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Use of distal turbidites to decipher landslide records of frequency, volume and failure mechanism: case studies from the Moroccan Turbidite System

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Proximal debris aprons of volcanic islands and continental slopes have been studied in detail in the search of evidence for landslide activity. However, records of occurrence are difficult to calculate in these locations due often to substantial overprinting and geomorphic complexities. Furthermore, processes of failure are often obscured in these proximal areas of the landslide. However, submarine landslides commonly generate turbidites that are recorded in the quiescent basin plain. Along with archived pelagic sedimentation, the turbidite record linked to landslides can provide accurate reoccurrence intervals. In addition, adequate core coverage can provide better resolution on the volumes involved in specific landslide events. Studies of the turbidite facies can also provide valuable insight into the landslide mechanism that generated the turbidite. Wynn and Masson (2003) and ongoing work has attributed multiple-stacked repetitive upwards-fining sand and mud interval facies in the turbidite (subunit architecture) to representing a multistage failure at source. This is best exemplified by the 165 ka Icod turbidite from the Icod landslide from the northern flank of Tenerife. Furthermore, this facies is present in other major turbidite events generated from the most recent large volume volcanic landslides, including the El Golfo (15 ka) and Las Playas II ($\sim$125 ka). Of note these large volume turbidites from catastrophic failures have well developed bedforms that associate these flows with surge-like processes of Mulder and Alexander (2000). These bedforms range from massive sands (Ta), through parallel laminated sands (Tb), cross laminated sands (Tc), convolute laminated sands (Tc, through laminated silts and muds (Td) and graded muds (Te). The volume, velocity profile, mud content and longevity of the flow have enabled the full sequence of bedforms observed to develop.

In addition smaller volume events are recorded in single and multiple fining-upwards packages. These are recorded in two facies: (1) a graded sand with parallel and cross laminations before a grain-size break and a limited mudcap, and (2) lower volume events with an ungraded structureless sand capped by a grain-size break and limited mud. Here the lower volume (2) facies is attributed to surge processes of Mulder and Alexander (2000) and the (1) facies mark a transition between the surge-like processes of the turbidites linked to catastrophic failures and the surge processes of the low volume events. The surge flows are attributed to small local failures of sediment accumulations on the volcanic island shelves. Here the sand fraction is stratified from the mud fraction during the flow and deposited rapidly, resulting in a lack of bedforms. The transitional surge to surge-like flows mark an increase in volume and mud content, where the flow is sustained for long enough for bedforms to develop. The implication is that turbidite processes can be inferred, where there is adequate core coverage for both volumetric calculations and facies analyses, and that this can provide insight into the landslide source.

This study presents a comprehensive appraisal of the provenance and recurrence of submarine volcanic island landslides in the Canary and Madeira archipelagos based on the distal turbidite record. This study also aims to show that the facies present in the turbidite record can enable insight into the failure source and mechanism. This is important in enabling appropriate geohazard assessment for a submarine area from a landslide and tsunami perspective.