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Locating submerged prehistoric settlements: A new underwater survey method using water-jet coring and micro-geoarchaeological techniques

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ABSTRACT

In the past few decades the field of submerged prehistory has produced important data highlighting ancient coastal habitation across the globe. Most prehistoric underwater sites are discovered by chance (e.g., by industry, fishermen or recreational divers). New methods for detecting submerged prehistoric settlements have been developed using sophisticated remote sensing devices, yet with limited success. Simple, practical, and inexpensive methods for locating submerged settlements remain rare. Over 60 years of underwater archaeology and submerged prehistory in Israel, specifically along the Carmel coast, has led to a model for locating and studying submerged settlements, based on sand removal by storms. This study aimed to take this model a step further by developing a new, inexpensive method to identify, locate and characterize submerged sites. We collected undisturbed paleosol cores from exposed areas as well as under a few meters of sand, using a newly developed water-jet core sampling system. The cores were analyzed using micro-geoarchaeological techniques initially developed on terrestrial sites. The rationale behind this methodology is based on established knowledge that where human settlements occur, sediments are enriched by specific mineralogical signatures (e.g., heated clay minerals) and anthropogenic micro-remain assemblages (e.g., phytoliths, ash pseudomorphs and dung spherulites). Additionally, micromorphology can assist in identifying micro-stratigraphic patterns typical of human settlements. We tested sediment cores in three underwater contexts: a) exposed prehistoric surfaces within two known Neolithic sites (Atlit-Yam and Neve Yam), b) exposed paleosols without visible archaeological remains (serving as a control), and c) as a blind test, a buried paleosol currently covered by 1–3 m of sand, where the existence of a site is unknown. In the cores taken from the exposed Neolithic settlements, the micro-geoarchaeological characterization showed clear anthropogenic signals (typical mineralogy, elevated micro-remain concentrations, micro-stratigraphy). In the paleosol control cores, there was an absence (or negligible presence) of anthropogenic signals. The 'blind test' at the sand-covered locality revealed sediments without anthropogenic enrichments (similar to the control paleosols), thus suggesting the absence of a submerged settlement in this specific location. The new method is time- and cost-effective and can easily be applied worldwide along the shallow continental shelf as well as in deep water. The new method will facilitate discovery of new underwater sites and provide selection criteria (e.g., where the highest anthropogenic signal exists) for investment in underwater excavations. Additionally, it can be used to check for anthropogenic signals in buried locations detected by remote sensing, and to understand the spatial organization of submerged sites.

1. Introduction

Submerged prehistoric sites produce exceptional data that is rarely visible in the terrestrial archaeological record (Fisher et al., 2011: 338; Bicket et al., 2014: 228). They contribute to understanding patterns of human movement across continents, expansion and origins of agriculture, coastal dwelling and lifeways, resilience associated with sea-level rise, as well as socio-economic and material culture of prehistoric

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coastal populations (Bergen 1983:51–52; Marcus and Newman 1983:63; Bednarik 2003:41; Broodbank 2013:130; Bailey 2014:295; Flatman and Evans 2014:7). One central methodological issue has been how to efficiently detect submerged prehistoric settlements (Bailey 2011:333; Bailey et al., 2017:3; Flemming et al., 2017: 6; Galili 2017; Galili et al., 2019; Grøn et al., 2021). Survey methods aimed at locating submerged prehistoric settlements can be divided into several categories: 1) Direct contact or visual surface observations: coastal patrols to locate artifacts washed ashore, shallow water snorkeling, scuba diving, deep diving using submersibles, etc. 2) Remote sensing acoustic and non-acoustic geophysical techniques operated from water surface: remotely operated vehicles, sub-bottom profilers, multi-beam and side-scan sonars, backscatters, swatch bathymetry, and imaging sonars, single-beam echo-sounders, boomers, sparker or chirp systems, geomagnetics, marine gravimetry, and electromagnetic surveys. 3) Airborne remote sensing: aerial photography, airborne LiDAR, satellite imagery and orthophotos, used for locating underwater features, paleosols and exposures in shallow water up to 10 m depth. 4) Coring and other types of sampling sediments in areas of interest, including: sea-bottom core drilling operated from surface vessel, manual, disturbed, sub-bottom jet drilling, manual sea-bottom coring, grab sampler operated from surface vessel, hydraulic dredging, mining equipment or excavation of trenches (Galili 2017; Missiaent et al., 2017). Each method has its advantages and limitations, and it is essential to choose the proper technique according to the nature of the studied area and site characteristics.

Despite the variety of methods used, most of the discoveries worldwide are the result of chance finds by divers and fishermen (Bailey 2014:291). In general, site detection is based on identifying suspected submerged terrestrial geomorphological features (e.g., submerged paleosols, river banks), or identifying anthropogenic remains, such as lithics, bones, charcoal and built structures and installations (Flemming 2011; Missiaent et al., 2017). Gagliano et al. (1982), working on 15 coastal sites in the United States, added to the above approach several analyses of sediments collected within and outside the sites showing that anthropogenic remains larger than 2 mm are more abundant within site perimeters in combination with higher phosphate concentrations. Murphy (1990) tested Gagliano et al.'s (1982) approach in an underwater prehistoric site off Florida's coast showing the possibility to use bones, charred matter and phosphate concentrations for underwater site prospection. This approach was not exploited further, partly because it focuses on known submerged sites while the sites are often heavily eroded and/or overlain by sediments. Macro-anthropogenic features (structures, installations, burials) are rarely exposed and thus only occasionally observed on the sea floor, while natural features are sometimes misinterpreted and identified as anthropogenic remains (Galili et al., 2019). This situation demonstrates the need to develop reliable and practical methods for locating submerged prehistoric settlements, as well as testing buried anomalies detected by remote sensing techniques (Flatman and Evans 2014:4; Bailey 2014:293).

Two main models are used to detect submerged prehistoric settlements, the Danish (Fisher 1995) and the Israeli (Galili et al., 2019). The Danish model is based on the premise that fishing sites share similar topography (e.g., river banks, estuaries) and thus maps and echo-sounding are used to locate plausible submerged targets which are later tested by diving (Fisher 1995). This model, applied successfully in the Baltic and the North Seas where hundreds of prehistoric sites were found, has recently been used internationally (Benjamin 2010; and see further discussion in Faught 2010; Flemming 2010; Ford and Halligan 2010; Hale 2010). In Israel, a practical model based on regular survey aimed at locating, documenting, rescuing and studying submerged prehistoric sites has been developed and applied successfully over the last 60 years (Galili 2017; Galili et al. 2017a, 2017b, 2017c, 2019). This model is based on the observation that nearshore sand covering paleosols—ones often containing anthropogenic remains—is constantly shifted by storms at sea, resulting in random, short-term site exposures. While marine erosion exposes the sites and enables their discovery, it is also responsible for their rapid destruction, physically by waves or currents, and chemically by oxidation. Thus, it is essential to locate, document and sample sites shortly after exposure. Priority is given to shallow water surveys (up to 15 m depth) where chances of submerged prehistoric sites being located and preserved are higher, and while simultaneously these sites are at higher risk (Galili 2017). Excavation of sites after sand removal by storms is conducted across the world (e.g., Bayón and Politis 2014 in Argentina).

To take these two models further, and to rapidly and cost-effectively evaluate buried anomalies and suspected locations, new techniques are necessary. To avoid costly trenching and large-scale underwater excavation, and based on previous knowledge about the submerged Carmel Coast settlements, this study presents a new method to identify submerged anthropogenic remains. The method is based on utilization of underwater manual coring as well as a newly developed underwater water-jet core sampling system operated by divers, combined with established micro-geoarchaeological techniques that were initially developed on terrestrial sites and now adapted to underwater contexts.

1.1. Terrestrial site survey using micro-remain indicators for anthropogenic activities

Site survey in terrestrial environments includes the traditional field walking, geophysical and chemical prospection methods (e.g., Gaffney et al. 2002; Campana and Piro 2008; Oonk et al. 2009). Simultaneously, new methods have been developed in the last few decades in the fields of geoarchaeology and microarchaeology (henceforth micro-geoarchaeology) (Goldberg and Macphail 2006; Weiner 2010; Canti and Huisman 2015). These focus on microscopic remains of human activity such as ash pseudomorphs, phytoliths, and dung spherulites. Similar to chemical prospection methods, these techniques highlight quantifiable differences between anthropogenic sediments and natural soils or sediments. The best-known example is the enrichment in P and Ca at human settlements which are related to specific human activities such as food processing or use of fire (Oonk et al., 2009; Parnell et al. 2001; Holliday and Gartner 2007; Dirix et al. 2013; Salisbury et al., 2013). Anthropogenic micro-remains (opal phytoliths, dung spherulites and ash pseudomorphs) similarly show high abundances within archaeological sites and low abundances to absence in natural soils and sediments (e.g., Cabanes et al., 2012; see specifically, Albert et al., 1999 for phytoliths; Gur-Arieh et al., 2014 for dung spherulites and ash pseudomorphs).

Phytoliths are biominerals that accumulate in and between plant cells. The most-known archaeologically are opaline phytoliths ($SiO_2 \cdot nH_2O$; mostly 2–200 μm) that are especially abundant in grasses, wild and domesticated. They are often found in large quantities at archaeological sites where grass accumulations took place, such as cereal storage, thatched roofs, or dung in livestock enclosures.

Ash pseudomorphs are composed of the mineral calcite ($CaCO_3$). These 10–50 μm micro-remains originate from biogenic calcium oxalate crystals (primarily whewellite, $CaC_2O_4 \cdot H_2O$, and weddellite, $CaC_2O_4 \cdot 2H_2O$) found in woody species, shrubs and herbs. Upon burning of calcium-oxalate containing plant tissues at temperatures between 400 and 700 °C these minerals transform into calcite while maintaining their original morphologies; hence these are known as ash pseudomorphs (Shahack-Gross and Ayalon 2013; Gur-Arieh and Shahack-Gross 2020). Ash pseudomorphs are typically identified in anthropogenic contexts as a product of combustion dating as early as the Lower Paleolithic (Karkanas et al., 2007; Berna et al. 2012; Mentzer 2014).

Dung spherulites are spherical calcitic microscopic remains (5–20 μm) that form in the digestive system of various animals, mainly ruminants, and are excreted in their dung (Shahack-Gross 2011; Brönnimann et al., 2017). In archaeological contexts they are abundant in animal gathering enclosures and combustion features where dung has been used as fuel (Gur-Arieh and Shahack-Gross 2020).

All three micro-remain types are extracted from archaeological sediments and natural deposits by rapid, easy, and relatively low-cost techniques, followed by absolute quantification that allows comparison between different sites and contexts (Katz et al., 2010 for phytoliths; Gur Arieh et al., 2013 for ash pseudomorphs and dung spherulites). Recently we showed that opal phytoliths can preserve under marine inundation for millennia (Ogloblin Ramirez et al., 2020). However, the potential for the preservation of calcitic ash pseudomorphs and dung spherulites under marine conditions was not tested before this study.

Two other micro-geoarchaeological methods are used frequently at terrestrial archaeological sites: micromorphology and infrared spectroscopy (Weiner 2010:8–9; Macphail and Goldberg 2018:517–518). Micromorphology works with thin sections of consolidated soil or sediment. Samples are collected in the field in the form of intact, undisturbed, oriented monoliths, allowing for stratigraphic and micro-stratigraphic study of deposits. Additionally, this technique allows identification, measurement and quantification of components such as flint, bone or charcoal (Berna and Goldberg 2007). Fourier Transform Infrared (FTIR) spectroscopy is a method that allows characterization of mineral assemblages from bulk sediment samples, with a focus on anthropogenic signatures such as presence of pyrogenic materials (Monnier 2018).

A pioneering study by Cabanes et al. (2012) conducted terrestrial site survey through phytolith quantification and mineralogy. The survey was done by sampling sediments along transects across the center of an Iron Age agricultural settlement up to 50 m away from its known perimeter (based on distribution of macroscopic artifacts). They showed that phytolith concentrations decreased from the center of the site, with significant concentrations also identified outside the architecture (indicating activity outside habitation structures), decreasing to levels similar to natural control soils only 20 m away from the architectural remains. Additionally, they showed that the ratio between quartz and clay, determined using FTIR spectroscopy, changed from the center to the periphery of the site. These data indicate that micro-remain and mineralogical signatures are useful to delimitate the presence and extent of archaeological sites.

Given the above, the aim of this study was to apply similar micro-geoarchaeoelogical survey to submerged prehistoric settlements. The method was developed through sediment core sampling at known submerged settlements and comparing their micro-geoarchaeological parameters to those found in control core samples taken from paleosols with no visible anthropogenic finds. The method was further developed to enable core sampling of paleosols covered by 1–3 m thick layer of sand, providing a 'blind test' (i.e., proof of concept) of its utility.

2. Study area

This research focused on the submerged landscape on the Carmel Coast, Israel, one of the richest locations for the study of submerged prehistoric sites. At least nine submerged prehistoric sites have been identified: Kfar Samir, Hisheley Carmel, Kfar Galim, HaHotrim, Tel Hreiz, Megadim, Atlit-Yam, Neve Yam and Habonin North (Galili et al. 2020). The sites, dating to the early Holocene, are embedded in the upper layer of a clay-rich paleosol (so called Carmel coast clay) that formed in association with brackish water lagoons that existed between coastal aeolianite ridges (locally termed *kurkar*) around 10,000–9500 years BP (Galili 1985; Galili et al., 2017a, 2017b, 2017c). This paleosol was later covered by sand dunes or beach sand and eventually flooded by the post-glacial rising sea (Galili and Weinstein-Evron 1985; Galili et al., 2020; Sneh and Klein 1984; Sivan et al., 2011). Human settlement existed in this coastal environment at the beginning of the Holocene, just after the terrestrial water bodies dried up, when sea level was lower than today (Galili et al. 1988, 2005; Galili and Nir 1993; Lambeck and Purcell 2005; Sivan et al., 2011). These sites, and the coastal paleosol on which they were established, are currently submerged and usually covered by quartz sand that originates from sediments transported by the Nile to the Mediterranean Sea and then carried by longshore currents and deposited underwater and on the shores of the eastern Mediterranean (Almagor et al., 2000).

The paleosols are characterized by smectite-rich clay and include quartz grains that originate from the Nile littoral cell (Stanley et al., 1998; Ogloblin et al. 2020). Additionally, they include ostracods, foraminifera and pollen that were previously used for paleoenvironmental reconstruction (Galili and Inbar 1987; Galili 2004; Galili and Weinstein-Evron 1985; Sivan et al., 2011). Initial results regarding the absence of anthropogenic micro-remains (phytoliths, ash pseudomorphs and dung spherulites) in these paleosols (Ogloblin et al. submitted) encouraged us to conduct the current study.

Two currently submerged sedentary settlements, Atlit-Yam and Neve Yam, are well-known owing to their rich architecture and other archaeological materials. These sites are located in the northern Carmel coast, between the Oren stream to the north and Mearot stream to the south (Fig. 1). These watercourses drain the western slopes of Mount Carmel providing the coast with pebbles and boulders originating from Cretaceous and Eocene calcareous formations as well as some volcanic tuff (Segev and Sass 2009). Atlit-Yam is located at depth of 8–12 m below sea level (bsl) 200–400 m offshore. The site expands over ca. 40, 000 m^2 and is dated to the late 10th - first half of the 9th millennium BP (Pre-Pottery Neolithic C, PPNC) (Galili et al. 1993, 2020). Neve Yam is partially inundated, with its western part submerged as much as 3 m bsl, and its eastern limit on the modern coast slightly above current sea level (Galili et al. 2017a, 2017b, 2017c, 2020). This site is approximately 20, 000 m^2, and is dated to the second half of the 8th millennium BP (late Pottery Neolithic/Early Chalcolithic, PN/EC; Wadi Rabah culture).

These sites present a unique opportunity to develop underwater sampling approaches and test the micro-geoarchaeological techniques mentioned above, as they have been studied comprehensively (Wreschner 1977; Galili et al., 2020). These sites yielded highly diverse finds that represent various human activities, are easily accessible in terms of depth and distance from the coast, and undergo random seasonal underwater exposure after sand removal during storms.

3. Materials and methods

To carry out the research it was essential to use methods that enabled underwater extraction of undisturbed core samples suitable for mineralogical, micro-remain and micromorphological analysis. Before the current research, two types of underwater paleosol sampling were conducted in Israel: one using manual PVC tubes to extract undisturbed deposits from exposed underwater areas and the other using a water jet system in sand-covered areas that resulted in collection of disturbed paleosol chunks (Galili 2004:354; for sampling with PVC tubes elsewhere see Menotti et al., 2005; Lewis 2007). In this study we first opted to test whether micro-remain concentrations can be used for site prospection as done on land. Therefore, the first core sampling campaign of this study was carried out in paleosol deposits within known sites, as well as in paleosol deposits where no visible prehistoric signs were present; both were naturally exposed of sand following storms (and were covered again in the following storms). Once we were convinced that this prospection method produces results comparable to terrestrial sites, we decided to further develop the method so that undisturbed core sampling will be done also in regions where the paleosol is buried below sand. By doing this we developed the capacity to search for submerged settlements in any location where paleosols are buried under sand, and overcome the need to excavate costly trenches to reach the paleosol or wait for the sea storms to remove the sand. We conducted this as a 'blind test' using a combination of water jetting and coring (details below). This was done in one locality only, as a proof of concept.

3.1. Sampling exposed underwater paleosols

Two types of deposits were collected: 1) natural submerged Carmel coast paleosols without visible anthropogenic remains (control samples)

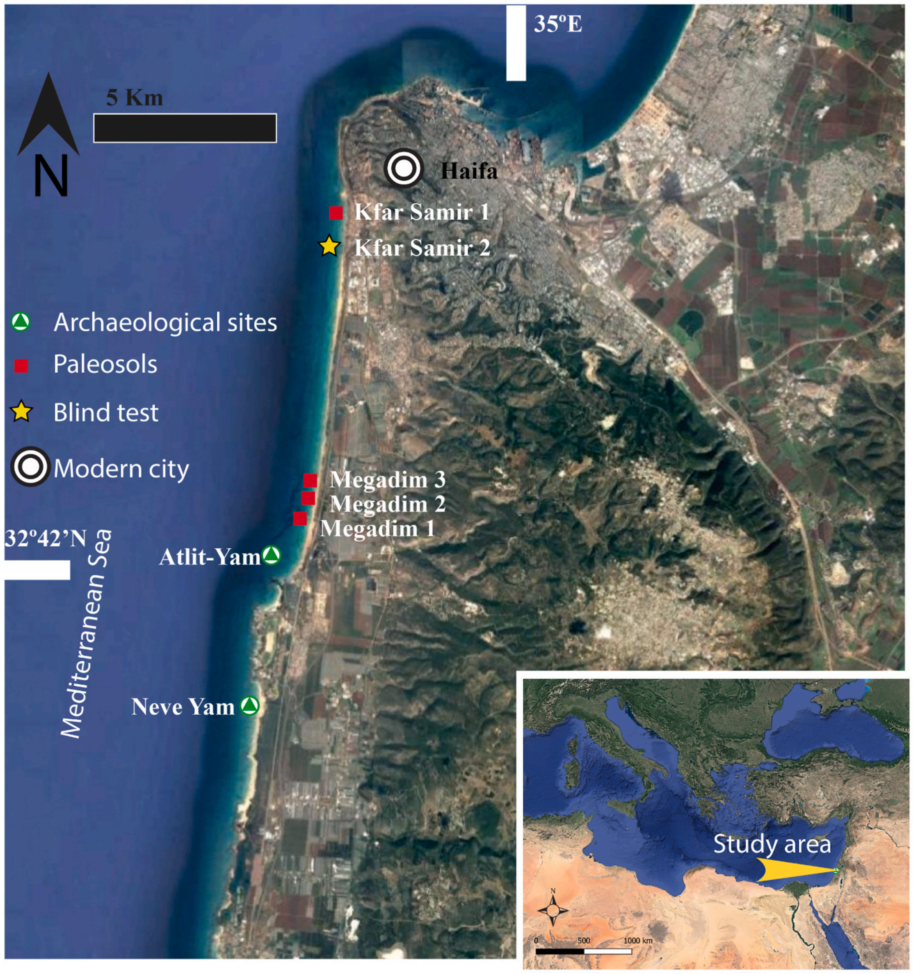

Fig. 1. Google Earth satellite images of the study area and its placement in the Eastern Mediterranean (yellow arrow in inset). The close-up image focuses on the northern Carmel coast, showing the position of the modern city of Haifa and the location of the archaeological sites, exposed paleosol and 'blind test' sampling localities. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

from around Kfar Samir and Megadim sites; Table 1, Fig. 1); 2) sediments from exposed areas within the submerged prehistoric settlements of Atlit-Yam and Neve Yam (intra-site samples; Table 1). All core samples were collected manually underwater along transects. Cores were collected using PVC tubes, 5 cm in diameter, 40–60 cm long. Samples were collected while diving at Atlit-Yam and Kfar Samir and while snorkeling at Neve Yam and Megadim (Fig. 1). The locations of sterile paleosol core samples were documented using a GoPro 5 camera equipped with GPS. The intra-site cores were sampled according to exposed visible features, outside of structures and installations, and their location was plotted on a site plan, previously documented by Galili et al. (1993, 2009). The distance between cores averaged 4 m. During sampling, approximately 20 cm of the PVC tubes were inserted into the sediments using a 2 kg hammer (Fig. 2a). The upper part of each core was labeled as sample number and to indicate the core orientation. The remaining 20–40 cm of the tube was used to manually rotate the tube and pull the cores out of the deposits while the diver's palm sealed the upper end of the tube – this produced a vacuum preventing the sample from dropping out of the tube. After extraction, the ends of the tubes were covered with plastic bags and sealed with rubber bands underwater (Fig. 2). Information regarding core location, context and observations of surrounding sediments were recorded underwater.

On land, extra plastic wrap and tape were applied to protect the cores during transportation until they were opened in the laboratory. Seawater was kept inside the cores (in the space where no sediment was inserted) to prevent drying. The cores remain intact owing to the sticky nature of the clay deposits.

Natural (macroarchaeologically sterile) submerged paleosol samples were collected in three different locations off modern-day Megadim and near Kfar Samir (Table 1). The four core samples from Megadim-1 were collected between 0.5 and 1 m bsl along an east-west 50 m transect. Samples from Megadim-2 (4 cores) and Megadim-3 (4 cores) were collected between 0.4 m and 1.5 m bsl in two north-south transects, covering 50 and 100 m respectively. Four cores were collected between two well-known concentrations of prehistoric remains in the proximities of Kfar Samir 1 (Galili and Weinstein-Evron 1985; Galili et al. 2019, 2020) at a depth of 2–5 m.

At Atlit-Yam, intra-site sediment samples include one core (AY-44) collected in an open area in the center of the site (Area D, Galili 2004), close to the eastern end of Structure 8 East (Fig. 3a, Table 1). This sample is assumed to represent the most intensive anthropogenic signature due to its placement at the center of the settlement, close to walls and various installations. Additional six cores were collected along a 40 m east-west transect on the southeastern edge of the site between Structure 32a (a stone-built pit filled with waterlogged herbaceous material) and Structure 5/1 (built of undressed stones in Area O) (Galili 2004). All cores were obtained at 9–10 m depth (Fig. 3a, Table 1). This set of samples is expected to show diminishing anthropogenic signals going eastwards towards the site's edge. At Neve Yam, four cores were collected between graves located in the intertidal zone at the graveyard part of the site, along a 10 m north-south transect (Fig. 3b, Table 1).

Table 1
Location and macroscopic description of the core sediment samples.

Sample type	Locality/ Site	Sample n°	GPS Location/context within submerged settlements	Sediment description	Macroscopic components (size range)
Natural submerged paleosols	**Kfar Samir 1**	KS-1	32° 47′ 49.45″N 34° 57′20.14″E	Brown silty clay	White inclusions, humified organic matter (0.5–1 cm)
		KS-2	32° 47′ 49.25″N 34° 57′19.48″E	Brown silty clay	White inclusions, humified organic matter (0.5–0.8 cm)
		KS-3	32° 47′ 49.85″N 34° 57′17.87″E	Brown silty clay	White inclusions, humified organic matter (0.5–0.8 cm)
		KS-4	32° 47′ 49.14″N 34° 57′17.28″E	Brown silty clay	White inclusions (0.5–1.5 cm)
	Megadim 1	M-1	32° 43′ 43.90″N 34° 56′48.21″E	Reddish brown silty clay	White inclusions (0.5–1 cm)
		M-4	32° 43′ 43.90″N 34° 56′48.24″E	Reddish brown silty clay	White inclusions (0.5–2 cm)
		M-5	32° 43′ 41.99″N 34° 56′48.12″E	Reddish brown silty clay	White inclusions (0.5–1 cm)
		M-6	32° 43′ 44.90″N 34° 56′48.26″E	Reddish brown silty clay	White inclusions (0.5–1 cm)
	Megadim 2	M-2	32°44′6.43″N 34°56′53.35″E	Reddish brown silty clay	White inclusions (0.5–1.5 cm)
		M-9	32°44′7.04″N 34°56′51.34″E	Reddish brown sandy clay	White inclusions (0.5–2 cm)
		M-10	32°44′7.71″N 34°56′53.21″E	Reddish brown sandy clay	White inclusions 0.5–1 cm)
		M-11	32°44′5.57″N 34°56′58.82″E	Reddish brown sandy clay	White inclusions (0.5–1.7 cm)
	Megadim 3	M-3	32°44′ 30.13″N 34°56′ 56.27″E	Dark grey silty clay	White inclusions, humified organic matter, shells (0.5–2 cm)
		M-13	32°44′ 29.73″N 34°56′ 55.47″E	Dark grey silty clay	White inclusions, humified organic matter, shells (0.5–2 cm)
		M-14	32°44′ 30.90″N 34°56′ 56.49″E	Dark grey silty clay	White inclusions, humified organic matter, shells (0.5–2 cm)
		M-15	32°44′ 31.00″N 34°56′ 55.62″E	Dark grey silty clay	White inclusions, humified organic matter, shells (0.5–2 cm)
Intra-site deposits	**Atlit-Yam**	AY-44	Near Structure 37	Grey sandy clay Light grey silty clay grey sandy clay Black silty clay Light grey sandy clay	White/black/red/grey inclusions, charcoal/charred matter, shells, flint, bone (0.5–3 cm)
		AY-64	Between Structure 32 and Structure 5	Dark grey silty clay	White inclusions, charcoal/charred matter (0.5–2 cm)
		AY-65		Dark grey silty clay	White inclusions, charcoal/charred matter (0.5–1.5 cm)
		AY-66		Dark grey silty clay	Light grey inclusions, charcoal/charred matter, flint (0.5–2.5 cm)
		AY-67		Dark grey silty clay	Red fragment, charcoal/charred matter, flint (0.5–1 cm)
		AY-68		Dark grey silty clay	White inclusions, charcoal/charred matter (0.5–1 cm)
		AY-69		Dark grey silty clay	White inclusion, shells, charcoal/charred matter (0.5–1 cm)
	Neve Yam	NY-40	N-stone built grave n° 107	light brown sandy clay Light grey sandy clay Dark brown sandy clay	White inclusions, charcoal/charred matter, flint (0.5–4 cm)
		NY-41	S-Stone built grave n°1 107	light brown sandy clay Light grey sandy clay	White inclusions, charcoal/charred matter, pottery, red fragment, flint (0.5–3.5 cm)

(*continued on next page*)

Table 1 (*continued*)

Sample type	Locality/ Site	Sample n°	GPS Location/context within submerged settlements	Sediment description	Macroscopic components (size range)
		NY-42	N-stone built grave n° 108	Dark brown sandy clay light brown sandy clay Light grey sandy clay Dark brown sandy clay	White inclusions, charcoal/charred matter, flint (0.5–5 cm)
		NY-43	S-stone built grave n° 108	light brown sandy clay Light grey sandy clay Dark brown sandy clay	White inclusions, charcoal/charred matter, red fragment, bone, flint (0.5–4 cm)
Water jetting experiment	**Kfar Samir 2**	KS-36	32°47′0.38″N 34°57′7.56″E	Brown silty clay	White inclusions (0.5–1 cm)
		KS-37	32°47′0.38″N 34°57′7.56″E	Brown silty clay	White inclusions (0.5–1.5 cm)
		KS-38	32°47′0.38″N 34°57′7.56″E	Brown silty clay	White inclusions (0.5–1 cm)
		KS-39	32°46′60.00″N 34°57′6.00″E	Brown silty clay	White inclusions (0.5–1.5 cm)

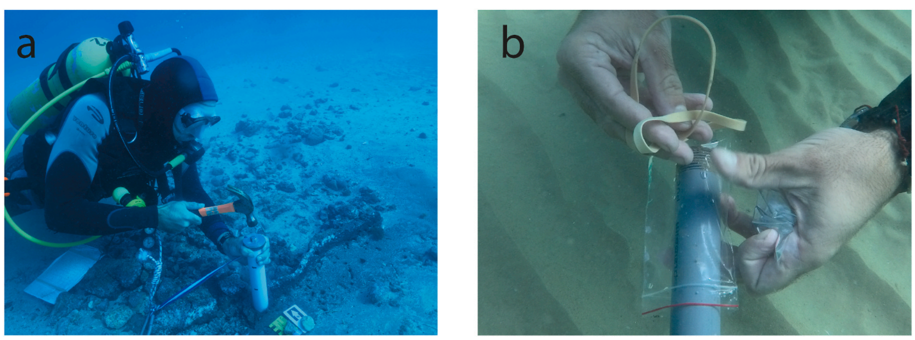

Fig. 2. Photographs exemplifying sampling procedures underwater. a) Extraction of a manual core. Photo by E. Galili. b) Core sealing with a plastic bag and rubber bands. Photo by A. Yurman.

3.2. Sampling sand-covered underwater paleosols

To test the new method in an area covered by sand, four cores were obtained from a locality off Kfar Samir South (Kfar Samir 2; Table 1, Fig. 1) that has not been exposed by storms of the last few decades. The presence of paleosols in this area was recorded by sub-bottom profiling and jet drilling (Adler 1985; Galili et al., 1999). However, we did not know if there was evidence for prehistoric settlement buried in this specific location. To obtain cores through 1.5–3 m of sand, a water jetting system was used (Fig. 4a), operated by a water pump (Yanmar Pump model YDP30TN, 30hp) mounted on a rubber Zodiac. The jetting system consisted of a 3 m long 1.9 cm diameter standard galvanized iron pipe attached to a 7.6 cm diameter flexible water supply hose (Fig. 4b). The coring device consists of a 4 m long galvanized iron pipe of 1.9 cm diameter, with a 1.9–2.5 cm iron adaptor attached to its bottom and a PVC tube (2.5 cm in diameter and 20 cm long) attached to the adaptor (Fig. 4c). On the upper part of the iron pipe was a screw to which a 90° connector was attached (Fig. 4d) that allows hammering the metal pipe into the paleosol without causing damage to the screw, and closing the connector with an iron plug. We utilized the following protocol for sampling with the water jet coring system:

1) The water jetting pipe was inserted vertically in the chosen location by divers on the sea floor. Jetting continued until it reached the clayey paleosol. Jetting created a vertical shaft ca. 10 cm in diameter.
2) While water jetting continued, the 4 m coring device was set vertically into the shaft parallel and adjacent to the water jet pipe and hammered into the paleosol using a 2 kg hammer (Fig. 4e).
3) Once the core and the PVC tube were inserted 10 cm into the paleosol, the top of the coring tube was sealed with a 2 cm iron plug screwed onto the 90° connector. While pulling the coring device out this plug produced a vacuum that allowed the extraction of the intact sediment core.
4) The coring tube with the PVC section at its bottom was manually released from the paleosol and pulled out of the shaft.
5) Finally, the PVC tube was removed from the coring pipe, and was sealed with plastic bags and rubber bands at both ends. After extracting the cores they were wrapped and transported to the laboratory as described above.

Three cores were collected under a 1.5 m thick layer of sand, along a 15 m long north-south transect. The fourth core was collected some 25 m west of the transect where a sandy bar existed and the sand cover was 3 m thick.

3.3. Post-sampling analyses

At the laboratory, wet sediments were gently pushed out of the manual (5 cm diameter) PVC tubes with a wooden cylinder with a diameter that fitted that of the tube. The sediment cores were pushed onto PVC tubes cut in half longitudinally. The sediment cores were then

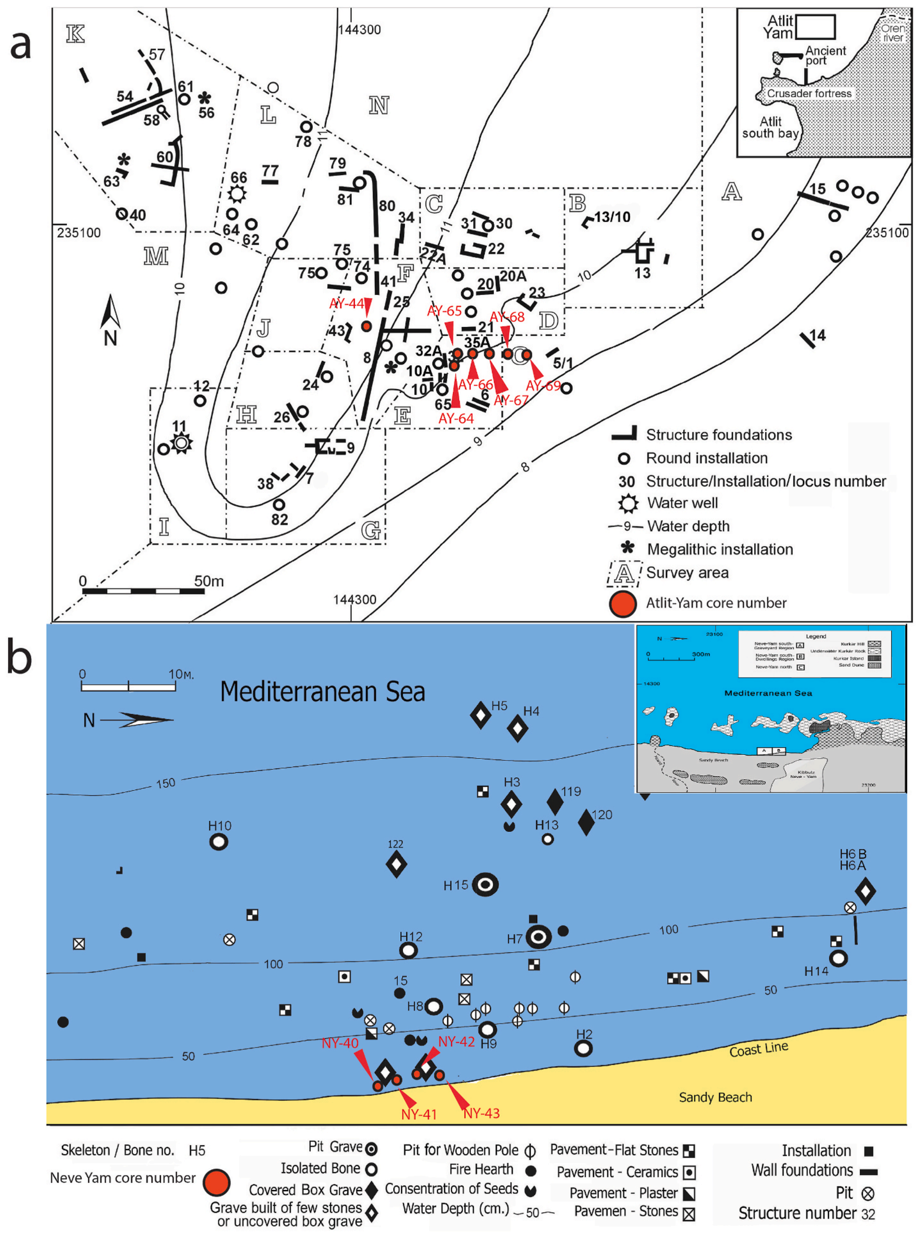

Fig. 3. Schematic drawings of features found at Atlit-Yam (a; modified after Galili et al. 2009) and Neve Yam (b; modified after Galili et al. 2020) by observations during diving, snorkeling and underwater excavation campaigns. The location of core samples is marked by red circles. Note that samples were collected along transects; from the center to the periphery of Atlit Yam and within a graveyard area at Neve Yam. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

carefully cut in half longitudinally using a sharp blade producing two half-cores. The 2 cm diameter PVC tubes extracted using the water jetting system were cut longitudinally on two opposite sides using an Dremel blade (Dremel 3000) and the sediment inside was exposed. The wet sediments were photographed and described and left to air dry for 7 days (Fig. 5a). Once dry, the half-cores were photographed again and physical description of sediment macroscopic characteristics (layering, color, macroscopic items) was recorded. One half-core was used for the collection of bulk samples for microremain and FTIR analysis, and the other for micromorphology.

Bulk samples (for mineralogy and micro-remain analyses): When different layers were identified along a sediment core, each was sampled individually by collecting a small amount of sediment required for analysis (ca. 1 g). If the sediment appeared homogenous, two samples were collected, one from the top 2–5 cm and one from the bottom 2–5 cm. The location of each sub-sample along the core was tagged and when sampling was completed, the sampled half-core was photographed again (Fig. 5b).

FTIR spectroscopy was used to detect the mineralogical composition of the sediments and their inclusions, identifying quartz, calcite, aragonite, heated or unheated clay, and carbonated hydroxylapatite (CHAP) (Weiner 2010). Spectra between 4000 and 400 cm^{-1} were collected with a Nicolet iS5 (Thermo Scientific) spectrometer using Omnic 9.3 software, using the standard potassium bromide (KBr) method (Weiner 2010:275–280).

Phytolith quantification was done following a modified version of Katz et al. (2010). Samples were ashed for 4 h at 550 °C in a laboratory furnace (Thermolyne F6000, Thermo Scientific) in order to remove organic matter which can mask phytoliths under the microscope, and can lead to skewed quantification (cf. Butler et al., 2020). Quantification was carried out at 200*x* magnification under plane polarized light (PPL) using a polarized light microscope (Nikon Eclipse 50i POL). On each slide a total of 16 fields of view were counted. Dung spherulite and ash pseudomorph quantification was done following the quantitative method of Gur-Arieh et al. (2013). All micro-remain concentrations are reported in millions per 1 gr of sediment.

Micromorphology: Two half-core samples from each of the three Megadim natural paleosol sampling, one from Kfar Samir 1 paleosol,

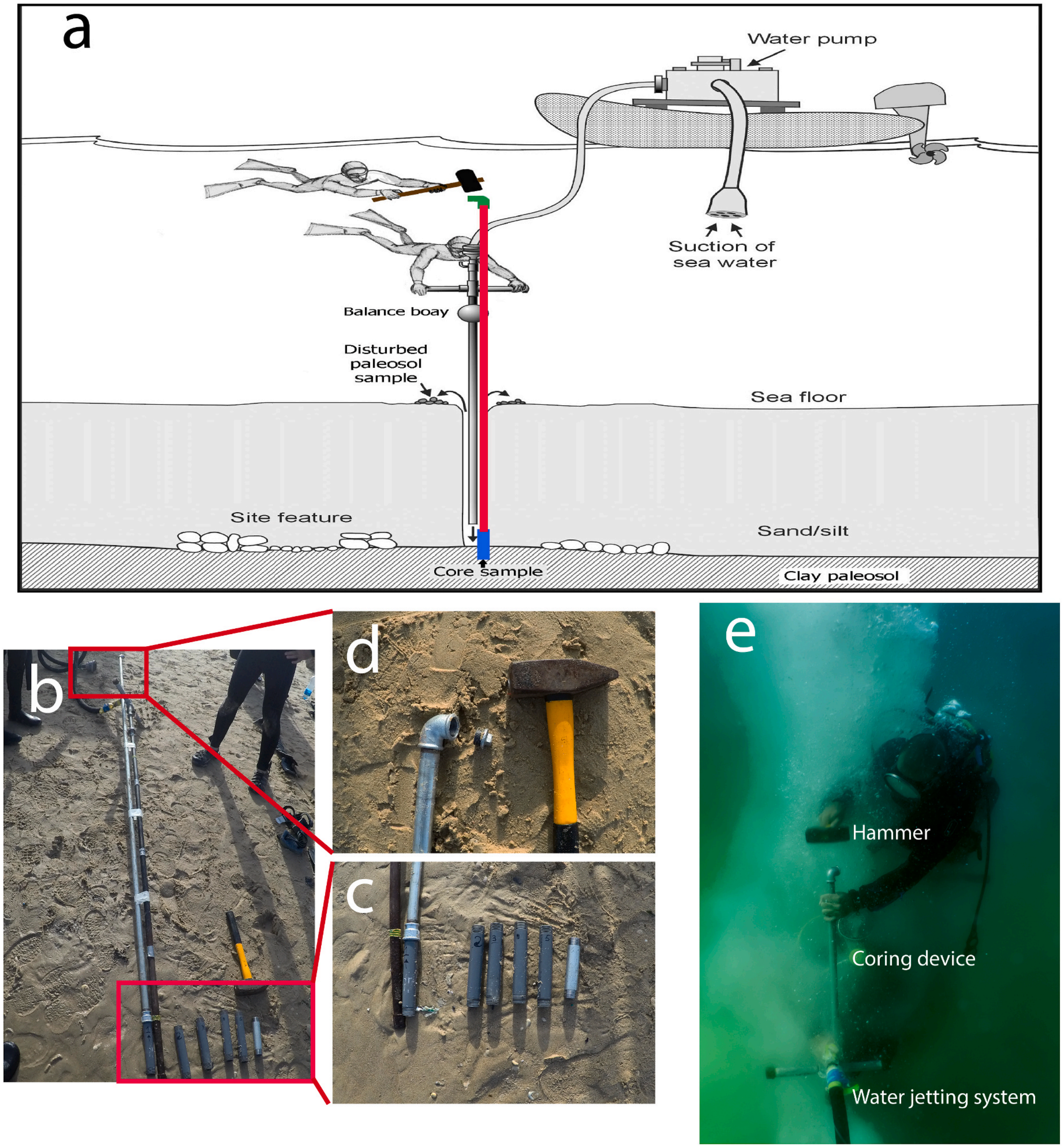

Fig. 4. a) Schematic drawing illustrating operation of a water jetting system with an additional pipe (red colored) for coring. b) Fitting the coring pipe on the water jetting system. c) Close-up on the bottom part of the pipe showing where PVC tubes for coring are inserted and can be replaced during system operation. d) Close-up on the top part of the fitted pipe showing a 90° connector that provides a surface for hammering down the core without damaging the pipe screw. Note also a plug used to close the pipe and generate vacuum before core removal ensuring the sediment remains intact in the core tube. e) Working underwater. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

five half-cores from Atlit-Yam (AY-44, AY-65, AY-67, AY-68, AY-69) and two half-cores from Neve Yam (NY-40, NY-42) were impregnated in preparation for production of thin sections. We tested two impregnation procedures. The first was conducted with polystyrene under vacuum and the second with acetone-diluted polyester resin (3:7 by volume) with 0.75% hardener (MEKP, by volume) without vacuum. Accelerator was not used in both types of impregnation to allow for slow and thorough penetration of the resin into the sediment pores. In the first procedure consolidation took two days and in the second about one month, after which the resin impregnated samples were placed in an oven at 50 °C for curing over a weekend, and then cut using a rock saw. The cut samples were prepared as 30 μm thin sections on 5 × 2 cm microscope slides at the Recanati Institute for Maritime Studies, University of Haifa. One sample, AY-44, was prepared on a 5 × 7 cm microscope slide by Quality Thin Sections, Tucson, Arizona. We found that impregnation by the second method produced better results, and that presence of sea salt did not hamper resin polymerization.

Thin sections were studied using a Nikon Eclipse 50i POL polarized light microscope, in both plane polarized light (PPL) and crossed polarized light (XPL). Quantification of grains of quartz, carbonatic components and humified organic matter was done by estimation of area using abundance charts (Stoops 2003). Micro-flint, micro-charcoal and micro-bone fragments of fine to coarse sand size (0.15–1 mm) were quantified by point counting under 200*x* magnification. The results are reported as concentration (number of micro-remains per cm^2 of the sample area counted on the thin section). Rare micro-remains (e.g., clay

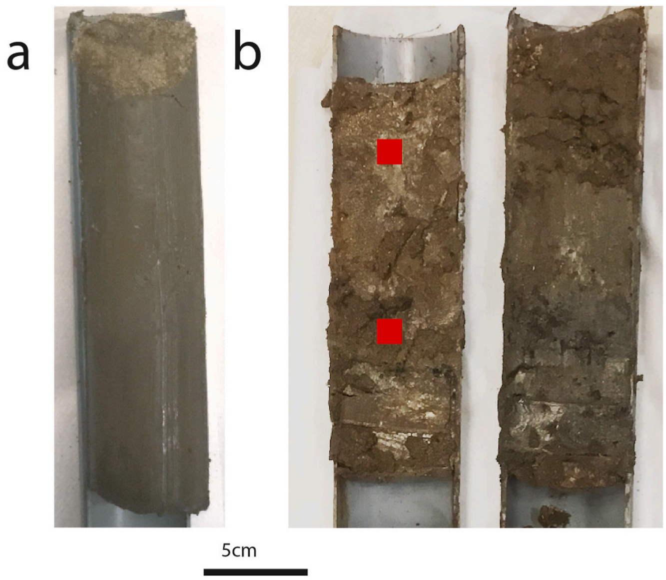

Fig. 5. Treatment of cores in the laboratory. a) Core after extraction from PVC pipe (sample M-3 from natural paleosol; see location in Fig. 1). b) Same core after longitudinal cutting with a sharp knife producing two half-cores: one used to sample sediments along the core (red squares indicate location of samples) for bulk analyses (mineralogy and micro-remains) and the other used for preparation of thin sections for micromorphological analysis. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

lumps) and observed phytoliths, ash pseudomorphs and dung spherulites were noted by presence or absence.

4. Results

4.1. Physical properties and mineralogy

All 20 natural paleosol deposits are homogenous, silty-clay, and brown-colored. Four cores, all from locality Megadim 3, include on top of the brown silty-clay paleosol an upper deposit containing organic matter and shells, indicating a post-paleosol deposition. Coarse inclusions are mainly calcareous (chalk, limestone, kurkar, shells) ranging in size between 0.5 and 2 cm. Particles of dark-colored (probably humified) organic matter also occur.

Intra-site samples are also silty-clay, brown, but can be either homogenous or composed of layers (i.e., localized micro-stratigraphy). In Atlit-Yam, only AY-44 (out of 7 core samples) shows layering. In Neve Yam, all four cores include layers. The observed layers vary in thickness between 0.2 and 6 cm and are dark/light grey, dark/light brown, black and white (Table 1). The intra-site deposits contain coarse inclusions ranging in size between 0.5 and 5 cm, including angular flint fragments, pottery sherds, charcoal, bone, and heated clay lumps (evidenced by FTIR, see below).

The cores retrieved by water jetting are similar to the natural paleosol showing homogenous brown silty-clay deposits with coarse calcareous inclusions up to 1.5 cm. The mineralogical composition in both paleosol and intra-site samples is dominated by clay (absorption bands at 3695, 3625, 1032, 915, 525 cm^{-1}), with some quartz (absorption bands at 1083, 797, 778 and 695 cm^{-1}) and calcite (absorption bands at 1432, 876, and 713 cm^{-1}) as detected by FTIR spectroscopy (Table 2). The relative amounts of these three minerals are quite similar in the paleosols, but vary in the intra-site samples (Fig. 6a). The layered intra-site samples, AY-44 and the four core samples from Neve Yam, include clay that had been heated to about 500–600 °C (Fig. 6b). This information is deduced from the lack of absorption bands indicative of structural water at 3695 and 3625 cm^{-1}, the shift of the main silicate absorption band from 1032 to 1040 cm^{-1} and the absence of the absorption band at 915 cm^{-1} (Berna et al., 2007). Unlike infrared spectra of the paleosol samples, the majority of the intra-site samples include absorption bands in the form of shoulders around 605 and 565 cm^{-1} that are indicative of carbonated hydroxylapatite (Fig. 6b). Regev et al. (2015, Fig. 5) showed a correlation between the shoulder height in infrared spectra and phosphate concentration. Based on this study we estimate that intra-site deposits have ca. 0.5–2% phosphate (see more on carbonated hydroxylapatite in section 4.3: presence of bones). The mineral aragonite was identified in both natural and intra-site samples. The deposits retrieved by the core water jetting sampling are composed mostly of clay, and some calcite and quartz, similar to the mineralogical composition obtained from the natural paleosol sampled at Kfar Samir 1 (Table 2).

4.2. Micro-remains

Phytoliths occur in negligible amounts in the natural paleosol samples with values below 0.05 million phytoliths per 1 gr of sediment (i.e., 0–3 total counted phytoliths). Ash pseudomorphs and dung spherulites are completely absent from the natural paleosols.

A highly variable presence of micro-remains occurs in the intra-site samples. Phytolith concentrations range between 0 and 1 million phytoliths per 1 gr of sediment (with the exception of AY-44 having up to 6 million phytoliths per 1 gr of sediment) (Fig. 7a). Ash pseudomorphs range between 0 and 1 million per 1 gr of sediment (except for AY-44 reaching 16 million ash pseudomorphs per 1 gr of sediment) (Fig. 7b). Dung spherulites range between 0 and 0.4 million per 1 gr of sediment (Fig. 7c). The micro-remain concentrations in Atlit-Yam seem to be random. AY-44 is particularly rich in phytoliths and ash pseudomorphs, while the samples located in the proximities of Structure 32 (AY-64 to AY-67) show low concentrations of dung spherulites (Table 2). The spatial distribution of the micro-remain concentrations in the transects at both sites is presented in Fig. 8. Micro-remains in the sediments sampled by core water jetting were found to be either negligible (up to 0.05 million phytoliths per 1 gr of sediment) or absent (ash pseudomorphs and dung spherulites).

4.3. Micromorphology

The differences between natural paleosol and anthropogenic intra-site deposits are clearly visible in micromorphological thin sections (Table 3). The natural paleosols are composed of a groundmass of clay and quartz (Fig. 9a). The latter comprises about 20% of the groundmass, dominated by fine or medium sand grain sizes and some silt. Fragments of chalk, limestone, kurkar, beachrock and shells, ranging 0.2–1 mm, occur in low abundance of less than 5% (Fig. 9b). Humified organic matter also occurs in abundance lower than 5% (Fig. 9c).

The anthropogenic intra-site sediments have a groundmass similar to that of the controls, yet the relative proportion between clay and quartz decreases and the abundance of quartz oscillates between 40 and 60% (Fig. 9d). Chalk, limestone, kurkar, beachrock and shell abundances vary between 10 and 20%. The abundance of humified organic matter is 5–10%. Not only the abundance of grains above (chalk, limestone, etc.) are higher in the anthropogenic deposits relative to the natural ones, the former also include other materials: micritic calcite from ash pseudomorphs and dung spherulites, phytoliths, charcoal (Fig. 10a), bones (Fig. 10b), possible pottery/brick fragments (Fig. 10c), and angular flint from knapping debris (Fig. 10d).

Microscopic charcoal, bone and flint were quantified by point counting of fragments (0.15–1 mm diameter) (Table 3). Charcoal concentration from intra-site samples is 5–7 fragments per cm^2 of the thin section, which contrast sharply with the natural samples that completely lack this material. Bone concentration in the intra-site samples range from 0.2 to 4.2 fragments per cm^2 of the thin section, while they are absent in natural paleosols. Angular flint concentration ranges 0.2 to 2.1

Table 2
Results of bulk analyses. Mineralogical composition was determined by FTIR spectroscopy: Cl (u/a) = Natural clay, unaltered by heat, Cl(a) = Clay altered by heat, Qz = quartz, Ca = calcite, CHAP = Carbonated hydroxyapatite, Ar = aragonite. Micro-remain concentrations are expressed as millions per 1 gr of sediment (in parentheses: actual micro-remain count).

Sample type	Locality/Site	Sample n°	Mineralogy	Phytoliths	Ash pseudomorphs	Dung spherulites
Natural submerged paleosol	**Kfar Samir 1**	KS-1	Cl (u/a), Ca, Qz	0.05 (3)	0	0
			Cl (u/a), Ca, Qz	0.04 (3)	0	0
		KS-2	Cl (u/a), Ca, Qz	0.04 (2)	0	0
			Cl (u/a), Ca, Qz	0.04 (3)	0	0
		KS-3	Cl (u/a), Ca, Qz	0.03 (2)	0	0
			Cl (u/a), Ca, Qz	0.02 (2)	0	0
		KS-4	Cl (u/a), Ca, Qz	0.02 (1)	0	0
			Cl (u/a), Ca, Qz	0.02 (2)	0	0
	Megadim 1	M-1	Cl (u/a), Ca, Qz	0.01 (1)	0	0
			Cl (u/a), Qz, Ca	0.02 (2)	0	0
		M-4	Cl (u/a), Qz, Ca	0.03 (2)	0	0
			Cl (u/a), Ca, Qz	0	0	0
		M-5	Cl (u/a), Qz, Ca	0	0	0
			Cl (u/a), Qz, Ca	0.03 (2)	0	0
		M-6	Cl (u/a), Qz, Ca	0.02 (1)	0	0
			Cl (u/a), Qz, Ca	0	0	0
	Megadim 2	M-2	Cl (u/a), Qz, Ca	0	0	0
			Cl (u/a), Qz, Ca	0.03 (2)	0	0
		M-9	Cl (u/a), Qz, Ca	0.03 (2)	0	0
			Cl (u/a), Qz, Ca	0.02 (1)	0	0
		M-10	Cl (u/a), Qz, Ca	0.02 (1)	0	0
			Cl (u/a), Qz, Ca	0	0	0
		M-11	Cl (u/a), Qz, Ca	0	0	0
			Cl (u/a), Qz, Ca	0.02 (2)	0	0
	Megadim 3	M-3	Cl (u/a), Qz, Ca	0	0	0
			Cl (u/a), Qz, Ca, Ar	0.05 (3)	0	0
		M-13	Cl (u/a), Qz, Ca	0.03 (2)	0	0
			Cl (u/a), Qz, Ca	0.03 (1)	0	0
		M-14	Cl (u/a), Qz, Ca, Ar	0.02 (1)	0	0
			Cl (u/a), Ca, Qz	0.02 (1)	0	0
		M-15	Cl (u/a), Ca, Qz, Ar	0.03 (3)	0	0
			Cl (u/a), Qz, Ca	0.02 (2)	0	0
Intra-site deposits	**Atlit-Yam**	AY-44	Cl (u/a), Ca, Qz	1.72 (214)	16.00 (144)	0
			Cl(a), Ca, Qz, CHAP	3.57 (341)	4.52 (89)	0
			Cl (u/a), Qz, Ca, CHAP	2.43 (326)	0.81 (18)	0
			Cl (u/a), Qz, Ca, CHAP	3.02 (384)	1.00 (24)	0
			Cl (u/a), Qz, Ca	5.90 (655)	0.53 (10)	0
		AY-64	Cl (u/a), Qz,Ca	0.21 (28)	0	0
			Cl (u/a), Qz, Ca	0.32 (38)	0.03 (2)	0.10 (4)
		AY-65	Cl (u/a), Ca, Qz, CHAP	0.60 (85)	0.24 (8)	0.10 (8)
			Cl (u/a), Qz, Ca	0.54 (65)	0.18 (7)	0.06 (2)
		AY-66	Cl (u/a), Ca, Qz	1.00 (124)	0	0.02 (1)
			Cl (u/a), Qz, Ca	0.50 (70)	0	0
		AY-67	Cl (u/a), Ca, Qz, CHAP	0.73 (87)	0	0.40 (21)
			Cl (u/a), Ca, Qz, CHAP	1.00 (119)	0.02 (1)	0.20 (11)
		AY-68	Cl (u/a), Ca, Qz	0.22 (32)	0	0
			Cl (u/a), Qz, Ca	0.34 (30)	0	0
		AY-69	Cl (u/a), Ca, Qz, CHAP	0.04 (4)	0.22 (6)	0
			Cl (u/a), Ca, Qz, CHAP	0.08 (6)	0.03 (1)	0
	Neve Yam	NY-40	Cl (u/a), Ca, Ar, Qz, CHAP	0.42 (48)	0.41 (10)	0.30 (9)
			Cl (u/a), Ca, Ar, Qz, CHAP	0.50 (47)	3.00 (64)	0.03 (2)
			Cl (u/a), Qz, Ca, Ar, CHAP	0.70 (83)	0.28 (10)	0
		NY-41	Cl (u/a), Ca, Qz, CHAP	0.34 (27)	0	0
			Cl (u/a), Qz, Ca, CHAP	0.80 (76)	0.52 (7)	0
			Cl (u/a), Qz, Ca, CHAP	1.04 (113)	0.12 (8)	0
		NY-42	Cl (u/a), Qz, Ca, CHAP	1.52 (147)	0	0
			Cl (u/a), Qz, Ca, CHAP	1.00 (123)	3.00 (74)	0.20 (12)
			Cl (u/a), Qz, Ca, CHAP	1.24 (129)	0.42 (10)	0
		NY-43	Cl (u/a), Qz, Ca, CHAP	0.60 (46)	1.21 (23)	0.20 (10)
			Cl (u/a), Qz, Ca, CHAP	0.42 (36)	3.23 (54)	0.07 (2)
			Cl (u/a), Qz, Ca, CHAP	0.70 (74)	1.24 (19)	0.10 (4)
Water jetting experiment	**Kfar Samir 2**	KS-36	Cl (u/a), Ca, Qz	0.03 (2)	0	0
			Cl (u/a), Ca, Qz	0.02 (2)	0	0
		KS-37	Cl (u/a), Ca, Qz	0.04 (3)	0	0
			Cl (u/a), Ca, Qz	0.04 (3)	0	0
		KS-38	Cl (u/a), Ca, Qz	0.03 (2)	0	0
			Cl (u/a), Ca, Qz	0	0	0
		KS-39	Cl (u/a), Ca, Qz	0.05 (3)	0	0
			Cl (u/a), Ca, Qz	0.02 (2)	0	0

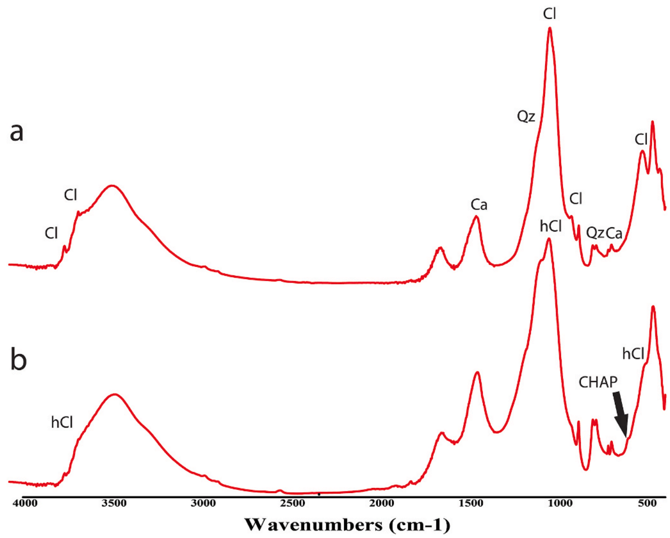

Fig. 6. FTIR spectra showing the mineralogical composition of natural paleosols and intra-site deposits. a) Representative spectrum of a natural paleosol (sample KS-4) noting absorbance bands typical of clay (Cl), quartz (Q) and calcite (Ca). b) Representative spectrum of an intra-site deposit (sample NY-40) noting absorbance bands typical of heated clay (hCl) and carbonated hydroxylapatite (CHAP) in addition to calcite and quartz.

fragments per cm^2 of the thin section while they are absent in the natural paleosols (that sometimes include natural, rounded, flint grains).

5. Discussion

The methodology described in this study is suitable for coastal as well as shallow and deep waters, based on a set of reliable, relatively 'cheap' sampling materials and tools, and routinely accessible laboratory techniques. The set of techniques applied here made it possible to differentiate anthropogenic from natural deposits with high certainty. Macroscopic archaeological materials (e.g., charcoal, bone, flint, pottery, heated clay lumps) are absent in the natural paleosol. As cores of small diameter (such as the 5 cm used in this study) may randomly include only sporadic macroscopic finds, the microscopic archaeological record becomes a useful tool to detect human activity remains. The method reported here is based on several key microscopic determinations for such cores: mineralogical composition of deposits as well as micro-remains that represent human activity, namely phytoliths, dung spherulites and ash pseudomorphs. The method works through comparison between unequivocal natural deposits and those suspected to carry anthropogenic signals. Here, we first set the stage by showing that submerged natural deposits are characterized by unheated clay, quartz and calcite, negligible concentrations of phytoliths (practically absent), and complete absence of dung spherulites and ash pseudomorphs. Our set of intra-site sediment samples differs from the natural paleosol by: (a) Having a higher variability of minerals, including CHAP together with clay, quartz and calcite. In certain locations the abundance of quartz is higher than in the natural paleosols, and in others the clay component is altered by heat. The origin of CHAP is probably from microscopic bone fragments (observed via micromorphology; see below). (b) Having significantly high concentrations of phytoliths. (c) Having dung spherulites, albeit in low concentrations. (d) Having low to moderate concentrations of ash pseudomorphs. The variable mineralogy and concentrations of micro-remains probably relate to activity areas and site structure (more below). (e) Having distinctive micromorphological characteristics that were not detected through the bulk analyses, such as micro-charcoal and abundance of micritic calcite.

Micromorphology can be used to detect most parameters identified through bulk analyses, including macroscopic remains such as flint and pottery. However, micromorphology cannot be used to quantify phytoliths, dung spherulites and ash pseudomorphs, and to determine whether or not clay has been heated and to what range of temperatures. We provide here point-count values that reflect the concentration of micro-charcoal, micro-bone, and micro-flint fragments. All quantitative parameters can be used for comparison with other submerged (and terrestrial) sites worldwide, serving as proxy for anthropogenic presence and site prospection. Micromorphology can further inform on site

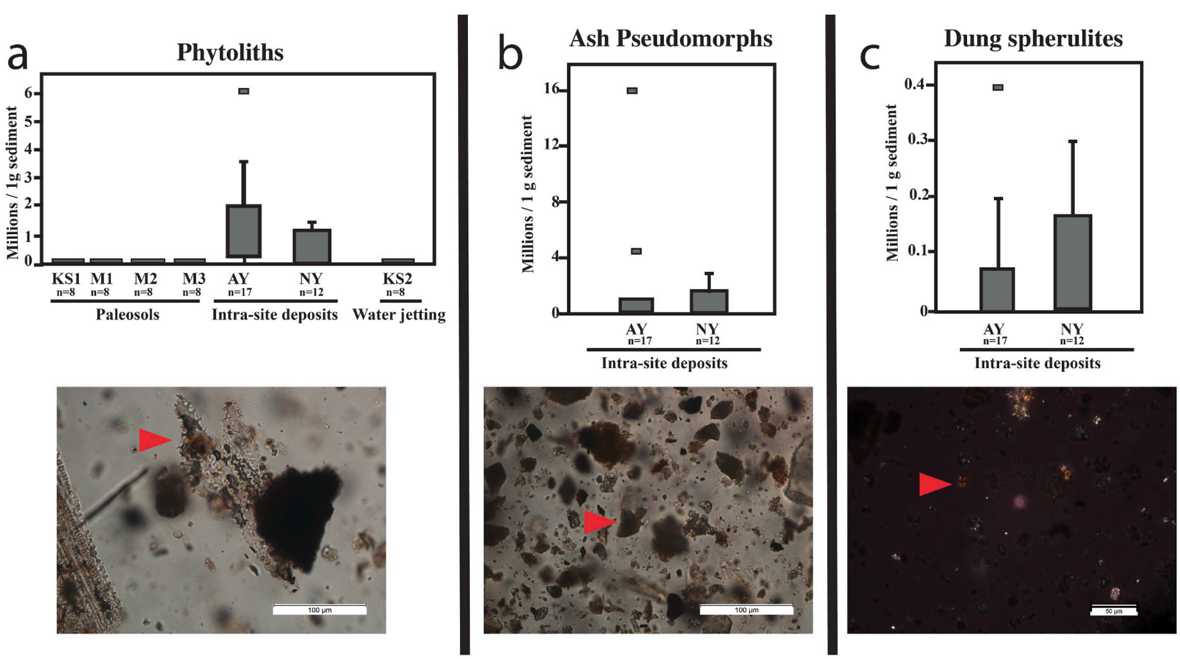

Fig. 7. Anthropogenic micro-remain images (bottom) and concentrations (top). a) Phytoliths (image in PPL). b) Ash pseudomorphs (image in PPL). c) Dung spherulites (image in XPL). The boxes show the data in relation to their interquartile range (IQR: Q_1 to Q_3), the whiskers indicate the variability (1.5IQR). Outliers are marked as well. Note the negligible concentration of phytoliths and absence of ash and dung micro-remains in the natural paleosols relative to their abundance in the intra-site deposits. Note also that the samples from the 'blind test' water jetting produced results similar to those of natural paleosols.

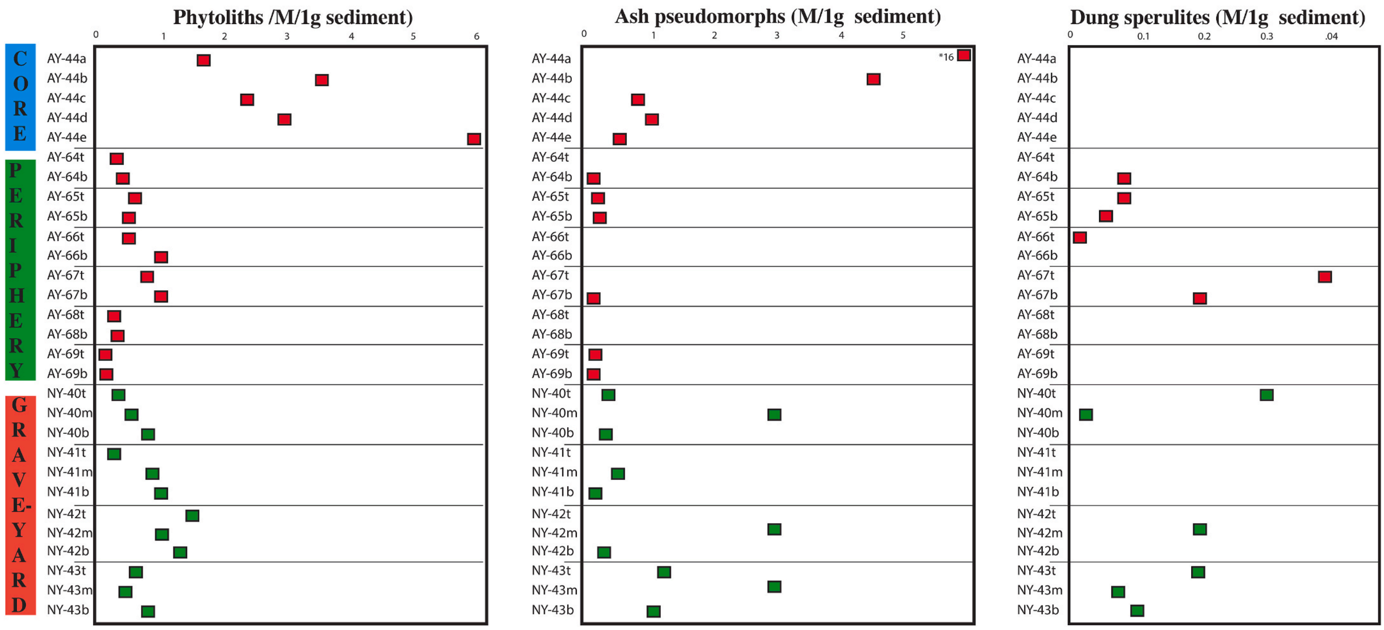

Fig. 8. Spatial and temporal (depth) distribution of micro-remain concentrations in the intra-site deposits (red squares: Atlit Yam; green squares: Neve Yam). Analyses were conducted according to core stratigraphy: AY-44 top to bottom (a–e), other samples sampled at the top (t), middle (m), and bottom (b). a) Phytolith concentrations. b) Ash pseudomorph concentrations. c) Dung spherulite concentrations. Note that meaningful differences are only those showing at least one order of magnitude, i.e., meaningful differences in phytolith concentrations exist between AY core and periphery, in ash pseudomorph concentrations between AY core and periphery as well as within NY deposits, and in dung spherulite concentrations between AY core and periphery as well as within NY deposits. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

formation processes (e.g., whether deposits are intact or disturbed).

The method presented here may be applicable to the detection of anthropogenic signals embedded in submerged paleosols detected by remote sensing methods in Israel and worldwide. Calcitic micro-remains (i.e., dung spherulites and ash pseudomorphs) dissolve in acidic or neutral depositional environments, thus they are better preserved in dry caves, rock shelters or sites in arid environments. However, they also occur in various open-air sites (Gur-Arieh and Shahack-Gross 2020). Opal phytoliths are durable in deposits with pH ranging ca. 4–10, yet they are known to have differential partial dissolution which can affect interpretation (Cabanes and Shahack-Gross 2015). Preservation of these signals in submerged environments will probably depend on local parameters, such as paleosol pore water pH. Where pH is acidic due to large amounts of organic matter and/or pyrite oxidation (Canti 2000), we do not expect preservation of the calcitic micro-remains, such as ash pseudomorphs, dung spherulites (Gur-Arieh and Shahack-Gross 2020) and bones (Cliquet et al., 2011: 112). Where pH is buffered by seawater, we expect all macro- and micro-remains to persist. Therefore, we propose that in each locality to be investigated in the future, baseline parameters should first be established from unequivocally natural deposits. After having this set of criteria established, underwater survey by manual coring (where possible), or water jet core drilling in the case of sand cover, can take place, followed by laboratory analyses.

The reported method refines previous trials to recognize anthropogenic signals in inundated environments. The pioneering study of Murphy (1990) utilized an approach similar to that presented here, yet, it focused on soil-science techniques (particle size analysis, sieving, and bulk chemical analysis to detect anthropogenic elements). These, inherently, do not focus on anthropogenic micro-remains and indeed Murphy (1990; as well as the precursor study of Gagliano et al., 1982) dismissed the importance of particles smaller than 2 mm. We show here that some of the important anthropogenic remains for site prospection are in fact the smaller, silt-size, fraction (phytoliths, ash pseudomorphs and dung spherulites).

Results from future underwater surveys are expected to vary in relation to cultural periods and site characteristics. For example, dung spherulites (characteristic to herbivorous livestock) are not expected to be present in sites that predate the Neolithic or where livestock rearing did not take place. Because we developed the method in submerged sedentary settlements, where prehistoric traces are abundant, it is expected that in order to detect ephemeral sites, where prehistoric remains are scarce, a denser network of cores should be applied. We also expect the method to be useful for the detection of pre-Neolithic sites, where intensive use of open space took place and especially repetitive use of fire.

The method is not limited to the mere detection of archaeological sites. The variable concentrations of micro-remains found in the submerged settlements may be further used to inform and focus research of site structure and activity areas and for detecting the perimeter of the sites buried under the sand. For example, in Atlit-Yam one core (AY-44) includes high concentrations of ash pseudomorphs and phytoliths associated with heated clay. The sample was collected from an open area among submerged structures with no visible anthropogenic remains. In terms of site occupation intensity, sample AY-44 was collected in the settlement's center and has the strongest and most varied anthropogenic signals among all samples from this site (Fig. 8). The cores collected along the transect at the site's edge have lower micro-remain concentrations that may relate to less intensive human activity at the site's periphery. As micro-remains still occur in the easternmost core, it can be concluded that the transect did not surpass the limit of human activity at Atlit-Yam (corroborated by presence of architectural features). At Neve Yam samples taken from the center of the site, phytolith concentrations are similar to those obtained along the transect in Atlit-Yam, while ash pseudomorph and dung spherulite concentrations appear (in a few samples) to be at substantially higher concentration (Fig. 8). It is worth noting that in 3 of the 4 cores from Neve Yam, the concentrations of ash pseudomorphs are higher in the middle layer. Such an observation may be used for planning of future excavations. Lastly, we note that dung spherulite concentrations in Neve Yam are extremely low. Given that the Neve Yam site represents a fully agricultural economy, including animal husbandry, the scarcity of dung spherulites may be explained by dissolution of these microscopic particles under inundation (e.g., low pH due

Table 3
Micromorphological quantifications. Quartz grains are medium sand sized and subrounded in all samples. They differ in abundance, expressed as % within the deposit groundmass (based on abundance charts; Stoops 2003). Carbonatic components are sand sized and rounded (rarely subrounded). They differ in origin and abundance. Abundance of humified organic matter is expressed as % within the deposit groundmass. Fragments of charcoal, angular flint and bone that are of fine to coarse sand size (0.15–1 mm) are presented as concentrations (number of fragments per 1 cm^2 of the thin section). The presence or absence of micro-remains (phytoliths, ash pseudomorphs and dung spherulites) as well as clay lumps is noted.

Sample n°	Quartz abundance	Carbonatic components (calcite and aragonite)	Humified organic matter	Charcoal (n°/per cm^2 of sample on thin section)	Angular flint (n°/ per cm^2 of sample on thin section)	Bone (n°/per cm^2 of sample on thin section)	Micro-remains (phytoliths, ash pseudomorphs, dung spherulites)	Clay lumps
KS-4	20%	Limestone, micritic calcite, shells (5%)	1%	0	0	0	No	No
M-1	20%	Chalk, limestone, micritic calcite, kurkar, shells (5%)	1%	0	0	0	No	No
M-4	20%	Chalk, limestone, micritic calcite, kurkar, shells (5%)	1%	0	0	0	No	No
M-2	20%	Chalk, limestone, micritic calcite, shells (sand, rounded 5%)	1%	0	0	0	No	No
M-6	20%	Chalk, limestone, micritic calcite, shells (5%)	1%	0	0	0	No	No
M-9	20%	Chalk, limestone, micritic calcite, shells (5%)	3%	0	0	0	No	No
M-13	20%	Chalk, limestone, micritic calcite, shells (5%)	3-%	0	0	0	No	No
AY-44	30–60%	Chalk, limestone, micritic calcite (ash), shells (15–20%)	5–20%	10	4	5	Yes	Yes
AY-65	50%	Limestone, micritic calcite (ash), shells (20%)	5%	4.1	2	2	Yes	Yes
AY-67	50%	Limestone chalk, kurkar, micritic calcite, shells (15%)	5–10%	12	2	0	Yes	Yes
AY-68	50%	Limestone, micritic calcite, shells (10%)	5–10%	10	2	4	Yes	Yes
AY-69	50%	Limestone, chalk, micritic calcite (ash) (15%)	5–10%	3.4	2	2	Yes	Yes
NY-40	50%	Limestone, chalk, kurkar, micritic calcite (ash), shells (50%)	5–10%	12	1	6	Yes	Yes
NY-41	50%	Limestone, chalk, kurkar, micritic calcite (ash), shells (50%)	5–10%	15	1	5	Yes	Yes

to pyrite oxidation; Canti 2000:270; Macphail and Cruise 2000:269), or due to wet-dry cycles of the intertidal zone, with only very few surviving post depositional processes.

The micro-geoarchaeological characteristics of the sediments retrieved below a sand deposit using the newly developed water jet coring system are similar to those of natural paleosols, implying that there are no settlement remains in the test locality.

6. Conclusion

The method presented here was developed and tested for detecting and studying submerged prehistoric settlements in shallow water (1–12 m depth); however, it may be useful to advance submerged prehistory on a larger scale or in deeper waters.

The method could be applicable for identifying unknown submerged prehistoric landscapes and sites off the Israeli coast and help to estimate the spatial distribution of known sites.

This method can be used worldwide for checking archaeological sites detected by industrial activities and remote sensing devices. For example, site A240 in Britain with archaeological material dating to 0.5 My BP, was identified by industrial coring 11 km off the coast and between 16 and 30 m bsl with low visibility, and spreading over an area of 3.1 km^2 (Tizzard et al. 2011). The method presented here may be useful for management and monitoring of the heritage and as a 'rescue archaeology' for such sites, collecting as much information as possible at relatively low cost and little time investment at sea. This approach can be further developed to work together with the industry (Missiaent et al., 2017), as well as with other methods (e.g., Filipova-Marinova et al., 2011). It will not only allow to detect sites but also to study them.

The new method may contribute to geoarchaeological studies which made significant methodological and theoretical advances in the last decades (Shahack-Gross 2017) and to maritime archaeology including harbors (Marriner and Morhange 2006; Morhange et al., 2016; Linderholm et al., 2021) and shipwrecks (Quinn 2006). It adds to the few geoarchaeological studies that have been done on submerged prehistoric sites (e.g., Macphail et al., 2010; Ismail-Meyer 2014; Faught 2014; Faught and Gusick 2011) and may further contribute to recognize the extension of submerged settlements based on microartifact spread and to the identification of activity areas in submerged settlements such as the pioneering study of Sill et al. (2016).

The time devoted for underwater sampling totaled one day in each location. The net time devoted for laboratory analyses was about one week per sampled locality, yet it should be taken into consideration that impregnation of micromorphological samples may take up to one month

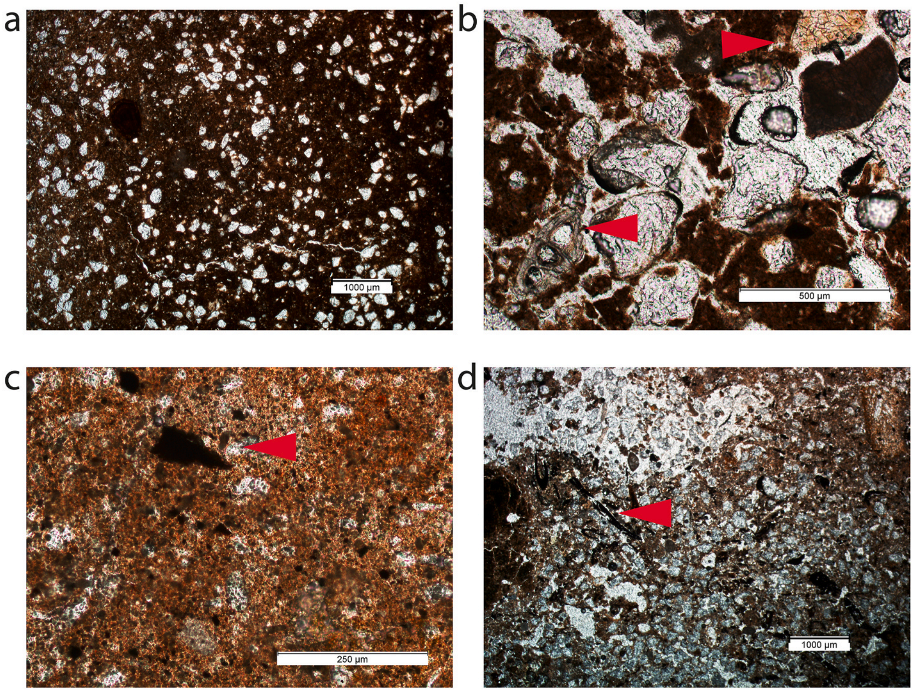

Fig. 9. Micromorphology of natural paleosols and intra-site deposits (all in plane polarized light; PPL). a) Groundmass of paleosol showing typical presence of quartz grains. b) Rock (greyish-brown fragment in upper right, arrow) and shell fragments (arrow) in natural paleosol. c) Humified organic matter in natural paleosol. Arrow points at a large fragment but note abundance of smaller dark particles. d) Groundmass in an intra-site deposit showing higher abundance of quartz grains relative to natural paleosols. Note also presence of charred (probably grass) fibers (arrow). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

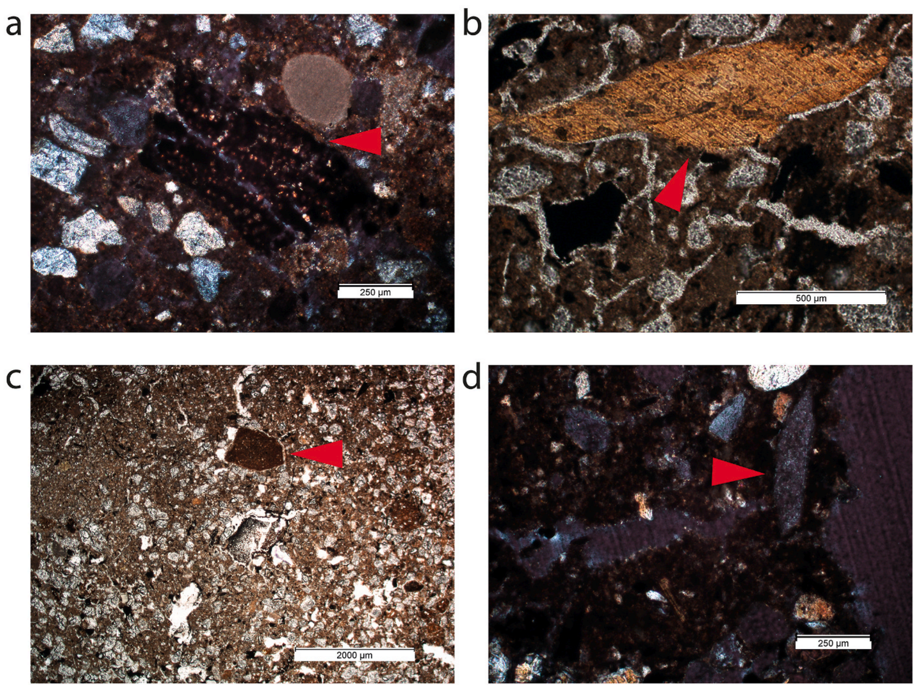

Fig. 10. Microscopic anthropogenic materials identified in intra-site deposits. a) Charcoal fragment with calcium oxalate crystals (orange dots) still embedded within (cross polarized light; XPL, arrow). b) Bone fragment, PPL (arrow). c) Clay lump (pottery/mudbrick fragment?) (arrow), PPL. d) Angular flint fragment, XPL (arrow). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

and thin section preparation may also take several weeks depending on production turn-around time. The overall cost of laboratory analyses was in the order of a few hundred dollars per locality. The new method is therefore time- and cost-effective, yet it requires significant expertise in micro-geoarchaeology.

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