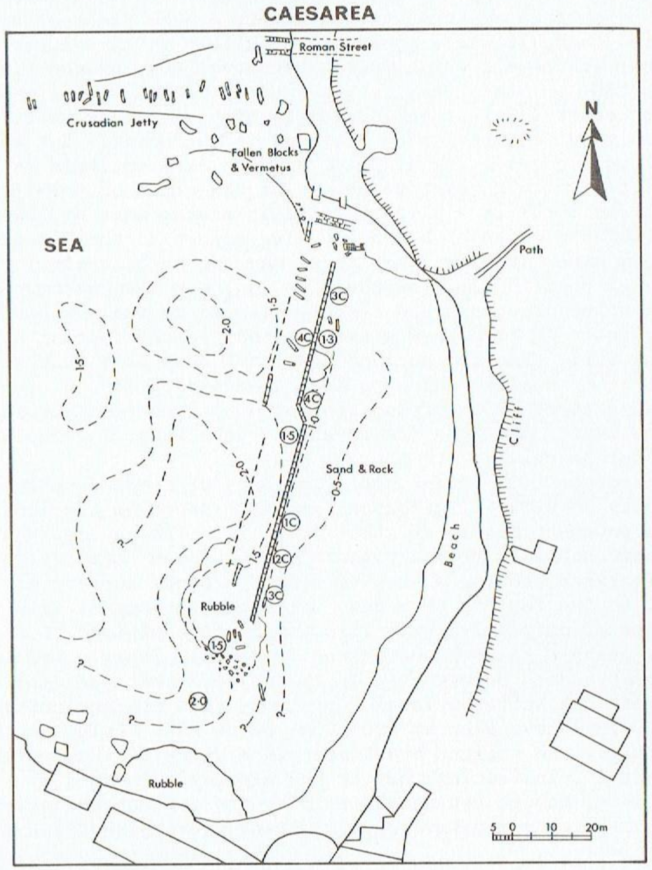


Figure 10. The double-faced wall in shallow water at Caesarea. The numbers inside circles indicate point depths in metres, and the contours are also marked in metres. Symbols 2C, 3C, etc., indicate the number of courses of masonry standing in situ. The elongated cylinder forms indicate columns used to strengthen the wall.

courses of stonework are curved by the slope. This implies some form of local compaction or slumping which may account for the subsidence of this wall in relation to the nearby shoreline indicators which are not displaced.

Offshore there are a number of structures indicating relative sea levels. Structure (6) consists of a paved course of stones on a gravel foundation, with the upper surface at a depth of 4.9m. Whether this was intended as a dry working surface adjacent to the water, or the floor of a flooded tank, it would appear to be within ± 0.5m of the ancient sea level, which would then have been between 4.4-5.4m below MSL.

Structure (7) is a cemented wall of header construction probably built with its foundations in the water. But since the lowest courses are at least as deep as 6.4m, this is consistent with a relative change of the order of 4-5m. Structure (8-9) is a pile of building stones more or less in situ at a depth of 5.2-5.6m. The report to the Electric Company makes it clear that these may not be in their original position, and neither the top, nor the bottom, of the courses of stones are clearly related to the ancient waterline. If the stone-gravel contact is the footing of a quay wall, then the ancient sea level must have been at about 3-4m to allow ships to dock alongside. If the stone-gravel contact is the foundation of a road or floor close to the water, then the sea level may have been at a depth of about 5m relative to present MSL.

Structure (10) is an area of masonry of header construction, probably in situ, with foundations at a depth of 5.4-5.8m and a pavement nearby at about 3.8-4.2m. The pavement surface may have subsided from a higher level. Taken together these two features provide a bracket from the upper surface of a quay, to the footing of a quay wall (both presumed) with a range of only 1.2-2.0m. This is the bare minimum to allow vessels to dock and unload, and would imply a sea level at about 4.8m. However, if it is presumed that the upper pavement has suffered local subsidence, then the ancient sea level would have been at 4.0-4.5m. below MSL. Lying on the remains of the ancient breakwater is a wreck of the 3rd-4th Century AD, indicating that it had already submerged by that date, though not necessarily by the present amount. The submergence may have been cumulative over several centuries.

Structure (11) consists of scattered cemented blocks with rectangular grooves cut across them. These may have been part of a drainage system to relieve water pressure on the sea wall, but it is more probable that the grooves are the indentations left by the wooden beams of the shuttering which originally supported the concrete during construction. Such holes have been found both above and below sea level in intact ancient moles such as the one at Thapsus in Tunisia. Nevertheless, the presence of such blocks indicates a broken or collapsed breakwater of advanced construction type.

The original suspicion that the city site at Caesarea contained sea level indicators resulting from multiple movements has been amply confirmed. The discontinuity on either side of an approximately north-south line about 150m

offshore is demonstrated by the new data. The nature of this discontinuity is unknown, but to the shoreward of it most indicators are within ± 0.5m of present sea level, whilst to the seaward of it, indicators are all compatible with a relative sea level at 4.5-5.0m below present MSL. The relative submergence of the offshore segment of the harbour could be attributed to the following possible causes:-

(1) A compaction or slump of unconsolidated material, either under normal conditions, or due to fluidization of some underlying strata in an earthquake.

(2) Differential subsidence due to the fact that the inner part of the city is built on the Kurkar, while the outer part is built on unconsolidated sediments.

(3) A local fault intersecting the area of the site.

(4) A major fault parallel to the coast intersecting the site.

Discussion of these alternatives will be postponed until the Discussion section of the present paper.

32. <u>TELL GIRITH</u> 34°52.5'E. 32°25'N.

Hebrew references only.
The Tell is on Kurkar close to the shore, and part of it has been eroded by waves. East of Tell Girith there are tombs of LB, and there is pottery on the Tell of the same period including imports from Cyprus.

33. <u>MIKHMORET</u> 34°52'E. 32°24'N.

Isserlin (1961)
The modern village fronts onto a small cliff-encircled bay on the north side of the Iskander (Alexander) river. Remains include LB, MI, and Hellenistic. Isserlin (1961) in a small excavation on the south side of the harbour found material of Persian and Hellenistic periods. Tombs on the north side of the harbour extend down to within 2m of the water; foundations of buildings on the south side project from the cliff at a height of 2.7m. There is no evidence of sea level change, but a very broad margin of possible error.

34. <u>TELL POLEG; TELL EL ASIR</u> 34°51'E. 32°15.5'N.

Hebrew references only.
Tell Poleg is located on an artificial breach in the Kurkar ridge near the Poleg river. Most of the finds belong to MBIIA, and the Tell was fortified in that period. Right on the shore is Tell El Asir, which was of the same date, but

not fortified. It is possible that there may have been a harbour in the Poleg river, or in the large lake just inland from the shore. The lake is now drained and dry.

35. APOLLONIA, Arsuf $34^{o}48.7$'E. $32^{o}12$'N.

Roman and Crusader structures are present on the cliff top at a height of 25 m above sea level, down the slopes of the cliff, and awash on the shore. A mosaic pavement was visible on the beach at a height of 3m until recently, but has now been broken-up. The most problematic feature is an open rectangular arrangement of masonry and natural rocks projecting about 50m into the sea, and extending about 100m along shore. Ledges of rock and scattered blocks lie around the outside of the rectangle, in depths of 2.0-2.2m at the outer edge. The area within the rectangle is less obstructed, and has a depth of about 1.0m. There is no obvious entrance or gateway, and it is not possible to say whether this structure was a landing stage, part of the city fortifications, or a harbour basin. The last-mentioned seems unlikely in view of the small size, shallowness, and lack of an entrance.

The Crusader city walls are constructed down the cliff face, and although some sections have slipped, many of them are still in place. It cannot be maintained that the masonry on the cliff face has all fallen from above due to erosion. At the southern edge of the Crusader city the wall comes down the cliff face and extends, in the form of ragged remnants of masonry, across the beach and just to the waterline. At the northern limit, the wall descends the cliff face and joins onto the northern border of the flooded rectangle.

Extensive snorkeling around the rectangle, in rather rough weather, failed to reveal any significant details, apart from depth measurements. The purpose of the structure is still unexplained. However, if it was a landing stage, it is at about the right level; if it is a harbour, it is at about the right level if one assumes that the area within the rectangle has silted up, and reef or beachrock has accumulated around it. The presence of Crusader walls on the cliff face and across the beach precludes any extensive erosion in the last 1000 years. The general indication is no change of level, with a margin of error of about 0.5m.

36. TELL MAKMISH $34^{o}46.5$'E. $32^{o}10$'N.

Avigad (1960, 1961).
The Tell is 600m southeast of the Accadia Hotel, near the shore. Avigad (1960) reports buildings and pottery from EB through the Persian period to the latest occupation in the Hellenistic. It was a Phoenician trading post for communications with Cyprus.

37. TELL MICHAL $34^{o}46.5$'E. $32^{o}9.5$'N.

Tell Michal is southwest of Tell Makmish, and closer to the shore. It has not been excavated, but pottery indicates a MB date.

38. TELL AVIV $34^{o}46.5$'E. $32^{o}6$'N.

Kaplan (1955)
Within modern Tel Aviv city there are about 30 ancient sites, most of them Bronze Age from EB to LB. Tell Aviv itself is slightly inland near the mouth of the Yarkon river rising from the alluvial plain. It was probably associated with a harbour, but this is usually assumed to have been further up-river.

39. TELL QASILE $34^{o}47$'E. $32^{o}6.2$'N.

Maisler (1950-51, 1951).
The site is 1.75km from the sea on the north bank of the Yarkon river. The city was built in the LB, and only a few sherds have been found from the MB period. There was a harbour, either a dug basin or a sheltered stretch of the river, where goods were trans-shipped from sea-going vessels to river boats.

40. TELL GARISHA $34^{o}47.5$'E. $32^{o}5$'N.

Sukenik (1935, 1938, 1944), Ory (1944)
The Tell is 4km east from the seashore, on the south bank of the Yarkon river. The site has been excavated, and shows remains from EB, MB and LB. It was presumably a staging post on the river transport system along the Yarkon.

41. YAFFO, Tel Aviv $34^{o}45$'E. $32^{o}3$'N.

Bowman (1955), Bowman et al. (1955), Kaplan (1955b, 1964a, 1964b, 1966, 1967a, 1970), Shapira (1966), Kaplan and Kaplan, K.K. (1975).
Yaffo is mentioned as a port from earliest times. The Tell is on a hill overlooking the sea, and there are large rocks, or small islands, 50-100m offshore. The modern fishing harbour is constructed by joining these up with a concrete breakwater. On the hill, foundations and pottery have been found from throughout the Bronze Age, and it can be assumed that the ancient harbour utilized the shelter of the reefs and rocks in the same way. The city was fortified in MB, and extremely important in LB. The city is also frequently referred to in Hellenistic and Roman times, and excavations have revealed remains from the Roman period (Kaplan, 1967a, p.118). In spite of the importance of the site as a harbour, no remains have been reported from close to the waterline,

and there is no evidence on which to base estimates of changes of level. This is partly due to the superimposition of the modern harbourworks.

42. TELL YONA $34^{o}44'$E. $31^{o}59.5'$N.

There is no archaeological evidence concerning this steep-sided mound on the shore. It is a prominent symmetrical feature, but now within a military compound. There is a depressed area of marsh and reeds next to it, which could have been a lagoon or harbour.

43. PALMACHIM, Yavne Yam $34^{o}41.5'$E. $31^{o}55.5'$N.

Mayer (1926), Ory (1945, 1948), Dothan (1952), Kantor (1956), Kaplan (1957, 1967b, 1969a, 1969b, 1969c).
The Tell is on a prominent headland, and wind-blow sand dunes were encroaching on the surrounding agricultural land at a rate of 1m per year until stablised artificially. A line of reefs extends northwards from a point seward from the tip of the promontory, providing sheltered anchorage between the reef and a broad sandy bay. In spite of the suitability of the site for construction of a harbour, no evidence for harbourworks has yet been found from any archaeological period.

In the Middle Bronze Age Yavne Yam was the only inhabited site on the coast in an area extending from 10km south of the Rubin river to 3km north of the river. The Tell shows remains from the MB, LB, Iron Age, and in the Hellenistic and later periods the city extended northwards along the low hills overlooking the bay. Walls and rock cuttings from several periods come down close to the water level around the promontory, and down to the beach further north. None of these gives a clear indication of ancient sea level, but there is no indication of any change, to within an accuracy of about $\pm$ 1m.

44. TELL HARAZ (location not shown on map).

Material of MBIIb have been found on this Tell (Magon, personal communication).

45. TELL HASHAVYA $35^{o}40.5'$E. $31^{o}52.5'$N.

The beach between Ashdod and Yavne Yam is coated with an almost continuous pavement of thick beachrock. The beach is about 50m wide, and 5m high at the back. Tell Hashavya slopes back from the shore road. Excavation indicates that the visible structures are part of a fortress which was occupied for a short time only in the 7th Century BC.

46. TELL MOR, Ashdod $34^{o}39.4'$E. $31^{o}49.5'$N.

Dothan (1959, 1960a, 1960b, 1973).
Tell Mor stands on the north bank of the Lachish river in an area of warehouses on the fringes of the modern industrial district of Ashdod. The Tell has been cut into on the north side as a result of grading the neighbouring waste ground. The Tell of ancient Ashdod itself is 7km southeast, near the Lachish river, but 4km from the sea. Dothan (1973) believes that Tell Mor was the location of the harbour for ancient Ashdod, which was a far more important city. Pottery and buildings of MB and LB have been found, including material from Cyprus. No structures have been found relating specifically to its function as a harbour, and presumably the river mouth sufficed, perhaps with simple wooden quays or jetties.

47. TELL YUNIS, Ashdod $34^{o}38.6'$E. $31^{o}48.6'$N. (approx).

Dothan (1973).
This Tell on the south side of the Lachish river near the mouth was settled in the first millennium BC.

48. ASHDOD-YAM $34^{o}37.2'$E. $31^{o}46.9'$N.

Kaplan (1969a, 1975), Bar-Yosef (1971), Edgerton et al (1974).
Bar-Yosef (1971, p.58) describes a Late Palaeolithic assemblage of microliths and bones found in the red loam on top of the coastal ridge just north of the mouth of Wadi Ibtah, about 3km south of Ashdod Yam. Bones included wild ox, gazelle, and roe deer. Similar prehistoric sites were found just north and inland from Ashdod Yam. At all sites the microliths are attributed to Kebaran Age.

The coastal site of Ashdod Yam itself can be divided into two areas, the southern one being Iron Age, the northern one Hellenistic to Crusader. The MI fortifications have been excavated by Kaplan (1969a, 1975) and are based directly on bedrock. Brick city walls and houses have been found from the 8th and 7th Century BC. Kaplan (1969a, p.138-40) considers that the area of the city has been reduced by coastal erosion, since the fortifications of beaten earth and sun-dried brick cannot have been designed to withstand the sea, and the city now seems too close to the sea, and with no seaward wall. While some erosion is certainly possible, a footnote suggests that the author (Ibid) is basing his estimate mostly on supposed evidence from other parts of the coastline for general subsidence of the Israeli coast. Sections across the city wall and trench outside it show that the earth and sand has never been disturbed by man to a depth of more than 50cm. Even where loose sand extends to some depth, the Kurkar is reached at a height still 4-5m above sea level. Thus the trench does not seem to have been designed found. This is odd, since the Bronze Age basin would have been inadequate, and artificial harbours were certainly common in these periods. Phythian-Adams (1921, p.83-84) speculates that the harbour may have been south of the city, towards Wadi Hesi, on the basis of a description of the 6th Century AD. Ashkelon was captured by the Arabs in 636 AD, and served as an important marine supply base both for Arabs and Crusaders at different times. A report of 985 AD (Phythian-Adams, 1921, p.85) describes the harbour as unsafe. Ashkelon was first captured by the Crusaders in 1153, but was retaken by the Arabs in 1187. Richard Coeur de Lion approached in 1191, and the Sultan Saladin instructed that the entire fortifications, city walls, and numerous towers should be destroyed to prevent them from falling into enemy hands. It was feared that the Crusaders would make Ashkelon the base of future operations against Jerusalem, and to cut off Arab contact with Egypt. The importance of the harbour is thus stressed (Phythian-Adams, 1921, p.87-88). When Richard took over the city the harbour was unusable, several barges and galleys were wrecked, and the army was faced with rebuilding the walls and towers. William of Tyre is quoted (Ibid, p.87) as saying that the port does not provide shore haven, the beach being sandy and the approach dangerous.

In spite of the historical evidence for its economic and military importance, there are thus plenty of records to show that the harbour was never actually a good one. The Arab destruction may have permanently reduced the safety of what ever shelter preceded that date.

The present shoreline is an unbroken smooth sandy beach, backed by a cliff about 20m high, and it is difficult to see how any harbour or shelter can have been obtained on such an exposed shore. William of Tyre confirms that the city then was a semi-circular shape (Phythian-Adams, 1921, p.86) so that the present straight shore cannot be attributed to any significant degree of erosional retreat in the last 1000 years. Crusader walls remain at present at the top of the cliff, on the cliff face, and at the foot of the cliff at many places along its length (Figure 11). At two places, A and B in the sections on Figure 11, there are masonry structures with columns horizontally embedded in them, similar to the waterside constructions at Caesarea. The wall with columns at location B has been undercut, and is tilted forwards in the sand, while the large cistern above has slid partly down the cliff. This erosion may have been due to wave attack or rainwater run-off, but does not indicate cliff retreat of more than a few metres. The massive construction at section A, with many columns still projecting from the wall, may even have been part of a harbour wall or dock for tying up ships. At the southern edge of the city, profile C, a vaulted building on the cliff top has been cut into by erosion and slumping of the cliff face. Immediately below this building there are large chunks of masonry at the waterline, and extending about 100m seawards, mingled with fallen columns. This again compares closely with the Crusader jetty on the north side of the harbour at Caesarea. Wherever the Hellenistic and Roman harbour was, it seems clear that the Crusaders built some sort of artificial ship haven at the south side of the city, probably continuous with the south end of the city wall.

The width of the sandy beach at present makes it difficult to assess whether the Crusader shoreline constructions are correctly related to present sea level. However, the jetty projects seaward into several metres of water, as one would expect; and the walls with embedded columns descend below the sand, to within a few metres of sea level. Thus there is no evidence for a change of level, and indication that the level is correct to within less than 1m of MSL.

In conclusion, Ashkelon is an important site with the possibility of relating material of the Neolithic, Bronze Age, and many later periods, to sea level. Estimates can be made now for the Bronze Age and the Crusader periods, but the site would repay further study.

50. ANTHEDON $34^{\circ}27'$E. $31^{\circ}32.2'$N.

The site is on a hill 4km north of Gaza, and about 1km back from the sea. Pottery of LB and Hellenistic periods has been found.

51. GAZA MAIUMAS $34^{\circ}25.5'$E. $31^{\circ}31'$N.

Ovadiah (1969, 1975)
The Bronze Age Tell (LB) is 5km from the shore, and was the basis for the cities of subsequent periods. In Roman times the city was expanded towards the shore, to form Gaza Maiumas, the Port of Gaza. The port city was renamed Constantia in the 4th Century AD. No remains of any harbour constructions have been found, either on land or under water. The straight sandy shore is back by low cliffs so that progradation cannot have concealed any remains, although some erosion is possible.

In 1965 a beautiful mosiac pavement was discovered on the edge of the cliff 10m above MSL between the road and the beach 300m south of the modern port. The pavement belonged to a synagogue constructed early in the 6th Century AD (Ovadiah, 1969, p.169). Between the synagogue and the beach, and at a lower level, is a complex of industrial rooms, plaster-lined vats and tanks, probably a dye works. These buildings pass under the synagogue, and appear to pre-date it by about 70-100 years. The lowest level within the dye works is about 5m above MSL.

To this day, dying in the eastern Mediterranean is often carried out on, or close to the beaches. Just north of Gaza in January 1976 when this site was visited, a group of Arabs had laid out heaps of freshly dyed wool in brightly-coloured piles over a 100m stretch of the sandy beach. Dyed wool laid out on rocks, hanging from trees, or spread on the sand, can be seen from time to time similarly in Turkey and Greece. Complexes of small tanks, channels, and shallow pools, cut in the rock have also been found at many ancient coastal sites, eg Tenaeron in southern Greece, (Flemming _et al._, 1973). It is probable that dye works were commonly close to the sea at many sites, and it is not surprising that the structures at Gaza border directly on to the sandy beach.

There is no evidence of a change of relative level, to within a margin of error of about ± 2m.

52. TELL EL AJJUL 34°24.5'E. 31°28.5'N.

Petrie (1931-1934), Maisler (1933), Tufnell (1962, 1975) The site lies 6km south of Gaza set back from the shore on the north bank of the Besor river. Tombs from the EB were found on the south bank of the river, but the remains on the Tell are of MB period. Petrie (1931-1934) identified the site with ancient biblical Gaza, though this is not now accepted (Tufnell, 1975, p.52). The river Besor reaches the sea across an alluvial flood plain between low hills, and in the 3rd and 2nd millennium BC, after the Flandrian rise of sea level, the sea would have extended back between the hills to form a broad estuary. Tell El Ajjul would then have been located on a natural harbour. The south corner of the Tell is now partly damaged by seasonal floods from the river. Although Tell El Ajjul was a large and prosperous city, with elaborate defensive fortifications, it was soon abandoned, possibly because the estuary silted up and the meandering river made navigation hazardous.

53. TELL EL QATIFA 34°18.5'E. 31°23.5'N.

No archaeological data.

The Tell slopes up directly from the beach. A barrier-reef of beachrock runs parallel to the present sandy beach, and 50-100m offshore, suggesting that the beach is being denuded of sand.

54. TELL EL RIDAN 34°17'E. 31°23'N.

The Tell slopes directly up from the shore, and pottery of Middle and Late Bronze Age has been found.

55. TELL EL JINAN 34°11'E. 31°21.5'N.

No archaeological details.

56. TELL RAFIA 34°13'E. 31°19.5'N.

The site has not been excavated, but the Tell is close to the shore, and pottery of EB and MB has been found.

DISCUSSION

The data for the coast of Israel are exceptionally detailed because of the close geographical spacing, and continuous occupation of many sites. However, the latter point also means that many structures are superimposed, or rebuilt, or show multiple use of the same stones, and this adds a complexity to interpretation. The results can only be summarized here.

The estimates of sea levels from each site, together with the probabilities of values on either side of the best estimate, are summarized in Table II (Appendix). The data for all the sites within each archaeological period were plotted separately along the coast (Figure 12), and the mean, mode, and standard deviation of vertical displacement relative to MSL were calculated, treating each probability entry in Table II as an independent estimate. Thus a mean and modal relative displacement of the coast for each period was obtained, together with a degree of scatter. This scatter may be attributed to a combination of observational error and differential tectonic movement between sites of the same age. The date from the right hand column of Figure 12 were plotted on a time-axis to produce Figure 13, showing the change of mean relative sea level with time. During the Late Palaeolithic and Neolithic the sea level could have been lower than the level of the sites recorded here, since they are land sites, not necessarily on the shoreline. The curve shows a rising sea level reaching very close to present MSL in the Early Bronze Age, or Middle Bronze Age. Thereafter, the sea level remains constant to within ± 0.5m, and within 0.7m of MSL. Tectonic movements are concentrated within 40km north and south of the Qishon Graben. An unexpected result is that the alluvial plain filling the Graben does not appear to have subsided detectibly in 4000 years, while the flanks of the Graben are unstable or subsiding.

Dor is unstable with probable submergence first, then uplift. Caesarea is bisected by a line of vertical displacement. The sites actually on the Carmel and immediately adjacent to it, Shikmona, and Atlit, are stable, and the instability in the south is related to the fault south of the Carmel Mountain. Ben Menahem _et al._ (1976, p.34, Figure 33) show a line of four epicentres along this fault in the period from 1961-1970, and none on the Qishon Graben. Arieh (1967) shows active faults on the Graben in the period 1903-1963.

Neev _et al._ (1973) assume that the submergence at Caesarea has been as much as 10m, while parts of the shoreline have been uplifted by as much as 20m. This massive displacement of the coast is alleged to have taken place along most of the

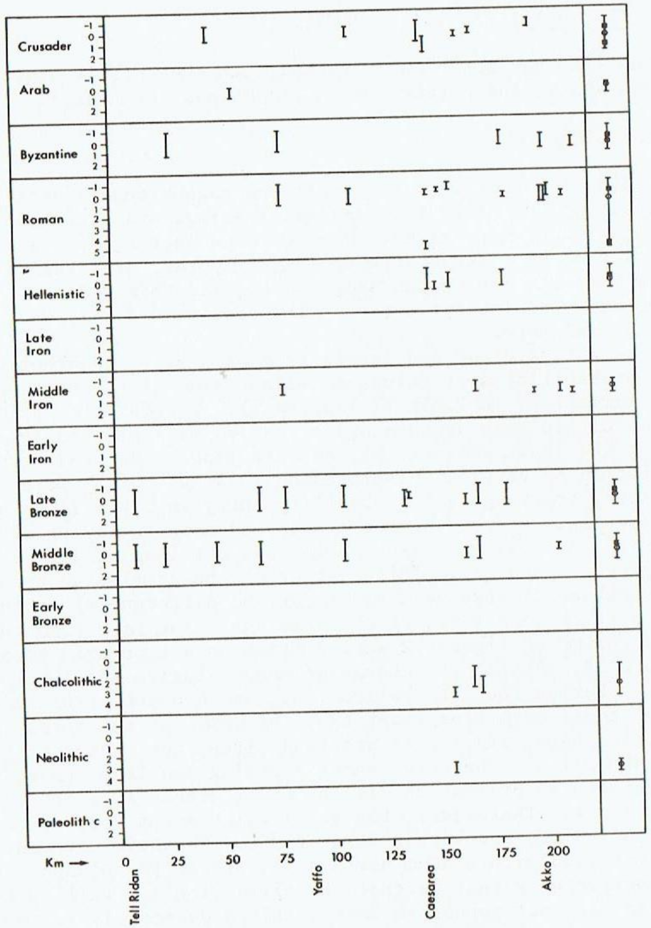


Figure 12. Summary of results grouped by archaeological period. The horizontal scale is in kilometres from Tell Rafiah in the south to Rosh Hanniqra in the north. Key cities are shown along the scale. The vertical bars indicate the upper and lower limits of the estimates of relative sea level, measured against the scales on the left margin, for each site and period. The data for each period were summed to give a total distribution of estimates for that period, including all probability estimates from Table II (Appendix), and the total range, mode, and mean are indicated in the right margin. The solid square indicates the mode of the distribution, the open circle the mean value. The Crusader and Roman periods give bi-modal distributions because of the local tectonic activity.

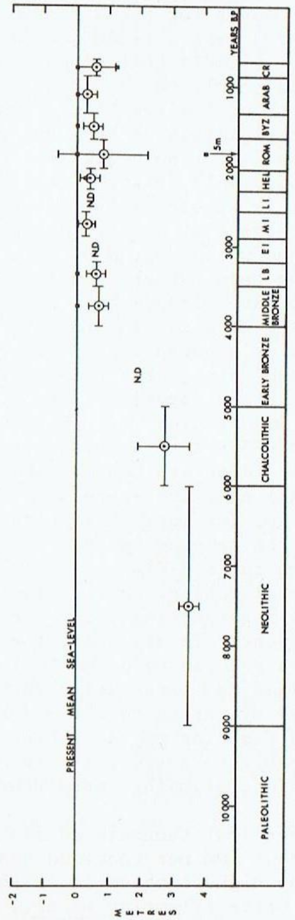


Figure 13. Relative sea levels for each archaeological period on the Mediterranean Coast of Israel. The horizontal bars indicate the lengths of the archaeological periods, while the vertical bars show the standard deviation for the estimates derived from Figure 12, and Table II.

Mediterranean shore of Israel. The present study indicates that there is indeed an unusual displacement at Caesarea, with differential vertical movement across the site, but it is important to consider mechanisms which are compatible with this being a relatively local event. Firstly, there is the presence of the south Carmel fault, which intersects the coast near Dor. Even in the immediate neighbourhood of the fault, the coast is not uniformly active. Atlit to the north of Dor is stable, as is the island off Magan Mikhael between Dor and Caesarea. The possible causes for the differential movement within the site of Caesarea have already been mentioned in the site description. It is unlikely that compaction or slumping of unconsolidated material could be the cause, on account of the extremely low gradient of the sea floor. On the other hand, the disturbance or fluidisation of a bed of sand or clay during an earthquake is not so unlikely. On the assumption that the submerged Crusader wall (Figure 10, 4-5) is built on foundations where Kurkar is absent, subsidence there may have been caused by a similar event at a later date. Such mechanism is purely speculative, and would depend on detailed evidence concerning the underlying beds, which is potentially available from the boreholes which have already been drilled.

It is possible that the structures on Kurkar ridges have subsided less than those on unconsolidated material, whether as a result of gradual processes, or a seismic event. The probability that a fault plane intersects the city site is inherently low, but not impossible. Two phases of fault activity are required, the first to submerge the outer breakwater by 4-5m before the 3rd or 4th Century AD, the second to submerge the Crusader wall near the shore some time after the 11th Century AD. These two (or more) movements could be successive movements on the same non-planar fault surface, distinct movements on two quite different fault surfaces which are close together or intersecting, or the results of successive movements on two or more intersecting fault surfaces which were all active during each event. In any case, the lack of damage to the aqueducts, and the precise adjustment of the piscina to present sea level, preclude any large scale vertical movement of the shoreline followed by return to the present sea level. Although earthquakes and faulting may have been the trigger for subsidence, it is reasonably to postulate such events in association with compaction, slumping, or differential subsidence.

The maximum rate of vertical tectonic activity in island arc areas of the world is about 10m per thousand years, while 5m per thousand years is the highest observed in the Mediterranean, and occurs in southwest Crete (Flemming et al., 1973b). The maximum rates from the coast of Israel are, 0.6m per thousand years at Acco, 2.5m per thousand years at Caesarea, and about 1.0m per thousand years at Dor. The rest of the displaced sites show vertical rates of movement of less than 0.5m per thousand years. Most sites show no signs of vertical displacement to within the accuracy of observation. In spite of the proximity of the Dead Sea rift the seismic activity of Israel is only moderate compared with the active regions of the Alpine belt (Arieh, 1967, p.2), and this is confirmed by Ambraseys (1971). Rates of vertical movement in other parts of the Mediterranean, such as mainland Greece and southwest Turkey are typically 1-2m per thousand years, while the

western Mediterranean is mostly stable, except in neighbourhood of the volcanoes (Flemming, 1969). Thus the coast of Israel, on the archaeological evidence presented here, is shown to be of intermediate or moderate Mediterranean type in terms of vertical movement. This is in complete contrast with the extreme instability proposed by Neev et al. (1973, 1976). There is little point in attempting a site by site, point by point, comparison of data and interpretation. Mazor (1975) has already published a critical commentary on Neev et al. (1973). The moderate vertical tectonism of the Israeli coast is incompatible with the concept of an active single fault running the length of the coast, and equally incompatible with the proposal that an active plate boundary passes parallel and close to the shore on the continental shelf or margin. However, the vertical movement is compatible with more elaborate models of the deformation of the Levant region involving downwarping towards the Dead Sea rift (Karcz and Kafri, 1973) combined with downwarping of the shelf to the north and west (Neev et al., 1976). In this model the coastline appears as a zone of minimal movement.

CONCLUSIONS

The Israeli coast contains a great reservoir of archaeological data, enabling the eustatic sea level and local tectonic movements to be analysed over at least the last 5000 years, and possibly longer. The present study has shown that simple snorkel surveys on many sites can reveal significant data, while intensive surveys with scuba, echo-sounder, dredging, underwater excavation, and accurate navigation, are required on the larger sites. A survey of this kind at Caesarea has already produced excellent results. Further surveys at Dor, Caesarea, Atlit, Acco, and Ashkelon, would be rewarding. These five sites have the potential to reveal a great deal more about the construction of ancient harbours in several archaeological periods. With regard to the earlier periods, more work is still required on the analysis and location of Bronze Age harbours, and the detection of submerged Neolithic sites.

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APPENDIX I

Caption to Table 2

Table 2 lists those archaeological sites for which significant data were obtained, and for which estimates of relative sea levels were derived, with probability spreads. The site numbers are the same as in the text. The period names are abbreviated as in the text, plus: Neo = Neolithic; Chalc = Chalcolithic; Hel = Hellenistic; Rom = Roman; Byz = Byzantine; Crus = Crusader. X and Y give the co-ordinates in kilometres relative to a straight line tangential to the coast starting in the south with Tell Rafia at X = 0, and with the Y axis perpendicular to this line. T is the age of the site, or the given period at the site, expressed in thousands of years, and centred on the date range of the periods listed in Figure 2. Z is the best estimate of vertical displacement in metres, with -ve = submergence. Z/T gives the rate of displacement relative to present sea level in metres per thousand years, -ve = relative submergence. The probability weightings are listed with the maximum weight always on Z, and lesser weights distributed on either side, in 25 cm classes. Negative values indicate degrees of submergence greater than Z; positive values indicate degrees of submergence less than Z, or relative uplift. If the total confidence level of the site is less than 10, the code (LW) for low weighting is marked in the right margin.

TABLE II (1)

								Probability weightings									
No	Name	Period	X	Y	T	Z	Z/T	+ 1.0	+ .75	+ .50	+ .25	Z	+ .25	+ .50	+ .75	+ 1.0	
1	Rosh Hanniqra	Byz	213.3	16.0	1.5	-0.5	-0.3	0	0	1	2	4	2	1	0	0	
3	Rosh H. Islands	MI(?)	211.5	16.0	2.7	-0.3	-0.1	0	0	0	0	5	3	2	0	0	
4	Achzib	Rom	208	14.2	1.85	0	0	0	0	0	0	5	3	2	0	0	
5	Achzib Islands	MI(?)	206.6	15.5	2.7	-0.4	-0.15	0	0	0	2	6	2	0	0	0	
6	Nahariya	MB	204.6	13.8	3.75	0	0	0	0	0	1	1	1	0	0	0	(LW)
7	Shavei Zion(N)	Rom	198	12.7	1.85	0	0	0	0	0	1	4	2	1	1	1	
8	Shavei Zion(S)	Rom	197	12.7	1.85	0	0	0	0	1	1	3	2	1	1	1	
9	Yassif River	Rom	195	12.8	1.85	0	0	0	0	2	2	2	2	2	0	0	
10	Acco	MI	194	11.6	2.7	-0.5	-0.18	0	0	0	2	7	1	0	0	0	
10	Acco	Crus	194	11.6	0.8	-0.5	-0.63	0	0	1	3	5	1	0	0	0	
16	Tell Abu Hawam	LB	180.3	11.0	3.35	0	0	1	1	1	1	2	1	1	1	1	
18	Bat Galim	Rom	181.8	14.7	1.85	-0.25	-0.14	0	0	0	2	6	2	0	0	0	
19	Tell Shikmona	Hel	179.8	17.3	2.15	0	0	0	1	1	2	2	2	1	1	0	
19	Tell Shikmona	Rom	179.8	17.3	1.85	0	0	0	0	1	6	2	1	0	0	0	
21	Atlit	Chalc	167	13.7	5.5	2.5	0.46	0	0	1	1	3	2	1	1	1	
21	Atlit	MB	167	13.7	3.75	0	0	1	1	1	1	2	1	1	1	1	
21	Atlit	LB	167	13.7	3.35	0	0	1	1	1	1	2	1	1	1	1	
21	Atlit	MI	167	13.7	2.7	0	0	0	0	1	2	4	2	1	0	0	
21	Atlit	Crus	167	13.7	0.8	0	0	0	0	0	1	6	3	0	0	0	
22	Neve Yam	Chalc	163.7	13.1	5.5	-2	-0.36	1	1	1	1	2	1	1	1	1	

No	Name	Period	X	Y	T	Z	Z/T	+ 1.0	+ .75	+ .50	+ .25	Z	+ .25	+ .50	+ .75	+ 1.0	
								Probability weightings									
23	Tell Nami	MB	161.9	12.5	3.75	-0.5	-0.13	0	0	2	2	3	2	1	0	0	
23	Tell Nami	LB	161.9	12.5	3.35	-0.5	-0.15	0	0	2	2	3	2	1	0	0	
25	Tell Nami(S)	Crus	160.9	12.5	0.8	-0.5	-0.63	0	0	3	3	4	0	0	0	0	
27	Dor	Hel	156.4	11	2.15	-0.2	-0.1	0	0	1	3	4	2	0	0	0	
27	Dor	Rom	156.4	11	1.85	+1.0	+0.54	0	0	0	0	5	3	1	1	0	
28	Nahal Dalia	Neo	154.3	10.5	7.5	-3.5	-0.47	0	0	1	2	4	2	1	0	0	
28	Nahal Dalia	Chalc	154.3	10.5	5.5	-3.5	-0.64	0	0	1	2	4	2	1	0	0	
29	Magan Mikhael	Rom	151	10.3	1.85	0	0	0	0	0	2	6	2	0	0	0	
30	Crocodilopolis	Hel	149.6	9.5	2.15	-0.25	-0.12	0	0	0	0	4	3	2	1	0	
31	Caesarea	Hel	145.2	8.4	2.15	0	0	1	1	1	1	2	1	1	1	1	
31	Caesarea (A)	Rom	145.2	8.5	1.85	-5.0	-2.7	0	0	1	2	6	1	0	0	0	
31	Caesarea(A)	Crus	145.2	8.4	0.8	-1.0	-1.25	0	1	1	1	3	2	1	1	1	
31	Caesarea(B)	Rom	145.2	8.4	1.85	0	0	0	0	0	1	8	1	0	0	0	
31	Caesarea(B)	Crus	145.2	8.4	0.8	0	0	1	1	1	1	2	1	1	1	1	
33	Mikhmoret	MI	133.1	6.2	3.35	0	0	0	0	1	1	3	2	1	1	1	
35	Apollonia	Rom	110.5	2.8	1.85	0	0	0	0	1	1	3	2	1	1	1	
35	Apollonia	Crus	110.5	2.8	0.8	0	0	0	0	1	2	4	2	1	0	0	
37	Tell Michal	MB	105.3	1.9	3.75	0	0	1	1	1	1	2	1	1	1	1	
37	Tell Michal	LB	105.3	1 9	3.35	0	0	1	1	1	1	2	1	1	1	1	
43	Palmachim	LB	78.2	0.2	3.35	0	0	1	1	1	1	2	1	1	1	1	
43	Palmachim	MI	78.2	0.2	2.7	0	0	0	0	1	2	4	2	1	0	0	
43	Palmachim	Rom	78.2	0.2	1.85	0	0	1	1	1	1	2	1	1	1	1	
43	Palmachim	Byz	78.2	0.2	1.5	0	0	1	1	1	1	2	1	1	1	1	
46	Tel Mor	MB	66	-1.1	3.75	0	0	1	1	1	1	1	1	1	1	1	(LW)
46	Tel Mor	LB	66	-1.1	3.35	0	0	1	1	1	1	1	1	1	1	1	(LW)
48	Ashdod-Yam	Arab	57	0.9	1 35	0	0	0	0	0	0	4	2	2	1	1	
49	Ashkelon	MB	45.8	2.5	3.75	0	0	1	1	1	1	2	1	1	1	1	

No	Name	Period	X	Y	T	Z	Z/T	+ 1.0	+ .75	+ .50	+ .25	Z	+ .25	+ .50	+ .75	+ 1.0	
								Probability weightings									
49	Ashkelon	Crus	45.8	2.5	0.8	0	0	0	1	1	1	4	1	1	1	0	
51	Gaza Maiumas	Byz	27	5.5	1.5	0	0	1	1	1	1	1	1	1	1	1	(LW)
52	Tell El Ajjul	MB	22	5.6	3.75	0	0	1	1	1	1	1	1	1	1	1	(LW)
54	Tell El Ridan	MB	8.6	12.4	3.75	0	0	1	1	1	1	1	1	1	1	1	(LW)
54	Tell El Ridan	LB	8.6	12.4	3.75	0	0	1	1	1	1	1	1	1	1	1	(LW)

as a moat flooded by seawater. Most of the brick city wall is 13-20m above sea level.

North of the Iron Age city is a large area of later ruins, partly covered by sand dunes. The most prominent feature on the shore is a fortress of Arab or Crusader construction, 10-11th Century AD. The four frontal towers of the fortress project from the sand dunes at the back of the beach, about 30m from the water's edge. A masonry platform extends in front of the towers, and shows through the beach in several places at a height of 2m above sea level. The foundations of the towers and platform are probably less than 1m above MSL.. The fortress was presumably built as close as was convenient to sea level, but while there can scarcely have been any relative uplift, there may have been relative submergence of the order of 1m.

An underwater survey using side-scan sonar and divers was carried out by Edgerton et al. (1967) in the search for possible remains of a Bronze Age harbour off Ashdod-Yam, which might have been the harbour for Tell Ashdod. The search revealed no structures of any kind, though some anchors and some pottery were found. Reefs of natural rock were found 2.4km offshore parallel to the shore, probably a submerged Kurkar ridge, in a depth of 30m. It is not possible that this reef could in any way be related to an ancient harbour.

49. ASHKELON, Askelon Figure 11. 34°32.7'E. 31°39.5'N.

Garstang (1921, 1922, 1924), Phythian-Adams (1921), Perrot (1955), Tamar and Berman (1974), Avi-Yonah and Eph'al (1975, p.121-130).

Avi-Yonah and Eph'al (1975, p.124) state that a Neolithic settlement on the shore at Ashkelon yielded the remains of round huts 1.0-1.5m in diameter and bell-shaped silos. Flint and bone tools, and many animal bones were found (Perrot, 1955). Tamar and Berman (1974) report another Neolithic-Chalcolithic site just south of Ashkelon, and 400m from the present shore. Excavation of the main city site shows occupation throughout the Bronze Age, Iron Age, Hellenistic, Roman and Crusader periods. The spectacular encircling mound and wall with towers was built in the Byzantine period.

The Bronze Age-Iron Age mound is adjacent to the shore, and slightly south of the centre of the site. South of this is the depression (figure 11, Section B-B) which is supposed to have been the position of the Bronze Age harbour (Avi-Yonah and Eph'al, 1975, p.121). The area is now silted up and overgrown so that the extent of the basin cannot be estimated, but it could have been at least 100m in diameter. The profile of the strata in the cliffs published by Garstang (1921, p.163) shows LB material at a level of 4-5m above sea level. Thus the earlier Bronze Age material must have been even closer to present sea level. The combination of the silted harbour depression, and the low altitude of

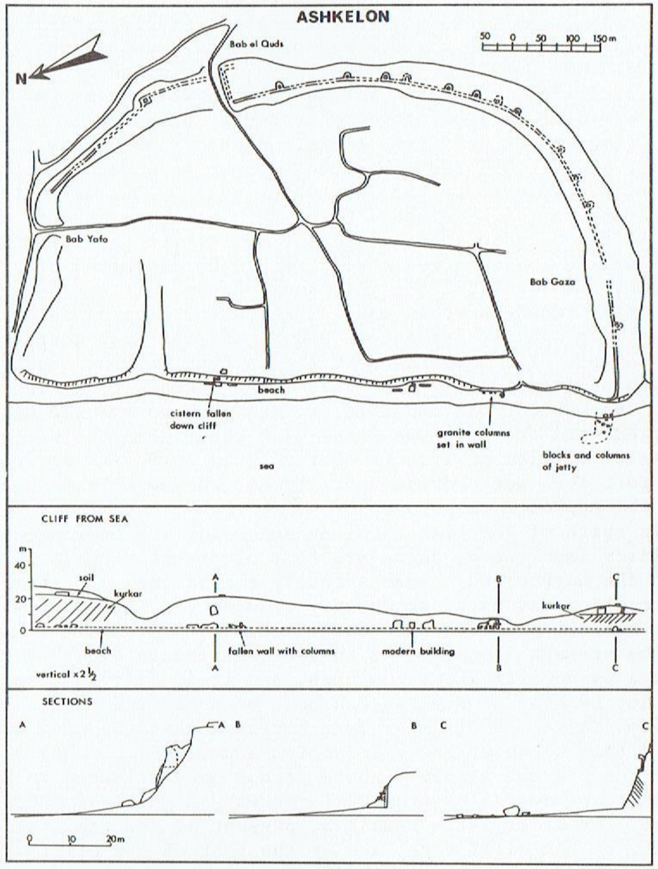

Figure 11. Sketch map of Ashkelon, based on Garstang (1922, 1924), and present observations. The map shows the semi-circular fortifications of the Byzantine-Arab-Crusader periods, and the lengths of city wall on the beach. The elevation view of the cliff has a vertical exaggeration at times 2.5. The sections of the cliff at the bottom have no vertical exaggeration.

Bronze Age strata, indicates that relative change of level cannot have been large, and is probably less than ± 1m.

Ram Gophna (Magon, written personal communication) reports three other Bronze Age sites close to Ashkelon.

In the Roman and Hellenistic periods Ashkelon was an important harbour, but no waterline structures have been