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Discussion

Structure and depositional processes of a gravelly tsunami deposit in a shallow marine setting: Lower Cretaceous Miyako Group, Japan—discussion

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Tsunamis are unexpected, violent events and can rarely be studied by direct observation, so that much of their hydrodynamic behaviour is uncertain. Careful examination of their deposits can therefore assist in determining flow conditions and depositional processes (Le Roux and Vargas, 2005), but a prerequisite is that such deposits be identified correctly. In our opinion, the paper by Fujino et al. (2006) does not meet this criterion.

The authors mention five features that, according to them, can only co-exist if they were formed by a tsunami, although they admit that each of these features individually may be attributed to other processes. Here we contend that all five features can occur together in a wave-dominated, shallow marine environment affected by storms.

Imbrication reflecting current reversals from seaward-to landward-directed is attributed by Fujino et al. (2006) to the onrush and backwash of successive waves during a single event. Because the environment was wave-dominated, as shown by an abundance of hummocky cross-stratified (HCS) sandstones, they rule out tidal action as a possible cause. However, strong wave action does not necessarily preclude tidal activity. Inversely directed imbrication is only described from the Koikorobe section, which is characterized by superimposed scours filled with fining-upward conglomerate and sandstone. This section may just as well represent a submarine channel zone in an otherwise wave-dominated environment, as supported by the lower basement topography in this area (Fig. 2 of Fujino et al., 2006). Tides generally tend to be enhanced along submarine channel systems, so that bi-directional imbrication could easily form in such an environment. It is also possible that the Koikorobe section was located opposite a river mouth where sporadic periods of high run-off caused an influx of coarse gravels with seaward imbrication, whereas flood-dominated tides produced landward imbrication in the upper gravelly portion of the cycles when conditions began to return to normal. The fining-upward cycles would fit well into this scenario.

The scour-and-grading structure at Koikorobe is interpreted by Fujino et al. (2006) to reflect alternating stagnant and brisk flow velocities during a single tsunami episode. The possibility that the cycles represent several discrete events separated by hiatuses is discarded because of the absence of bioturbation and the lack of surface disturbance by waves. However, it should be pointed out that the base of each subcycle is erosional, so that any disturbance by waves would not be preserved. Bioturbation could likewise have been removed by

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erosion or may be absent from this section because the high-energy conditions within a channel zone do not favour burrowing organisms. In any case, in their Fig. 3 bioturbation is only shown to occur at the base of the North Haipe section and at the top of the Koikorobe section, whereas HCS sandstones in the rest of the sections (not part of the tsunami bed) are apparently undisturbed. The absence of bioturbation is therefore not a viable criterion for tsunami deposition.

A strong argument that hiatuses in fact did exist between the "tsunami sub-events" is shown by Fig. 3 of Fujino et al. (2006). In the North Haipe and North Hiraiga sections, the tsunami interval is correlated with a unit consisting of thin, discrete conglomerate beds separated by HCS sandstones. Hummocky cross-stratification would normally be interpreted to indicate storm wave action, whereas the intercalated conglomerate beds could be deposited from debris flows, or alternatively could represent gravelly beds migrating onshore under wave action (Bourgeois and Leithold, 1984). The HCS sandstone units are up to 5 m thick, which probably indicates fairly long stormy periods. We therefore do not understand how these intervals can develop during a single tsunami episode. There is also no apparent difference in these two sections between the tsunami unit and underlying as well as overlying, amalgamated HCS sandstones containing similar, discrete conglomerate interbeds.

The fine sandstones capping the subcycles are attributed to intervals of stagnant water after wave run-up and before backwash developed, which Fujino et al. (2006) explain by the long wavelengths of tsunamis. However, backflow develops immediately after the run-up phase when dense, sediment-laden water returns seaward under the influence of gravity, which is unrelated to the wavelength. It is therefore unlikely that sand would have time to settle after each wave run-up instead of being swept out to sea as part of the backwash.

The presence of beach gravels and corals in the deposit is considered by the authors to reflect a destructive tsunami event, but large storms are also perfectly capable of eroding beaches or coral patch-reefs and redistributing the clasts over the lower shoreface.

A condensed organic layer is taken by Fujino et al. (2006) as evidence for a tsunami event, because "although other phenomena may provide organic debris, few can effectively sort it". We see no problem in sorting organic material from other sediments, for example by settling during the waning stages of a storm, or from the tail of a turbidity current. However, it is not clear to us how a tsunami might sort organic debris so that it becomes "intercalated within the upper part of the tsunami deposit" (subtitle to Fig. 4). Organic matter requires a long time to settle from suspension and should therefore be deposited last, instead of being intercalated with the upper alternating sandstone and mudstone at the top of the "tsunami" unit.

The good preservation of molluscan fossils, while it might indicate rapid deposition and little reworking (or simply in situ preservation), does not necessarily require a tsunami explanation. We have observed many coquinas with the majority of shells well preserved, in different shallow marine settings where there is no evidence of tsunami deposition (Le Roux et al., 2004, 2005, 2006).

Our own observations of probable tsunami deposits along the Chilean coastline are radically different from those described by Fujino et al. (2006). Most are very similar to normal debris-flow deposits, but typical features include protruding, wave-polished boulders, megaclasts ripped up from the substrate, sediment plumes injected from below into the deposits, sand dykes and sills injected from the deposits into the substrate, and a wider alongshore distribution than normal debris flow deposits, because such events would generally affect the whole coastline and not only certain confined sections. Although Fujino et al. (2006) interpret a large part of the North Haipe and North Hiraiga sections as representing a single tsunami deposit, thus apparently satisfying the last criterion, we cannot but disagree. If the authors should insist on such an interpretation, they should explain how these sections differ from the under- and overlying deposits also containing unbioturbated HCS sandstones and discrete conglomerate beds, which they themselves interpret as lower shoreface to inner shelf deposits. None of the other characteristic features of tsunami deposits is mentioned by Fujino et al. (2006). In summary, we consider their evidence for tsunami deposition to be unconvincing and better accounted for by normal shallow marine processes.

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