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Article

Possible Evidence for Sea Salt Production by Solar Evaporation at a Newly Discovered Submerged Neolithic Site off the Carmel Coast, Israel

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Abstract

The submerged Early Holocene landscape of the Carmel Coast (Israel) has yielded remarkable evidence of Neolithic settlements and their associated material culture, preserved on and within the seafloor. Here, we report on the preliminary documentation of a newly discovered submerged Neolithic site near N. Mearot Inlet, containing series of rectangular clay basins arranged in a grid pattern. Following their initial identification, sediment cores were extracted from the basins and the ramparts around them and analyzed for their pollen, phytoliths, and mineralogical composition; however, more samples are to be taken and the analyses have yet to yield more conclusive results. Comparisons with later case studies suggest that the polygonal cracking of the clay and the basins' morphology, size, and spatial organization are more consistent with salt evaporation pans, which were operated ca. 7000 years BP, than with plot-and-berm agricultural use, though agricultural use cannot be ruled out entirely.

Keywords: underwater archaeology; submerged prehistory; plot-and-berm; evaporation pans; maritime archaeology; paleosol; coastal resources

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1. Introduction

Coastal environments have long represented dynamic zones of human practice, where communities have engaged with, transformed, and been shaped by the resources their surroundings afforded. Compared to inland territories, coastal regions offer diverse environmental niches rich in resources, and, as such, have attracted human societies since prehistoric times [1,2] and ([3], p. 126). In this article, we present preliminary observations and initial assessments of unique underwater features, most probably associated with activities to exploit coastal resources (i.e., seawater for salt production or fresh groundwater for agriculture).

In modern Israel, human intervention in the coastal environment (e.g., sand quarrying and construction of breakwaters and jetties) has reduced the availability of sand, resulting in coastal and underwater erosion. Consequently, sea storms have removed the protective layer of sand and randomly exposed the ancient substrate, revealing numerous shipwrecks dated from the Early Bronze Age (ca. 5000 years BP) onwards, as well as submerged paleolandscapes and inundated settlements dated from the Pre-Pottery Neolithic to the Chalcolithic periods (ca. 9200 to 6500 years BP), with 11 sites documented [4].

In the autumn of 2021, during an underwater survey, a submerged paleosol surface was discovered on the seafloor south of the Nahal (stream) Mearot Inlet (hence the N. Mearot Inlet site), south of the Neve Yam Pottery Neolithic site (Figure 1). A series of rectangular basins/depressions made of cracked clay arranged in parallel rows along the shoreline were identified (Figures 2 and 3), along with some other finds. To date, these clay basins have no clear manmade or natural parallel among the known inundated prehistoric landscapes and sites.

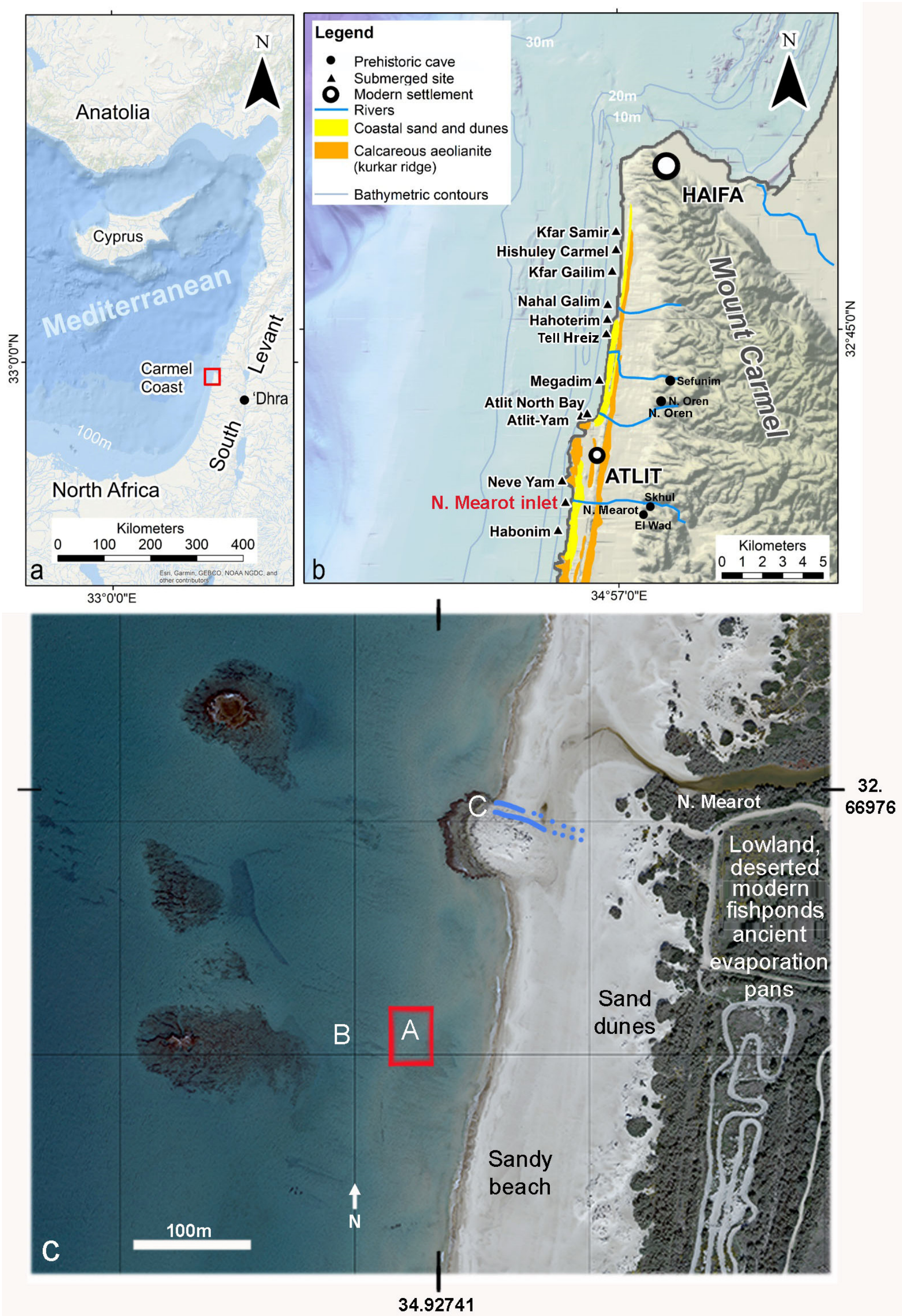

Figure 1. Orientation map: (**a**) the Eastern Mediterranean and the location of the Carmel coast; (**b**) submerged settlements discovered off the Carmel coast, and the location of the submerged N. Mearot Inlet site; (**c**) the N. Mearot Inlet site: A—the location of the submerged basins; B—the skeleton; C—rock-cut installation (pumping station) for salt production (E. Galili).

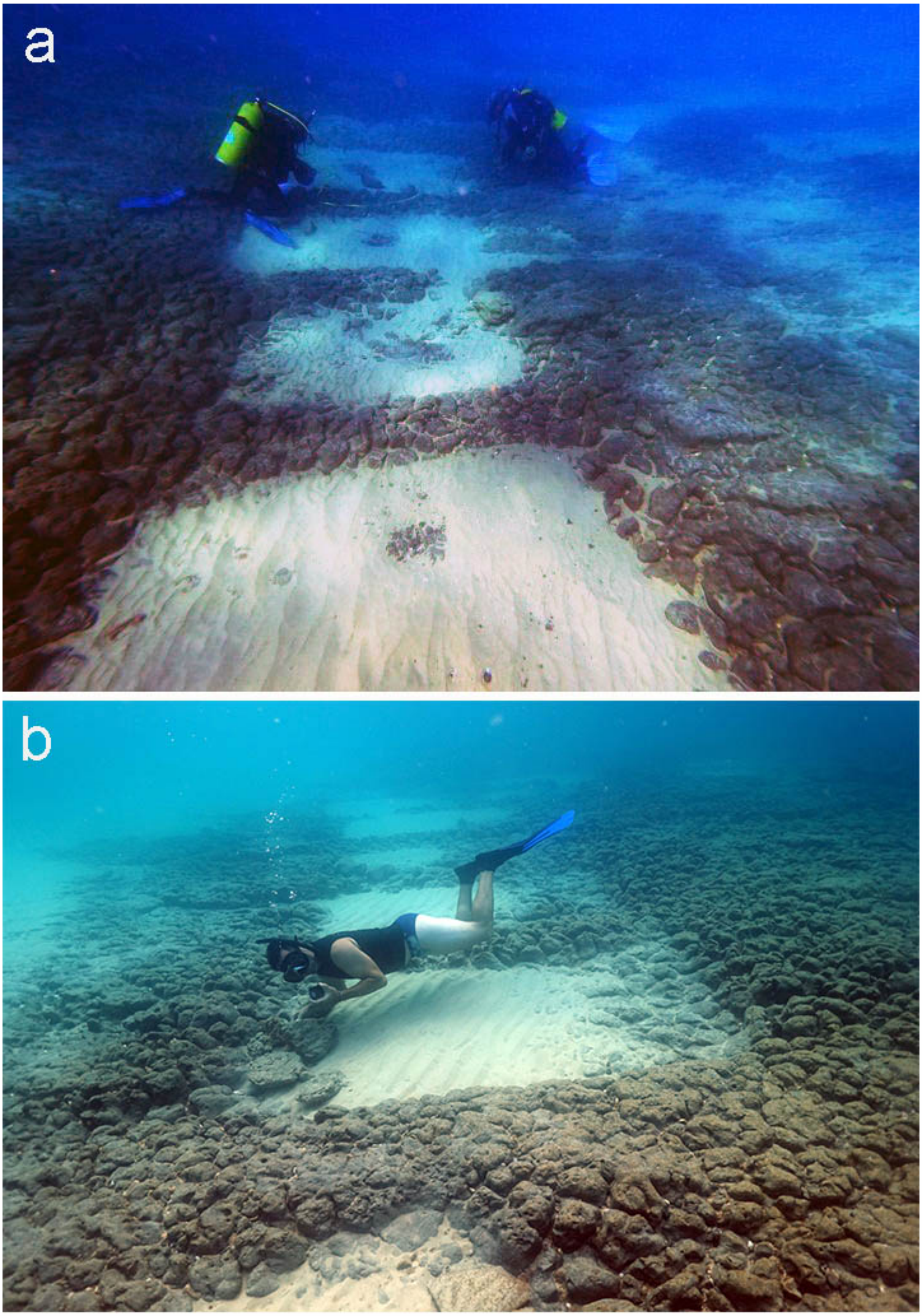

Figure 2. The submerged clay basins (looking north). Note the polygonal structure of the paleosol in and around the basins ((**b**): E. Galili, (**a**): A. Sotiriou).

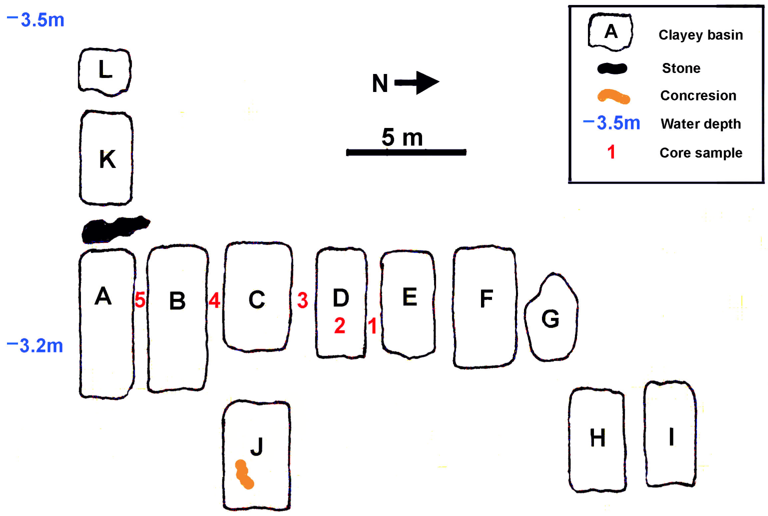

Figure 3. Plan of the submerged clay basins and the locations of the core samples (E. Galili).

This article presents a preliminary description of the finds in the N. Mearot Inlet site, along with the initial analyses carried out, and discusses in detail the two main interpretive hypotheses regarding the function of the basins: evaporation pans for the production of sea salt, or plot-and-berm agricultural facilities[1]. The study is based on the physical characteristics of the basins, while acknowledging that further investigation will be necessary to reach a definitive functional attribution.

2. The Site and the Geomorphological Setting

The N. Mearot Inlet site[2] is situated 230 m south of the inlet of Nahal Me'arot, about 800 m south of the submerged Pottery Neolithic village of Neve Yam [4]. The coastal plain in this region is relatively wide (3–4 km) and features three coastal kurkar (aeolianite-cemented calcareous sandstone) ridges running parallel to the coast, with elongated low troughs between them. Between Kibbutz Neve Yam in the north and the Maharal Stream estuary in the south, the sea penetrates the coastal kurkar ridge. The eroded ridge is fragmented, with some sections submerged or partly submerged, creating a rocky belt with small reefs and islets some 150 to 200 m offshore. The coastline here runs mostly east of the submerged kurkar ridge and features small, elongated sandy bays and several rocky capes (peninsulas, remnants of that ridge) (Figure 1c). Between the rocky reefs and the sandy coastline, elongated sandy troughs stretch (up to 6 m deep). In these troughs, beneath the sandy seafloor, lies a hard, dark clay-rich loamy paleosol of terrestrial origin deposited during the Late Pleistocene to Early Holocene (referred to as the "Carmel coast clay" [5,6]). The clay surface slopes westward along the seabed gradient. This paleo-coastal landscape at Neve Yam shore was inundated by the sea during the first half of the Holocene and is covered by quartz sand (1–2 m thick) for most of the year. In the upper part of this clay the remains of the submerged Neve Yam and the N. Mearot Inlet sites were identified [4]. The kurkar and the clay are exposed when sea storms remove the overlying sand. The site is located on the floor of one such sandy trough, bordered by the submerged kurkar ridge and a small reef to the west, the coastline to the east, and a small rocky peninsula to the north (Figure 1c).

3. Methodology

Systematic surveys, by walking along the coast, snorkeling, and scuba diving, have been carried out in the northern Carmel coast since the 1980s. The surveys have aimed to locate and document newly exposed paleosols and prehistoric remains, which are randomly exposed on the shallow sea bottom (max. depth 10 m) [7]. During one of these surveys, the N. Mearot Inlet site was discovered. The features identified at the site were measured, photographed, and documented using scuba gear, an underwater camera, a measuring tape, and a writing board (for details on the methodology of underwater surveys and excavations of submerged prehistoric sites, see [8]). Additionally, five sediment cores were collected using a manual coring system (for details, see [9]), one from the bottom of one basin and four from the clay ramparts surrounding the basins, (Figure 3). The intensity of documentation and sampling at the site was dictated by the limitations imposed by the random, unexpected, and short-duration exposure of the site. The site was totally covered with sand again about two weeks after its initial exposure. Exposing the site by underwater excavation methods is a highly costly operation that should be planned and funded in advance. In this case, given the short time window of exposure and limitations associated with sea conditions and logistics, only limited sampling and documentation were possible. More sampling and research will be possible when the site is exposed again (for detailed explanation of this regard, see references [4–6]), or when an organized pre-planned excavation operation on the site is possible.

Pre-screening sedimentological analyses for mineralogical characterization were carried out using Fourier Transform Infrared (FTIR) spectroscopy applying the KBr method. Additionally, pollen and phytolith extractions were conducted to obtain data on paleobotanical indicators (for analytical details, see [9]). The analyses were carried out at the Environmental Micro-History Laboratory at the University of Haifa and at the Laboratory of Archaeobotany and Ancient Environments, Section of Paleobiology, the Steinhardt Museum of Natural History, Tel Aviv University, Israel. In this preliminary study, we applied some basic microarchaeological analyses to the available core samples. More comprehensive studies will be conducted after additional samples are extracted from the basins, depending on sea conditions and the site's exposure.

4. Results

4.1. The Finds

The finds consist of a series of clay basins, several flint artifacts, a single pottery sherd, and human bones, all embedded in the paleosol near the basins or resting upon it, suggesting human activity associated with the basins.

4.2. The Rectangular Basins

A total of 12 depressions were documented, dispersed over ca. 16 m × 12 m. More basins may be overlain by sand or may have been eroded (Figures 1–3). The documented basins are rectangular in form, arranged in a reticulated pattern along several parallel alignments oriented along a north–south axis. A maximum of seven depressions were observed in a single row. The depressions (length 2.5 m to 3.5 m, width 1.5 m to 2 m) are surrounded by clay ramparts (height 0.3 m, width 0.8 m to 1 m) that delineate them. They were discovered at a depth of 3.2 m to 3.8 m underwater, ca. 80 m from the coastline. Near and within some depressions, concretions composed of sand and shells, cemented together with an orange substance (most probably iron oxides) were found, forming symmetrical, vault-like features protruding above the paleosol surface (Figure 4). These features were most probably formed by minerals carried by underwater springs seeping onto the sea bottom. The well-preserved condition of these features and the absence of marine fauna and flora on them suggest that the ancient land surface was recently exposed by storms after being covered by sand for thousands of years [5,6].

Figure 4. Concretions composed of sand and crushed shells, cemented together with an orange substance, forming vault-like features protruding above the paleosol surface (E. Galili).

4.3. The Human Remains

Eighteen bone fragments were identified at the site, at ca. 4.1 m depth, some 20 to 30 m west of the basins. Some bones were embedded in the clay in partial articulation, while the others were loosely scattered some 2 to 10 m around the articulated bones (Figure 5). The remains were documented in situ and included lower limb bones (leg and foot bones) related to one individual. The skeleton was identified as an adult male aged >15 years. The determination was based on the long bone morphology: the long bone shafts were very robust in nature, showing adult development, and the femur bone cross-section was significantly thick, consistent with a male bone structure ([10], pp. 218–221) and [11]. The articulated human remains seemed to belong to a disturbed burial. The scattered bones most probably originated from the same burial, which was eroded by post deposition processes (on dry land, during or after inundation).

4.4. The Flint Artifacts

The artifacts were embedded in or scattered on the paleosol, some 10–30 m west of the basins. The assemblage consists of nine artifacts, including two tools (nos. 1, 2) (Figure 6), six flakes (debitage) (Figure 7 nos. 3–8), and one chunk (debris) (Figure 7 no. 9). Tools: The tools consist of an elongated sidescraper (no. 1) with semi-steep flaking on its dorsal side. It was made on a blade blank with some preparation on its base. The other tool (no. 2) is a knife with a natural back made on a primary blade, with its back covered with cortex. Debitage: Two of the flakes (nos. 4, 6) are typical Levallois flakes, with few preparations on the dorsal side and preparation of the base, similar to the *chapeau de gendarme* Levallois technique. Two of the flakes are primary (nos. 5, 7), and two (nos. 7, 4) bear double patina. Flake no. 6 bears a burin flaking and a hinge on its distal end. Flake no. 7 is a core on a primary flake. Six of the artifacts (flakes 5, 6, 7; tools 1, 2; and chunk 9) are covered with an orange patina, similar to Middle Paleolithic flint artifacts from the Kfar Samir Neolithic site ([7], p. 448). The double patinated flakes (nos. 7, 4) suggest the possible secondary use of Middle Paleolithic scattered artifacts by later Neolithic/Early Chalcolithic coastal dwellers (see also [12]).

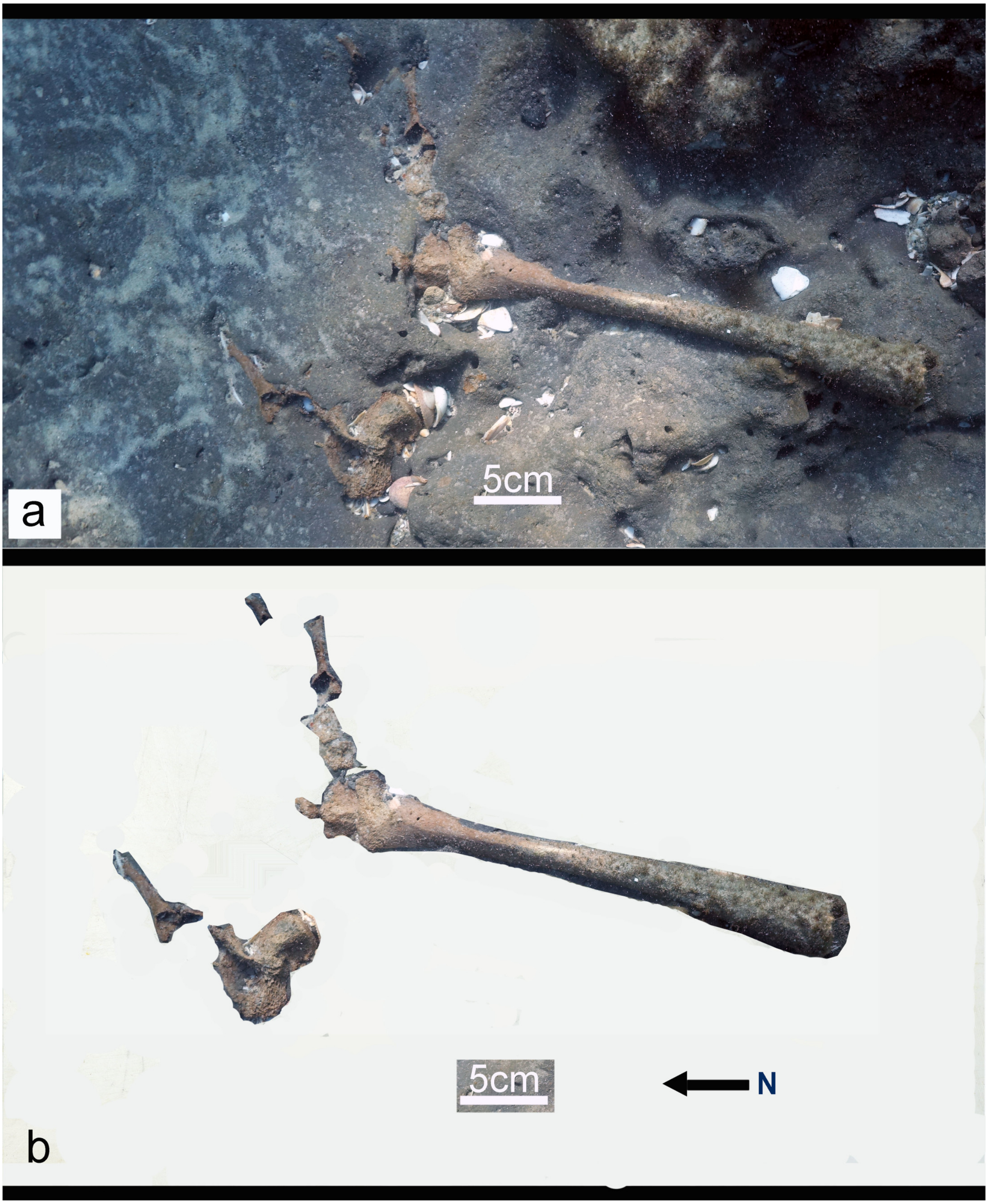

Figure 5. (**a**,**b**) Disturbed burial: the bones embedded in the paleosol on the sea bottom (E. Galili).

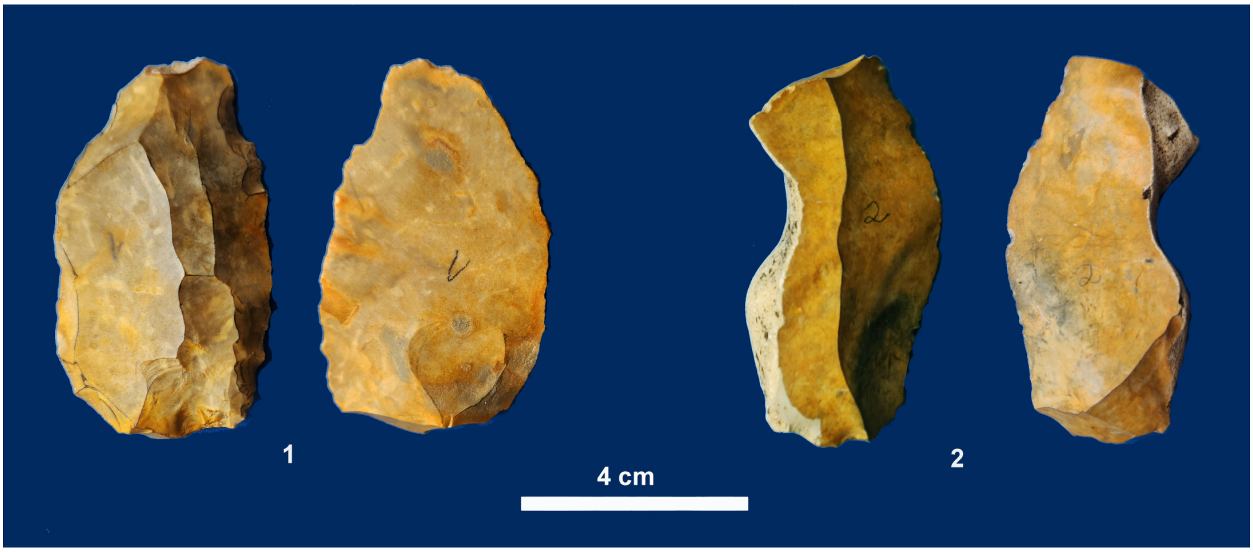

Figure 6. Flint tools collected at the site: (**1**) side scraper on a blade, (**2**) knife with a natural back (E. Galili).

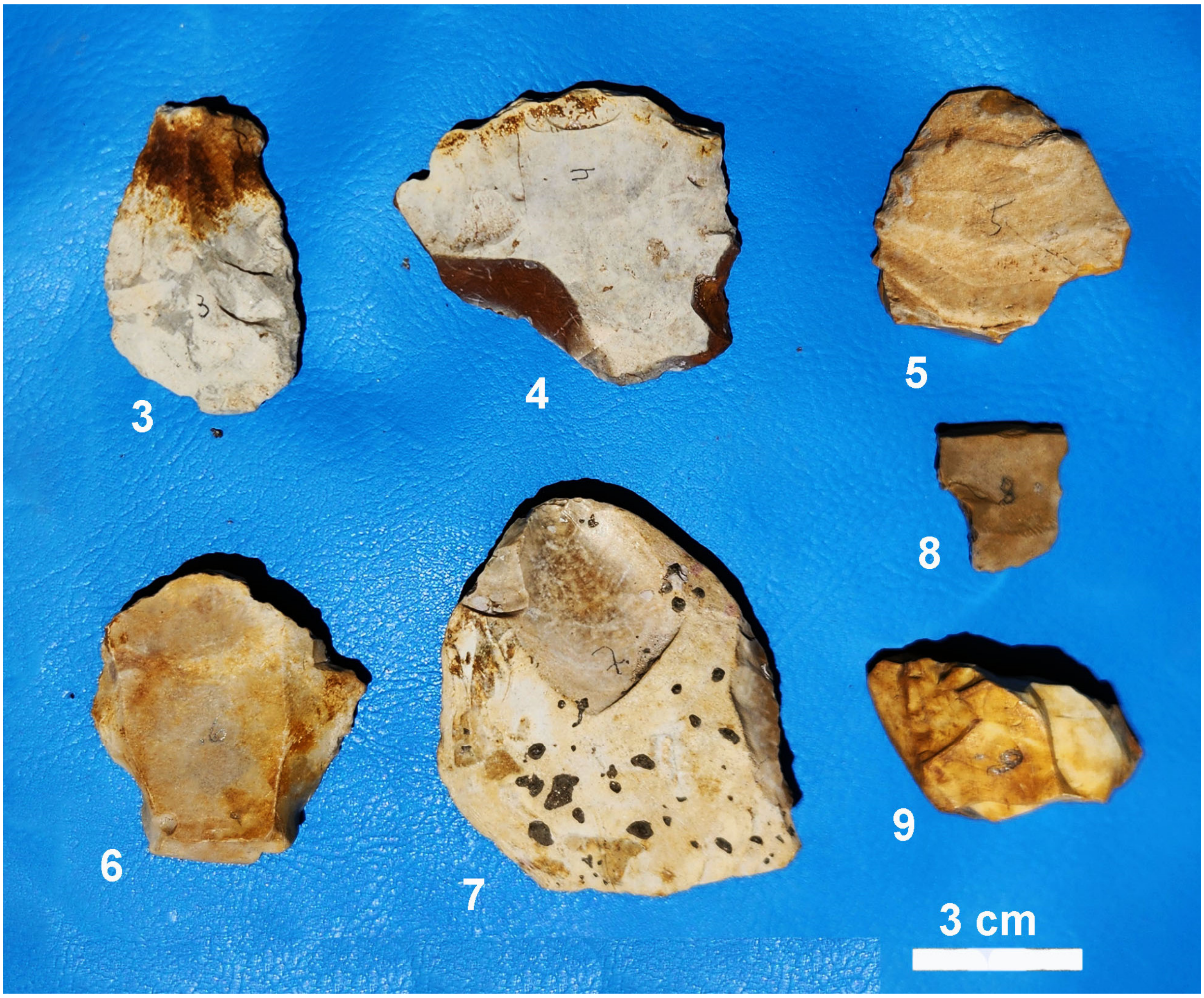

Figure 7. Flint artifacts: 3–8, flakes; 9, chunk (E. Galili).

4.5. A Pottery Sherd

A single fragment of a bowl, heavily eroded, was found at the site (Figure 8). It consists of a section of the base (ca. 30% of the base, diameter 9.5 cm) and part of a wall (max. 4 cm long). The base, which is the most common type among the Neve Yam Pottery Neolithic site vessels, is regular and flat ([6], p. 188, Figure 45, nos. 16–20). The surviving side of the vessel tilts outwards and curves slightly inwards. The inner concave surface is grey, while the outer surface is reddish. In the 10 to 13 mm thick broken section of the sherd, a 2 mm thick reddish layer is visible, covering the outer surface. Numerous grey, red, and black tempers (up to 4 mm in size) can be seen on the inner and outer surfaces (Figure 9). Similar finds, in terms of the typology of the pottery vessel, the clay, and the tempers, were found at the nearby Neve Yam site, dated to the Late Pottery Neolithic period and associated with the Wadi Rabah cultural entity ([6], pp. 172–188).

Figure 8. Pottery sherd: inner part, base and side of an open bowl (E. Galili).

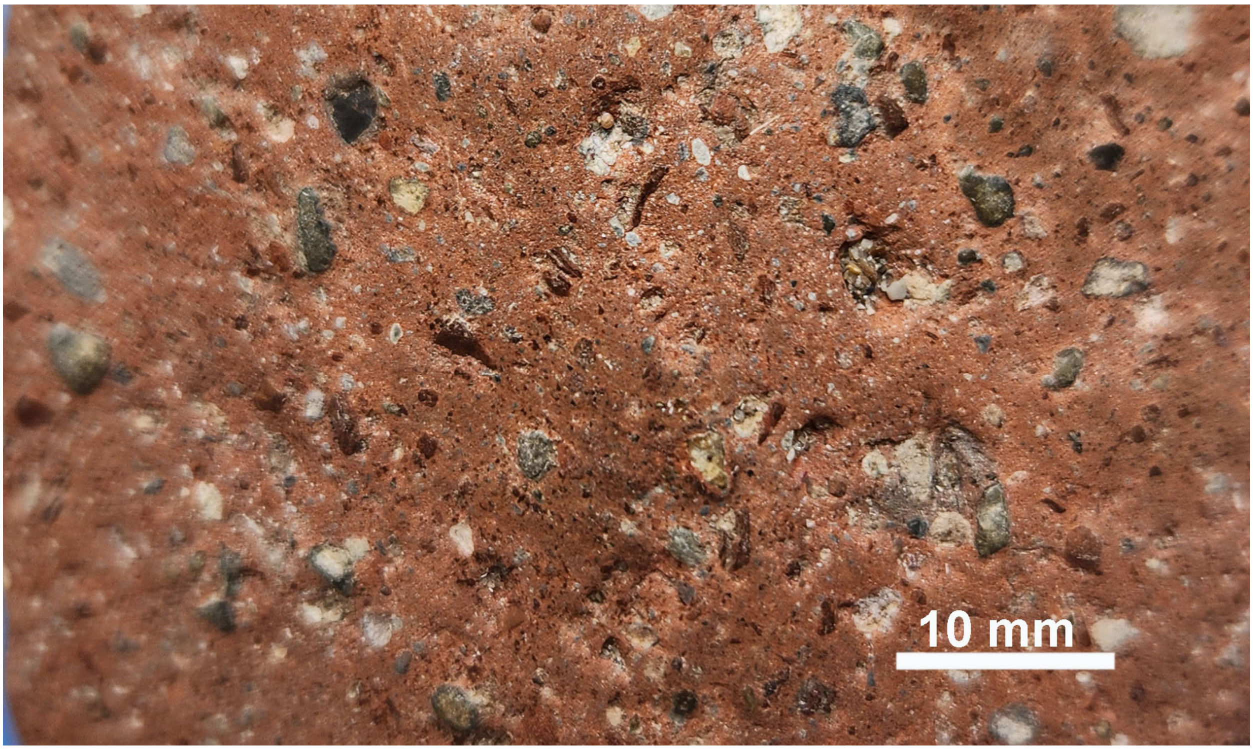

Figure 9. The outer side of the bowl fragment with black, red and grey tempers in the clay (E. Galili).

4.6. Results of the Micro-Analysis Pilot Study

Sediment cores from the lower parts of one basin and from the surrounding uplifted berms were analyzed. Macroscopically, the sediments within and surrounding the basin present a polygonal crack structure similar to that characteristic of salt pans [13]. All samples were mineralogically composed of unaltered clay, quartz, and minor traces of calcite, similar to known samples of Carmel coast clay [9]. The pollen analysis carried out on the samples revealed no preserved pollen grains, probably due to unfavorable preservation conditions resulting from oxidation and drying episodes in the clay (Langgut Dafna, personal communication, 2026), as evidenced by the cracking texture of the clayey basins. The phytolith analysis revealed no significant results, though phytoliths were found in very small amounts (0 to 0.05 million phytoliths per gram of sediment). No distinctive layer of dark grey anthrosol (sandy loam mixed with domestic refuse, as expected in the case of plot-and-berm agriculture) has been identified so far in the studied basins. Furthermore, despite the negligible amount of phytoliths (<0.05) found, no other key micro-indicators of agricultural contexts have been identified. Regarding the possibility of salt production, future analyses to search for microbiomes related to hypersaline contexts, which may have been preserved, are required.

5. Discussion

More than sixty years of underwater archaeological research on the northern Carmel coast, between Haifa and Dor, has revealed wide submerged prehistoric landscapes and exposed paleosols (Carmel coast clays). These paleosols of terrestrial origin were deposited during the Upper Pleistocene–Early Holocene [14,15]. Embedded on and within the paleosols, the remains of more than ten inundated settlements have been recovered. The finds consist of one Pre-Pottery Neolithic C settlement, Atlit-Yam, and more than ten Pottery Neolithic–Chalcolithic sites (ca. 9200 to 6500 years BP) [8] (Figure 1a). Despite the intensive research which has been carried out in the region, no symmetrical rectangular clay formations similar to those discussed here have been recorded to date. It is suggested that these depressions are not natural formations originating from erosion or depositional processes. Instead, given their pattern, they are most probably anthropogenic features built on the nearshore or backshore by humans when the sea level was lower. The indirect dating of the basins based on sea-level considerations (see below) suggests that they may represent some industrial or agricultural activity associated with the coast, possibly with the nearby Pottery Neolithic settlement of Neve Yam, or another coastal community [4]. Given that the mineralogical and botanical data have not been fully indicative so far, macroscopic documentation provides the primary source of information for assessing the possible functions and dating of these features, which may include evaporation pans for salt production or agricultural plots.

Among the most fundamental yet archaeologically elusive resources in coastal regions are salt and freshwater, both unevenly distributed across landscapes, and whose deliberate exploitation signals significant levels of environmental knowledge and economic organization in prehistoric communities [16–19]. Regarding the function of these basins, we consider the two above-mentioned, and most probable options: salt evaporation pans and plot-and-berm agricultural systems. Other possible functions, such as domestic structures and fishing facilities, were also considered, but were found less probable. The identification of the basins as domestic structures is not supported by any parallels or any of the finds. No living floors or dwellings were found in or around the basins. Furthermore, the known submerged Neolithic architectural remains in the Carmel coast usually reflect foundations made of undressed stones [4,6,7]. As for fishing, given the unfavorable sea conditions in this unprotected coast, the nomad sand covering the paleosol and consequent rapid coastal

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changes that must have occurred during their operation, using these basins for fishing in the intertidal zone is highly doubted.

5.1. Groundwater-Harvesting Plot-and-Berm Agricultural Systems

Research aimed at identifying plot-and-berm agricultural systems has established a set of methodological toolkits. The geoarchaeological identification of plot-and-berm agrosystems draws on an integrated methodological toolkit spanning remote sensing, sedimentology, micromorphology, and archaeometry. At the landscape scale, geomorphological survey, drone photogrammetry, and geophysical prospection document the diagnostic checkerboard morphology of low-lying plots delimited by raised berms, while the portable Optically Stimulated Luminescence (OSL) profiling of berm interiors provides construction chronologies and distinguishes depositional phases with minimal excavation [20–24]. Sedimentological and pedological analyses of plot fills have consistently identified a distinctive dark grey anthrosol, a 30 to 50 cm thick sandy loam formed by the systematic admixture of domestic refuse into inert aeolian sand, sharply contrasting with the well-sorted, organic-poor, massive structure of surrounding natural dune deposits [25–28]. FTIR spectroscopy is usually applied in archaeological contexts to characterize the mineralogical composition of such anthropogenic admixtures, identifying pyrogenic carbonates, fired clay, and plant ash indicative of deliberate organic soil enrichment [29].

At the microscopic scale, thin-section micromorphology has long been established as a primary tool for recognizing agricultural soils and their formation processes [26]. It is particularly well suited to resolving the internal fabric of plot-and-berm anthrosols. In agricultural contexts, the key micromorphological indicators include a granular-to-crumb microstructure generated by bioturbation and root activity, charred plant tissue, occasional phytolith assemblages reflecting cultivated taxa, ash aggregates, and faunal excrement pedofeatures [20,27].

The coastal aquifer of the Carmel coast consists of kurkar sandstone overlain by impermeable clay deposits of terrestrial origin, which in turn are covered by a 1–2 m thick layer of quartz sand [28,29]. In some areas on the beach and the shallow seafloor, where the unconsolidated top sand was removed by waves and currents, small amounts of freshwater naturally seeped out. These visible freshwater seeps likely informed ancient populations about the availability of exploitable groundwater in the region. Groundwater exploitation on the Carmel coast during the Neolithic period is evidenced by numerous water well finds [30–32]. At the Atlit-Yam site, a 5 m deep well was excavated, with its bottom located some 15.5 m below present sea level. This well is the oldest known stone-built well to date. At the Kfar Samir and Kfar Galim Late Pottery Neolithic sites, wells constructed with stone pebbles and wooden branches were discovered and excavated [3]. Furthermore, the nearby Neve Yam site was a fully agricultural, sedentary village, relying on cultivation of wheat, barley, and legumes, as well as animal husbandry [7]. It is therefore reasonable to assume that the Neolithic populations of the Carmel coast were aware of groundwater resources in their environment and knew how to exploit them in various ways.

The nature of the discovered basins and the evidence of water springs may suggest that these depressions were gardens (plot-and-berm agrosystems) where grains and legumes were grown, using a method that exploited the high groundwater near the coast, a technique called "*Mawasi*" that was, and still is, used in the region. The Mawasi system is a traditional method of irrigating gardens directly from high groundwater tables, without the need to dig wells or construct elaborate channels (see [24,33]). This method relies on small depressions and/or raised berms which are created within the garden area. These depressions act as groundwater catchments, allowing water to naturally seep or flow laterally from the high groundwater zone. Water movement is driven by the proximity of the water table and the soil's permeability. This system often involves minimal intervention, utilizing the natural capillarity of the soil or slight grading to direct water to plants [24,33].

Ancient Examples: Indigenous communities in arid regions, such as parts of North Africa and the Middle East, historically used similar surface-feeding methods, leveraging high groundwater tables to sustain crops and gardens. Archaeological excavations south of Caesarea revealed an early Islamic plot-and-berm agrosystem in the coastal dunes [20,34,35]. Similar finds from the southeastern Mediterranean coast are described by Taxel and Roskin [35,36] and Taxel et al. [23].

Modern Applications: Some small-scale farmers in semi-arid zones of the Middle East, such as Jordan and Palestine, still utilize Mawasi-like practices, benefiting from natural groundwater levels without requiring extensive infrastructure. In the Gaza Strip, the subterranean freshwater lens in the coastal dunes is exploited by excavating sunken plots surrounded by berms for protection, allowing crop roots to reach the groundwater naturally.

5.2. Evaporation Pans for Salt Production Using Sea Water

Identifying ancient salt production sites is highly challenging because salt dissolves easily, leaving scarce physical evidence. The geoarchaeology of salt pans poses substantial analytical challenges, rooted fundamentally in the high solubility of halite, which renders direct physical evidence exceptionally rare in the archaeological and geological records. Over the past two decades proxy-based approaches, targeting the physicochemical consequences of salt presence rather than the mineral itself, have become the dominant investigative strategy, with a growing toolkit of methods applied across ceramics, soils, and sedimentary sequences.

Two principal investigative directions can be distinguished. The first, and by far the more extensively developed, concerns materials associated with the briquetage technique: the artificial evaporation of brine in fired ceramic vessels [16,17,37]. Analytical approaches have included SEM-EDS (Scanning Electron Microscopy with Energy-Dispersive Spectroscopy), XRF (X-Ray Fluorescence), XRD (X-Ray Diffraction), FTIR, and ICP-MS (Inductively Coupled Plasma Mass Spectrometry), targeting primarily Na and Cl concentration gradients within ceramic fabrics, alongside marine-specific tracers, such as bromine and boron, whose elevated concentrations in seawater relative to terrestrial substrates offer greater discriminatory power [38]. However, combustion deposits associated with the evaporation stage are the most prominent archaeological proxy [18,39,40]. This method is less relevant to our study, because neither visible macro combustion traces were found in the rectangular basins, nor charred pottery vessels that may have been used for salt production.

The second direction, the detection of salterns relying on solar evaporation, remains considerably less developed methodologically. Salt production by this technique was inherently seasonal and climatically constrained, dependent on the solar radiation intensity, air and water temperatures, wind regime, and relative humidity, with productive evaporation effectively ceasing below approximately 10 °C and peaking between 20 °C and 45 °C [41]. Because solar salterns generate no fired ceramic assemblage and leave no combustion features, their material signature is substantially more diffuse than that of briquetage sites. Geochemical soil analyses targeting anomalous concentrations of Na, Cl, Mg, Ca, B, and Br relative to unaffected control sediments, alongside sedimentological criteria, such as polygonal cracking and halite crystal fabric analysis, constitute the primary identification toolkit, though their application in saltern contexts remains sparse [13]. At the protohistoric site of Puntone (Tuscany), for instance, ICP-OES soil analyses detected elevated concentrations of Mg, Na, Cl, and B within pit fills interpreted as brine collectors, having geochemical signatures consistent with the final stages of solar evaporation rather than artificial heating [40]. A promising but largely untested avenue involves the biomolecular detection of halophilic microorganisms via ancient DNA (aDNA). However, archaeological applications of this method have so far yielded inconclusive results, and the approach remains in its infancy. The robust identification of ancient solar salt production therefore continues to depend on the convergence of multiple independent proxy lines, with both saltern detection and their biomolecular dimension representing underexplored frontiers in archaeometric research [34].

The possibility that the depressions served as evaporation pans for salt extraction using seawater is hence considered. Salt is among the most critical resources in human prehistory, essential for food preservation; animal husbandry; and human health, nutrition, and survival. It is essential for maintaining proper fluid balance, nerve function, and muscle contraction. Salt enables the preservation and storage of food, especially in the absence of refrigeration. Its significance is reflected in its use for cultural, religious, and economic purposes throughout history. The natural formation and extraction of salt through evaporation pools have played a crucial role in the development of civilizations and trade routes. Today, salt remains an indispensable mineral in human diets and various industrial applications [42].

Across the ancient Mediterranean and Europe, evidence of intentional salt production takes varied and often ambiguous forms: briquetage ceramic assemblages in the sub-Carpathian region of Romania document evaporation techniques as early as the sixth millennium BC [43,44]. Long tradition of salt extraction infrastructure found in Iberia and Western Europe points to the earliest evidence for solar evaporation of salty spring water dated to the Neolithic Period (ca. 7500 cal. years BP) [17,19,45]. In the Eastern Mediterranean specifically, low-lying coastal zones with flat impermeable substrates, the proximity to seawater, and long arid summers represent ideal conditions for solar evaporation salt production; yet, direct prehistoric evidence of such infrastructure in this region is not available [46].

The physical conditions of the Carmel coast are suitable for sea salt production, as attested to by more than 20 salt production installations discovered between Atlit and Dor (for details, see [46]). The installations, dated to different historical periods, consist of rock-cut pumping stations in the form of saltwater wells, rock-cut channels, and flat slopes intended for lifting seawater and conveying it to clay basins in the backshore, which served as evaporation pans. One such installation was found at the outlet of Nahal Me'arot, some 250 m north of the discussed submerged clay basins (Figure 10) ([46], installation B1, pp. 38–42, Figures 34–40). This installation features a pair of parallel channels cut into the kurkar rock, starting on the western side of a rocky cape at an elevation of 0.5 to 0.8 m above sea level. These conduits measure 0.5 to 0.7 m wide and 0.4 to 0.8 m deep. While the northern channel extends 22 m toward the east, the southern one reaches 42 m, with its floor sloping slightly westward in the final 8 m stretch. At their western entrances, the channels widen into shallow funnels designed to catch the tops of incoming waves. During sea storms, these channels directed seawater up to 40 m inland (Figure 10b). Approximately 150 m further to the east, low-lying clay basins (presently deserted fishponds) likely functioned as pans for large-scale industrial solar evaporation. The tradition of salt production on the Carmel coast continues, as demonstrated by the salt company established at Atlit in 1926, which operates to this day, using the principle of conveying seawater to clay evaporation pans on the backshore, as in ancient times [46] (Figure 11). Salt production in excavated evaporation pans close to the coast is still practiced on the Mediterranean coasts, e.g., on the northern coast of Gozo Island, near Malta (Figure 12).

Figure 10. Installation for salt production in the outlet of Nahal Mearot: (**a**) aerial view of rock-cut channels (white arrows) aimed at conveying sea water to the backshore, looking east; (**b**) the channels conveying sea water eastward, using wave energy (E. Galili).

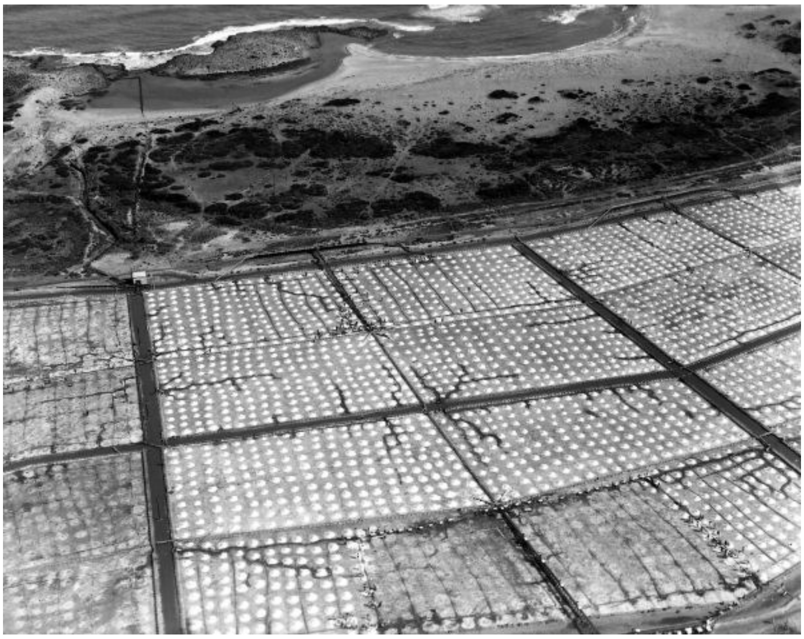

Figure 11. Modern salt production in Atlit: evaporation pans used during the salt-harvesting period in the early 20th century (the Jewish National Archive).

Figure 12. Salt production by using evaporation pans close to the coast in northern Gozo Island, Malta (looking north) (AQUAZOOM).

Producing enough salt to fulfil the needs of a permanent, coastal population requires considerable amounts of evaporation pans. Producing salt pans in coastal sand is not possible, as such pans are not impermeable and cannot hold water. Excavating them in the coastal kurkar rock requires a high investment in labor. Thus, excavating evaporation pans in the available coastal clay, which is impenetrable and can hold sea water to enable salt crystallization, must have been the preferable practice.

5.3. Function Considerations (Salt Pans or Plot-and-Berm Agriculture?)

The identification of prehistoric agricultural plots presents analogous interpretive challenges: their physical traces are subtle; their boundaries difficult to define; and their functional attribution depends on a convergence of morphological, sedimentary, and archaeobotanical evidence that is rarely conclusive in isolation [20,22,34,38,42]. As to salt extraction, the earliest infrastructure for salt production remains extraordinarily difficult to identify and interpret from the archaeological record [17,19,34,45]. The identification and study of both salt pans and plot-and-berm agriculture features are thus challenging and demand a multidisciplinary approach.

As evident from the micro-geoarchaeological analyses, no distinctive layer of sandy loam mixed with domestic refuse, as expected in the case of plot-and-berm agriculture, has been identified so far in the studied basins or in the ramparts surrounding them. The negligible amount of phytoliths (<0.05), and the lack of ash aggregates and faunal excrement, together with the size and morphology of the basins, suggest that they were not used for high groundwater agriculture.

The use of geochemical analysis of salt evaporation pans is limited, and all studied cases are found above sea level [16,17,34,38,40]. Our initial micro-geoarchaeological analyses did not yield definitive positive or negative proxies for salt production. However, macroscopic examinations of the clay basins and the ramparts around them reveals extensive polygonal cracking not observed in other paleosol exposures in the area. Such cracking is a diagnostic sedimentological characteristic of ephemeral saline pan deposits, produced by repeated cycles of evaporation and desiccation [13], and its presence here may therefore support the salt pan interpretation.

The small size of the basins, and the limited height of the berms found (up to 30 cm), is not typical of known plot-and-berm agriculture, where the berms are much higher (often 1 to 5 m high for protection against wind and sea spray (Table 1). Salt evaporation pans, on the other hand, are often small basins with low surrounding ramparts, similar to the discased ones.

Table 1. Characteristics of ancient salt pans versus known plot-and-berm ancient agricultural fields.

Feature	Salt Pans	Plot-and-Berm Agriculture
Main goal	Salt crystallization	Agriculture/groundwater harvesting
Water regime	Controlled evaporation	Moisture retention
Basin depth	Very shallow	Deeper depressions
Cell size	Usually smaller	Usually larger
Berm height	Low hydraulic dividers	Often 1 to 5 m high for protection against wind and sea spray
Salinity of water	Extreme	Fresh/brackish groundwater
Run-up waves, onshore winds, salty spray and salinity of the air	May assist the operation of salt pans	Saline sea spray may interfere with agriculture; the plots should be protected by high berms
Geometry	Dense modular ponds	Expanded through the landscape
Soil properties	Impenetrable and can hold the sea water to enable salt crystallization	Sandy loam mixed with domestic refuse

Additionally, indirect evidence of salt production on the Carmel coast has been found in a later Chalcolithic site. The earliest evidence for table olive production was documented at the submerged Middle Chalcolithic site of Hishuley Carmel (ca. 6500 years BP), situated on the northern Carmel coast ca. 12.2 km north of the N. Mearot Inlet site [47]. This specialized production is highly likely to have required substantial quantities of sea salt. Because the Hishuley Carmel assemblages slightly postdate those from the Nahal Mearot Inlet, they corroborate the large-scale, industrial utilization of sea salt along the Carmel coast during prehistory. Consequently, the novel discoveries from Nahal Mearot provide further empirical evidence supporting this regional socio-economic practice.

5.4. Dating Considerations

The single pottery sherd found is similar in shape and texture to the pottery finds recovered at the Neve Yam site, dated to the Late Pottery Neolithic period (ca. 7000 years BP) [4,7]. Since the Levallois technique was identified in some of the flint artifacts, they appear to be of Middle Paleolithic origin. However, as noted above, the clay paleosol in the region is dated to the Upper Pleistocene–Early Holocene [14,15]; thus, it seems that the flint artifacts are not in their original depositional location. They may have been transported to the terrestrial paleosol naturally by streams or brought by Neolithic inhabitants for reuse as raw materials [12]. The skeleton has not yet been dated by C14. However, the direct association of the skeleton, the single pottery sherd and the flint artifacts with the clay basins is yet to be established. Therefore, for the dating of the discussed features, we must rely on sea-level considerations. Assuming that the rectangular basins are manmade and, given that there are no traces of modern or ancient underwater construction works in the area, it is reasonable to assume that the basins were built on the coast under terrestrial conditions when the sea level was lower. Judging by the sea level curve derived from the archaeological and geomorphological markers on the Carmel coast [7] (Figure 13), a possible date for the basins may thus be estimated. Assuming that the installations represent industrial activity associated with salt production, they were probably located at the ancient backshore (not too far from the coastline and not too close to it) to enable exploitation of the seawater. Given the sea conditions and wave climate in the region, a logical elevation of ca. 1 to 1.5 m above sea level must have enabled easy access to the sea water on one the hand, the avoidance of total flooding by waves on the other hand, and facilitated occasional feeding of the basins by wave swash or manually when needed. The local sea level curve suggests that around 7000 years BP, the sea level at the site (which is currently at a water depth of ca 3 to 4 m below sea level) was ca. 5.5 to 7.5 m below the present level, and the basins were ca. 1 to 1.5 m above sea level, some 50 to 70 m inland from the coastline during this period (the Pottery Neolithic period). It is therefore suggested that the rectangular basins date to the Pottery Neolithic/Late Chalcolithic period (ca. 6800–7500 years BP, Figure 13). In the less probable case of plot-and-berm agriculture, the basins may have relied on groundwater at elevation of ca. 4 to 5 m below present sea level (ca 0.5 to 1 m below the basins). Hydrological investigations and studies of coastal wells on the Carmel coast indicate that the groundwater level near the beach is close to, or slightly higher than, sea level [33]. We may thus assume that during their period of functioning, the groundwater level below the possible agricultural plots was ca. 4 to 5 m below the present sea level, and so was the sea level during that period. The sea level curve of the Carmel coast suggests that such a level prevailed during ca. 5800–6000 years BP (Figure 13).

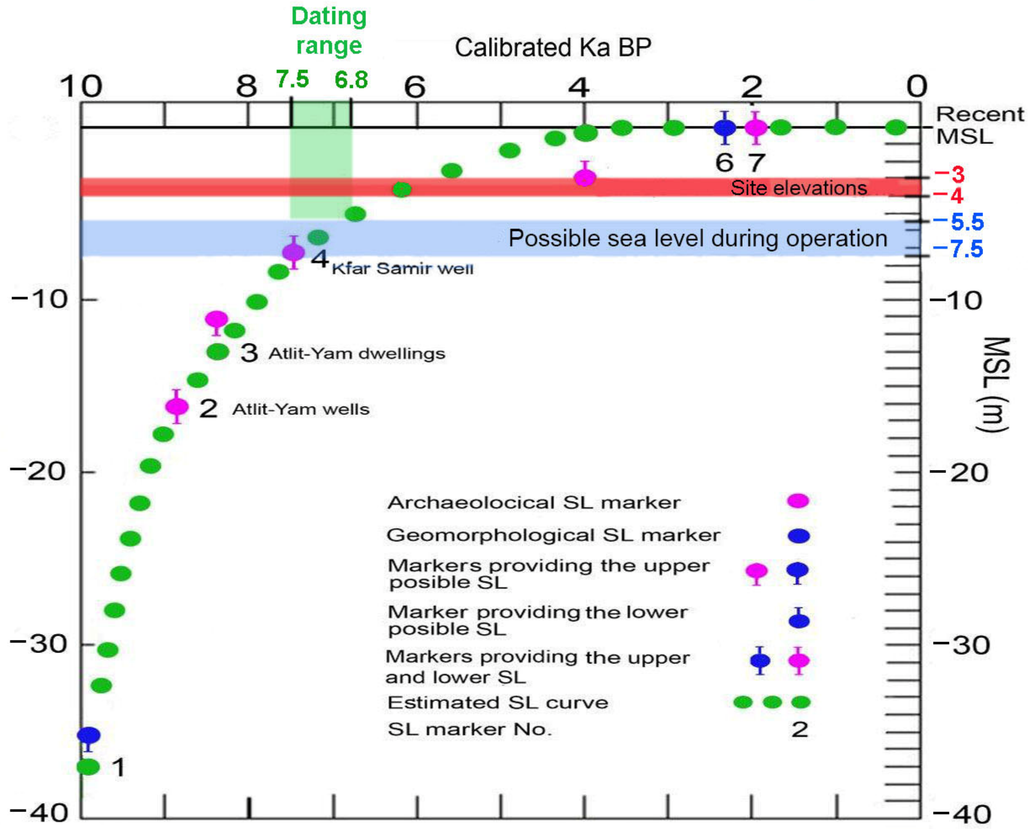

Figure 13. A curve depicting the sea-level changes in the Carmel coast during the Holocene (based on archaeological and natural markers); the possible sea level under which the basins functioned (in red) and the range of possible dating of the installations (in green) (modified after ([7], Figure 23.23)) (E. Galili).

6. Conclusions

The two most probable functional interpretations of the basins, salt production and plot-and-berm agriculture, are considered, both of which situate them within the broader framework of Late Neolithic/Chalcolithic coastal resource exploitation and management.

Further sampling, especially targeting the basins, followed by a wider range of geochemical and biomolecular analyses will be applied when the site is re-exposed to better identify the use of these features.

Based on the data in hand, no unequivocal evidence emerges for the use of these architectural features. However, the use of these basins as solar evaporation pans for salt production is considered the more probable hypothesis. This interpretation is supported by the arguments summarized in Table 1, chiefly the geomorphological conditions of the Carmel coast backshore, which are favorable for salt production, the phisycal characteristics of the basins which support salt production and the numerous salt production installations dated to historical periods documented between Atlit and Dor.

The discussed basins could have been fed with seawater either manually or by exploiting wave swash and run up—a hydraulic strategy with deep roots in the region.

The basins were most probably created on dry land, some 50–100 m east of the contemporaneous coastline, at a time when the sea level stood approximately 5.5 to 7.5 m below its present level. Based on sea-level reconstructions of the Carmel coast, their construction is attributed to the Pottery Neolithic period, dating to ca. 7500–6800 years BP (calibrated).

As a crucial resource for human nutrition, food preservation, animal husbandry, and exchange, salt must have been a significant economic commodity for Neolithic/Chalcolithic communities. Its controlled production would have required organizational complexity and territorial resource awareness consistent with the evidence recovered at the nearby Neve Yam site.

If confirmed as prehistoric salt production infrastructure, these submerged features would represent the earliest known evidence of intentional, organized sea salt extraction in the Mediterranean, and possibly elsewhere.

Within the wider context of the Eastern Mediterranean Neolithic, the potential production of sea salt would represent a further dimension of the economic transformations associated with the transition to food-producing societies. Beyond agriculture and animal husbandry, the systematic exploitation of coastal resources may have contributed to food preservation, livestock management, and the circulation of valued commodities between communities. These practices reflect an increasingly active role of human groups in modifying and managing coastal environments, reinforcing perspectives that view Neolithic coastal landscapes not merely as settings for human activity, but as social–ecological systems shaped through long-term processes of dwelling, resource intensification, and socio-economic innovation. Such a finding may contribute to our understanding of Neolithic subsistence diversification, inter-site economic networks, and the capacity of coastal communities to engineer and exploit their immediate environment in sophisticated and sustained ways.

Though less probable, agricultural use of the basins as plot-and-berm agrosystems during ca. 5800 to 6000 years BP cannot be excluded.

The discussed features underscore the exceptional research potential of the submerged prehistoric landscapes and settlements of the Carmel coast, and the urgent need for targeted, multidisciplinary investigation before further erosion compromises this irreplaceable archive of early coastal inhabitants.

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Notes

[1] The plot-and-berm method relies on the natural rise and movement of groundwater through the soil surface, allowing water to feed plants' roots in a sustainable, low-tech manner.

[2] Assemblage no. 217 in map 7, The National Digital Database on underwater and coastal archaeological sites, coordinates: 32.667115 N, 34.927444 E, unpublished report.

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