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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 Cyprian 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 Percem, 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 Percem, 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 eolian processes. However, recent outcrop studies have identified evidence for preservation of tsunamiites 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; Fujiiwara 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 (14C, OSL, material culture) indicate that it was formed by the 13 December A.D. 115 tsunami. Without the geo-

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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 cm³, 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 D2) (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 shell (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 de-
position. The fragmentation is consistent with intense wave turbulence, shell-to-shell impacts, and shells striking the harbor mole 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 reorienting 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 14C and OSL dates, and pottery ages, which showed intense scour of the seabed (Fig. 2; Table DR11). 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 14C dated from W7. OSL dates of the sands from the same units from W6 resulted in similar ages. The 14C dates from the lower sand unit (E) of 3130–2841 B.C., 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 reorienting 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.

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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 tsunamiite 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).

ACKNOWLEDGMENTS

This study was funded by Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grants (Reinhardt, Boyce), a NSERC Undergraduate Student Research Award (Hengstum), a Geoarchon Laboratories Research Grant (Goodman), and an anonymous donor (NK).

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Manuscript received 30 March 2006

Manuscript revised received 3 July 2006

Manuscript accepted 17 July 2006

Printed in USA