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SEDIMENTOLOGICAL EFFECTS OF TSUNAMIS, WITH PARTICULAR REFERENCE TO IMPACT-GENERATED AND VOLCANOGENIC WAVES; Joanne Bourgeois, Patricia L. Wiberg, Dept. of Geological Sciences, Univ. of Washington, Seattle, WA, and Thor A. Hansen, Dept. of Geology, Western Washington University, Bellingham, WA

Impulse-generated waves (tsunamis) may be produced, at varying scales and global recurrence intervals (R.I.), by several processes. Great-thrust earthquakes in the Pacific generate tsunamis, with an R.I. of O(10) yr. Other tectonically induced motions, associated slope failures, and other submarine failures also generate tsunamis, typically on the same or smaller scale as great-thrust earthquakes. Some prehistoric submarine landslides may have produced very large tsunamis (1). Explosive volcanic-island eruptions such as Krakatau generate major tsunamis, with an R.I. of O(100-1000) yr. Meteorite-water impacts will produce tsunamis, and asteroid-scale impacts with associated mega-tsunamis may occur, with an R.I. of O(10-100) m.y.

A bolide-water impact would undoubtedly produce a major tsunami (2), whose sedimentological effects should be recognizable. Even a bolide-land impact might trigger major submarine landslides and thus tsunamis. But explosive volcanic eruptions also generate tsunamis. In all posulated scenarios for the K/T boundary event, then, tsunamis are expected, and we must determine where to look for them, and how to distinguish deposits from different tsunamis. Also, because tsunamis decrease in height as they move away from their source, the proximal effects will differ by perhaps orders of magnitude from distal effects.

Data on the characteristics of tsunamis at their origin are scarce. Some observations exist for tsunamis generated by thermonuclear explosions and for seismogenic tsunamis, and experimental work has been conducted on impact-generated tsunamis (3). The energy released by a major (i.e., 5-km radius) asteroid impact is at least several orders of magnitude greater than any historical tsunamigenic event (2), however, and experiments are done on a much smaller scale. The initial wave height for seismogenic tsunamis is O(10) m, for volcanogenic explosions perhaps up to 100 m, for submarine landslides up to 100s of m (1), and for meteorite impacts, up to the depth of the water (i.e., c. 5 km). Initial heights decrease as the waves spread radially, and wavelengths and periods have been observed to increase with distance from the source. Open-ocean data on tsunami wave heights are rare; coastal run-up measurements are common. Most measured or theoretical heights for seismogenic tsunamis away from their source are 10s of cm to about 1 m. Estimates for a meteorite impact range from 10 m to 100 m at a distance of 5000 km from the source (2). All tsunamis of interest have wavelengths of O(100) km and thus behave as shallow-water waves in all ocean depths. Typical wave periods are O(10-100) minutes.

We can estimate the effect of these tsunamis in the marine and coastal realm by calculating boundary shear stresses (expressed as U*, the shear velocity). For example, take a water depth of 100 m, and tsunami wavelength of 110 km and wave period of 1 hr (within the range of most tsunami cases), for varying wave heights (H). For a typical large seismogenic tsunami (H = 1 m), U* = 1.4 cm/sec. For a significantly dissipated, impact-generated wave, or possibly a Krakatau-type wave (H = 10 m), U* = 11.3 cm/sec. For a distal (5000 km from source) but potentially large impact-generated wave (H = 100 m), U* = 96 cm/sec. Because tsunamis are long-period waves, they will have thick boundary layers; thus, given sufficient shear stresses, large volumes of sediment may be suspended, thereby generating turbidity currents which may flow into deeper water. Also, waves break in water about as deep as wave height, so the largest tsunamis will break before they even reach the continental shelf, also generating large volumes of suspended sediment.

On the outer shelf, then, seismogenic tsunamis may weakly transport very fine sediment (if it can be eroded from a bed that is typically cohesive), but in most cases they would have less than the effect of a large storm. Volcanogenic tsunamis may have an order of magnitude greater effect if the source of the explosion is appropriately positioned. Impact-generated tsunamis may produce major marker layers in shelf sediments as well as the deep sea. All these tsunamis should have an effect on very-shallow-water environments and coastal plains, but the larger tsunamis have low enough recurrence intervals that the probability of preserving the coastal record is very low.

An event layer at the K/T boundary in Texas occurs in mid-shelf muds. This layer comprises a graded basal layer (coarse sand) with large mud and calcareous intraclasts, overlain by parallel-laminated to wave-rippled very fine sand. The characteristics of the layer require a two-step event, with initially large shear velocities (order of 50 cm/sec), followed by deposition of fine sediment from suspension on a bed experiencing small shear velocities (order of 1 cm/sec). A boundary layer at least 10s of m thick is required in order to suspend enough sediment to form the upper layer. Only a large, long-period wave, i.e., tsunami, with a wave height of O(50) m, is deemed sufficient to have produced this layer. Such wave heights imply a nearby volcanic explosion on the scale of Krakatau or larger, or a nearby submarine landslide also of great size, or a bolide-water impact in the ocean. A 10-km-diameter bolide could hit the deep ocean up to about 5000 km away and produce the required conditions; a more proximal impact in shallower water could also produce the layer. If the tsunami were produced by explosive volcanism, we would expect an ash layer to cap the sandy bed, or at least to be found in Caribbean or Atlantic cores; we know no reports of such a layer.

(1) e.g., G.W. Moore, J.G. Moore, 1985, Geol. Soc. Am. Abstr. 17(7), p. 668.
(2) e.g., D.E. Gault, C.P. Sonnett, 1982, Geol. Soc. Am. Spec. Paper 190, p. 69; D.R. Lowe, G.R. Byerly, 1988, 19th Lunar Science Conf., p. 693-694.
(3) e.g. Gault and Sonnett, note 2, various tsunami symposia.