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Resolving the landslide mechanism and tsunamigenic potential of catastrophic volcanic island flank collapses: Canary and Madeira Archipelagos

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Volcanic islands naturally facilitate the occurrence of large-scale landslides due to eruptions, seismic activity and the generation of over-steepened edifices. Landslide-induced tsunami generation is sensitive to a number of parameters including: landslide volume, initial acceleration, maximum velocity and retrogressive behaviour. These parameters are difficult to calculate from events in the geologic record, since the volcanic island debris aprons are complex areas and involve overprinting of events. Furthermore, predicted conditions for future events are based on information from the proximal landslide area, and are often over-estimated.

Turbidites are generated from volcanic island flank collapses and records of landslide occurrence can be constructed from these more distal gravity flow archives. With appropriate mapping of a respective turbidite with sediment cores, accurate volume estimates can be made and added to those from the proximal debris avalanche. In addition, recent studies have shown that the landslide mechanism (single block or multi-stage) can be deduced from the turbidite architecture by the presence/lack of subunits (repeating sequences of turbidite sand and mud). Subunits represent multistage events, and furthermore, the study of the interbedded mud intervals can provide details on the time required between events to allow the mud to settle and consolidate.

The Icod turbidite in the Moroccan Turbidite System originating from the northern flank of Tenerife (165 ka) is composed of a series of seven subunit events. These have developed from a multistage retrogressive failure during the Icod landslide. Of the $\sim$360 km3 volume of the landslide, 210 km3 comprises the turbidite. This is then divided between the subunits, where the initial three are the most volumetrically significant (70-75 km3) compared to the upper four (15-25 km3). Geochemical, grain-size, petrological and geotechnical data have shown the subunit events are the product of the landslide mechanism, rather than flow reflection, multiple sources or multiple pathways. Analysis of the distal deposit highlights the presence of seven upwards-fining sands with intervening muds. These muds present suspension fallout deposition between each failure and demonstrate conservative time intervals of 3 to 22 days. From studying the turbidite associated with the landslide numerous properties of the landslide event can be gleaned. Firstly, the Icod flank collapse has been shown to be multistage and retrogressive. Therefore, the overall considerable volume has been shown to be distributed amongst the subunit events. The result here is that the mass entering the ocean at once is decreased, and thus the potential tsunami wave amplitude is reduced. Study of the debris avalanche shows considerable slide material disaggregation and flow transformation from avalanche to debris flow. This shows the slide material has low coherency, which will affect the tsunami wave properties. Importantly, this case study is not ubiquitous and can be applied to others in the study area. The implication is that catastrophic volcanic landslides in the Canary Islands are commonly multistage and not single block failures, so the tsunamigenic potential is much reduced.