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Forum Reply

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Sea-level–induced seismicity and submarine landslide occurrence

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We would like to thank Urlaub et al. (2014) for their Comment responding to our paper (Brothers et al., 2013) and continuing a dialog on the important topic of submarine landslide age dating. The processes that lead to submarine slope failure are poorly understood in part due to the limited number of well-dated landslide deposits, yet it is widely accepted that earthquakes play a central role in triggering both submarine and terrestrial landslides. An overarching goal of our paper was to test for a causal relationship between seismicity and rapid sea-level rise. To a first-order, our results suggested that large (100+ m) and rapid (10+ mm/yr) changes in eustatic sea-level can potentially modulate seismicity rates on passive continental margins– regions that experience large earthquakes relatively infrequently. Such a relationship may help tie together processes that precondition slopes to fail, such as increased sediment supply, and processes that actually trigger failure, such as earthquakes. Landslide age dating was not the focus of our analysis. We compiled age data from published sources much like previous studies that also described an apparent increase in landslide frequency following the Last Glacial Maximum (e.g., Owen et al., 2007; Lee, 2009). We focused on the time period between 16 ka and 8 ka because the rate and magnitude of sea-level rise over this period was sufficient to induce lithospheric flexure (Luttrell and Sandwell, 2010). Our paper did not discuss a potential tie between modern sea-level rise and future landslides.

We agree that there is a need to expand the database of landslide ages and a need to critically reevaluate those already in the database. Results by Urlaub et al. (2013) were not published at the time that our manuscript was accepted to Geology. Nevertheless, we fully recognize and commend their rigorous analyses. Given the large uncertainties in landslide age-dates and the need for additional landslide age-control on all margins, it is still too early to reject a link between rapid, late-Pleistocene sea-level rise and submarine landslide occurrence (e.g., Smith et al., 2013). Here we respond to additional points by Urlaub et al. (2014).

DATABASE OF LANDSLIDE AGES

(1) Error bars on slide ages: We used the published age-data and selected the midpoint of the uncertainty bounds. In most cases, the 4 k.y. bin widths used to compute the age distribution sufficiently covered the published range in age uncertainty.

(2) Selection of landslide age-data: A Madeira turbidite, first described in Weaver and Rothwell (1987), was given an age estimate of ca. 15 k.y. B.P. by Owen et al. (2007) based on a relative dating method. The Saharan landslide listed at 15–16 k.y. B.P. needs to be omitted in favor of the more recent estimate of ca. 60 ka. The Nice landslide was added for completeness, but had little affect the final age distribution. The four age-dates reported by Embley (1982) for mass wasting to the south of Baltimore Canyon are from cores separated by more than 100 km. New multibeam bathymetry data throughout this region (Andrews et al., 2013) has allowed us to map a complex of distinctive landslides along the slope and upper rise (e.g., Chaytor et al., 2009), thus is it unlikely the deposits described in Embley (1982) represent a single landslide. Finally, we included the Canary event in our analysis, in part, because other studies have described a causal link between volcanic activity and rapid changes in eustatic sea-level (e.g., Kutterolf et al., 2012).

SLIDE FREQUENCY AND MELTWATER PULSES

Brothers et al. (2013) referenced results from Korup (2012) for the time-cumulative volume of sediment remobilized during Late-Pleistocene/early Holocene sea-level transgression as a percentage (~50%) of the total volume remobilized since ca. 125 ka. Meltwater pulses are associated with small increases in plate bending stress; however, we agree that any causal relationship between landslides and meltwater pulses is difficult to resolve given the uncertainties in landslide age data.

MASS FLOW ACTIVITY ON SUBMARINE FANS

Deep-water sandy turbidite activity during sea-level transgression is not an unusual observation, but is atypical within the framework provided by early sequence stratigraphic models (e.g., Kolla and Perlmutter, 1993). Our discussion of this concept seems to have been misconstrued in the comment. Interestingly, even Urlaub et al. (2013) show an apparent increase in submarine landslide frequency during late-Pleistocene sea-level transgression along margins characterized by relatively low terrestrial sediment input. If seismicity rates increased along continental margins during rapid sea-level transgression, earthquake-triggered landslides provide a potential source for deep-sea turbidites.

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