Earthquake-triggered Submarine Sediment Gravity Flows in Action

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Submarine sediment gravity flows are significant and far-reaching hazards that link the seemingly disparate processes of earthquakes and episodic sediment redistribution. These flows develop when sediments derived from river bottoms, ocean floors, or failed submarine sedimentary slopes become suspended in the water column. Once the water column becomes sufficiently dense, rapidly traveling flows may develop that scour the seabed and entrain even more sediment. The flows then accelerate and become turbulent currents that can travel hundreds of kilometers. This phenomenon transports a major fraction of global sediments from land to sea, and threatens the millions of km of seafloor cables that enable global communications. Earthquake-generated seismic shaking is a well-documented trigger of sediment gravity flows. When preserved, the sedimentary deposits left behind when the flows stop (called 'turbidites'), serve as geologic recorders of past earthquakes. Much of our understanding of the conditions and mechanisms that generate sediment gravity flows comes from sparse and remote observations only of their impacts, hampering useful inferences from the turbidited record about earthquake recurrence and assessments of the hazards flows pose.

Data provided by the seafloor cabled Dense Oceanfloor Network system for earthquakes and tsunamis (DONET), located atop the Nankai subduction zone. This region has previously documented turbidites and sediment flows, all offering a novel opportunity to eliminate the non-uniqueness inherent in existing flow models derived only from end-product observations. DONET provides direct records of seismic shaking within a few km of where flows originate and travel, from numerous types of earthquakes with varied seismic wave characteristics. DONET was developed and is operated by the Japan Agency for Marine-Earth Science and Technology and the National Institute for Earth Science and Disaster Prevention, and now includes 49 seafloor stations where pressures, temperatures, and three component ground velocities and accelerations are recorded continuously. These numerous types of continuous measurements permit the detection of flows as they develop and their impacts, in addition to measuring those conditions that fail to produce flows. We analyze the shaking characteristics from multiple earthquakes, particularly from a M6.0 event that occurred <20 km of a DONET station on April 1, 2016 and from the M6.1 and M7.1 Kumamoto, Japan earthquakes on April 14 and 16, 2017. The April 1st event generated peak ground accelerations in excess of 0.6 g at multiple sites, and was likely capable of causing slope failures in most comparable environments. We analyze bathymetric data to identify likely flow paths and unstable slopes for these events. We examine seismic data for signals generated by slope failures, as well as the temperature and pressure records for flows evident as pulses of warmer but denser shallow water transported to deeper sites. We distinguish pressure and temperature changes attributable to oceanographic circulation from those due to sediment gravity flows using simulated data from a regional ocean modeling system and from coherence analyses. Finally, we use recorded seismic ground motions and sediment property data from previously collected cores as input parameters to simple slope stability models. We test gravity flow triggering assumptions by comparing slope stability model predictions to our inferences from the comprehensive DONET data.

Keywords: submarine sediment gravity flow, DONET array