Geophysical Research Abstracts
Vol. 14, EGU2012-4614, 2012
EGU General Assembly 2012

Progressive and frontally-confined seafloor sediment failure in response to volcanic debris avalanche emplacement

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The marine sedimentary record around volcanic islands provides an archive of volcanic events, the largest of which are landslides associated with volcanic edifice collapse. Such events are among the largest mass movements known on the Earth's surface, and may generate devastating tsunamis. However, accurate assessments of tsunami hazard rely on a full understanding of landslide failure processes and emplacement dynamics.

Here, we use a high-resolution geophysical dataset collected from offshore Montserrat, in the Lesser Antilles volcanic arc, to investigate the structures and emplacment processes of large landslide deposits. The largest deposit off Montserrat, with a volume of ~20 km3, is dominated by seafloor sediment rather than blocky material derived from the parental volcanic collapse. The failure of a consistent stratigraphic package of seafloor sediment occurred beyond the margins of the volcanic debris avalanche, affecting 70 m of stratigraphy and propagating progressively downslope for 30 km on gradients of <1°. This failure involved limited downslope movement, disrupting sediment approximately in-situ and producing a unit rich in compressional deformation structures. There is little accumulation at the deposit toe, and the unit remains frontally confined, abutting its equivalent undeformed stratigraphy. On lower-resolution seismic profiles, the deposit has a chaotic character, but our results show that such attributes cannot be taken to imply significant material disaggregation or transport.

We discuss potential mechanisms of seafloor sediment failure in light of landslide deposit structures around Montserrat. We propose a model of deformation driven by undrained loading, where an over-running surface load results in excess pore pressure within the underlying strata. This underlying weak package both enhances the overall propagation distance of the landslide, enabling deformation to progress on very low gradients, and also becomes incorporated within the final deposit, dramatically increasing the final volume. Similar deformation processes may be relatively common, with evidence for comparable frontally confined and notably thick landslide deposits both around other volcanic islands and in continental margin settings. The identification of such deposits relies on detailed seismic imaging of internal deformation structures. As a mechanism for producing large volume submarine mass movements, recognition of this style of failure is important. The limited material evacuation implied by the process is likely to strongly reduce the tsunamigenic potential of these landslides, in contrast to retrogressive processes and frontally-emergent, more mobile submarine landslides.