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The tsunami of 13 December A.D. 115 and the destruction of Herod the Great's harbor at Caesarea Maritima, Israel

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ABSTRACT

Underwater geoarchaeological excavations on the shallow shelf (~10 m depth) at Caesarea, Israel, have documented a tsunami that struck and damaged the ancient harbor at Caesarea. Talmudic sources record a tsunami that struck on 13 December A.D. 115, impacting Caesarea and Yavne. The tsunami was probably triggered by an earthquake that destroyed Antioch, and was generated somewhere on the Cyprian Arc fault system. The tsunami deposit consisted of an ~0.5-m-thick bed of reverse-graded shells, coarse sand, pebbles, and pottery deposited over a large area outside of the harbor. The lower portion of the deposit was composed of angular shell fragments, and the upper portion of whole convex-up *Glycymeris* spp. shells. The sequence records tsunami downcutting (~1 m) into shelf sands, with the return flow sorting and depositing angular shell fragments followed by oriented whole shells. Radiocarbon dating of articulated *Glycymeris* shells, and optically stimulated luminescence (OSL) dates, constrain the age of the deposit to between the first century B.C. and the second century A.D., and point to the tsunami of A.D. 115 as the most likely candidate for the event, and the probable cause of the harbor destruction.

Keywords: tsunami, shell taphonomy, Caesarea, Israel, geoarchaeology, marine archaeology.

INTRODUCTION

On 13 December A.D. 115, a tsunami struck the ancient port city of Caesarea (Israel) and was recorded in the Talmud (Shalem, 1956; Amiran et al., 1994). According to the description, the wave impacted the Levantine coast with effects recorded at Caesarea and Yavne (Fig. 1). The tsunami was likely caused by a powerful earthquake that destroyed the city of Antioch (Fig 1; Ambraseys and Jackson, 1998) and originated somewhere along the eastern Cyprean Arc (Ben-Avraham et al., 1995).

The construction of Caesarea's harbor by Herod the Great in 21 B.C. is well documented by excavation work and descriptions of the harbor by the historian Josephus Flavius (Whiston, 1999; Holum et al., 1988). The reasons for the rapid decline in the harbor, about one century later, are less clear, and heavily debated (Reinhardt and Raban, 1999; Hohlfelder, 2000). However, the favored interpretation has been the catastrophic destruction of the harbor by an earthquake; although the role of a tsunami has been considered, no conclusive evidence has ever been found (Raban, 1992, 1999; Reinhardt and Raban, 1999; Mart and Perecman, 1996).

Records of sub-recent (past 2000 yr) tsunamis in the eastern Mediterranean are based primarily on textual records with variable accuracy (e.g., Neev et al., 1973; Amiran et al., 1994; Mart and Perecman, 1996; Ambraseys and Jackson, 1998; Karcz, 2004), none of which has been substantiated with geological or archaeological evidence. Here we present clear evidence for an ancient tsunami recorded in shallow shelf deposits at Caesarea, and infer the impact on the harbor structure. While we do not have the resolution in radiocarbon, optically stimulated luminescence (OSL), or ceramic dating to precisely confine the event to a given year, or decade, the A.D. 115 tsunami is an excellent candidate for creating the deposit. The evidence from Caesarea shows that thick and extensive tsunami deposits can be preserved in shallow clastic shelf environments.

TSUNAMI EVIDENCE

Clear evidence of a paleo-tsunami is most often detected where marine allochthonous sediments are found in an otherwise terrestrial freshwater or brackish system in coastal lakes, estuaries, lagoons, etc. (e.g., Goff et al., 2001; Dawson et al., 1990; Carey et al., 2001; Minoura and Nakaya, 1991; Atwater, 1992; van den Bergh et al., 2003). The occurrence and characteristics of tsunami deposits on the shallow shelf receive little attention, as it is often perceived that the deposits have low preservation potential or would be impossible to differentiate from tempestites produced by large-scale storms or other shelf erosional processes. However, recent outcrop studies have identified evidence for preservation of tsunamites in Cambrian and Holocene shelf sequences, showing that they can be preserved in shallow shelf environments. The interpretation of these examples is hampered, however, by the lack of recent sedimentary analogs for comparison (Pratt, 2002; Fujiwara et al., 2000).

The lack of baseline information is, in part, due to limitations of sediment coring and to problems in retrieving representative coarse-grained sediment stratigraphy in clastic shelf settings. Underwater geoarchaeological excavations provide several advantages for recovering and studying these types of deposits. They can penetrate most sediments, they expose large areas for stratigraphic analysis, and, in archaeological sites, large quantities of material culture can be recovered for dating (Reinhardt, 1999). We used this approach at Caesarea to document a thickly stratified shell deposit whose taphonomic characters and dating (^{14}C, OSL, material culture) indicate that it was formed by the 13 December A.D. 115 tsunami. Without the geo-

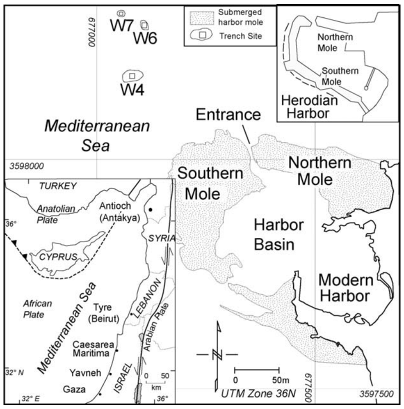

Figure 1. Location map showing harbor ruins and excavation sites outside of harbor (W4: 677079, 3598186; W6: 677100, 3598300; W7: 677045, 3598318). Insets show regional tectonic framework of eastern Mediterranean (bottom left) and layout of Herod's harbor (upper right).

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*Deceased

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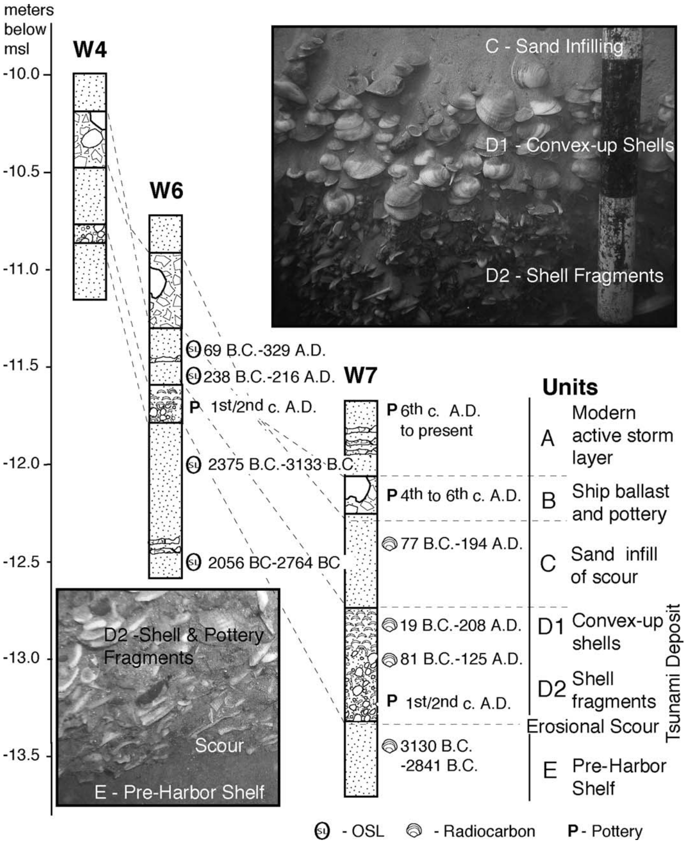

Figure 2. Radiocarbon dates, performed at Geochron Laboratories and calibrated (Stuiver and Reimer, 1993; Stuiver et al., 1998) and corrected for marine reservoir (Hughen et al., 2004; Reimer and McCormac, 2002). Error represents 1 σ limits. OSL dating of quartz followed Aitken (1998) and Rink and Forrest (2005). D_E was determined using the single-aliquot regenerative-dose (SAR) protocol (Murray and Wintle, 2000; Rink and Odum, 1991). See Table DR 1 (see footnote 1) for details.

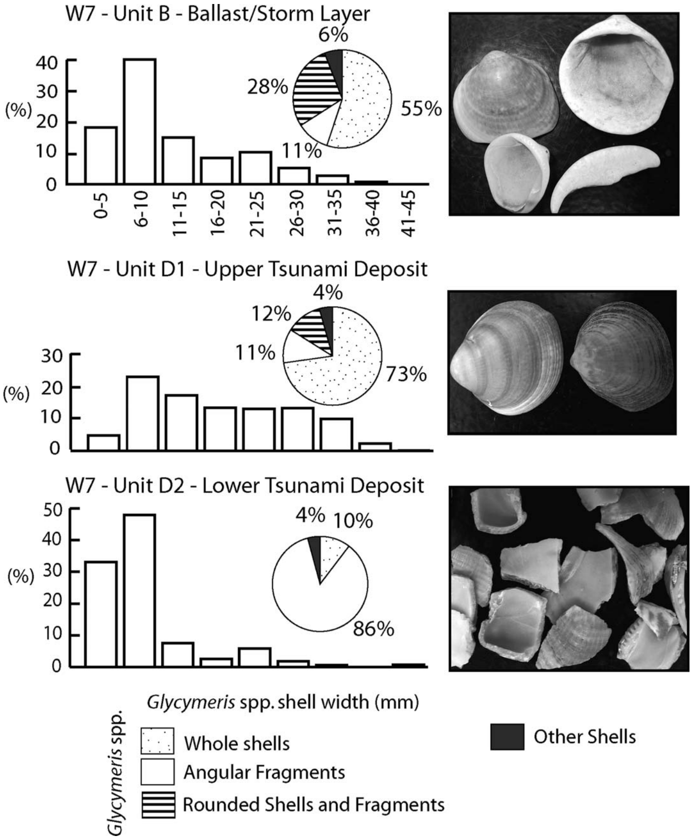

Figure 3. Shell layer taphonomic characters. Bar graphs show size distribution of whole *Glycymeris* valves, pie charts show distribution of shells and fragments.

archaeological excavations, this deposit would not have been recognized, as sediment coring would not have provided a broad exposure to identify and map the taphonomic and sedimentary characteristics of the tsunami deposit.

RESULTS

We excavated trenches to depths of up to 2.2 m at several sites outside the harbor as part of an earlier study at Caesarea (Boyce et al., 2004; Fig. 1). At three sites (W4, W6, and W7) the trenches revealed a sequence of shelf sands containing an upper horizon of Byzantine-era ship's ballast and pottery (0.5 m thick, Unit B; Fig. 2) and an underlying distinctive shell layer at 1–1.5 m depth (Fig. 2). The thickness of the shell horizon varied (0.2–1 m) but could be correlated across excavation areas as a continuous horizon. The shell deposits were predominantly *Glycymeris* (mostly *violescens*), which inhabits the infralittoral zone, typically below 18 m water depth (Barash and Danin, 1992). Two sediment samples from each shell subhorizon in Area W7 (~1000 cm^3, 700–800 g) were sorted by shell content, and fractional weight abundance (%) was calculated for whole unrounded *Glycymeris* shells, angular *Glycymeris* fragments, rounded whole *Glycymeris* shells, and other shell fragments (Fig. 3). The whole *Glycymeris* shells (unrounded) were further sorted into size fractions.

The shell taphocoenosis was clearly different between the modern storm active unit (A and top of B) and the tsunami shell beds (D1 and 2) (Fig. 2). The ballast deposit (Unit B) contained abundant whole *Glycymeris* shells (55%) with a large percentage of rounded shells (28%), and the size distribution of the whole shells was skewed with a predominance of shells in the 6–10 mm range. The taphonomic characters of the shell in the upper ballast layer were commensurate with the accumulation of shell amongst the ballast stone from multiple storm events. This is typical storm deposition, and has been seen elsewhere in the harbor excavations (e.g., Reinhardt, 1999). There was no distinct orientation to the shells and they were predominantly whole, rounded, disarticulated *Glycymeris* shells.

In contrast, the deeper shell horizon was characterized by two subunits (D1 and D2; Fig. 2), which were separated by a sharp uneven contact. The upper horizon (D1) consisted of 73% convex-up–oriented disarticulated *Glycymeris* shells, a smaller quantity (12%) of rounded shells, angular fragments (11%), and other shell material (4%), and the size distribution of the whole *Glycymeris* shells displayed low peakedness with a relatively even distribution through the size range (Fig. 3). Horizon D2 was different in taphonomic character from Unit B and D1, as it consisted of 86% angular fragments, 10% whole shell, 4% other shell, and no rounded fragments. The distribution of whole shell was also different, as it was skewed toward smaller valves with more than 80% of the valves being less than 10 mm in diameter. These taphonomic characters are distinctly different than those of the shells in the ballast deposit (Unit B)

There is taphonomic evidence of fragmentation in the lower portion of the shell horizon (Unit D2), which can only be indicative of a tsunami. The high percentage of fragmented shells (and abundant stress fractures), along with their angular breaks, is atypical of storm shell accumulations on the shelf (Fig. 3). The *Glycymeris* shells are very robust with no preexisting weakness, and tend to degrade through abrasion rather than any significant breakage, as seen in the shells in the upper ballast deposit. The abundance of fragmented *Glycymeris* shells in the lower part of the shell unit, and their lack of rounding, indicates a high-energy event horizon with no subsequent reworking since deposition. The fragmentation is consistent with intense wave turbulence, shell-to-shell impacts, and shells striking the harbor moles or bedrock under high wave energy, as generated by a tsunami.

The accumulation of whole *Glycymeris* shells (D1) on top of the shell fragments (D2) likely indicates differential settling of shells after the tsunami. The smaller angular fragments would settle out of the water column first, followed by the larger valves, which would sink in a helical path and at a slower rate (Brett, 2003). The convex-up orientation is due to deposition under a unidirectional current, and likely from the return flow of the tsunami wave. This is a characteristic orientation for bivalve shells in riverbeds and in tidal currents (Brett, 2003; Allen, 1984). In the modern environment, densely packed convex-up *Glycymeris* orientations were observed in shallow (1–2 m), narrow (2–3 m) rills in the sandstone bedrock to the east of the excavation sites, where strong storm surge waves orient the shells. The shells from the upper tsunami unit were oriented convex upwards but were not stacked vertically and did not form any "nests," indicating rapid continuous deposition without sustained oscillatory currents re-orienting the shells (Brett, 2003; Allen, 1984). The thickness of the shell horizon is atypical of the normal shelf stratigraphy, as storm accumulations are normally composed of thinner shell layers because the storms cannot sort and concentrate enough shell material to form an accumulation up to 50 cm in thickness.

Additional evidence for the tsunami origin for the shell deposit comes from the distribution of ^{14}C and OSL dates, and pottery ages, which showed intense scour of the seabed (Fig. 2; Table DR1[1]). Articulated *Glycymeris* shells were found in the sand (E) below the shell unit, in the shell horizon (D-1 and 2), and in the overlying sand (C) up to the ballast deposition, which were ^{14}C dated from W7. OSL dates of the sands from the same units from W6 resulted in similar ages. The ^{14}C dates from the lower sand unit (E) of 3130–2841 B.C., and from the overlying fragmented shell unit of 81 B.C. to A.D. 125, were corroborated with OSL dates of 2375–3133 B.C. and 238 B.C. to A.D. 216, and with small pottery fragments characteristic of the first and early second centuries A.D. ('Eastern Sigillata B' and Early Roman bag-shaped jars of 'Riley 1A' type; Raban, 2004), indicating a significant erosional scour that is also seen in the truncation of faint sedimentary and bioturbation structures in Unit E. The overlying sand (Unit C) has OSL and ^{14}C dates similar to the tsunami deposit (Fig. 2). Such evidence is commensurate with scour from a tsunami wave, deposition of shells, followed by infill of sand from the receding tsunami and/or through storm deposition after the event. The rapid infilling of the erosional scour is indicated by the articulated *Glycymeris* shells within Unit C, which indicate little reworking (Fig. 2). Considering the error on the ^{14}C and OSL dates, it could have taken anywhere from years to decades for the shelf to re-equilibrate and infill the tsunami scour. Abundant ceramic material from the fourth to sixth centuries A.D. was present in Unit B, indicating the upper limit of the active storm layer within the stratigraphy.

The pottery in the shell horizon indicates that the tsunami occurred after the construction of Caesarea in the late first century B.C., and after Josephus described the harbor in grand terms between A.D. 75 and 79. Josephus referred to seismic events throughout the region, and had the harbor withstood a tsunami, he would have mentioned it, as a glorification of the harbor's strength and engineering prowess (Josephus Flavius; Antiquities of the Jews XV.9.6, in Whiston, 1999). The radiometric dates further constrain the event to no later than A.D. 200, making the A.D. 115 tsunami the likely candidate for the shell deposit. No complete or accurate record of all tsunami events exists; however, the other known events for the Levantine coast are either too old (20–26 B.C. flooding at Pelusium) or too young (A.D. 306 destruction at Sidon and Tyre; Mart and Perecman, 1996).

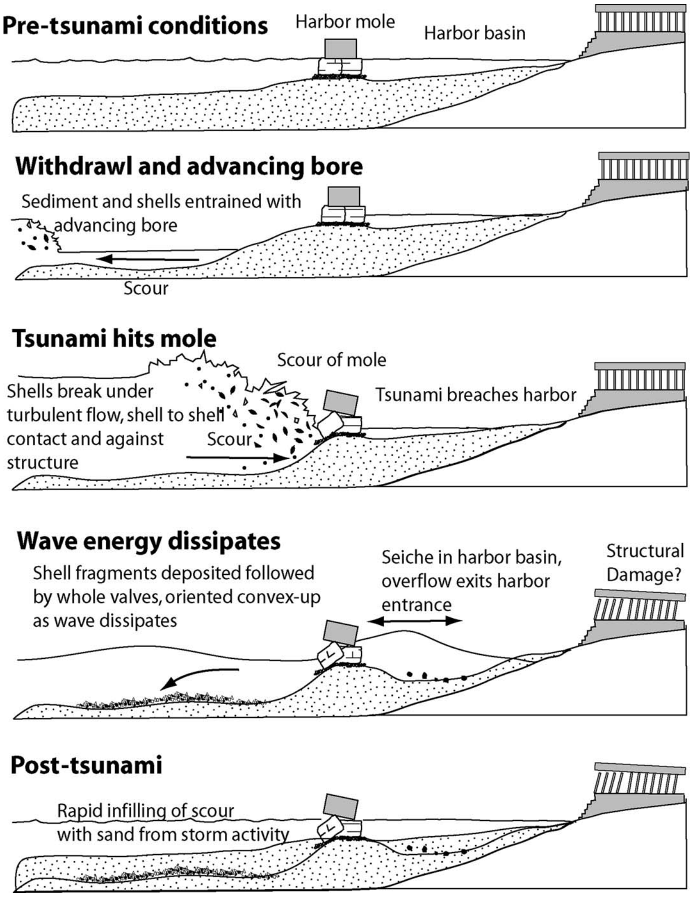

Figure 4. Sequence of events with tsunami impact on the harbor.

IMPACT ON THE HARBOR

In a previous study (Reinhardt and Raban, 1999) we presented evidence indicating seismic damage in the first to second centuries A.D. that severely compromised the Caesarea harbor structure. We presented evidence that seismic activity was the cause of the destruction of the harbor; although, considering the new data, some of the evidence could equally be interpreted as a result of a tsunami (Fig. 4).

The harbor mole was constructed of large (390 m^3) concrete blocks (caissons) laid on the seafloor (e.g., Raban et al., 1999). The impact of the tsunami bore would have shifted the mole's foundation and undermined its shoreward edge, causing the offset of the caissons as observed in the modern harbor ruins (Raban et al., 1999; Reinhardt and Raban, 1999; Fig. 4). The impact of the tsunami may have also loaded the underlying sediments to the point of liquefaction, leading to further foundering of the caissons. It is envisioned that during the impact of the tsunami bore, significant quantities of shoreface sediments and shell materials would have impacted onto the mole and bedrock surfaces, generating a large volume of broken shell material. The articulated *Glycymeris* shells in the tsunami deposit indicate transport from the deeper shelf, as the shallowest habitation depth for these bivalves is 18 m. In the harbor itself, the tsunami and resulting seiche would have been highly destructive, causing further erosion and undercutting of the harbor mole. High-energy conditions represented in the first- to second-century A.D. sediments from the inner harbor may be from this event (Reinhardt and Raban, 1999). In the subsequent return flow phase, further erosion of the shelf may have occurred, and the graded shell bed (Fig. 2; Unit D) records the sorting and deposition of the shell materials with the waning tsunami. The inclusion of pottery

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[1] GSA Data Repository item 2006231, OSL and radiocarbon data, is available online at www.geosociety.org/pubs/ft2006.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA.

fragments in D-2 indicates transport of sediment from the shallower harbor area, indicating deposition by return flow of the tsunami. In a final phase, the tsunamite was buried and the remaining scour depression was infilled by sand deposited by longshore currents and storm activity on the shelf.

While earthquake damage cannot be ruled out as a contributing factor to the demise of Caesarea's harbor, our new data point to the tsunami of 115 A.D. as a contributing cause of its early destruction. Further work is required to better constrain the extent of the tsunami deposit at Caesarea and to correlate it with other potential shelf sediment records at Yavne and other coastal sites impacted by the tsunami. Historical sources record a large number of destructive tsunami events in the eastern Mediterranean; we anticipate that investigation of shelf sediment records on these coasts will yield important geological information about these events, and insights into their destructive effects (e.g., Sidon and Tyre; Marriner et al., 2006).

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