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Timing and frequency of large submarine landslides: implications for understanding triggers and future geohazard

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ABSTRACT

Large submarine landslides can have serious socioeconomic consequences as they have the potential to cause tsunamis and damage seabed infrastructure. It is important to understand the frequency of these landslides, and how that frequency is related to climate-driven factors such as sea level or sedimentation rate, in order to assess their occurrence in the future. Recent studies have proposed that more landslides occur during periods of sea level rise and lowstand, or during periods of rapid sedimentation. In this contribution we test these hypotheses by analysing the most comprehensive global data set of ages for large (>1 km^3) late Quaternary submarine landslides that has been compiled to date. We include the uncertainties in each landslide age that arise from both the dating technique, and the typically larger uncertainties that result from the position of the samples used for dating. Contrary to the hypothesis that continental slope stability is linked to sea level change, the data set does not show statistically significant patterns, trends or clusters in landslide abundance. If such a link between sea level and landslide frequency exists it is too weak to be detected using the available global data base. It is possible that controlling factors vary between different geographical areas, and their role is therefore hidden in a global data set, or that the uncertainties within the dates is too great to see an underlying correlation. Our analysis also shows that there is no evidence for an immediate influence of rapid sedimentation on slope stability as failures tend to occur several thousand years after periods of increased sedimentation rates. The results imply that there is not a strong global correlation of landslide frequency with sea level changes or increases in local sedimentation rate, based on the currently available ages for large submarine landslides.

1. Introduction

Submarine landslides include the largest mass flows on Earth and can be far larger than landslides on land (Hampton et al., 1996). For instance, the Storegga slide offshore Norway has a volume of over 3000 km^3, and covers an area larger than Scotland (Haflidason et al., 2004). For comparison, collapse of the Mt St Helens volcano in 1980 involved ~3 km^3 (Voight et al., 1985), whilst the annual global flux of sediment from rivers into the ocean is ~11 km^3 (Milliman and Syvitski, 1992, Talling et al., 2007). Submarine landslides can generate damaging tsunamis and therefore pose a significant geohazard. The Storegga slide produced a tsunami that locally had ran up of 20 m around the North Sea coasts, ~8100 years ago (Haflidason et al., 2005). A slump containing 5–10 km^3 of sediment triggered a tsunami that killed 2200 people in Papua New Guinea in 1998 (Tappin et al., 2001). The landslides themselves can damage seafloor infrastructure, such as that used to recover oil and gas, or seafloor telecommunication cables that carry more than 95% of the global internet traffic. Such cables were broken by a large submarine landslide and the flow of sediment it generated off Grand Banks, Canada, in 1929 (Piper and Aksu, 1987). Numerous hypotheses have been put forward for what causes large submarine landslides, including earthquakes, rapid deposition or gas hydrate dissociation (e.g. Maslin et al., 1998; Stigall and Dugan, 2010; Masson et al., 2011). These hypotheses are poorly tested, and even less is known about the effect of other preconditioning factors such as fluid flow focussing in the slope (Dugan, 2012).

It has been proposed that future climatic change and ocean warming may increase the frequency of large submarine landslides, such as through triggering by gas hydrate dissociation (Maslin et al., 1998; Tappin, 2010). It is therefore important to know if past large landslides coincided with major climatic events, or were more frequent during periods of rising sea level. It is also important to understand the timing of large submarine landslides to document

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their frequency and assess the hazard they pose, and to constrain the factors that precondition and trigger slope failure. The timing of landslides and factors such as sea level or sedimentation rate can potentially provide a test for failure mechanism hypotheses.

Comparisons of landslide frequency with sea level have been undertaken previously by Maslin et al. (2004), Owen et al. (2007), Lee (2009), and Leynaud et al. (2009), who used compilations of between 16 and 43 large submarine landslides. All studies suggest an increased landslide occurrence during periods of glaciation and/or during glacial to interglacial transitions. Several other authors report an increased recurrence interval of submarine landslides from various geographical locations worldwide during sea level lowstand and during sea level rise (e.g. Paull et al., 1996; Prins et al., 2000; Piper et al., 2003; Lebreiro et al., 2009; Henrich et al., 2010; Lee et al., 2010). These studies are largely qualitative and are not supported by any rigorous statistical analysis. Importantly, they do not take fully into account uncertainties in the determination of landslide ages. These uncertainties can be large, as illustrated by changes in understanding of the age(s) of the Storegga slide. Early studies were based on three cores containing turbidites deposited in an adjacent depositional basin that had no physical connection to the Storegga slide scars. The slide was interpreted as a three-phase event, one of which was older than 30 ka (Bugge et al., 1988). This was then revised by later work that used a more extensive (>90) core data set (Haflidason et al., 2005), to show that the slide was one main event that occurred ~8100 years ago. This significant change in age of the Storegga slide is cautionary, as many other slides are dated using small core data sets comparable to that originally used to date Storegga and similar scientific approaches to obtain landslide ages (e.g. Pearce and Jarvis, 1992; Wynn et al., 2002).

Moreover, the age of a landslide is always accompanied by an uncertainty interval as the accurate age determination is complicated by a number of factors. The main uncertainty is typically related to the location of samples, not the uncertainty in the dating method, which is often radiocarbon dating. Samples for dating submarine landslides can originate from its source area (scar) or the depositional zone. They can be taken above the scar as well as above, below or within the landslide deposit (Fig. 1a–d). These dates usually provide minimum or maximum emplacement ages, rather than exact ages. Their proximity to the exact age depends strongly on sedimentology. For instance, the time gap between landslide and sample age will be large if the boundary between pre- and post-failure sedimentation is disturbed by along-slope sediment transport (deposition and erosion), subsequent minor scarp failure or bioturbation (Fig. 1g).

1.1. Aims

This contribution assembles a data set of ages for 68 large volume submarine landslides, of which 67 are previously published. The data set also includes new radiocarbon dates for the Walker-Massingill slide in the Gulf of Mexico. The ages are derived by dating of the landslide itself, or by dating of the turbidite generated by a landslide. Only landslides (or turbidites) with volumes in excess of 1 km^3 are included in this study. Each data point underwent a critical review to avoid interpretation errors and is assigned an individual uncertainty interval.

The first aim is to address the following questions. Given the available ages for these landslides, and taking into account uncertainties in these ages, is there an association between sea level and the timing of seafloor failure? Does landslide frequency vary significantly with sea level, or could the pattern of landslide ages be random and unrelated to sea level? We apply basic statistics to the data set and assess whether the impact of sea level cycles on landslide timing is as strong as previously suggested (Maslin et al., 2004; Owen et al., 2007; Lee, 2009).

The data set is then subdivided to consider the frequency of landslides in different settings that comprise (i) glaciated margins, (ii) river-dominated systems, (iii) sediment-starved margins, and (iv) the north-west African margin where there is an extensive data set. This is done to accomplish the second aim. Is there a significant association between landslide timing and sea level in particular subsets of the data?

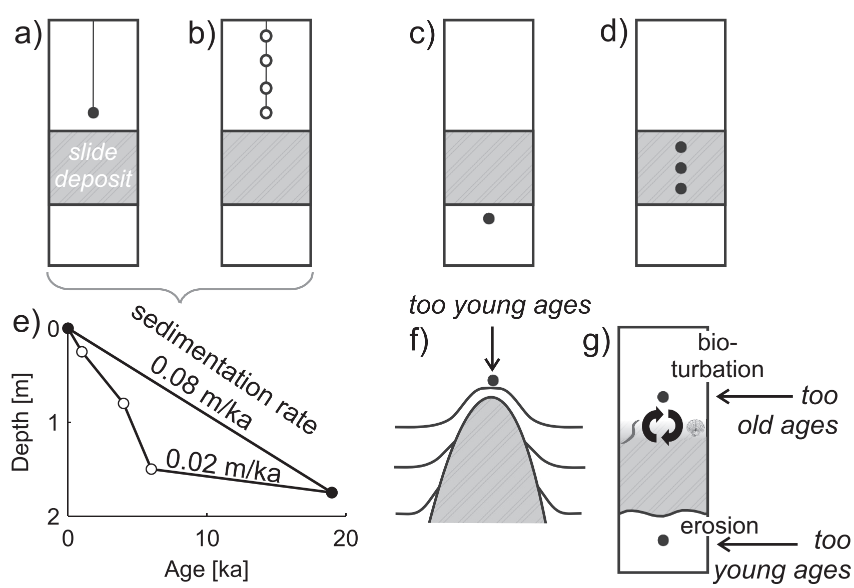

Fig. 1. Different sampling strategies for radiocarbon dating of submarine landslides. The rectangles represent sediment cores with hemipelagic background sedimentation (white) and a landslide deposit (grey). Open and filled black circles indicate the position of the sample. A minimum age is obtained by taking one (a) or several samples (b) from the hemipelagic unit above the landslide deposit. A maximum age is obtained when samples are either taken from the hemipelagic unit below (c) or within (d) the failure deposit. A linear average sedimentation rate for the core based on one sample can be significantly different from actual temporary sedimentation rates (e), which can be calculated when several samples between the top of the core and the top of the failure deposit are available. Samples above the deposit can give an age too young if located on a local high (f) and bioturbation on the top as well as erosion at the base of the failed deposit (g) are possible sources of uncertainty to the estimated ages.