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The Anthropogenic Affect—Humans and Geology: An Example from Tel Dor, Israel

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Abstract: Geology usually deals with rocks formed long ago, which are static and stable over the span of human lifetime. This study aims to analyze anthropogenic influence on the formation of geological features in the southeastern Mediterranean. Tel Dor, along Israel's northern coast, was chosen due to the continuous presence of humans in the area for over 4000 years and the protective environment of its natural bays that preserve geomorphological changes. This allows for the examination of whether and how humans affect their (geological) environment. Three rocky platforms were chosen in the shallow waters of the South Bay adjacent to the Tel, and four cores were extracted. Results show the extent of the direct and indirect anthropological influences on the landscape. The presence of building stones consisting of dolomite, which is not found along the Carmel coast, is an example of direct influence (importation). The evolution of a biological and non-biological reef upon the sturdy base of the port constructions is an indirect influence. The formation of a non-biological reef upon an archaeological feature is a unique process. It would not have consolidated without the presence of anthropogenic activity. This study shows how human interference in the coastal area can trigger a chain reaction of geological processes lasting more than 2000 years.

Keywords: geology and humans; coastal construction; beachrock; geology and archaeology

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1. Introduction

Recent developments in the archaeological and geoarchaeological study of harbors in the Levant [1,2] demonstrate the complex stages in their evolution, from unmodified basins used for anchoring to enclosed, artificial harbors. These developments co-occur with natural processes, such as gradual sea level rise, increase in sediment supply, and variations in wave energy. Construction in the shallow marine environment changes circulation and patterns of sedimentation, creates currents, and often demands further intervention to prevent silting up. This can take the form of dredging or the creation of flushing channels and requires considerable investment in maintenance. After a harbor falls into disuse, an abandonment facies of sediment readily identifiable by geoarchaeological analysis covers the basin [1,3,4].

The coastal zone where these harbors are located, is a dynamic area where complex interactions occur between saline and fresh water, land, air, and biology (including humans). It is highly influenced by changes in sea level, which can drown existing landscapes or expose new ones. Cliff notches [5], marine terraces, cave deposits, and karstic formation [6–9] are often used to reconstruct past sea levels along with biocorrosion (e.g., lithophaga borings) and bioconstruction, such as vermetid reefs [6,10,11]. Where available, archaeological remains are also a powerful tool for sea level reconstruction [12,13]. These studies are usually based on the present-day location of water wells, fish ponds, walls, or floors, which were obviously not constructed underwater.

As a result of sea level fluctuations, changes can occur in larger-scale coastal processes, such as sediment supply, wave and current magnitudes, and directions and tidal range. This can affect the nearshore in many ways, leading to changes that occur over various spatial and temporal scales. Thus, the coastal configuration (i.e., its morphology) observed in the present-day landscape can differ from that of the past when said archaeological features were in use. This is often overlooked and leads to a bias in the interpretation of the ecological setting of archaeological landscapes [14].

Similar to their effect on the geomorphology of the landscape, natural changes in the coastal area (such as sea level fluctuation) and/or human intervention can affect the formation of geological features. This has been highlighted in a number of recent studies and summarized by [15], who examined the geological formation known as beachrock. While eolianite (or aeoliantie) is sand (lithogenic, mainly quartz, or biogenic) that lithified in a series of complex chemical processes lasting thousands of years [16,17], beachrock, by contrast, is a coastal conglomerate that can be formed in just a few years [15,18,19]. Formation occurs under the sediment surface at a depth of tens of centimeters in the transitional zone between saline and fresh water. The processes involved in the cementation remain somewhat debated [20–24]. However, most agree that freshwater and warm temperature are required. Thus, modification of river courses by ancient settlers, for example, can affect the formation of beachrock by introducing or removing freshwater into the coastal system of a given area.

Along the eastern Mediterranean coasts, two types of beachrock can be recognized. The first contains no anthropogenic input. For the most part, it visually and chemically resembles eolianite and is generally composed of quartz grains cemented by calcium carbonate. However, due to rapid lithification (ranging between several months to a few years) and due to a long history of anthropogenic activity in the area, it is common to find whole or partial pieces of humanmade glass, pottery, and even plastic [15] embedded within the beachrock. This constitutes the second type of beachrock.

Regardless of the type of rock, once formed in the shallow marine environment, eolianite, or beachrock abrasion platforms create a hard substrate, which can then serve as a colonization platform for benthic creatures, such as bryozoa, algae, Mollusca, etc. The skeletons of these benthic creatures produce a thick, hard crust of calcium carbonate on top of the rock that strengthens its resistance to wave activity. These Vermetidae (Vermetus triquetrus Bivona or Dendropoma petraeum) can then colonize the outer edges of these platforms [25]. They live at the intertidal to subtidal zone at average water depths of 25 cm and create populated colonies, which can reach a thickness of several centimeters. They precipitate their skeletons on top of those of dead shells, keeping a constant and unchanged distance from the sea level. They leave behind a new, hard, rocky surface that did not exist before, which is rich in quartz, calcite, and aragonite.

The aim of this study is to examine the anthropogenic contribution to the lithification of coastal rocks in the southeastern Mediterranean. The archeological site of Tel Dor was chosen as a case study due to continuous human activity in the bay over the last 4000 years—a period of rising sea level and increased sedimentation rates. We argue that once a harbor infrastructure is abandoned and becomes exposed to the elements, other biological and geological formation processes take place, which have not been addressed in previous studies of harbors. We present a phenomenon undocumented before in Bronze or Iron Age harbors: the formation of a composite reef on the remains of harbor infrastructure, exposing intricate feedback mechanisms between anthropogenic and natural formation processes. This is a unique case where natural rock development postdates an early maritime structure. The result is a reef, which, in turn, modified coastal processes within the bay and changed the geometry of the coast. The interaction between human and natural formation processes opens a new way to understand the anthropogenic role in the development of coastal rocks.

2. Study Area

Tel Dor is the largest archaeological site along the Carmel coast of northern Israel (Figure 1). It was inhabited almost continuously from the Middle Bronze Age (ca. 1950–1550 Before the Common Era—BCE) to the Late Roman Period (ca. 250 CE) [24,26]. Recent coastal and underwater studies at the site found evidence for the use of its South Bay as an anchorage in the Middle and Late Bronze Age (ca. 1950–1200 BCE) and a built harbor infrastructure in the Iron Age Ib (1050–900 BCE) as well as the Iron IIc (700–586 BCE). This highlights its importance for the study of the development of ancient harbors, a major manifestation of anthropogenic pressure on the environment [27–29].

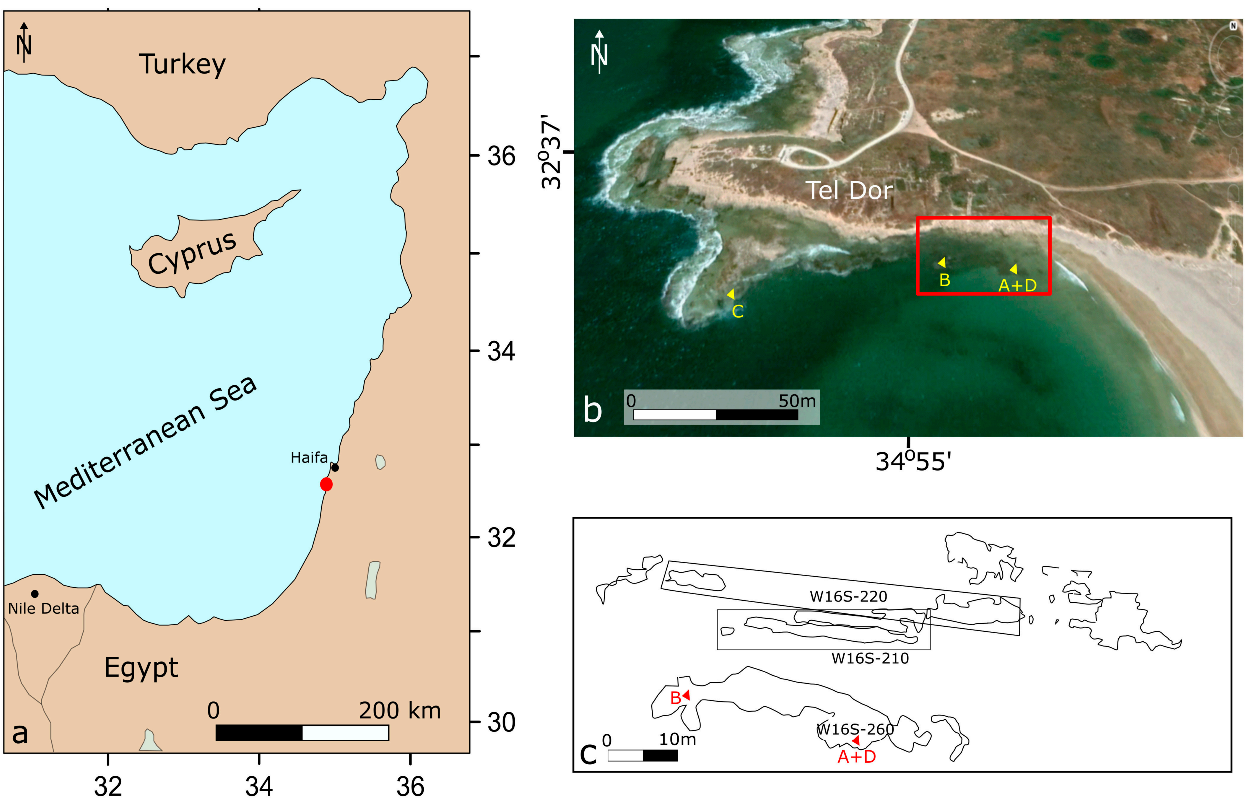

Figure 1. The archaeological site of Tel Dor, central Israel. (**a**) General location map. Red dot marks the location of Tel Dor. (**b**) An oblique view of the south slope of Tel Dor. The location of the cores mentioned in the text (marked A, B, C, and D) are denoted by yellow triangles. Image—Google Earth. (**c**) Sketch of the archaeological features discussed in the text (after [28]).

2.1. Geological Background

Tel Dor is located along the tectonically stable Carmel Coast of Israel. It lies approximately 20 km south of the modern city of Haifa (Figure 1a). While most of the Nile littoral cell and the coast of Israel is characterized by straight, exposed, quartz-dominated sandy shores, Dor's coastline is composed of four semi-enclosed protective bays: The North Bay, Love Bay, the South Bay, and the Tantura Lagoon [24,28,30,31]. The South Bay, the focus of this study, is an approximately 280 m long and 250 m wide pocket beach. It is bordered by an eolianite tombolo to the south and an eolianite headland in the north, creating a protected area of roughly 300 m seawards from the shore [32]. The stratigraphy of the beach is relatively simple. Sivan et al. [33] divided the area into three main units: eolianite bedrock, covered by 5 m of clay, which ceased to be deposited approximately 8938–8166 years before present [29] in a coastal marsh/wetland. This unit is, in turn, covered by 5 m of sand. Shtienberg et al. [32] on the other hand, refined this into six units: base eolianite, followed by red to brown silty loam (paleosol), grayish clay (fresh- to brackish-water wetland), poorly sorted sand interpreted as a tsunami unit [34], another dark, silty clay, fresh- to brackish-water wetland deposit, and sand. Deposition of coastal sand began approximately 7000–6000 years before present [29,32].

As stated above, Dor, much like the rest of the Israeli coastal plain, is characterized by eolianite cliffs and bedrock [2]. In addition to eolianite, beachrock, which is usually found at the shoreline, is also common along the Israeli coast [18,19,35]. Although in some cases it is impossible to determine the difference between the two visually, the lithification pattern and environment is very different and can help shed light on anthropogenic versus natural processes in coastal areas.

2.2. Archaeological Background

In the Middle and Late Bronze Age, maritime activity in Tel Dor was based on utilizing these natural features, which served as proto-harbors. Stone anchors and pottery were found in all bays, attesting to their maritime use during these periods [24,28–31]. The use of natural bays as anchorages continued in later periods in both the North Bay as well as the Tantura Lagoon, where 25 shipwrecks dated from the Roman to the Ottoman period were found [30,36]. During the Iron Age I, ca. 1150–1050 BCE, Dor experienced a period of relative prosperity due to maritime trade, mainly with Egypt and Cyprus. This is reflected in both traded items found at the Tel as well as in the 11th century BCE Report of Wenamun, an Egyptian priest who arrived at the port of Dor in route to Byblos [37–39]. One result of this prosperity was an ambitious building program implemented on the southern edge of Tel Dor, overlooking the South Bay during Iron Ib (ca. 1050–900 BCE). It included the construction of the "Monumental Building" on the top of the Tel, a public building constructed of boulders with ashlar corners, as well as massive fortification of the rounded "Bastion", also built of boulders [40,41]. Two massive parallel ashlar walls, semi-submerged by the waterline of the South Bay, were previously interpreted as quays belonging to the "Sea People's" harbor of Dor [24]. The northern one (W16S-220), closer to the Tel, extends in an east–west direction for at least 70 m, and it is made of ashlar blocks up to 2.3 m in length, 1.4 m in width, and 1 m thick. The southern wall (W16S-210), extending also east–west for approx. 30 m, is made of large paving stones, approximately 2 m long, 1 m wide, and 0.3 m thick (Figure 1). The results of underwater excavations carried out in 2016 and 2017 proved that it is far more likely that these structures were the foundations of a massive coastal fortification and adjacent ashlar paving, as they rest on a bed of sand, with their base located at a depth of 1.25 m below mean sea level (MSL). Given that sea level would have been even lower than it is today, this would imply a depth far too shallow for any ship to anchor in. The date of this elaborate feature is provided by ceramic remains found between and beneath the stones of the walls. These include fragments of imported Egyptian amphorae, none of which date to later than Iron Ib [28]. Another factor indicating that W16S-210 and W16S-220 were not used for maritime-related activity is the presence of a reef running parallel to them for a length of at least 70 m. This feature effectively blocks any access of boats to the area [42]. Underwater excavations have shown that this reef (W16S-260) is a composite of a 0.5–0.7 m thick stone crust resting on top of an anthropogenic feature, i.e., ashlar blocks varying in size from 0.2 by 0.3 m up to 0.25 by 0.6 m, covering an overall area of a minimum of 450 m^2, with a maximum depth of 2.5 m (Figure 1). It was interpreted as a mole for anchoring boats. Goods could then be unloaded to the paved area (W16S-210), before being taken into the city via a sea gate in the coastal wall (W16S-220) [28]. The Dor coastal and maritime structures are, therefore, the earliest datable harbor installations in the Iron Age Levant, predating those of Atlit, further to the north, by a century [43]. This marks a transitional phase in human maritime adaptation to maritime activity from the use of natural anchorages to modified bays and built harbor infrastructure [1,27].

2.3. Climatic and Cultural Background

The overall history revealed at Tel Dor shows adaptation to climate change and sea level rise. The foundation of Dor in the Middle Bronze Age I (ca. 1950–1750 BCE, Table 1) was characterized by the Canaanite archaeological culture [40]. The climate conditions during this period were still dry following a markedly arid episode in the area, known as the 4.2 ka BP event [44]. Sea level was approximately 3 m below their current level [13]. The climate improved, becoming more humid until a dry climatic event occurred at the end of the Late Bronze Age, at approximately 1300–1200 BCE [44], coinciding with a brief hiatus at the settlement of the site, until ca. 1150 BCE. During Iron I, Iron II, and Iron III periods (ca. 1150–500 BCE), the material culture transitioned between late Canaanite and Phoenician archaeological cultures [40]. Climatic conditions were humid, becoming drier towards the end of the period [44]. Sea level was approximately 2 m below the current level and seems to have been stable throughout the Iron Age and into the Persian period (ca. 500–300 BCE) [13]. During the Hellenistic period (ca. 300–1 BCE), Dor underwent a cultural transition from a city with more Phoenician traits, to those more commonly found in the wider Hellenistic world [45]. Sea level rose sharply in the period between 200 and 1 BCE, destroying important harbor infrastructure and inundating parts of the coast of Dor [13].

Table 1. Chronology [40,45], climate [44], and sea level [13] at Tel Dor. Forward slashes indicate the range of dates provided. * The South Bay of Dor fell into disuse as a port after the Roman period. There is evidence for scarce settlement on the Tel afterwards, but the port shifted to the North Bay [31]. BCE—Before the Common Era.

Period (and Archaeological Culture)	Chronology Tel Dor [ref]	Climate [41]	Sea Level (below Present-Day Level)
Middle Bronze Age I (Canaanite)	1950–1750 BCE [40]	Dry	approx. −3 m [13]
Middle Bronze Age II-III (Canaanite)	1750–1550 BCE [40]	More Humid	
Late Bronze Age (Canaanite)	1550–1200/1150 BCE [40]	Humid, but later dry climate event ca. 1300–1200 BCE	approx. −2.5 m? [13]
Iron Age Ia, (late Canaanite—Phoenician)	1200/1150–1100/1050 BCE [40]	Humid	approx. −2 m [13]
Iron Age Ib (late Canaanite—Phoenician)	1100/1050–925/900 BCE [40]	Humid	approx. −2 m [13]
Transition Iron Age Ib-II (Phoenician)	925–875 BCE [40]	Humid	−1.5 m [46]
Iron IIa and IIb (Phoenician, Israelite)	900–700 BCE [40]	Drier	Stable [46]
Iron Age IIc (Iron Age III)	700–586/500 BCE [40]	Drier	
Persian Period (Phoenician)	500–300 BCE [45]	?	Stable [46]
Hellenistic Period	300–50/1 BCE [45]	?	Rises rapidly [46]
Roman Period *	1 BCE–222/250 CE (?)		

3. Materials and Methods

On the basis of field observations and previous studies [28,29], three coastal platforms were chosen in shallow water adjacent to the southern flank of Tel Dor to extract cores (Figure 1) using a Shaw portable 41 mm hard rock drill/corer. The height of the top of each platform was measured at core-point relative to MSL (provided by the Survey of Israel) by a theodolite. Core A, the eastern-most core, was drilled on part of the artificial, humanmade wall W16S-260 [28]. This feature was selected due to its wide outcrop, ease of access, and its potential to be affected by both anthropogenic activity and natural processes. The elevation of the platform during the drilling was 3 cm above MSL. Core B was extracted from a platform located on the southern edge of wall W16S-260 (and may or may not be part of it). The top of the platform was at sea level. Core C was drilled on a natural abrasion platform located along the northwestern edge of the Tel. It is located away from archaeological influences and, thus, served as a control for the native environment. Core D was extracted at the same location of Core A in order to verify its findings. All core segments were marked, labeled, and documented at the field.

In the lab, the cores were washed to remove salts using distilled water to minimize the effects of washing on the carbonate content. The cores were then dried overnight in an oven heated to 40 °C. Selected segments were vacuum-impregnated with Polipol 354-L-UV and styrene for thin section preparation. In order for the solution to fill all pores in the rock, it was left in a vacuum at −0.9 bar for 24 h. After drying, thin layers were cut from each segment using a customized saw to create slides. Petrographic analysis was carried out using a petrographic Olympus BX53 microscope. The type and crystal shape of the cement matrix, grain size distribution, grain shape and angularity, and the porosity of the rock were examined to help differentiate between eolianite and beachrock, which may appear similar to the naked eye. Slides showing a grain-supported, well sorted, round, homogeneous grain distribution with very fine crystals of micritic were characterized as eolianite. Beachrock was identified by matrix-supported conglomerates with a varying grain size distribution, sharped angled grains, and coniferous, flat fibrous crystals.

The final determination of rock type for each core segment was made by mineralogical analysis carried out using X-ray diffraction [47]. According to the crystal compound sought and its lattice structure, the XRD device generates an X-ray with a specific wavelet. The X-ray is directed at a powdered sample and hits it with an incident beam with a known angle. After hitting the sample, the beam is refracted by the atomic plains of the crystal. The diffracted beam is recorded by the device. By examining the relations between the incident beam and the reflected beam, the identification of unknown crystalline materials can be established. To achieve this, samples weighing 0.5 g each were extracted from each core segment, ground to a powder, and analyzed using a Rigako Miniflex 600 XRD. Data were processed using the PDXL software package. The device was set to detect the three main minerals commonly found in the eastern Mediterranean coastal area. Quartz, calcite, and aragonite abundances were calculated from the reference intensity ratio (RIR) method [48], using reference values from the ICDD PDF2 database [49]. The RIR method uses the ratio between the peak intensity of the mineral examined and a known mineral (in this case corundum) and provides the relation between the two minerals (I/Ic = 3.13, 3.32, and 1.17 for quartz, calcite, and aragonite, respectively). A system of two equations normalizes the value of corundum and leaves the ratio of the minerals the device was set to detect. The ratios calculated in this study were quartz/calcite and aragonite/calcite. Out of these ratios, the relative part of each mineral in a sample was calculated. In samples where none of the three minerals were found in any significant amount, the device was set to detect dolomite. Only the main and highest peak of each mineral (quartz (0,1,1), calcite (1,0,4), and aragonite (1,1,1)) was quantified into its share in the sample. In cases of phase shifts where the XRD was not able to associate the peak location (2-theta) into a phase name, phases were selected manually.

4. Results

In general, the petrographic analysis allowed for the distinction among three different rock compositions. In all cores, segments with homogeneous quartz sand grains were identified as eolianite, and segments with a conglomerate of shells, biogenic grains, and quartz sand grains were classified as beachrock. These often contained indications of anthropogenic debris, such as pottery fragments. Biogenic layers controlled by Vermetidae were labeled as such. Results are presented in Figure 2.

The deepest layer of Core A was found to be composed of three homogeneous-looking eolianite segments. Petrographic and XRD analysis revealed that the second (middle) segment differs from the other two. Mineralogically, this segment is the only one that visually looked like eolianite but turned out to contain aragonite. The petrographic slide of this segment shows that it is composed of numerous whole and well-developed ooids (Figure 3). Above this lies a thin layer of beachrock containing small pottery particles. Above this beachrock, a dense, non-local rock was found. XRD revealed that this segment is composed entirely of dolomite, with no calcite, quartz, or aragonite present. This is overlain by a 25 cm beachrock layer, composed of three segments which contain quartz sand grains, aragonite, bioclasts, and shell fragments. The bottom segment is smaller and has less shell fragments than the other two segments. The middle beachrock segment contains large pottery residue. The top of the upper segment is broken, and it is characterized by the presence of voids and pores. At the top of Core A, a thick (18 cm) dense Vermetidae reef composed of two segments containing quartz, calcite, and aragonite was found. The bottom Vermetidae segment contained the highest fraction of quartz found in the entire core (59%).

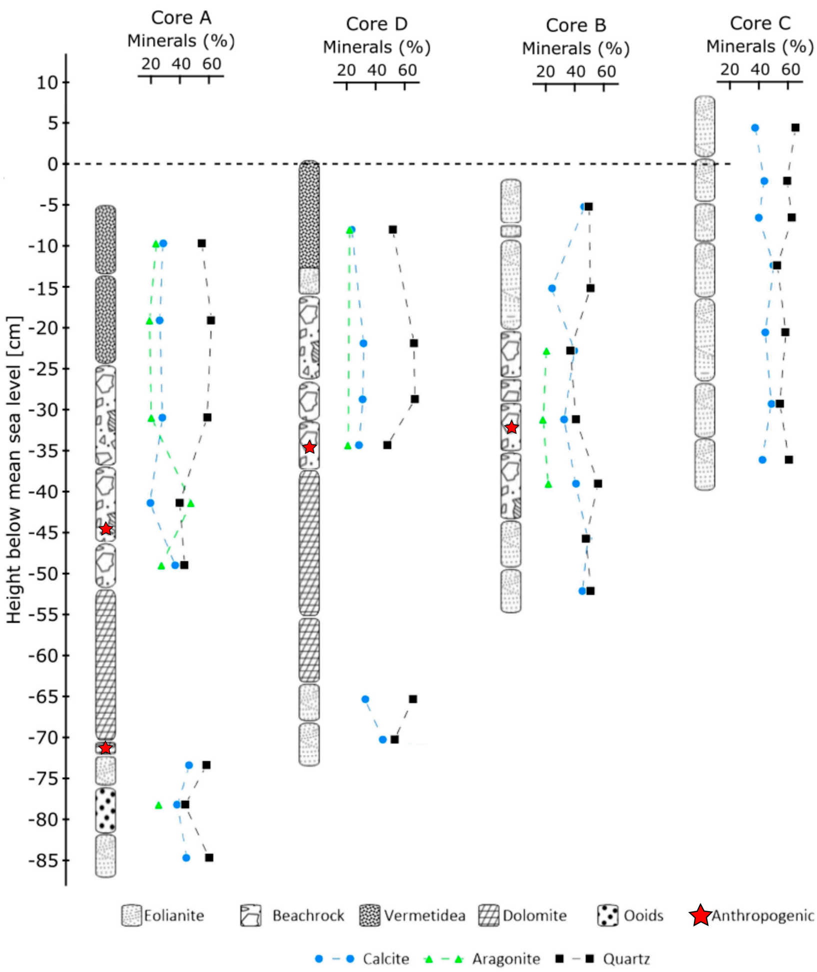

Figure 2. The lithological sequence of all cores and their major mineralogical components. See Figure 1b for locations. The cores are divided into the separate segments described in the Results. Y-axis denotes height relative to present-day mean sea level. Please note that the top of core A and B are below mean sea level, i.e., the top of the platform that was cored was slightly under the surface of the water, and that Cores A and D appear next to each other for convenience of comparison.

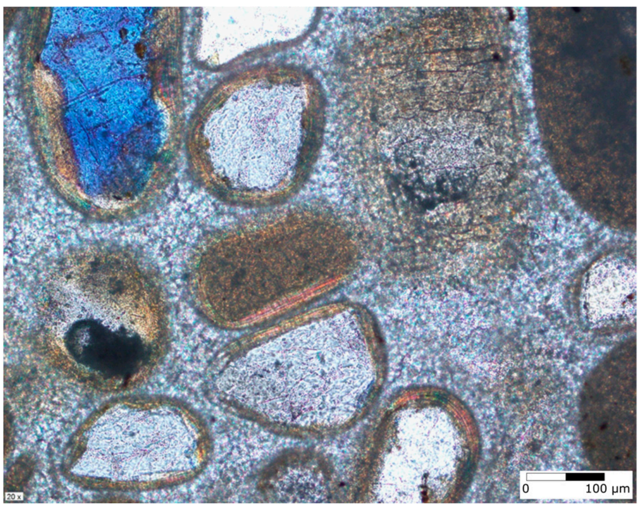

Figure 3. Petrographic slide showing the rounded ooids found in Core A (Figure 2).

Core B is unique. Its deepest layer, composed of eolianite, is overlain by a 19.5 cm thick beachrock made up of four segments. The deepest had the greatest amount of quartz

(58%) in all of Core B. Above this, a section was found with pottery embedded in it. The next segment was less than 2 cm thick and was not analyzed in the XRD. The top beachrock segment is the only one in all the cores with a greater amount of calcite than quartz. Above this was the only instance where an eolianite layer, 17.5 cm thick, was found above a beachrock layer. In addition, there is no evidence of Vermetidae in the top of the core.

Core C was homogeneous throughout its entire length, consisting only of eolianite. The quartz quantity varied from 51–64% and calcite levels changed between 36–49%. The eolianite did not contain any aragonite.

Core D, which was drilled to verify the complex sequence of Core A, follows the same sequence as the latter, from the dolomite layer through the three segments of beachrock to the Vermetidae. However, beneath the dolomite layer, two segments of eolianite were found (compared with three in Core A), both lacking significant ooid presence (<10%). The second segment in the beachrock layer consists of 68% quartz, thus making it the segment with the most amount of quartz in this core. The amount of calcite was in the range of 24–32% through all the core segments except for the last segment, which comprised 46% calcite. Aragonite was found only in two segments, the Vermetidae layer and the third beachrock segment, which also contained pottery in it.

5. Discussion

The coastal landscape adjacent to Tel Dor has undergone significant anthropogenic intervention for at least 4000 years, as is evident from the rich archaeological finds from the area that date back to the Bronze Age. The current study shows that careful analysis of various humanmade features can help shed light on the often symbiotic connection between geological and anthropogenic processes. Core analysis presented here suggests that the composition of wall W16S-260, adjacent to Tel Dor, can be used to verify that the landscape we observe today was deeply impacted by anthropogenic activities. The structure of wall W16S-260 and its development through time mirrors the evolution of the Tel from its heyday to the abandonment of its marine structures and disuse of the South Bay.

Comparison of Cores A, B, and D, extracted from archeological features, and that of Core C, which acted as a control point taken from the undisturbed abrasion platform at the edge of the headland, indicates major differences between the natural sequence in the area and that which was influenced by human activity. Core C shows a homogenous natural sequence that would have been exposed solely to erosion, either natural (wind, waves) or anthropogenic (chiseling). Conversely, the other cores display complex sequences that exemplify accretionary processes.

5.1. Geological Processes

Previous studies at Tel Dor used a series of radiocarbon dates to provide high-accuracy absolute chronology for the stratigraphic sequence of the archaeological strata. At the same time, a meticulous study of the pottery found within each of these strata allowed for the construction of a typological sequence that can be assigned to both relative and absolute chronologies [50,51]. The typology of the pottery associated with wall W16S-260, from which cores A and D were extracted, can therefore be given a date. As the pottery precedes Iron IIa and is likely from Iron Ib or the transitional Iron Ib/Iia phase [28], the wall can be said to have been constructed no later than ca. 1100–900 BCE—it was most likely built in two phases, used as a sea wall in the Iron Age Ib, and modified to be used as a mole in the later part of that period or during the transition to Iron Age IIa [28].

Since Cores A and D were cored adjacent to each other, they are nearly identical in their composition. Their sequence commences with a thick fossilized Vermetidae reef. Sisma-Ventura et al. [10] dated the contact of this sequence with the underlying eolianite rock across the northern coasts of Israel. Since this contact marks the onset of modern colonization at a given location, it can be taken as a good indicator of the arrival of Vermetidae to the area. For the study area, a contact age of 510 years before present, corresponding to the calendar year of 1490, was obtained [10]. Sivan et al. [11] obtained a similar measurement of 560 ^{14}C BP. Therefore, it can be assumed with confidence that the 18 cm Vermetidae section was formed in Dor sometime during the past 600 years. Arrival of modern Vermetidae to the northern Israeli coast can be documented going back at least 1500 years [11]. Thus, the young contact date would indicate that at Tel Dor, the conditions for colonization become favorable only approx. 600 years ago, i.e., sea level would have had to have been at least 21 cm lower than today (Figure 4), as it was during the Crusader period [46].

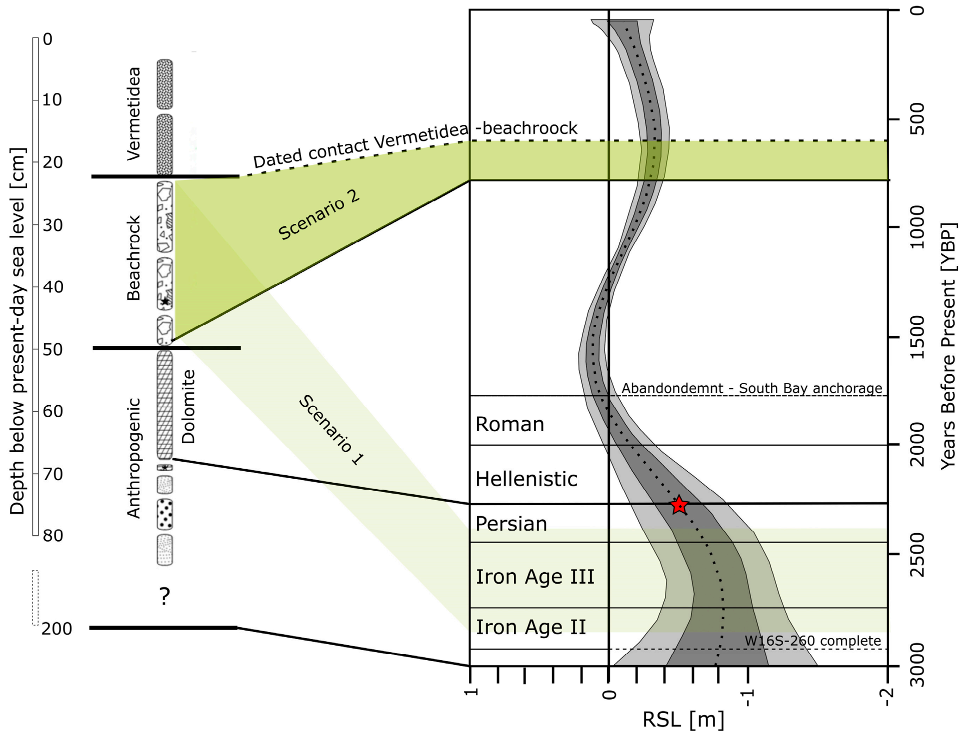

Figure 4. Conceptual model showing the correlation of sea level oscillation (modified after [46]) and the main phases of Core A, which are correlated to years before present (years BCE + 2000) on the basis of deductions explained in the text. Green represents the two possible scenarios for beachrock formation. RSL—relative sea level (in meters). The ages provided indicate the possible periods when the rocks were emplaced up to the dolomite layer. Above the dolomite, ages represent possible dates of formation resulting from anthropogenic influence as explained in the text. Red star marks when sea level was 50 cm below present-day level during the transition between the Persian and Hellenistic periods.

Beneath the Vermetidae level, a beachrock sequence was found. The similarities in the characteristic and thickness of the beachrock segments in Core A (25 cm), Core B (19 cm), and Core D (18 cm) imply that there is a temporal connection between them. The beachrock lithified on site and was not brought from afar as construction material. This is evident by the presence of local pottery fragments within the rock, which indicates that it most likely lithified in situ. The abundance of beachrock found in the different cores begs the question of the source of freshwater in the area, as freshwater plays an important part in beachrock formation ([52] and references therein). Tel Dor lies between two stream outlets: the perennial Dalya stream, which flows 1.5 km south of the Tel and has a historical base flow of 1 million m^3, and the intermittent Maarot stream, which flows 2 km to the north. Aerial photographs taken by the RAF from 1919 [53] show the Tel area before the beginning of modern settlement. A clear channel can be seen flowing in a southeast to northwest direction and enters the sea several hundred meters to the south of the study area. It is outside the scope of the current study to establish whether this channel was in place at the time of beachrock lithification and how its flow would alter the adjacent seawater chemistry. However, it does indicate the past presence of rivers in the area, which today have no morphological expression in the field. Groundwater seepage is another possible source of fresh water. Currently, the rate of penetration of aquifer waters to the sea in the vicinity of the Tel is 7.1 m^3 per day per meter beach [54]. It is possible that when sea level was lower, the aquifer–sea boundary was westward of its current position and could have been responsible for injection of fresh water into the system.

Beachrock lithifies beneath the surface at a depth where the sediment is static and allows for its lithification. For the creation of the various beachrock layers uncovered in the cores, the top of the mole (W16S-260) at the time would have had to have been buried under sediment for a substantial amount of time, which would allow for its lithification. Considering the lower sea level in Dor as late as 550 years ago (i.e., the beachrock is necessarily older), this situation is most certainly possible (Figure 4). In addition, it should be noted that the beachrock uncovered in this study is not "typical" in that it was not formed on a sandy beach but rather on top of a humanmade feature. For this to occur, at least 25 cm of sediment (the thickness of the beachrock segment) would have had to have been deposited on top of the dolomite building block. As sea level rose, the mole would have created a shallow lagoonal setting behind it. Sand could, thus, be accumulated and eventually cover the top of the dolomite block and ground water could seep through the gaps in paving blocks, providing a freshwater source for beachrock formation. This is a situation that can be currently seen on many beaches across Israel today and would have allowed ideal, calm conditions for the formation of beachrock. Analysis of the cores for this study raises the question as to whether human interference in the natural landscape was what allowed for lithification of beachrock and subsequent colonization by Vermetidae. Constraints on the formation of these features is presented in Section 5.3.

5.2. Anthropogenic Influence

As stated above, the dolomite block would have been brought to the Tel from afar during the Iron Age I/II. The closest dolomite source to Tel Dor is the foothills of Mount Carmel, located approximately 2.5–3 km to the east. It should also be noted that dolomite as construction material is not ubiquitous in the Tel Dor area. Hence, this could have been used by ancient builders to strengthen the construction or emphasize its uniqueness since it appears that the entire underwater structure that encompasses wall W16S-260 (and possibly even wall W16S-220) contains a layer of dolomite [28]. Alternatively, it could have been a ballast stone salvaged for building, a phenomenon seen in the construction of the 9th century BCE Atlit mole to the north, where ballast stones were reused to form the foundation [55].

Beneath the dolomite layer, the core sequences begin to differ. Core A consists of a thin beachrock layer containing pottery. The last segment of Core A was initially interpreted as homogenous eolianite. However, the second segment (of three) was found to contain high ooid concentrations. To date, there is no evidence for recent formation of ooids along the southeast Mediterranean coast. Due to completeness of the ooids and their geographical placement, it is proposed that the stone, which makes up this level, is also non-local. It could have been brought to the site as a result of marine trade with countries in North Africa [56,57] or as ballast. A more local option is that it was quarried from rock that contains ooids, which can be found a few kilometers away [58]. In any event, it is important to point out that the stone was not quarried locally but imported, even if from close by. The last segment in Core A is typical eolianite, which is representative of the local bedrock. However, since the bottom of the mole (and therefore the bedrock) is located at least 1.3 m below the bottom of the core [28], this segment clearly cannot be bedrock and, thus, must also be a building block. It is possible this layer made up the older port, which relied on the natural landscape and/or local construction materials requiring minimum transportation. The calcite fraction in all eolianite segments and especially the ones found in Core C (>36%) are higher than the typical 20% reported for eolianite in Israel (e.g., [59,60]). This could be an indication that the eolianite used here was also sourced from somewhere else.

The sequence described in Core B is unusual in that it comprises two eolianite units separated by beachrock. The rock sequence found in this area does not consist of eolianite above beachrock. Thus, the beachrock in Core B formed before the top eolianite segment was emplaced. The platform's distance from the coastal cliff today negates the possibility that the eolianite rock originated from natural erosion or collapse of the adjacent cliff. Since, as stated above, there seems to be a connection among the segments of beachrock in the different cores, we conclude that the top eolianite layer of Core B belongs to a later phase of construction. The lack of Vermetidae indicates that the top of the rock at the time of their arrival to the area would have been exposed above sea level [25]. This strengthens the possibility that the platform was used as a dock or to load/unload goods, perhaps expanding wall W1S-260 to the west.

Core C, which constitutes a control site, shows a stratigraphic sequence that apparently had no anthropogenic influence. It is composed entirely of eolianite. Lack of a Vermetidae or beachrock on this flat platform implies that it was eroded/quarried recently (since there is evidence for the presence of Vermetidae at the edges of the platform) and that the area from which the core was extracted was above sea level during the main activities at Dor. Core C was taken from the edge of the site, in an area where it clearly is part of the natural cliff. It, therefore, is assumed to represent the natural eolianite ridge and, hence, the locally sourced building material. It appears uniform throughout the core.

5.3. Towards a Chronology

The sequence uncovered in the coring of wall W16S-260 shows a complex nature that was made possible only by human intervention. The construction of a mole on a hard substrate, most likely a natural occurring eolianite platform, led to the preservation of this feature. Abandonment of the harbor probably led to its infill with sand, covering the mole and creating the conditions ripe for the formation of a new geological feature—beachrock. Subsequent rise in sea level slowly flooded this mole and allowed for the colonization by local biological organisms and for the construction of a bio-platform. In time, this feature would become the biogenic rock observed today, which was not there before.

While lacking exact dates for the different layers described in the cores, knowledge of formation processes and sea levels, combined with past dating, can provide some constraints (Figure 4), particularly with regard to the earliest date possible for the emplacement of the different units (i.e., the terminus post quem). Cores A and D were extracted from nearby sites and are nearly identical in their composition. The bottom of wall W16S-260, roughly 1.3 m beneath the bottom of Core A, was dated by pottery found at its base to the late Iron Age Ib or to Iron Age II. During this period, sea level was lower than today by as much as 1.5 m [51] (Figure 4).

Two possibilities for the construction of the mole (wall W1S-260) can be formulated. The first postulates that the entire wall up to, but not including, the beachrock segment was built at one time during Iron Age Ib-II out of material at hand (i.e., local rocks and ballast). Given the projected average sea level at the time, this would mean that it may have protruded out of the water by at least 50 cm. Another possibility is that the wall was built in phases. The initial phase was built during Iron Age Ib-II. Subsequent rise in sea level (Figure 4) would mean that the top of this feature would have to be built up to keep it functional since a mole and/or a breakwater [28] must be above sea level. The possibility, thus, exists that at least the top part of the humanmade wall, the dolomite block, could have been emplaced as sea level rose above the level it was during the Iron Age II, ca. 225 BCE (2225 BP). It would then probably have been emplaced before sea level rose past 50 cm below the present-day level (red star on Figure 4) since higher levels would render the structure useless.

Given either possibility, the overlying beachrock could have also been formed during one of two periods—during low sea level that prevailed after the Iron Age I-II transition (Scenario 1 in Figure 4), or when sea level dropped again past the depth of the top of the wall (i.e., between 20–45 cm lower than today) approx. 750 year BP (ca. 1250 CE—Scenario 2 in Figure 4). The overlying beachrock unit, however, would have to belong to a period after the maritime structure was abandoned, thus allowing it to form in situ as a result of naturally occurring geological–geochemical processes. Beachrock is formed in the intertidal zone and is thought to form under a sand cover. Thus, given the depth of its base (~50 cm) and top (20 cm), it would have begun to form when sea level was at least 20–40 cm lower than today. The top of the beachrock can be no younger than the date provided for the contact between this layer and the overlying Vermetidae, i.e., it is at least 600 years old. Given that the archaeological evidence points to abandonment of the harbor only from the Roman period, we assume the more recent date for the formation of beachrock, as presented in Scenario 2 of Figure 4.

5.4. A Word about Engineering

An interesting observation is that according to the chronology presented above, the mole represented by wall W16S-260 has been exposed to the action of the waves for at least 2500 years, if not longer. While it is hard to tell how much it has been affected by erosion during this period, what is almost certain is that it was constructed and based properly in order to assure its durability against the waves. The cores examined in this study reveal that wall W16S-260 was constructed on a stable, hard, natural foundation. Geophysical measurements conducted near the wall [29,61] show the continuation of this hard rocky substrate adjacent to the southern edge of the Tel, which can be correlated with the projected continuation of the wall. This could indicate that the entire Tel was constructed on more durable rock, and has, thus, managed to thrive throughout the ages, while other contemporary coastal sites have been partially lost to erosion of the waves.

6. Conclusions

The three cores (A, B, and D) taken from within the boundaries of the archaeological site attest that human influence on the natural landscape was both direct and indirect. Examples of direct influence can be seen in the dolomite layers of Cores A and D and the top eolianite layer of Core B, all of which were used as building blocks for harbor facilities and, thus, purposely brought to their current locations from elsewhere. From an indirect point of view, coastal energy would have been reduced due to the placement anchorages, moles, and other marine structures distributed in the harbor. Together with recurring management, use, and abandonment of marine structures, this most probably provided partial conditions needed for the lithification of the beachrock found in the different cores by providing a lagoonal setting with little wave energy. As a result of increasing sea level, the artificially raised platform could be colonization by the Vermetidae found in Cores A and D. If not for the lower dolomite layer at the base of the mole and if it were not for the layer of aforementioned beachrock, it is doubtful that the structure would have reached the necessary height needed to allow the Vermetidae colony to thrive. Thus, what started as anthropogenic interference that needed to be maintained as a result of shifting sea levels created the ideal conditions for the formation of beachrock. This eventually led to the biological processes of rock formation evident today on the surface. By interfering in the natural environment, the ancient builders set in motion a chain reaction of processes lasting over 2000 years.

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References

1. Marriner, N.; Morhange, C.; Kaniewski, D.; Carayon, N. Ancient harbour infrastructure in the Levant: Tracking the birth and rise of new forms of anthropogenic pressure. *Sci. Rep.* **2014**, *4*, 5554. [CrossRef] [PubMed]
2. Morhange, C.; Giaime, M.; Marriner, N.; Hamid, A.A.; Bruneton, H.; Honnorat, A.; Kaniewski, D.; Magnin, F.; Porotov, A.V.; Wante, J.; et al. Geoarchaeological evolution of Tel Akko's ancient harbour (Israel). *J. Archaeol. Sci. Rep.* **2016**, *7*, 71–81. [CrossRef]
3. Raban, A.; Artzy, M.; Goodman, B.; Gal, Z. (Eds.) *The Harbour of Sebastos (Caesarea Maritima) in Its Roman Mediterranean Context*; BAR International Series 1930; Archeopress: Oxford, UK, 2009; 222p, ISBN1 10: 1407304127/1-4073-0412-7. ISBN2 13: 9781407304120.
4. Preiser-Kapeller, J. Harbours and maritime networks as complex adaptive systems—A thematic introduction. In *Harbours and Maritime Networks as Complex Adaptive Systems*; Preiser-Kapeller, J., Daim, F., Eds.; Verlag des Römisch-Germanisches Zentralmuseum: Mainz, Germany, 2015; pp. 1–23.
5. Goodman-Tchernov, B.; Katz, O. Holocene-era submerged notches along the southern Levantine coastline: Punctuated sea level rise? *Quat. Int.* **2016**, *401*, 17–27. [CrossRef]
6. Ruggieri, R.; De Waele, J. Lower-to Middle Pleistocene flank margin caves at Custonaci (Trapani, NW Sicily) and their relation with past sea levels. *Acta Carsologica* **2014**, *43*, 11–22. [CrossRef]
7. Borzì, L.; Anfuso, G.; Manno, G.; Distefano, S.; Urso, S.; Chiarella, D.; Di Stefano, A. Shoreline evolution and environmental changes at the NW area of the Gulf of Gela (Sicily, Italy). *Land* **2021**, *10*, 1034. [CrossRef]
8. Distefano, S.; Gamberi, F.; Borzì, L.; Di Stefano, A. Quaternary coastal landscape evolution and sea-level rise: An example from South-East Sicily. *Geosciences* **2021**, *11*, 506. [CrossRef]
9. Distefano, S.; Gamberi, F.; Baldassini, N.; Di Stefano, A. Quaternary evolution of coastal plain in response to sea-level changes: Example from South-East Sicily (Southern Italy). *Water* **2021**, *13*, 1524. [CrossRef]
10. Sisma-Ventura, G.; Guzner, B.; Yam, R.; Fine, M.; Shemesh, A. The reef builder gastropod Dendropoma petreaum—A proxy of short and long term climatic events in the Eastern Mediterranean. *Geochim. Cosmochim. Acta* **2009**, *73*, 4376–4383. [CrossRef]
11. Sivan, D.; Schattner, U.; Morhange, C.; Boaretto, E. What can a sessile mollusk tell about neotectonics? *Earth Planet. Sci. Lett.* **2010**, *296*, 451–458. [CrossRef]
12. Sivan, D.; Wdowinski, S.; Lambeck, K.; Galili, E.; Raban, A. Holocene sea-level changes along the Mediterranean coast of Israel, based on archaeological observations and numerical model. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **2001**, *167*, 101–117. [CrossRef]
13. Yasur-Landau, A.; Shtienberg, G.; Gambash, G.; Spada, G.; Melini, D.; Arkin-Shalev, E.; Tamberino, A.; Reese, J.; Levy, T.E.; Sivan, D. New relative sea-level (RSL) indications from the Eastern Mediterranean: Middle Bronze Age to the Roman period (~3800–1800 y BP) archaeological constructions at Dor, the Carmel coast, Israel. *PLoS ONE* **2021**, *16*, e0251870. [CrossRef] [PubMed]
14. Rivera-Collazo, I.; Ramos-Vélez, M.; Rodríguez-Delgado, E.; Cantú, K. The power of archaeology to address interpretation biases in modern geomorphology. *Geomorphology* **2021**, *389*, 107843. [CrossRef]
15. Fernandinoa, G.; Elliff, C.I.; Francischini, H.; Dentzien-Dias, P. Anthropoquinas: First description of plastics and other man-made materials in recently formed coastal sedimentary rocks in the southern hemisphere. *Mar. Pollut. Bull.* **2020**, *154*, 111044. [CrossRef] [PubMed]
16. Yaalon, D.H. Factors affecting the lithification of eolianite and interpretation of its environmental significance in the coastal plain of Israel. *J. Sediment. Res.* **1967**, *37*, 1189–1199. [CrossRef]
17. Gavish, E.; Friedman, G.M. Progressive diagenesis in Quaternary to Late Tertiary carbonate sediments: Sequence and time scale. *J. Sediment. Res.* **1969**, *39*, 980–1006.
18. Friedman, G.M. Holocene chronostratigraphic beachrocks and their geologic climatic significance. *Geochem. Soc. Spec. Publ.* **2004**, *9*, 125–142. [CrossRef]
19. Galili, E.; Zviely, D.; Ronen, A.; Mienis, H.K. Beach deposits of MIS 5e high sea stand as indicators for tectonic stability of the Carmel coastal plain, Israel. *Quat. Sci. Rev.* **2007**, *26*, 2544–2557. [CrossRef]
20. Moore, C.H. Intertidal carbonate cementation Grand Cayman, West Indies. *J. Sediment. Res.* **1973**, *43*, 591–602.
21. Hanor, J.S. Precipitation of beachrock cements: Mixing of marine and meteoric waters vs. CO_2-degassing. *J. Sediment. Res.* **1978**, *48*, 489–501.
22. Meyers, J.H. Marine vadose beachrock cementation by cryptocrystalline magnesian calcite—Maui, Hawaii. *J. Sediment. Petrol.* **1987**, *57*, 558–570.
23. Morse, J.W.; Mackenzie, F.T. *Geochemistry of Sedimentary Carbonates. Geochemistry Sediment*; Developments in Sedimentology 48; Elsevier Science: Amsterdam, The Netherlands, 1990; 706p.

24. Raban, A. Dor-Yam: Maritime and coastal installations at Dor in their geomorphological and stratigraphic context. In *Excavations at Dor. Final Report I, A: Areas A and C. Introduction and Stratigraphy (Qedem Reports I)*; Stern, E., Ed.; Hebrew University of Jerusalem: Jerusalem, Israel, 1995; pp. 285–354.
25. Sisma-Ventura, G.; Antonioli, F.; Silenzi, S.; Devoti, S.; Montagna, P.; Chemello, R.; Shemesh, A.; Yam, R.; Gehrels, R.; Dean, S.; et al. Assessing vermetid reefs as indicators of past sea levels in the Mediterrnaen. *Mar. Geol.* **2020**, *429*, 106313. [CrossRef]
26. Stern, E. *Dor, the Ruler of the Seas: Nineteen Years of Excavations at the Israelite-Phoenician Harbor Town on the Carmel Coast*; Israel Exploration Society: Jerusalem, Israel, 2000; 400p.
27. Yasur-Landau, A. The archaeology of maritime adaptation. In *The Social Archaeology of the Levant: From Prehistory to the Present*; Yasur-Landau, A., Cline, E., Rowan, Y., Eds.; Cambridge University Press: Cambridge, UK, 2019; pp. 551–570. [CrossRef]
28. Arkin Shalev, E.; Yasur-Landau, A.; Gilboa, A. The Iron Age Maritime Interface at the South Bay of Tel Dor: Results from the 2016 and 2017 excavation seasons. *Int. J. Naut. Archaeol.* **2019**, *48*, 439–452. [CrossRef]
29. Lazar, M.; Engoltz, K.; Basson, U.; Yasur-Landau, A. Water saturated sand and a shallow bay: Combining coastal geophysics and underwater archaeology in the south bay of Tel Dor. *Quat. Int.* **2018**, *473*, 112–119. [CrossRef]
30. Kingsley, S.A.; Raveh, K. *The Ancient Harbour and Anchorage at Dor, Israel. Results of the Underwater Surveys 1976–1991*; Bar Publishing: Oxford, UK, 1997; 264p.
31. Arkin Shalev, E.; Gambash, G.; Yasur-Landau, A. Disheveled tenacity: The north bay of Roman and Byzantine Dor. *J. Marit. Archaeol.* **2019**, *14*, 205–237. [CrossRef]
32. Shtienberg, G.; Gadol, O.; Levy, T.E.; Norris, R.D.; Yasur-Landau, A.; Rittenour, T.M.; Tamberino, A.; Lazar, M. Changing environments and human interaction during the Pleistocene—Early Holocene from the shallow coastal area of Dor, Israel. *Quat. Res.* **2022**, *105*, 64–81. [CrossRef]
33. Sivan, D.; Eliyahu, D.; Raban, A. Late Pleistocene to Holocene wetlands now covered by sand, along the Carmel Coast, Israel, and their relation to human settlement: An example from Dor. *J. Coast. Res.* **2004**, *204*, 1035–1048. [CrossRef]
34. Shtienberg, G.; Yasur-Landau, A.; Norris, R.D.; Lazar, M.; Rittenour, T.M.; Tamberino, A.; Gadol, O.; Cantu, K.; Arkin Shalev, U.; Goblin, I.; et al. A Neolithic mega-tsunami event in the eastern Mediterranean: Prehistoric settlement vulnerability along the Carmel Coast, Israel. *PLoS ONE* **2020**, *15*, e0243619. [CrossRef]
35. Galili, E.; Zviely, D. Geo-archaeological markers reveal magnitude and rates of Israeli coastal cliff erosion and retreat. *J. Coast. Conserv.* **2019**, *23*, 747–758. [CrossRef]
36. Mor, H.; Kahanov, Y. The Dor 2001/1 shipwreck, Israel—A summary of the excavation. *Int. J. Naut. Archaeol.* **2006**, *35*, 274–289. [CrossRef]
37. Waiman-Barak, P.; Gilboa, A.; Goren, Y. A stratified sequence of Early Iron Age Egyptian ceramics at Tel Dor, Israel. *Agypt. Levante* **2014**, *24*, 315–342. [CrossRef]
38. Gilboa, A. Dor and Egypt in the early Iron Age: An archaeological perspective of (part of) the Wenamun report. *Agypt. Levante* **2015**, *24*, 315–342. [CrossRef]
39. Yasur-Landau, A. The memory machine: How 12th-century BCE iconography created memories of the philistines (and other sea peoples). In *MNHMH/MNEME. Past and Memory in the Aegean Bronze Age Proceedings of the 17th International Aegean Conference, University of Udine, Department of Humanities and Cultural Heritage, Ca' Foscari University of Venice, Department of Humanities, 17-21 April 2018, Aegaeum 43*; Peeters Publishers: Leuven, Belgium, 2019; pp. 413–422.
40. Gilboa, A.; Sharon, I. Between the Carmel and the sea: Tel Dor's Iron Age reconsidered. *Near East. Archaeol.* **2008**, *71*, 146–170. [CrossRef]
41. Sharon, I.; Gilboa, A. The SKL town: Dor in the Early Iron Age. In *The Philistines and Other "Sea Peoples" in Text and Archaeology*; Killebrew, A.E., Lehmann, G., Eds.; The Society of Biblical Literature: Atlanta, GA, USA, 2013; pp. 393–468.
42. Galili, E.; Rosen, B. Fishing gear from a 7th-century shipwreck off Dor, Israel. *Int. J. Naut. Archaeol.* **2008**, *37*, 67–76. [CrossRef]
43. Haggi, A. Report on underwater excavation at the Phoenician harbour, Atlit, Israel. *Int. J. Naut. Archaeol.* **2010**, *39*, 278–285. [CrossRef]
44. Langgut, D.; Finkelstein, I.; Litt, T. Climate and the Late Bronze collapse: New evidence from the southern Levant. *Tel Aviv* **2013**, *40*, 149–175. [CrossRef]
45. Nitschke, J.L.; Martin, S.R.; Shalev, Y. Between Carmel and the sea: Tel Dor: The late periods. *Near East. Archaeol.* **2011**, *74*, 132–154. [CrossRef]
46. Dean, S.; Horton, B.P.; Evelpidou, N.; Cahill, N.; Spada, G.; Sivan, D. Can we detect centennial sea-level variations over the last three thousand years in Israeli archaeological records? *Quat. Sci. Rev.* **2019**, *210*, 125–135. [CrossRef]
47. Guinier, A. *X-ray Crystallographic Technology*; Hilger and Watts: London, UK, 1952; 343p.
48. Hubbard, C.R.; Snyder, R.L. RIR-Measurement and use in quantitative XRD. *Powder Diffr.* **1988**, *3*, 74–77. [CrossRef]
49. Gates-Rector, S.; Blanton, T. The Powder Diffraction File: A quality materials characterization database. *Powder Diffr.* **2019**, *34*, 352–360. [CrossRef]
50. Gilboa, A.; Sharon, I. An archaeological contribution to the early Iron Age chronological debate: Alternative chronologies for Phoenicia and their effects on the Levant, Cyprus and Greece. *Bull. Am. Sch. Orient. Res.* **2003**, *332*, 7–80. [CrossRef]
51. Sharon, I.; Gilboa, A.; Jull, A.J.T.; Boaretto, E. Report on the First Stage of the Iron Age Dating Project in Israel: Supporting a Low Chronology. *Radiocarbon* **2007**, *49*, 1–46. [CrossRef]

52. Mauz, B.; Vacchi, M.; Green, A.; Hoffmann, G.; Cooper, A. Beachrock: A tool for reconstructing relative sea level in the far-field. *Mar. Geol.* **2015**, *362*, 1–16. [CrossRef]
53. Wachsmann, S.; Raveh, K. A concise nautical history of Dor/Tantura. *Int. J. Naut. Archaeol.* **1984**, *13*, 223–241. [CrossRef]
54. Swarzenski, P.W.; Burnett, W.C.; Greenwood, W.J.; Herut, B.; Peterson, R.; Dimova, N.; Shalem, Y.; Yechieli, Y.; Weinstein, Y. Combined time-series resistivity and geochemical tracer techniques to examine submarine groundwater discharge at Dor Beach, Israel. *Geophys. Res. Lett.* **2006**, *33*, L24405. [CrossRef]
55. Haggi, A.; Artzy, M. The harbor of Atlit in northern Canaanite/Phoenician context. *Near East. Archaeol.* **2007**, *70*, 75–84. [CrossRef]
56. Fabricius, F.H.; Berdau, D.; Münnich, K.O. Early Holocene oöids in modern littoral sands reworked from a coastal terrace, southern Tunisia. *Science* **1970**, *169*, 757–760. [CrossRef]
57. Lakhdar, R.; Soussi, M.; Ben Ismail, M.H.; M'Rabet, A. A Mediterranean Holocene restricted coastal lagoon under arid climate: Case of the sedimentary record of Sabkha Boujmel (SE Tunisia). *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **2006**, *241*, 177–191. [CrossRef]
58. Mauz, B.; Fanelli, F.; Elmejdoub, N.; Barbieri, R. Coastal response to climate change: Mediterranean shorelines during the Last Interglacial (MIS 5). *Quat. Sci. Rev.* **2012**, *54*, 89–98. [CrossRef]
59. Almagor, G.; Perath, I. The Mediterranean Sea Coast of Israel. In *Geological Survey of Israel Report GSI/28/2012*, 3rd ed.; Geological Survey of Israel: Jerusalem, Israel, 2012; 438p. (In Hebrew)
60. Dan, J.; Yaalon, D.H. Trends in soil development with time in the Mediterranean environments of Israel. In *Transaction of the Conference on Mediterranean Soils*; SECS: Madrid, Spain, 1966; pp. 139–145.
61. Lazar, M.; Basson, U.; Himmelstein, A.G.; Levy, T.E.; Arkin Shalev, U.; Yasur-Landau, A. The door to Dor: Tracing unseen anthropogenic impact on an ancient port. *Geoarchaeology* **2021**, *36*, 203–212. [CrossRef]