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Holocene tsunamis from Mount Etna and the fate of Israeli Neolithic communities

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[1] Field evidence reveals that the Neolithic village of Atlit-Yam (Israeli coast) was destroyed in an event which also caused the sudden death of tens of inhabitants. Archaeological evidence and numerical simulations support the notion that the village was destroyed, ~8.3 ka B.P., by a tsunami triggered by a known Holocene flank collapse of Mt. Etna volcano (Italy). The filling of a water well within the village confirms inundation by a tsunami wave train and a sediment layer, composed of a clayed-sandy matrix and other detritus including reworked marine sediment, indicates tsunami inundation. This scenario shows that tsunamis generated by sector collapses from coastal volcanoes can seriously threaten near-shore settlements thousands of kilometres distant from the tsunami source. **Citation:** Pareschi, M. T., E. Boschi, and M. Favalli (2007), Holocene tsunamis from Mount Etna and the fate of Israeli Neolithic communities, *Geophys. Res. Lett.*, *34*, L16317, doi:10.1029/2007GL030717.

1. Introduction

[2] Atlit-Yam is a prehistoric village, today located on the sea floor at a depth of 8–12 m, offshore of the current Israeli coast. Its remains are embedded in the upper layer of a dark clay which fills a submerged trough bounded by two aeolian calcarenite ridges [*Galili et al.*, 1993; *Sivan and Porat*, 2004] (Figure 1a). In the early Holocene the current coastline was located further to the west. Sea level rise, associated to ice-volume changes following the last Glacial Maximum (ca. 19 ka) [*Bard et al.*, 1990], caused flooding of low lying areas so that Neolithic settlements on the Israeli palaeoshore were inundated and new settlements became established along the new shoreline. However, field evidence indicates a more sudden ingress of sea-water as the cause of Atlit-Yam's demise. The exceptional conservation of the archaeological remains at Atlit-Yam allows insight into the life of this Neolithic village during the time of destruction. Village activities included fishing, incipient animal domestication and herding, hunting, agricultural activities [*Galili et al.*, 2002, 2004]. However, geological and archaeological evidences indicate that these activities came to a sudden and catastrophic end.

2. Review of Field Data

[3] The Atlit-Yam site has been described in detail by *Galili et al.* [1993, 2005, and references therein]: here we review some key lines of evidence that point to a sudden demise of the village, and the cause of that demise. First, the site is covered by a hardened clay layer which allowed the preservation of cultural artefacts, animal bones, botanical material and human remains, as discussed below. Second, no vertical age-dependent stratification of cultural remains is there observed but a horizontal mosaic, older relicts mixed with younger material, the latter (= the majority) dating around 8.4 ± 0.1 ka B.P. (aging/times are calibrated values, unless otherwise stated). Finally, no paved or plastered (i.e. trampling) floor can be discerned just below the clay upper surface [*Galili et al.*, 1993, 2002]. Within the remains, clues from the arrangement of three types of fossilized anthropogenic material are particularly instructive when trying to determine the fate of this flooded village: (1) a concentration of fish bones and cereal (found at *Locus 10/A* in Figure 1b) [*Galili et al.*, 2004]; (2) a water well (structure *n. 11* in Figure 1b) [*Stanley and Galili*, 1996]; and (3) human remains [*Hershkovitz and Galili*, 1990; *Galili et al.*, 2002].

2.1. Fish Bones and Cereal Concentration

[4] These remains consist of: (1) 175 litres of well preserved fish remains, (2) 10 litres of well preserved seeds comprising domesticated charred cereals and associated weeds, and (3) other organic and inorganic remains. These latter materials include human bones, as well as sheep, goat and cattle bones, and flints. Some of the fish bones are also blackened by fire. The distribution of the fish remains forms a bent, upward enlarging cone, with the remains concentration being densest along the cone axis (Figure 1c). The cone is orientated in a NE-SW direction and extends from (a not yet fully excavated) fire hearth located few decimetres below the surface of the clay layer. A lens-shaped zone of wheat seeds occurs at the top core of the fish remains cone (Figure 1c). These remains have been $^{14}C_{cal}$ dated at 8,340 ± 80 ka B.P. [*Galili et al.*, 2002]. Although this small zone of seeds has a sharp and well defined border, no evidence of a container which may have housed the seeds has been found [*Galili et al.*, 2002, 2004]. The distribution of the fish remains and wheat seeds does not appear consistent with a naturally accumulating concentration, nor with their collection in a refuse pit. However, their condition and placement seem consistent with preparation and storage; the fish being split, gutted and spread (without spine removal), with the wheat assembled alongside them for future use and consumption [*Galili et al.*, 2004]. However, some points remain unresolved. It is unclear why the villagers did not consume this stored food, and why human bones lie beside this apparent food store. In addition, it is difficult to ascribe a natural or human scenario to such a distribution of the remains, embedded in the clay, with the fish parts apparently being thrown away from the hearth, with some remains penetrating below it (Figure 1c). In addition, although the presence of a

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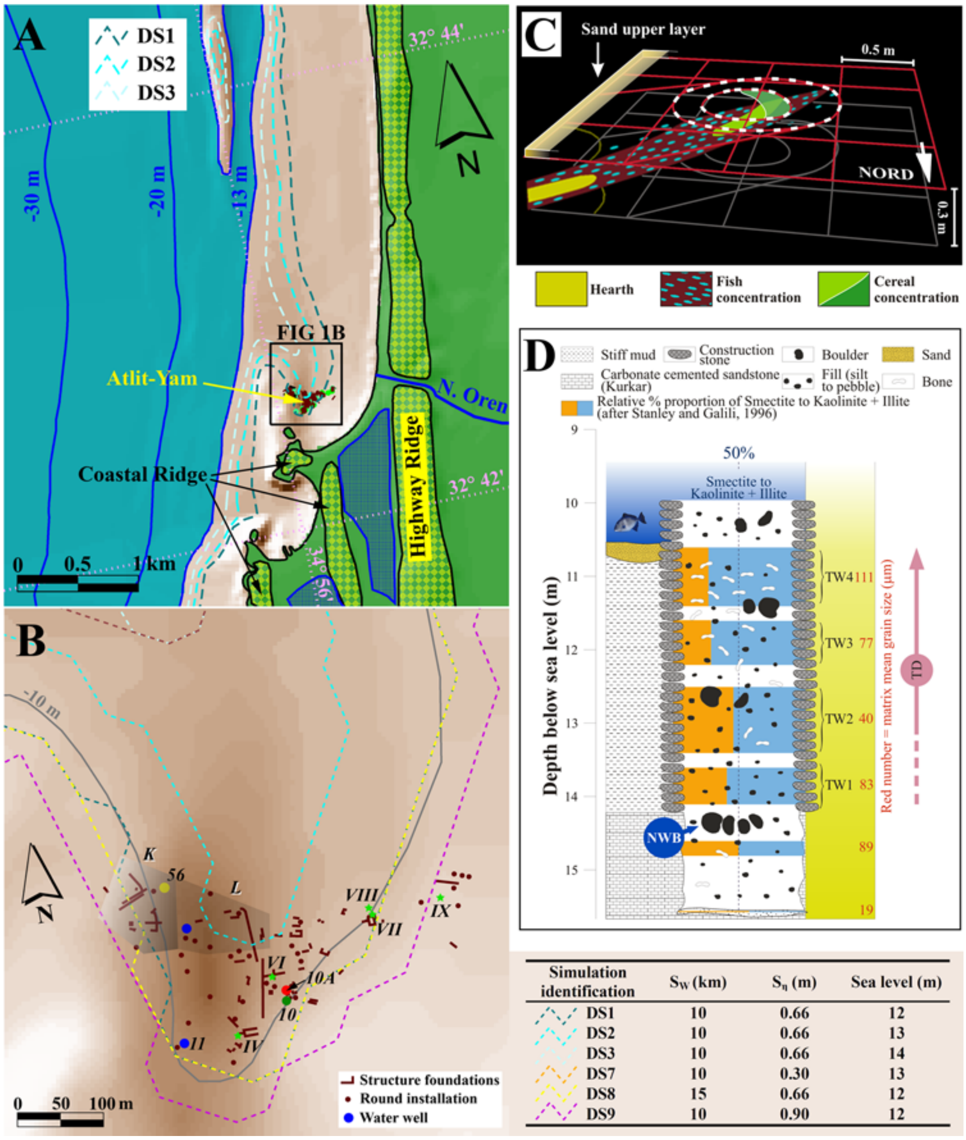

Simulation identification	S_W (km)	S_η (m)	Sea level (m)
DS1	10	0.66	12
DS2	10	0.66	13
DS3	10	0.66	14
DS7	10	0.30	13
DS8	15	0.66	12
DS9	10	0.90	12

Figure 1. (a) Map of the Atlit-Yam area. Green areas are currently a.s.l. Yellow-green areas are ridges. About 8.5–8.3 ka B.P., a coastal plain area was exposed (brown region), today submerged. The box FIG 1B locates Figure 1b. Dotted blue-azure lines are the maximum estimated inundation of our detailed simulations: DS1, DS2, and DS3 (table in Figure 1b). (b) Human bones mentioned in the text are marked by Roman numbers; Latin numbers identify installations; in areas *K* and *L* (highlighted as brown shading) a great number of human remains were found [after *Galili et al.*, 2005]. Maximum estimated inundation zones of some detailed simulations are according to the table's key (bottom right inset). Positive input crest width (S_w) and height (S_η) of DSn simulations (Text S2) are listed in columns 2 and 3 of the table; a sea-level lower than the present one was used (column 4). (c) Cereal and fish concentration at *Locus 10/A* projected onto a vertical and horizontal plane [after *Galili et al.*, 2004]. (d) Well stratigraphy [after *Stanley and Galili*, 1996]. We suggest that TW1, TW2, TW3, and TW4 possibly identify four tsunami waves in tsunami deposit TD. Aligned stones at NWB probably identify a well bottom [*Galili and Nir*, 1993].

long-perished, organic, container may explain the sharp edges of the seed zone, the fact that they are charred is again difficult to explain. Finally, at this location, as at others across the village, the absence of a village trampling floor just below the clay upper surface contrasts with the high preservation of all the other excavated cultural remains.

2.2. Water Well

[5] This shaft was completely filled. Below a superficial sandy stratum, the lower (3 m thick) well fill (TD) comprises a clay mixed with sandy soil matrix, of fluvial and marine origin [*Stanley and Galili*, 1996] (Figure 1d). The deposit contains sparse small boulders and cobbles (0.15–0.35 m) and numerous smaller cobble to gravel grade clasts including thermally fractured limestone pebbles. The clay assemblage of this layer comprises kaolinite plus illite, with minor smectite (Figure 1d). The well fill TD sequence is vertically stratified, showing variations in both matrix and embedded remains that define the following main units: (1) Multiple layers in the clay assemblage, characterized by different proportions of smectite and illite + kaolinite as well as average grain-sizes (Figure 1d).

(2) Many animal bones (some articulated), marina fauna and water-logged and charred plant remains occur in the uppermost two meters. In comparison, only a few (none articulated) animal bones and plant remains occur in the lowermost, one meter thick, portions of TD. Faunal remains consist of wild animal bones (including small reptile and rodent fauna), adult and immature domesticated animal bones (including dog, cattle, goat and pig bones), shallow marine fauna (foraminifera and molluscs), some fish bones, and insects. In addition fragments of human bones are present [*Galili et al.*, 2004; *Kislev et al.*, 2004]. ^{14}C dating reveals a confused situation, with no clear chronological/vertical stratigraphic order [*Galili et al.*, 2002]. Below TD, the lowest well stratum contains a few animal bones and flint remains; moreover smectite prevails in the clay assemblage. This deeper stratum (below aligned stones identified as NWB in Figure 1d) was interpreted as the normal fill for an active well operating in the framework of a fast rising sea [*Galili and Nir*, 1993]; in contrast, TD stratum has been interpreted as refuse pit [*Stanley and Galili*, 1996]. However, some interpretive problems remain. *Stanley and Galili* [1996] postulated that, in the clay assemblages of the well, illite was primarily derived from lateral source terrains, kaolinite from marine sediments from the North, and Nilotic smectite was transported from the South, along the Nile littoral cell, by longshore currents. To explain the kaolinite + illite dominance over smectite during the period when the well was inferred to have been used as a refuse pit (stratum TD), *Stanley and Galili* [1996] hypothesized a reverse (in respect to the present) North-to-South coastal current down the Northern Israeli coast (Text S1 of the auxiliary material).[1] However, at the well-bottom the dominance of Nilotic smectite should support a re-reversed South-to-North circulation. Moreover, it seems strange that, along the Israeli inner shelves, marine circulation should have switched three times in Holocene, and somewhat suspicious that one of the changes apparently occurred just as the well became used as a refuse pit. Other difficulties in explaining the well sequence arise from: (1) the confused date ordering obtained from analysis of the organic remains; (2) the transition between a layer containing few animal bones to one containing many animal bones, at which point a change occurs from non articulated to both articulated and not-articulated bones; (3) the relatively high frequency of immature domesticated animals, when we expect consumption of domesticated adult animals for food resource maximum exploiting; and (4) the occurrence of thermally fractured limestone pebbles. (5) Bones of small animals (rodents, small reptiles, etc.) found in the well cannot be food remains because they are too fragile to survive integral or survive at all if eaten by men or dogs. (6) Finally, the presence of human bones is extremely strange because tradition was to bury human corpses [*Galili et al.*, 2005, and references therein], not to throw them into a refuse pit.

2.3. Human Remains

[6] Sixty-three human skeletons have been discovered at the site. These range from intact and nearly complete skeletons to a few fragmentary bones, both articulated and no. The human remains are spread all around the village, being found both inside and outside of dwellings and in open areas. Some skeletons (37 cases) have been interpreted as "primary burials", because largely articulated, flexed and almost intact [*Galili et al.*, 2005]. Others clearly resemble non-burial positions and occur with various settings with arrangements spanning from isolated (single) skeletons to groups of bones from several individuals. These include for example: (1) an isolated hemi-skull (*Homo VI*), (2) two pieces of the maxilla of a juvenile (relicts of *Homo IV*) in close proximity to one another, (3) a mature male (*Homo VIII*) lying near a child of 2–3 years in age (*Homo VII*), and (4) a few pairs of children's skulls in close proximity to one another [*Galili et al.*, 2002; *Hershkovitz and Galili*, 1990] (Figure 1b). Human remains are embedded or partially embedded in clay deposits or in carpets of field stones; sometimes a trampling floor is clearly detectable below them [*Galili et al.*, 2002, 2005; *Hershkovitz and Galili*, 1990]. Other organic or inorganic remains often occur near, under and above the human remains. Several bone fragments have shell encrustations. Some human bones are partly burnt and some bones of *Homo IX* lie below a pile of charcoal [*Hershkovitz and Galili*, 1990; *Galili et al.*, 2005].

[7] No birds were found in the archaeological funding [*Galili et al.*, 2002].

3. Tsunami Hypothesis

[8] All of these findings can be explained in terms of a tsunami, funneled into the village from the NE and following the inter-ridge trough within which Atlit-Yam was sited (Figure 1a, Text S1). In the ninth millennium B.P., Atlit-Yam was located some hundred meters inland [*Galili et al.*, 1993] (Figure 1a). This distance is comparable with observed tsunami penetrations at other sites [*Jaffe et al.*, 2006], and the presence of the off shore structure would have promoted tsunami funneling and wave concentration [*Bondevik et al.*, 2005]. In a tsunami event, deposition of extensive/massive metric-thick strata of sediments, discontinued sediment accumulations and erosive areas can occur [*Dawson and Shi*, 2000]. In addition, damage from a tsunami is often most marked at sites where there have been some degree of human disturbance of the environment [*Goff et al.*, 2006]. While all this suggests that Atlit-Yam was a location of high tsunami hazard, it also explains the scattered distribution of remains embedded in an upper layer of inhomogeneous hardened clay as follows.

[9] (1) A tsunami can scour a village floor [*Gelfenbaum and Jaffe*, 2003], removing it and thereby explaining why no a trampling floor was found in many places in Atlit-Yam.

[10] (2) Evidence of deep inland penetration and backwash is usually explained by the incorporation, within the tsunami deposit, of sediments derived from in-shore slopes [*Dawson and Shi*, 2000]. While this would explain the illite fraction in the clay assemblage of Atlit-Yam well, the apparent circulation anomaly outlined by *Stanley and Galili* [1996] could consist in the tsunami passage.

[11] (3) Multiple normal and inversely graded beds [*Gelfenbaum and Jaffe*, 2003] occurring in the well also suggest passage of multiple tsunami waves. Paleodeposits

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[1] Auxiliary materials are available in the HTML. doi:10.1029/2007GL030717.

of the Storegga tsunami (Norway) show patterns of chaotic sedimentation with marine sediments resting adjacent to layers of terrestrial turf and twigs. In addition, in the organic detritus facies, large and heavy fragments (including water-logged wood fragments, seeds, cones, etc.) are expected in a tsunami deposit [*Bondevik et al.*, 1997]. Moreover, on-land, tsunami currents may cause incorporation of terrestrial sediments including plant macrofossils into the sediment assemblage, thus complicating paleoenvironmental interpretation [*Dawson and Shi*, 2000]. As a consequence, the tsunami-filled well of Atlit-Yam would resemble a refuse pit, with the chaos introduced by the tsunami passage causing the jumbled dating sequence.

[12] (4) A tsunami occurring in a clay environment is known to preserve detritus [*Schlichting and Peterson*, 2006]. In line with this, the clay matrix of the upper few meters of the Atlit-Yam well, i.e. the stratum above the aquifer level at tsunami-time, displays well preserved (and very fragile) organic remains, including those of pest beetles in seeds. In contrast, below the aquifer level, more intense deterioration occurred in the tsunami deposit, erasing a large fraction of organic remains.

[13] (5) Foraminifera and other marine and terrestrial fauna found in the well are also consistent with a tsunami deposit [*Dawson and Shi*, 2000]. During its inland penetration a tsunami is fast enough to capture small terrestrial reptiles and rodents, but not birds.

[14] (6) The fish and cereal distribution at *Locus 10/A* can be explained by their incorporation within a tsunami flow. This washed from NE to SW over the structure on which they were arranged/stored. While tsunami debris can wrap around or pile up against immobile objects [*Gelfenbaum and Jaffe*, 2003], around the edges of buildings tsunami scour can be so severe to cause undermining and structural damage [*Jaffe et al.*, 2006]. Therefore the passage of a tsunami around the hearth structure at *Locus 10/A* can well explain scouring and the presence of fish remains embedded in the clay tsunami deposit, partially underlying the hearth itself (Figure 1c).

[15] (7) The upper portions of Atlit-Yam dwellings appear disrupted by tsunami passage. As in recent cases [*Jaffe et al.*, 2006], only the foundations of poorly constructed buildings and traces of wall courses remained.

[16] (8) At Atlit-Yam, incrustations of calcareous shells partially covering some bones [*Hershkovitz and Galili*, 1990], testify permanent marine incursions close to the tsunami event, may be by it favored.

[17] (9) Wet some-decimeters-thick water-saturated clay layers take months to completely dry [*Ringrose-Voase et al.*, 2000]. During such time anaerobic oxidation of organic detritus darkened the tsunami mud layer covering the village ruins.

[18] (10) A tsunami directly injures human victims by blunt trauma and penetrating objects [*Keim*, 2006]. In the 2004 Sumatra event, people were bludgeoned by concrete slabs and felled trees, stabbed by jagged sheets of metal and glass, tangled up in manacles of wire and impaled on tree limbs and bamboo. Soil, small pieces of wood, glass, and metal in the contaminated saltwater penetrated soft tissue at high velocity. Further causes of death included drowning or entrapment inside collapsing buildings [*Keim*, 2006]. Bricks, flints, plant matter, pebbles and stones thus provided lethal debris for human beings and animals at Atlit-Yam. Indeed, at Atlit-Yam, some bone break patterns could indicate impact, as does the loss teeth, or presence of broken teeth, in *Homo VIII*. According to *Hershkovitz and Galili* [1990] these likely occurred immediately post-mortem or just before death.

[19] (11) Even the burnt remains scattered all around the village [*Galili et al.*, 2005] can be explained by tsunami passage. Fires can spread through a city struck by a tsunami, originating from hearths, firesides, etc., as recounted by Charles Davy in his chronicle of the 1755 Lisbon earthquake and related tsunami (http://www.fordham.edu/halsall/mod/1755lisbonquake.html). However, fires at Atlit-Yam resemble localized events involving organic material. This can be explained in terms of spontaneous combustion. When wet hay is stored in bulk under conditions that inhibit ready heat dissipation, a slow oxidation process (triggered by bacterial fermentation) begins [*Encyclopædia Britannica*, 2007]. However, at Atlit-Yam leaves, branches, seeds, grass and other plant matter, were buried under a cover of mud in sun-warmed local pockets. This provided conditions ideal for spontaneous combustion. It would explain, for example, the charred wheat lens of *Locus 10/A*, and nearby fire-blackened fish bones. In fact, wheat is a well known candidate for spontaneous combustion (www.samfs.sa.gov.au/community/domestic.asp).

[20] (12) Thermally fractured limestone pebbles in the well and spread all around the village could be: (1) scraps dispersed by a tsunami passage (but, according to *Galili et al.* [1993], AtlitYam was a pre-pottery village) or (2) directly generated in the tsunami clay assemblage possibly sensitive to heating by spontaneous combustion.

4. Tsunami Simulation

[21] What, then, is the most likely candidate for the source of the tsunami that destroyed Atlit-Yam and its population? If we assume that the age obtained for the charred wheat of *Locus 10/A* (i.e. 8,340 ± 80 ka B.P.) marks the timing of the tsunami, then this date coincides with a likely tsunami triggering event caused by the Holocene collapse of the eastern flanks of Mt. Etna volcano (Sicily, Italy) [*Calvari et al.*, 1998] (Text S1). Simulations of this tsunami, associated with a 25 km^3 debris avalanche deposit off-shore of Etna, have shown that it had the potential to impact all of the Eastern Mediterranean [*Pareschi et al.*, 2006a, 2006c].

[22] Tsunami simulations were performed using a numerical model based on non-linear and dispersive Boussinesq equations [*Wei et al.*, 1995; *Pareschi et al.*, 2006b] (Text S2). A tsunami triggered by a landslide at Mt. Etna, involving a volume of 25 km^3 and an average offshore landslide velocity of 50 m/s, was considered [*Pareschi et al.*, 2006a]. The simulations indicated arrival of a tsunami wave train with the following features in the Levantine Basin (Figure 2a). First, a train of waves, related to phase dispersion [*Ward*, 2001], reaches the continental shelves of Israeli. Second, the tsunami wave front, moving from the West into the Levantine Basin, turns South-East and strikes the Israeli coasts from the North-West (Figure 2a). In addition, the temporary tsunami impact on the continental shelves of Israel from the North-East would explain for

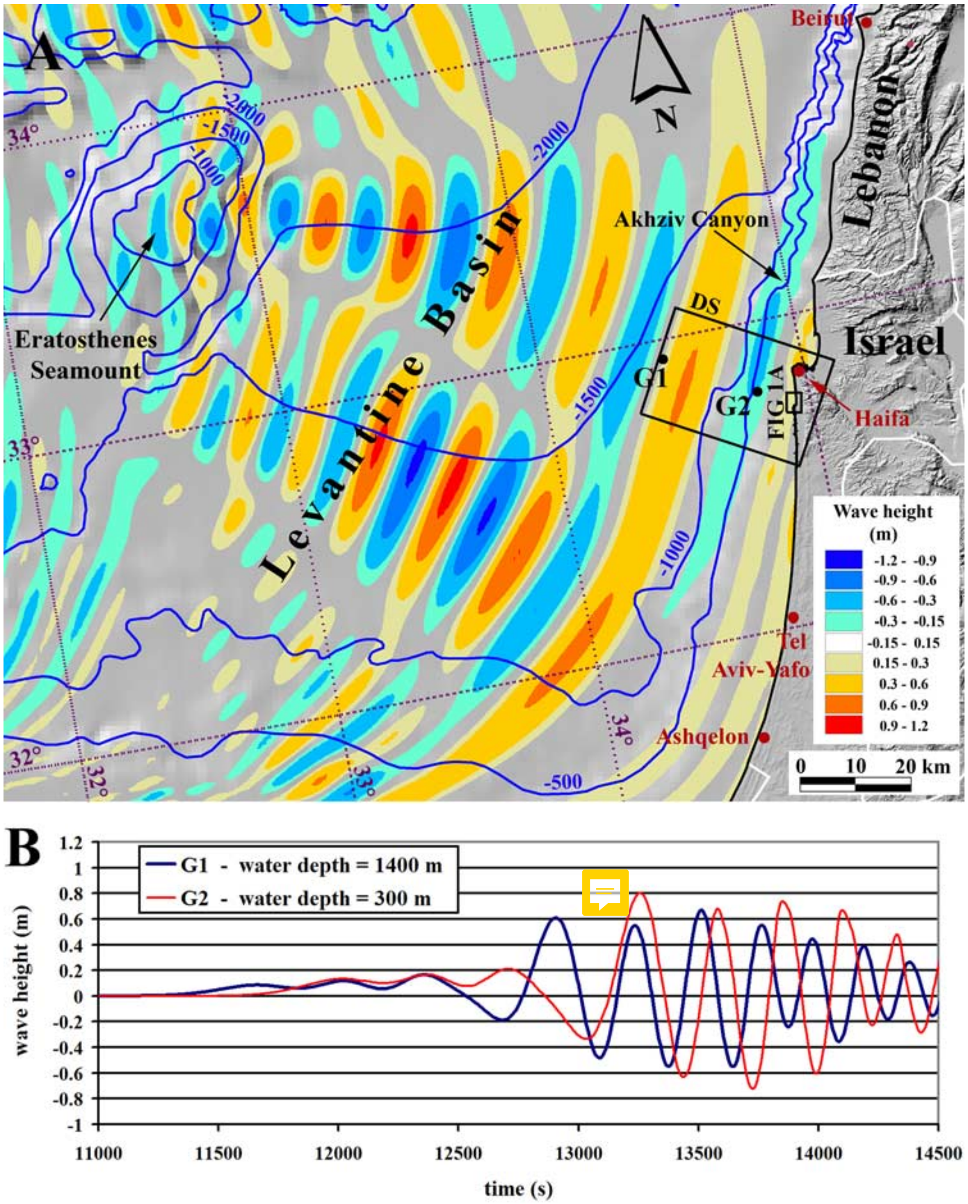

Figure 2. (a) Simulated tsunami wave train in the Levantine Basin, as triggered by the Holocene sector collapse of the eastern flanks of Mt. Etna. Snap shot is for 13,000 s after the entrance into the sea of the Mt. Etna landslide. The simulation reveals the first arrival of a trough (to cause initial sea withdraw). Box marked DS locates the zone covered by our detailed simulations. (b) Tsunami wave heights of the wave train as function of time, at computational gauges G1 (blue line) and G2 (red line) respectively (see Figure 2a for location). Wave train mainly develops as a consequence of phase dispersion, and long wavelengths precede shorter ones.

example the observations from the Atlit-Yam well, where the clay assemblage shows evidence of: (1) a marine sediment transport from the North-East and (2) probably at least four tsunami waves, each characterized by different illite + kaolinite over smectite ratios (Figure 1d). As a whole, a 25 km^3 Mt. Etna landslide with average submarine velocities in the range 50–15 m/s [*Pareschi et al.*, 2006a] suggest waves with maximum amplitudes of 0.3–0.9 m, 40.5 km offshore Israel (where the sea depth is 1300 m), as resumed in the table of Figure 1b.

[23] To further quantify the impact of a Mt. Etna tsunami at Atlit-Yam itself, we used a high-resolution computational grid in a paleo-reconstructed environment (domain DS of Figure 2a; Text S2). Input data to these additional detailed simulations are those from the table in Figure 1b, providing the positive wave peaks and widths of the Mt. Etna tsunami wave train. We use sea level values between −14 m and −12 m with respect to current sea level (table in Figure 1b and Text S1). Our detailed simulations show that a sea-level of −14 m is too low to allow a Mt. Etna tsunami to reach Atlit-Yam. Indeed, the water table (∼ sea level at tsunami time) must have been positioned around −13 ± 1 m because, in the well tsunami deposit, transition from a few to many (also articulated) animal bones occurs there.

[24] Also tsunami wave crests below 0.3 m (at 40.5 km offshore) are too low to reach the village. In all other

simulated cases, tsunami waves strike Atlit-Yam (Figure 1b), moreover the first four tsunami crests of Figure 2b are all able to reach the village and contribute to well filling.

5. Conclusions

[25] Geological and archaeological arrangements (from literature) at a Neolithic village, offshore Israel, are reinterpreted as due to a tsunami from Mt. Etna volcano. In the future, other traces of Mt. Etna tsunami impact in the Levantine Basin should be looked for. If coastal evidences might have been destroyed by sea level rise, we expect evident submarine tsunami marks, because the tsunami occurred ~8.3 ka B.P., during the deposition of Sapropel S1. Such a Mt. Etna tsunami, occurring today, could be utterly devastating to coastal communities of Israel, Lebanon and Syria.

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[1] *Pareschi et al.* [2007] (hereafter referred to as PBF07) suggested that the tsunami generated by the collapse of Mount Etna ca. 8,300 yr B.P., destroyed the Neolithic village of Atlit-Yam on the Israeli coast. The main issues raised by PBF07 are examined here as they relate to finds from the site, as well as from other inland Neolithic sites from the Levant.

[2] *Pareschi et al.* [2006] first suggested that the tsunami occurred ca. 8,000–7,500 yr B.P. and later PBF07 shifted the date to ~8,300 yr B.P, but no explanation for this shift was offered. If the tsunami occurred at 8,000–7,500 yr B.P., then sediments from Water Well 11 which date to 8,370–8,210 yr B.P. (Figure 1) (but which are said to be tsunami related according to PBF07) would have actually pre-dated the assumed tsunami. (All dates are calibrated years B.P., groups of dates from the same structure were averaged with ±1sigma. Dating by E. Boaretto, Radio-carbon Dating Laboratory, Weizmann Institute, Israel.) Similar sediments from Water Well 66 dated to 8,640–8,540 yr B.P. [*Galili et al.*, 2002] and the concentrations of fish bones and wheat from Locus 10/A dated to 8,425–8,360 yr B.P. also pre-date the tsunami (Figure 1). Alternately, if the tsunami destroyed the village in 8,300 yr B.P. (PBF07), how can the settlement exhibit an uninterrupted sequence of occupation from ca. 9,400 to 8,000 yr B.P.? [*Galili et al.*, 2002] (Figure 1). The same argument applies to the more recent proposed Etna cone collapse of 7,590 ± 130 B.P. [*Calvari and Groppelli*, 1996]. As noted above, this event also post-dates many of the so-called 'tsunami features' identified by PBF07. The end of the occupation of Atlit-Yam ca. 8,000 BP, clearly relates to a well-documented Mediterranean sea level rise following the end of the last glaciation [*Bard et al.*, 1996; *Galili et al.*, 2005a].

[3] The human skeletal pathologies identified at Atlit-Yam are mainly associated with infectious diseases resulting from chronic health problems and dental diseases, and are not associated with natural disaster. "Fresh" injuries relating to trauma, which are expected to be found on victims of such a violent event, were not detected. Loss of teeth and partially burnt bones, both features specified by PBF07 as tsunami related, are in fact common in Neolithic human osteological assemblages in the region [*Hershkovitz and Galili*, 1990].

[4] Burial practices at Atlit-Yam were similar to those identified in other Pre-Pottery Neolithic (PPN) sites in the Levant. Most of the human skeletal material was recovered from formally prepared graves with the deceased interred in a flexed position [*Galili et al.*, 2005b]. Isolated bones were found throughout the site but represent primary graves disturbed in antiquity by human activities such as building, as well as more recent marine agents. Such isolated human bones are common in other submerged Pottery Neolithic (PN) sites [*Galili et al.*, 1998], as well as terrestrial PPN sites.

[5] In all features the faunal assemblage resembles that reported for neighboring submerged PN sites [*Horwitz et al.*, 2006] and other Levantine PPN sites. It clearly differs from assemblages that have undergone sudden and violent catastrophes, where animal bones are usually found in anatomical articulation [*Lyman*, 1994]. About half of the animal bones bear cut marks attesting to intentional butchery, which in turn indicates that they represent food refuse and not natural mortalities. Moreover, the species and age distribution of animals does not resemble that expected for a catastrophic population, but points to selection and management of a limited range of taxa for meat production [*Horwitz and Tchernov*, 1987; *Galili et al.*, 1993].

[6] The concentrations of fish bones and cereal grains, cited by PBF07 as evidence for the sudden abandonment of the site, differ in nature and each appears to have accumulated at a different time [*Galili et al.*, 2004]. Such food concentrations have been reported from terrestrial PPN villages in the southern Levant and represent food stores that had not been consumed.

[7] The use of abandoned installations and water wells as garbage pits is a common phenomenon in prehistoric sites throughout the Eastern Mediterranean (e.g., Mylouthkia,

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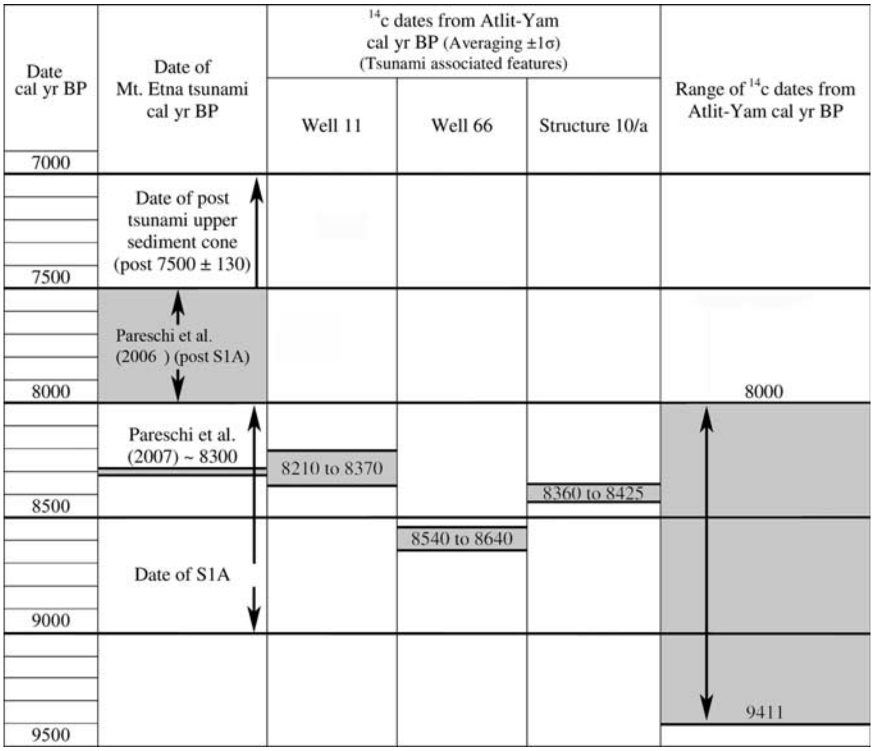

Figure 1. Comparative time scales of the Etna tsunami and the assumed tsunami features, as proposed by *Pareschi et al.* [2006, 2007], and the occupation of Atlit-Yam.

Cyprus [*Peltenburg*, 2003]). Thus, the deposit recovered from the upper parts of the Atlit-Yam water wells, containing a mixture of consumed animal bones and cultural material, is typical of debris associated with human activities, and does not represent debris introduced into the wells by a tsunami.

[8] The three uppermost built stone courses of Water Well 11 survived in situ above the sea floor. Thus the large stones and artifacts found inside Well 11 could not have circumvented this wall unless humans deliberately threw them in. The presence of insect and rodent remains inside the wells may be attributed to natural mortalities or remains of prey introduced by raptors. The fine sediments in the well may have been introduced by wind and sea storms, although seasonal overflow by the neighboring Nahal Oren stream cannot be excluded.

[9] The site is embedded within the upper layer (ca. 10 m. thick) of a hard homogeneous clay of terrestrial origin (Carmel Coast Clay Formation), which is dated to ca.

Table 1. Field Evidence and Finds Observed at Atlit-Yam Versus Expected From a Tsunami Impact

Subject	Expected in Case of a Tsunami Scenario	Observed Field Evidence and Finds
Dating	7,600–8,000 yr B.P. [*Pareschi et al.*, 2006]	The proposed tsunami post-dates sediments *Pareschi et al.* [2007] argue are tsunami deposits (TD)
Dating	~8,300 yr B.P. [*Pareschi et al.*, 2007]	The site was occupied until 8,000 yr BP, i.e., 300 years after the proposed tsunami.
Architecture	No structures or installations are expected to survive the tsunami while in an in situ and upright position	Well-preserved un-cemented stone structures, paved stone surfaces, including in situ 1.5 m high stone megaliths in upright position
Human burials	Unburied skeletons randomly scattered, twisted and in strange positions, formal graves destroyed, various mortuary contexts	Majority in formal, prepared graves, individuals in flexed position, isolated bones result from disturbance to primary graves in antiquity.
Human pathologies	Evidence of fresh trauma, mainly to the skull	Mainly chronic diseases, no fresh injuries or penetrating objects relating to trauma.
Fauna	Articulated skeletons with complete bones	No articulated skeletons, few complete bones, all bones consumed, many cut marks.
Fauna distribution	Random, no patterning	Mainly in water wells fill with other garbage, or in open spaces, rarely in dwellings.
Fish/cereal concentrations	Many contemporaneous cases of abandoned food, representing a single disastrous event	Fish and grains are not contemporaneous; food stores/caches are common in terrestrial Neolithic sites.
Water wells	Total destruction of the superstructures	The courses of the upper structure of Well 11 perfectly preserved.
Wells fill	Contemporary typical tsunami deposits dated to a single event in all pits, shafts and wells	Deposits in wells and pits represent anthropogenic refuse and are not contemporary.

10,000–12,000 yr B.P. [*Galili and Weinstein-Evron*, 1985]. Given its date and structure, there is no basis for considering this to be a "tsunami mud layer" (PBF07).

[10] The presence of well-preserved human skeletons still in their original burial position, undisturbed paved stone surfaces, wall foundations and stone-built installations (all of which were constructed without cement), the preserved stone super-structure of Water Well 11 which lies above the sea floor and the 1.5 m high standing stones in Structure 56, could not have survived a destructive tsunami. Similar features are recorded from PN settlements off the Carmel coast and are also typical of terrestrial PPN settlements in the southern Levant.

[11] According to PBF07, the tsunami funneled into the village from the northeast (typo?). Given the morphology of the Atlit Bay and the general setting of the site, a northwest direction of a potential tsunami is more logical.

[12] Historic tsunamis did hit the Levant [*Salamon et al.*, 2007] and the location of the village before abandonment, about 1.5–2 m above sea level, could have exposed it to potential tsunami hazards. In our opinion however, the destruction of the village some 8,300 years ago by a tsunami as proposed by PBF07, finds no support in the archaeological, anthropological, faunal, botanical or sedimentary record from the site (Table 1). Instead, the data indicate that the village was abandoned ca. 8000 years B.P. due to the gradual post-glacial rise in sea level rise, similar to coastal Neolithic villages all over the world. The site was first covered by coastal sand dunes that protected it from abrasion by marine agents and then submerged by the rising sea. Due to the sea level rise, the subsequent PN villages in the region were built farther to the East [*Galili et al.*, 1993].

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