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Tsunami deposits in the geological record

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Abstract

A review is presented here of tsunami deposits in the geological record. It begins with a discussion of the relationships between the processes of tsunami generation and propagation and the sedimentary responses. This is followed by a consideration of the sedimentary processes associated with the passage of tsunami waves across coastlines. Attention is also given to the sedimentary processes associated with tsunami-triggered gravity backwash flows and comparisons are made with turbidity current action. We observe that despite sedimentary evidence for recent tsunamiites, geological research on ancient tsunamis has not identified stratigraphic units associated with onshore tsunami sedimentation. Equally, it is noted that nearly all published studies of sedimentary processes associated with modern tsunamis have not considered patterns of sediment transport and deposition in the offshore zone.

Keywords: Tsunami deposits; Geology; Offshore; Sedimentation; Run-up

1. Introduction

Tsunami deposits are well documented from modern, historical and late Quaternary times (e.g. Dawson and Shi, 2000; Scheffers and Kelletat, 2003), but they have rarely been described from the longer, more ancient, geological record. There may be two obvious reasons for this apparent paucity of ancient tsunami deposits. Firstly, it may indicate a tendency toward erosion of tsunami traces in the rock record. Tsunamis typically affect environments subject to permanent or frequent current reworking, such as floodplains, coastal areas, shallow seas and submarine canyons, and these environments generally have a low preservation potential for 'event deposits' (Clifton, 1988; Einsele et al., 1996). Secondly, it may reflect a tendency for the geological characteristics of tsunami processes (tsunamiites) to mimic those produced by other abrupt, high-energy marine and littoral processes (Shiki, 1996; Shiki et al., 2000). To examine these issues, we review the reported incidence and effects of tsunamis in the pre-Quaternary record and consider the likely geological imprints of such palaeotsunamis.

It is important that any study of the geological expression of tsunamis consider their depositional signatures in terms of their physical genesis. In this regard, the physics of tsunamis generally link three overlapping but quite distinct processes: (1) generation by any force that disturbs the water column, (2) propagation, either from open ocean to more restricted coastal waters, entirely within shallow nearshore waters or within lakes; and (3) inundation of onshore areas (Gonzalez, 1999). To this we add an important (but largely neglected) fourth tsunami-related process: *traction*, the tsunami-generated backwash current from shoreline into deeper-waters (Einsele et al., 1996) (Fig. 1).

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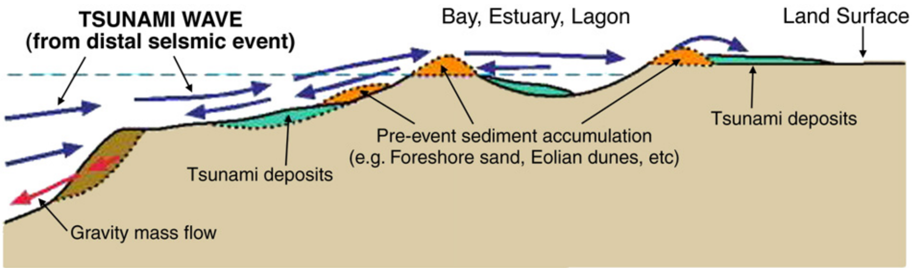

Fig. 1. Schematic illustration of principal pathways of tsunami sediment transport and deposition (after Einsele et al., 1996).

This paper considers the nature of each of these four tsunami phases in turn. The 'generation' phase concerns the nature of the tsunamigenic source mechanism (earthquake faulting, impact cratering, landslide etc.) and although this has implications for the magnitude and extent of the tsunami generated, it is not expected that it will have any recognisable sedimentary signature (beyond any physical trace of the causative mechanism, e.g. sea floor fault scarp, crater, landslide scars and debris fields). By contrast, the other three phases are thought likely to leave a potential imprint in sedimentary depositional environments. During the propagation of a tsunami from the open ocean across areas of continental shelf and shelf edge towards the coast, sea-bottom sediment can be disturbed and mobilised. In the inundation phase, tsunamis erode, transport and deposit sediment onshore during run-up. During the traction phase, pulses of tsunami backwash may generate turbidity currents that move seaward towards the abyssal zone via submarine gullies and canyons.

2. Generation

Tsunamis arise from any significant disturbance of the marine water column, either by 'bottom-up' displacements of the seabed (earthquakes, volcanic eruptions, and submarine landslides), or by 'top-down' strikes onto the sea-surface (asteroid and comet impacts, coastal landslides) (Fig. 2). In simple terms, the larger the disturbance the larger the consequent wave, but the wave height in the open ocean (tsunami height) increases as it enters more restricted coastal waters, and again as it arrives at the shore (inundation height) and surges on land (run-up height). For instance, satellite altimetry measured the wave height of the 26 December 2004 tsunami midway across the Indian Ocean at about 1 m (Gower, 2005), while post-event field surveys in Sumatra, Thailand and Sri Lanka recorded inundation heights of up to 13 m (Lay et al., 2005). The degree of amplification (shoaling) of tsunamis in the nearshore zone (typically threefold to sixfold over a wide range of conditions — Ward, 2001) is a crucial element of geological studies of past tsunamis. A general 'rule-of-thumb' noted by Lowe and de Lange (2000) is that a minimum inundation height of 5 m is needed to leave a 'recognisable' deposit in the onshore sedimentary and geomorphological record. All tsunami wave heights, however, are a function of their initial amplitude of the wave at source, and this varies

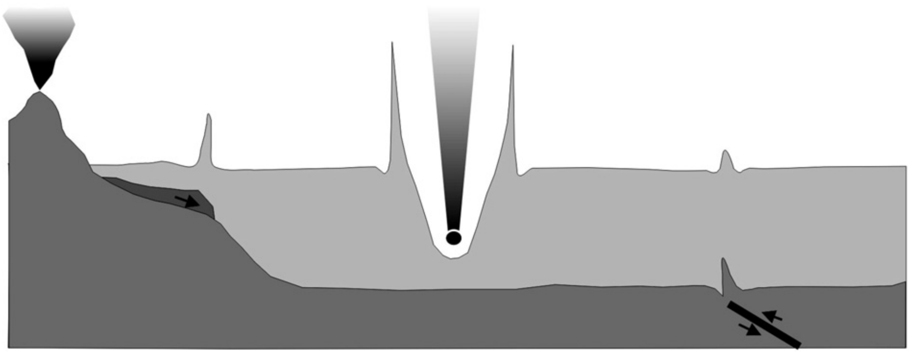

Fig. 2. Cartoon showing three main mechanisms for generating tsunamis: great earthquakes, giant slope failures and large bolide impacts. Displacement of the sea floor by large earthquakes produce an initial wave pulses several metres high, roughly equivalent to the amount of vertical seabed displacement. Sliding masses from steep continental shelves of coastal and island volcanoes build waves tens of metres high above their leading edges. Bolide impacts larger than 1 km in size can penetrate to the deep-ocean floor and instantly displace the entire water column, generating in the first moments of the impact tsunami amplitudes equivalent to the ocean depth.