where X is the ion considered, P_i is the precipitation depth for storm event i, $[X]_i$ is the concentration measured in the precipitation from storm event i, and n is the number of storm events. The formula used in calculating the variance of the VWM is

$$\mathrm{Var(VWM)} = \frac{n}{\left(\sum_{i=1}^{n} P_i\right)^2} \times \left[\frac{n \sum_{i=1}^{n} P_i^2 [X]_i^2 - \left(\sum_{i=1}^{n} P_i [X]_i\right)^2}{n\,(n-1)} \right]$$

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14. Because there is substantial local variation in SO_4^{2-} * due to variations in altitude and other factors, this map is useful only for the depiction of regional trends.
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Holocene Sea Level Changes at the Coast of Dor, Southeast Mediterranean

Abstract. *Geological, geomorphological, and archeological data of changes in sea level during the Holocene at the Mediterranean coast of Dor provide a eustatic curve of the region. This curve shows that sea level was approximately 2 meters below the present level 4000 years ago, rose to 1 meter below the present level 3000 years ago, and was 1 meter higher than the present level 1500 years ago. It then dropped to 1 meter below the present level about 800 years ago.*

Paleogeographic and morphologic evidence of elevated coasts during the Holocene time as compared with recent sea level is available from a variety of locations around the world. The findings are based mostly on high notches, terraces with coastal sediments, coral shells, and fossils. Archeological evidence of elevated and low coasts has come mostly from the Mediterranean, which provides numerous archeological structures at its shores and at the near shore. The main archeological findings consist of marine installations built to adapt to sea level at the time of their construction—for example, quays, moles, shipyards, mooring stones, fish tanks, and salt tanks.

Many researchers (*1–8*) have concluded that sea levels have been rising and falling in historic times. Opinions about sea level height at the Roman period (that is, from the third century B.C. to 476 A.D. in the western Mediterranean and from 37 B.C. to 324 A.D. in Israel) range from 1.0 m below (*8*) to 2.0 m above the present level (*5*). Opponents of the theory that sea level is higher today than in historical times emphasize the instability of the Mediterranean and the seismic movements that took place either in historical or more recent times (*9–12*). Archeological excavations have exposed marine installations that do not coincide with present sea level and yet do not prove eustatic movement. Therefore, the possibilities of regional tectonic movement, or even local tectonic movements, must be considered.

The coast of Dor (the research area) is located at the southeastern part of the Mediterranean (142°400′N and 225°250′E). At the research area, there is a sharp transition from a relatively sandy area with wide beaches in the south to another area composed of embayments, cliffs, and islets in the north. It has been suggested that a recent movement was responsible for the creation of embayments (*13*). There is another proposal suggesting that a local vertical movement, relatively recent, lifted the coast of Dor (*12*). However, in the case of Caesarea (*14*), 13 km to the south, the Roman harbor is 5 m or more below the present sea level (*7*).

Paleogeographic evidence indicates that when the coastline of Dor was west of the present coast, about 12,000 years ago, the inlets were topographic depressions with sandstone (Kurkar) at the bottom, at least 5 m below today's sea level. These depressions gradually filled with water as sea level rose. Radiocarbon dating of organic clay samples taken from the bottom of the marshland, 4.4 m below present sea level, were given an age of 11,400 ± 420 years (*15*). The influence of the neighboring sea (to the south) is indicated by remnants of marine fauna, foraminifera, and brackish water. The clay 3.8 m below present sea level is given an age of 9415 ± 480 years (*15*). At this period the coast of Dor formed a transition from an aquatic stage (the source of its water being inland) to a marine stage with the water source from the sea. In samples from 3 m below present sea level in the south and 1.5 m

Table 1. Archeological marine installations. Height is given as above or below current sea level.

Type	Age	Number of stages	Height (m)	Function	Sea level at time of building
Sea wall	Pre-Byzantine		−0.40*	Probably an ancient mole	Low
Warehouses	Roman ceramics (*28*)	>1	0.50*		
Three drainage channels	Pre-Roman	2	−0.70† −0.120†	Prevent clogging of anchorage; circulation	Low (−1.20 m)
	Post-Roman	1	0.50 + 0.80†		High (0.50)
Shipyard, three slipways	Persian 2250 years (*28*)		2.5 + 0.10†	Anchored on land	Low
Wave catcher; rock-cut pools; canal	Persian	2 or 3	−0.30† −1.50†	Breakwater; piscina or salt tanks (?); drainage	Low Low
Fish tanks	Byzantine ceramics 1600–1400 years	2 or 3	−0.30† 0.90† 1.00†	Marine agriculture or small piscina	High
Quay	3200 years (*28*)	2 or 3	−0.37* 0.30* 0.50*	Harbor	Low
Well	Several 100 years	1	0.14	Sweet water	Low

*Measurement from the top of the walls. †Measurement at the base of the installation.

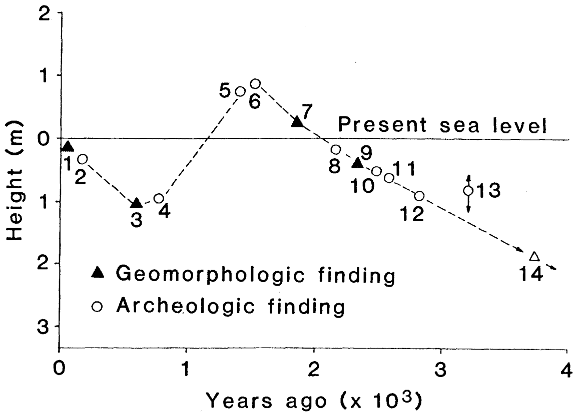

Fig. 1. Changes in sea level during the last 4000 years at the coast of Dor. The evidence which helped to reconstruct the changes in sea level: (1) present abrasion platform, (2) well, (3) beach rock, (4) rock cut pools, (5) canal, (6) fish tanks, (7) notches in installations, (8) shipyards, (9) notches in installations, (10) drainage channel, (11) sea wall, (12) canal, (13) base of quay, and (14) the top of the marshland at the north (no date).

in the north, there is evidence of a joining of the marshlands and the sea, as marine sediments (sand, shells, and gravels) cover the clay.

Geomorphologic evidence shows coastal wave cut terraces at a level of 3 to 4 m above current sea level. These appear to be a remnant of an ancient transgression, which might represent the Flandrian transgression between 8000 and 6000 years ago (*16*). On this terrace there is an archeological site that is 3900 years old (*17*).

Archeological marine installations located on the abrasion platforms or nearby were destroyed and apparently not restored, indicating a changing relation of sea and land in historic times. It is possible that the sea rose above the present sea level and then dropped below it. Notches cut into the man-made marine installations during historical periods are quite small in comparison with natural notches cut more recently. They perhaps indicate a short period of use.

Beachrock appears at the embayments at Dor; some is partially underwater and some is at the shore. Its appearance at the present coastline and also under water containing pottery shards indicates its relatively young age. Cementation of the platform beachrock occurred at a time later than the absolute age of the shards and when sea level was lower than that at present. The energy of the waves prevents the creation of beachrock on the coast today. A decrease of hydrostatic pressure, caused by declining of (relative) sea level (*18*), probably supported formation of the beachrock.

From mapping and leveling of important archeological marine installations, the principal sites and their bases in relation to present sea level have been determined. The main archeological elements (Table 1) reveal indications of human building activity during different historical eras in which sea level changed—for example, rock-cut pools in which the base is above present sea level and a well that was used at the beginning of the present century. In 1915 the well was 7.5 m from the coastline (*19*); today it is flooded by tides. This installation suggests that sea level has risen 0.12 m during the past 70 years (*20*).

Some investigators (*2, 5–7*) assert that sea level was higher in the Mediterranean during the first centuries A.D. than that at present. Oscillations of the sea level of the oceans, which were higher than at present during the first centuries A.D., are represented by various eustatic curves (*1, 3–4*). There are many sea level indicators implying the phenomenon eustasy.

There are three major theories dealing with sea level changes. (i) Even and identical changes in time and space, resulting in universal transgressions (*1, 4*); a rise in sea level at a certain time will occur at the surface of all the oceans identically. (ii) Identical changes in time but not space; transgression would be a universal event, but sea level would vary in height according to latitude (*21*). (iii) Various changes in both time and space, with transgressions being local events (*22*). Curves based on data points from a limited area do not show great diversity in shape (*23–26*), whereas those using data points from different coastal areas show great diversity (*1, 2, 4*).

The periodic sedimentation at the coast of Dor is evidence of a rising sea level during the past 12,000 years. During the Holocene several transgressions also apparently took place. (i) During one transgression, sea level was above that at present, as shown by the coastal terraces that are now 3 to 4 m above sea level. This may represent the Flandrian transgression (*16, 27*), which was followed by a regression. (ii) During another transgression in the first centuries A.D. (Fig. 1), sea level also rose above that now, as indicated by notches and marine installations (Table 1). This was apparently followed by a regression below the current sea level (Fig. 1), as indicated by beachrock, notches, and some of the marine installations (Fig. 1 and Table 1). (iii) Finally, there was another transgression, with a rise of the sea to the level of that today, as indicated by present abrasion platforms.

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