

TSUNAMI EVENT IDENTIFIED IN A SEDIMENTARY RECORD OF THE GAZA STRIP, PALESTINE

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Abstract:

The outcrop of the tsunami deposits, about 6 m thick, is located in the archaeological site Tel Askan in the Al Zhraa locality, southwest of the Gaza City. These deposits are unconformably underlain by sand dunes and sharply overlain by a palaeosol. They are pale gray sands mixed with volcanic ash and fine-grained deposits, and are intercalated with peat, few centimetres thick. The sand-sized grains are well rounded and well sorted, and consist mainly of quartz and subordinate of feldspar. Both macro- and microfossils were observed from tsunami deposits. Additionally, rip-up clasts and pottery shards were observed, indicating higher-flow regime. The potteries in tsunami deposits provide evidence for tsunami inundation at distance of about 1 km from the present shoreline.

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Key words: tsunami, sedimentology; pottery shard, rip-up clast; Gaza Strip

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INTRODUCTION

Tsunamis are among of the most dangerous fast-paced threats affecting coastal population centres and economic infrastructure (Morton *et al.*, 2007). By using data from past events, an understanding of how often they occur and their scale potential is facilitated (e.g. Salamon *et al.*, 2007; Yolsal *et al.*, 2007). Tsunami catalogues are assembled based on historical documents, witness reports and field data (Papadopoulos *et al.*, 2014); and there is a decrease in a number of occurrences reported each century due to limitation of written and instrumentally recorded records closer to the present, as the catalogue goes back in time (Goodman-Tchernov *et al.*, 2016). Modern tsunami field description have resulted in a better understanding of the sedimentological signatures left behind in the aftermath of a tsunami (e.g. Jaffe *et al.*, 2003; Goto *et al.*, 2011, 2012; Bahlburg and Spiske, 2012; Aránguiz *et al.*, 2016). Through contrasting these modern analogues, a new knowledge has increased the ability to identify older events in a sedimentary record. Nevertheless, these modern deposits are usually described in the first weeks, months and years after the initial event, while decades, centuries or more can pass before field events are described. Modern descriptions therefore cannot fully account for the taphonomic changes occurring in older deposits, but they provide a baseline from which past deposits can be analyzed and interpreted.

Usually, a detection of an anomalous sedimentary horizon as a tsunamite is achieved by contrasting the suspected

deposit with known tsunamigenic indicators, showing that the deposit does not comply with other transport mechanisms such as storms and floods, and agreeing to a historical record (if available). Comparisons of non-tsunamigenic deposits with recognized tsunamites within the same study area provided useful examples to direct the distinction between various depositional scenarios (e.g., Goff *et al.*, 2004; Kortekaas and Dawson, 2007; Morton *et al.*, 2007; Phantuwongraj and Choowong, 2012; Pilarczyk *et al.*, 2014; Sakuna-Schwartz *et al.*, 2015). One way to solve this was by coastal boulder deposit evaluations (Shah-Hosseini *et al.*, 2013). Tsunamis were shown to move large boulders during tsunami events (Scheffers, 2002; Goto *et al.*, 2010; Paris *et al.*, 2010; Scheucher and Vortisch, 2011), while storms were also shown to have the ability to dislodge and cause boulder movement depending on the relative roughness of the underlying surface and wave characteristics (Weiss, 2012; Zainali and Weiss, 2015) though storm moved boulders result in more orderly boulder fields while tsunami transported boulders are less organized. Although a proxy toolbox may be used to assess whether a deposit qualifies as tsunamigenic, the applicability varies widely depending on the specific environment of the site (e.g. Dominey-Howes, 2007; Bruins *et al.*, 2008; Chagué-Goff, 2010; Goff *et al.*, 2012; Pilarczyk *et al.*, 2014; Nelson *et al.*, 2015).

The tsunamis deposits are a valuable source of information for geologists and emergency planners. Therefore, in this paper the tsunami events examined in a sedimentary record in the Gaza Strip would be the first work in this

area. The selected field site is named Tel Askan and is located in the Al Zhraa locality to the southwest of the Gaza City in the Gaza Strip, in which the tsunami deposits and archaeological outcrop were formed by excavation works. Tel Askan is one of the most prominent archaeological sites in the area, and was a dominant coastal locality throughout the Antiquity. It is one of the oldest Phoenician sites dated at 6000–4000 BC (Negev and Gibson, 2001). First occurrences were accidentally discovered while excavating for foundations of a residential complex in 1998.

GEOGRAPHICAL AND GEOLOGICAL BACKGROUND

The Gaza Strip is located at the southern part of Palestine’s Mediterranean coast, approximately 12 km south of Ashkelon (Fig. 1). The coastal plain contains parallel shore aeolian ridges (locally termed Kurkar ridges) that generally extend in the NNE-SSW direction. The surface elevation ranges from the mean sea level to approximately 110 m a.s.l. The depressions, which contain alluvial deposits, are approximately 20–40 m a.s.l. (Ubeid, 2010, 2016). The dominant source for sediment is the Nile River. Its moderately well sorted quartz sand is moved by a long-shore transport in a northerly direction (Klein, *et al.*, 2007; Zviely *et al.*, 2007; Ubeid, 2011; Ubeid and Albatta, 2014; Ubeid and Ramadan, 2017). The area has a rich catalogue of earthquakes and tsunami events (e.g. Ambraseys and Karcz, 1992; Ambraseys *et al.*, 1994; Amiran, 1994; Soloviev *et al.*, 2000; Fokaefs and

Papadopoulos, 2007; Altinok *et al.*, 2011; Salamon *et al.*, 2011, 2007; Papadopoulos *et al.*, 2014). Within these tsunami catalogues, the Gaza Strip is associated with events that occurred in 1032, 1068, 1546, and possibly 1759 AD (Maramai *et al.*, 2014). Past studies suggested that there were coastal tsunami deposits from the Bronze Age eruption of Santorini, though the deposits of which have been neither dated nor analysed in detail (Pfannenstiel, 1960). The tsunamis in this region are presumably initiated by landslides and submarine slumping triggered by near and far field earthquakes and volcanic eruptions; such as those originating in the Cypriot and Aegean arcs (e.g. Fokaefs and Papadopoulos, 2007; Salamon *et al.*, 2007; Yolsal *et al.*, 2007; Katz *et al.*, 2015).

MATERIALS AND METHODS

Field Procedure

A classical field work survey was conducted aimed at identifying anomalous, possibly tsunamigenic horizons along the eroded coastline of the Gaza Governorate, and focusing at the Al Zhraa locality (Fig. 1) where the excavation work shows some features in deposits expected to attribute to ~3.5 ka Santorini eruption (Pfannenstiel, 1952, 1960; Friedrich *et al.*, 2006), and a natural alluvial deposit (Rosen, 2008). Identified sections were cleaned, described and photographed, and rock samples, potteries, shells and organic remains were collected to be used for comparison with the sediments from the coastal section.

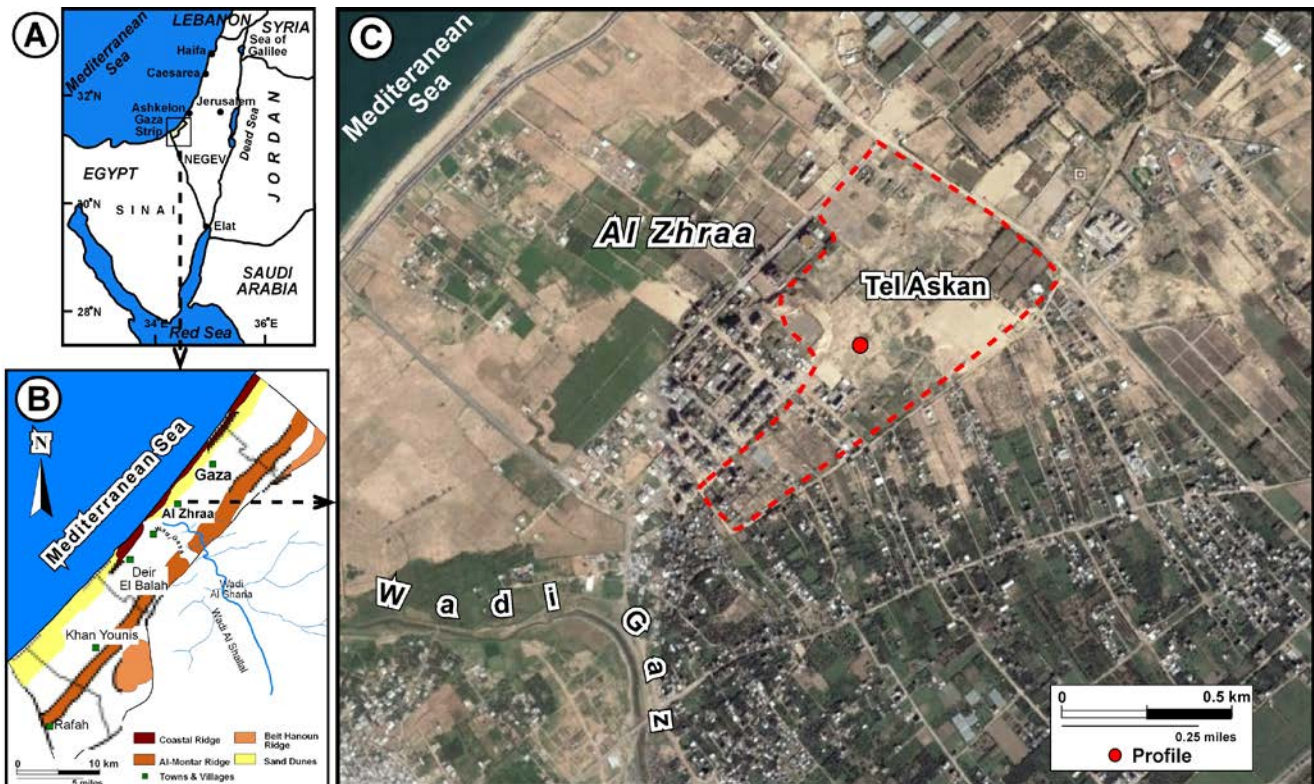


Fig. 1. Location map of a research area; the red polygon shows a layout of the archaeological site (Tel Askan).

Laboratory analysis

In order to clarify the field observations, laboratory analysis was done. Initially, the samples were dried at 110°C in an oven for a complete removal of moisture. Sedimentation method, using hydrometer and dispersive calgon, was applied to separate grain sizes for each fine-grained sample. In order to identify physical properties and mineral composition of the sand grains, sand-sized fractions were separated from finer particles using US mesh sieve #200. The Olympus binocular microscope was used to study grain morphology, in addition to fossils and bioclast contents.

RESULTS AND DISCUSSION

An onshore profile was collected from an outcrop excavated to the southwest of the Gaza City (about 800 m to the east from the beach) (Fig. 1). The studied section is at 30 m a.s.l. It consists of three tsunami units, composed of sand mixed with silt, clay and volcanic ash. It was intercalated with peat, few centimetres thick. It is unconformably underlain by aeolian sand and sharply overlain by a palaeosol (locally termed Hamra) (Figs 2 and 3). The underlying friable aeolian sand is fine- to medium grained and highly resembles the beach sand documented earlier (Ubeid, 2010, 2011;

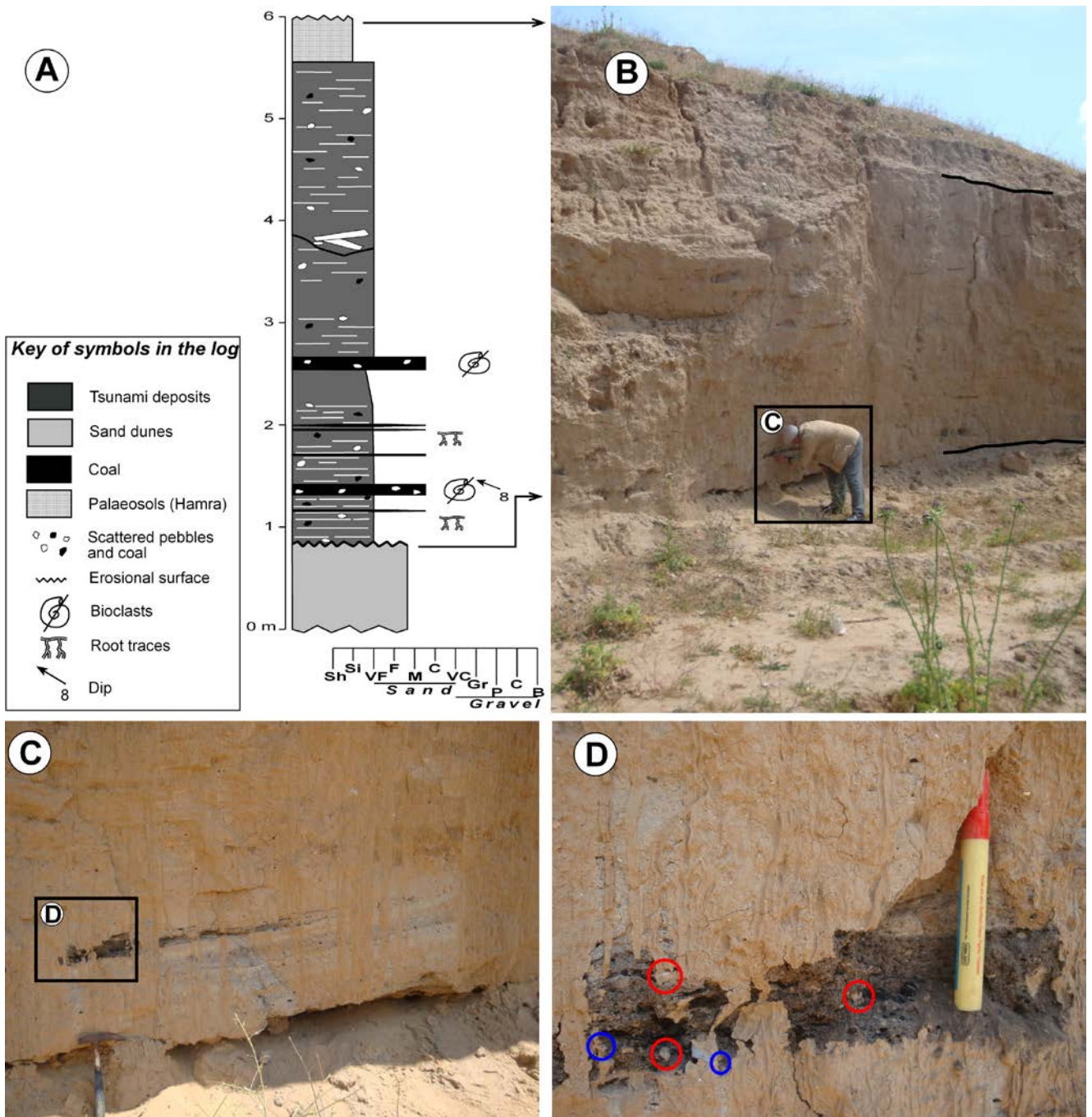


Fig. 2. (A) stratigraphic section with the sedimentary succession in the profile, (B) coastal archaeological site of Gaza Strip, (C) erosional surface between the tsunami deposits and the sandy dunes, (D) intercalated coal in the tsunami deposits (red circles – pebbles, blue circles – bioclasts).



Fig. 3. Tsunami deposits sharply overlain by the Hamara palaeosol.

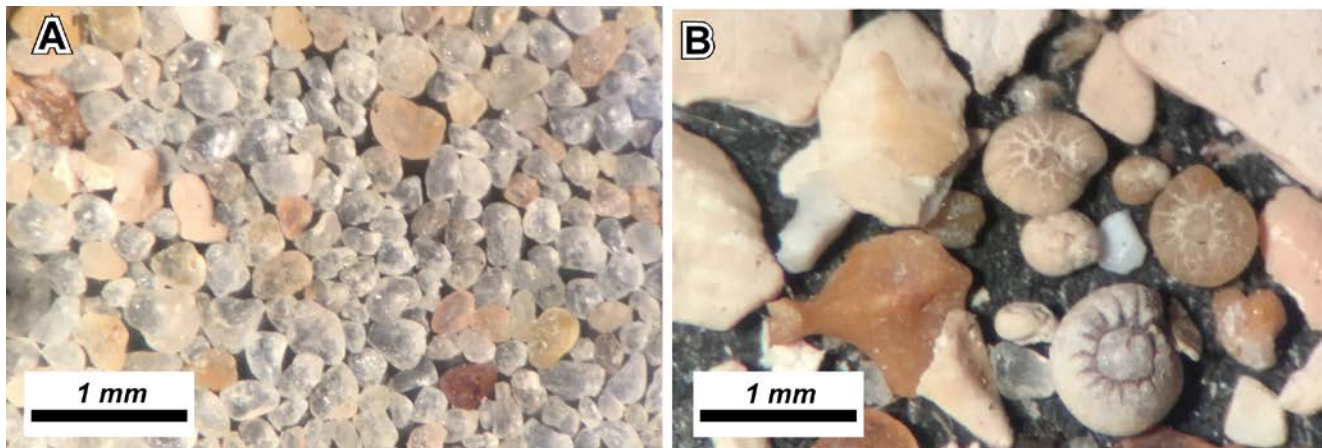


Fig. 4. Microscopic photographs: (A) grain shape and composition, (B) microfossils and carbonate bioclasts.

Ubeid and Albatta, 2014; Ubeid and Ramadan, 2017; Ubeid *et al.*, 2018). The overlying palaeosol is composed of reddish-brown fine-grained to very fine sand, silt and clay, with scattered small- to medium size pebbles and snail shells.

The deposits of tsunami units are distinguished from the other deposits in the sequence by their pale grey colour as well as Kurkar and Hamra deposits in the Gaza Strip. Overall, the grain-size analysis of these units proved that they are composed of about sand (57%), silt (32%) and clay (11%). The sand of these units consists of rounded- to well-rounded and well sorted fine- to very fine grains. They are

mainly composed of quartz with subordinate amount of feldspars (Fig. 4A).

Thickness and geometry

The lower unit (unit 1) is up to 2 m thick. Its erosional base overlays the aeolian sand and it is gradationally underlain by the second unit (unit 2) (Fig. 2). The unit 2 is about 1.5 m thick and sharply overlies the Hamra palaeosol (Fig. 3). It is planar in shape and dips about 10° towards the



Fig. 5. Lenticular tsunami deposits unit 3 and slumping boulders of these deposits; dashed line shows the erosional surface.

west. The lower part of these laminated units pass upwards into massive with rip-up clasts, shells, bioclasts and spots of dispersed peat. The laminae are from 1 to 5 cm thick and pinch out eastwards. Intercalated peat deposits were observed in these units.

The third unit (unit 3) is located some metres eastwards of the previous units. It is diagnostically lenticular in shape, with a concave base and a flat top (Fig. 5). It is erosionally underlain by the unit 2 with slumping boulders and overlain by the Hamra palaeosol with lenses of conglomerates. The maximum thickness of this unit is about 2 m. The unit is massive and consists of fine-grained sand, mixed with volcanic ash. It contains scattered fossils, pebbles and pottery shards with no preferred orientation.

The sedimentary contacts in the succession are important, because they indicate changes in the sedimentation pattern. The abrupt basal contacts indicate a rapid change in the depositional pattern consistent with sudden influx of the tsunami sediments. Upper contacts which range from gradual to abrupt reflect patterns of the post tsunami deposition.

Fossils

Both macrofossils and microfossils were found in the tsunami deposits. The microfossils were composed mainly

of fine- to medium carbonate bioclasts and subordinate foraminifera fossils (Fig. 4B). Most of the foraminifera were yellow stained. Macrofossils consist of marine mollusks, mainly bivalve types, in addition to bones of vertebrates and various plant fossils (Fig. 6A–B). The bivalves in the unit 1 and the unit 2 were oriented, while they were chaotic in the unit 3. Overall, presence of marine and brackish organic remains in water and scattered bioclasts shells provide evidence for marine incursion. Yellow foraminifera and bioclasts are present throughout the deposits, and were recorded in other tsunami deposits as well as are a part of corrosion features (Pilarczyk *et al.*, 2014; Goodman-Tchernov *et al.*, 2016).

Peat

Peat deposits observed in the unit 1 and the unit 2 form relatively small lenses, tens of metres long and maximum 10 cm thick. They contain coarse material e.g. coarse sand, small pebbles and fragments of Hamra (Figs 2D and 6A–C). However, the peat deposits refer to a tidal marsh sedimentation, in which peat develops from subaerially exposed, well-vegetated marsh soils in the intertidal zone. The spots of peat in the upper part of the unit 1 suggest that the tsunami flow eroded some peat (Moore *et al.*, 2007; Peters *et al.*, 2007).

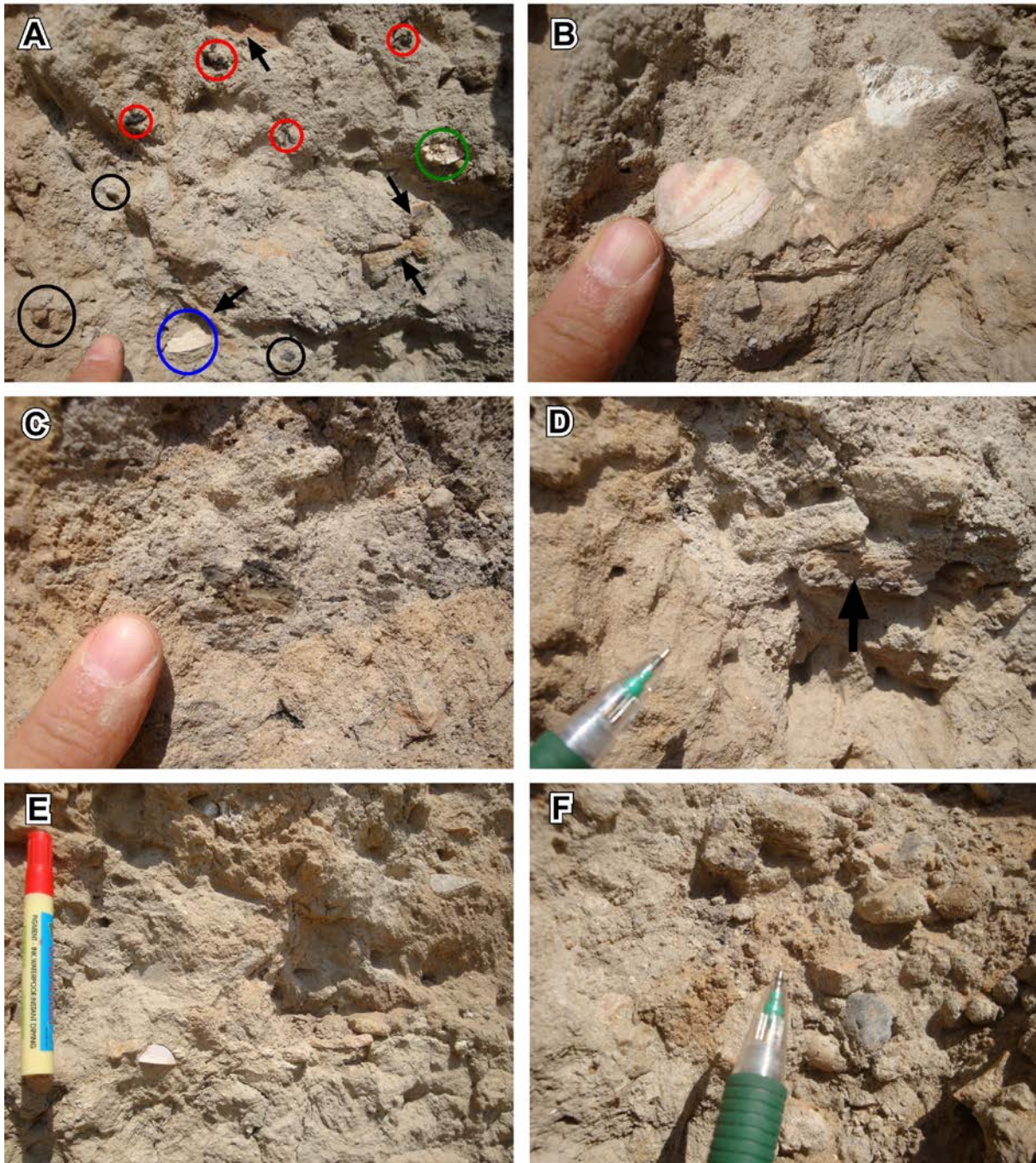


Fig. 6. Tsunami deposits content: (A) general view with bivalves, bones of invertebrates (marked by blue and green circles respectively), peat of plant remains (marked by red circles), rip-up clasts (marked by black circles) and pottery clasts (marked by black arrow); (B) bivalves and bones of invertebrates in tsunami deposits; (C) peat (black colour); (D) pottery clasts; (E) oriented shells and pottery clasts indicate a low-flow regime; (F) chaotic rip-up clasts and potteries indicate high-flow regime.

Pottery shards and rip-up clasts

The units of the tsunami deposits were dominated by flat-lying pottery. These shards can be assigned to the 4–5 century BC (Negev and Gibson, 2001; Hoffmann *et al.*, 2018). They were imbricated in the lower parts of the unit 1 and the unit 2, oriented to the west, suggesting a palaeoflow direction of the tsunami (Fig. 6E). They are chaotic in the upper part, especially in the unit 3 with no preferred orien-

tation. The pottery shards indicate high-energy of tsunami and provide evidence for marine incursion. The flat-lying pottery, in addition to the imbricated shells in the units 1 and 2, were reported in the tsunami-derived deposits identified offshore at Ashqelon and Caesarea (for location see Fig. 1) (Goodman-Tchernov *et al.*, 2009; Hoffmann *et al.*, 2018).

Rip-up clasts are usually composed of pebbles and cobbles of silica, Hamra palaeosol and peat (Fig. 6F). They indicate high-energy and also suggest that the material was

not overwhelmed for long periods, enough to break apart the material into individual grains. These materials are previously described from turbidites, channel surges, subaquatic dunes and bars and tsunami deposits (Morton *et al.*, 2007). Boulder-size fragments with no preferred orientation were observed in the unit 3, indicating to channel rock collapse (Scheffers, 2002; Goto *et al.*, 2010; Paris *et al.*, 2010).

Overall, these rip-up clasts in the lower part and in the western part of the section and particularly flat-lying pottery shards imbrication, in addition to lamination in the lower parts of the units 1 and 2 clearly indicate a high-flow regime. On the other hand, the chaotic rip-up clasts in the unit 3 suggest hyper-concentrated flow, caused by the catastrophic effect of a strong tsunami.

In sense of Hoffmann *et al.* (2018) the pottery shards in their study area at Tel Tel Ashkelon, located to the north of the Gaza Strip provide a terminus post quem of around 5–4 century BC. At that time, sea level indicators suggest a similar sea-level as today (Sivan *et al.*, 2001, 2004; Lambeck *et al.*, 2014; Goodman-Tchernov and Katz, 2016). Due to coastal erosion and cliff retreat, coastal geomorphology has changed dramatically in recent years, as described above (Katz and Mushkin, 2013; Barkai *et al.*, 2017). Consequently, in this study the rip-ups of the Hamra palaeosol combined with pottery shards which were eroded by high energy current flow of the tsunami, suggest that the sea was further west than its present shore, meaning that the deposits within this study were even further inland relative to today.

Run-up and inundation distance

Run-up is defined as the elevation of the tsunami relative to sea level at maximum inundation and inundation distance farthest inland of tsunami penetration. However, studies of modern tsunamis document that the maximum elevation reached by a tsunami and the maximum extent of inundation is often beyond the maximum extent of sedimentation and sedimentation may be discontinuous near the limit of inundation (Gelfenbaum and Jaffe, 2003; Jaffe *et al.*, 2003). The eroded zone may also underestimate the run-up and inundation distance. Therefore, the highest recorded elevation and farthest distance inland of tsunami deposits is found to represent a minimum estimate of the run-up and inundation distance of the tsunami (Peters *et al.*, 2007).

The pottery shards in tsunami deposits provide evidence for tsunami inundation for about 1 km in the coastal zone from the present shoreline. The elevation of the coastal ridge at the studied section is about 30 m a.s.l. This indicates that a maximum overtopped by the tsunami inundation is about 30 m at about 1 km inland in the open coast and may be found more than this distance up wadis. This estimation of height elevation of inundation supposed that neither uplift nor subsidence occurred subsequent to a tsunami. Coastal uplift or subsidence that occurred during the time between deposition and elevation measurements of the deposit or barrier may have a significant effect on run-up determinations from paleotsunami deposits. In regions

where uplift or subsidence estimation rates are known, correcting for coastal uplift or subsidence improves run-up estimates (Peters *et al.*, 2007).

CONCLUSIONS

An anomalous depositional sequence found in ancient the Gaza City's Mediterranean shoreline has specific waterborne characteristics and may fit tsunamigenic criteria. Physical characteristics of tsunami deposits recognized in this study are: lamination of sand mixed with fine-grained deposits and volcanic ash, including rip-up clasts, foraminifera and pottery clasts.

The results show how sedimentological records can be valuable for understanding the history of a cultural heritage site within archaeological areas, expanding the tsunami catalogue. Ancient, natural, anomalous coastal deposits of uncertain origin may also be worth reconsidering in the context of better understanding of sedimentological indicators related to a tsunami.

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