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Sea level rise and submarine mass failures on open continental margins

D.E. Smith [a,*], S. Harrison [b], J.T. Jordan [c]

[a] Oxford University Centre for the Environment, South Parks Road, Oxford OX1 3QY, UK
[b] Department of Geography, University of Exeter, Cornwall Campus, Penryn, Cornwall TR10 9EZ, UK
[c] Department of Geography, Environment and Disaster Management, Coventry University, Coventry CV1 5FB, UK

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ABSTRACT

Submarine mass failures (which include submarine slides or submarine landslides) occur widely on open continental margins. Understanding their cause is of great importance in view of the danger that they can pose both to coastal populations through tsunamis and to the exploitation of ocean floor resources through mass movement of the sea floor. Present knowledge of the causes of submarine mass failures is briefly reviewed, focussing on the role of sea level rise, a process which has previously only infrequently been cited as a cause. It is argued that sea level rise could easily have been involved in at least some of these events by contributing to increased overpressure in sediments of the continental margin whilst causing seismic activity. The Holocene Storegga Slide off South West Norway may have been partly caused by the early Holocene sea level rise in the area, accentuated by meltwater flux from the discharges of Lake Agassiz–Ojibway in North America. Relative sea level rise increased water loading on the Norwegian continental margin, increasing overpressure in the sediments and also causing seismic activity, triggering the Holocene Storegga Slide. Given that some forecasts of future sea level rise are not greatly different from rises which obtained during the early Holocene, the implications of rising sea levels for submarine mass failures in a global warming world are considered.

1. Introduction

Continental margins are amongst the most dynamic regions of the ocean floor. In recent decades much interest has focussed on the large numbers of mass failures present on open margins, originating principally on the Continental Slope and Continental Shelf edge (e.g. Hünerbach and Masson, 2004; Masson et al., 2006; Owen et al., 2007; Lee, 2009; Tappin, 2010). The complexity of these failures, frequently termed submarine slides or submarine landslides, derives from their structure and composition and the processes involved. Some authors have drawn attention to the possibility that sea level rise may generate some submarine mass failures (e.g. Owen et al., 2007; Lee, 2009), although Urlaub et al. (2013), considering mass failures over the past 180,000 years, maintain that no strong link between the frequency of major events and global sea level rise can be identified. The present paper aims to contribute to the debate by reviewing the role of sea level rise as published for submarine mass failures on open continental margins since the Last Glacial Maximum (LGM) and we suggest that sea level rise played a part in one of the largest failures yet recognised. A brief outline of possible future sea level rises as climate changes is then given and attention drawn to the similarity between forecast rates of rise in the future and rates in the past when some failures occurred.

2. Submarine mass failures: summary of characteristics

Submarine mass failures on continental margins occur on a range of slopes, some on slopes as low as below 1°. Failures normally take the form of a scarp facing downslope, with an apron of sediment below (Fig. 1). Below the scarp they include the products of cohesive rotational and translational slides, with débris avalanches, which involve the free fall of rock or unconsolidated material, while at lower levels they comprise débris flows (debrites) and turbidity flows (turbidites) (e.g. Amy and Talling, 2006; Masson et al., 2006; Chaytor et al., 2007; Leynaud et al., 2009). These deposits may be mixed with marine pelagic and

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* Corresponding author. Tel.: +44 1926 426307.
E-mail addresses: david.smith@ouce.ox.ac.uk, davidsmith@quaternary.wanadoo.co.uk (D.E. Smith).

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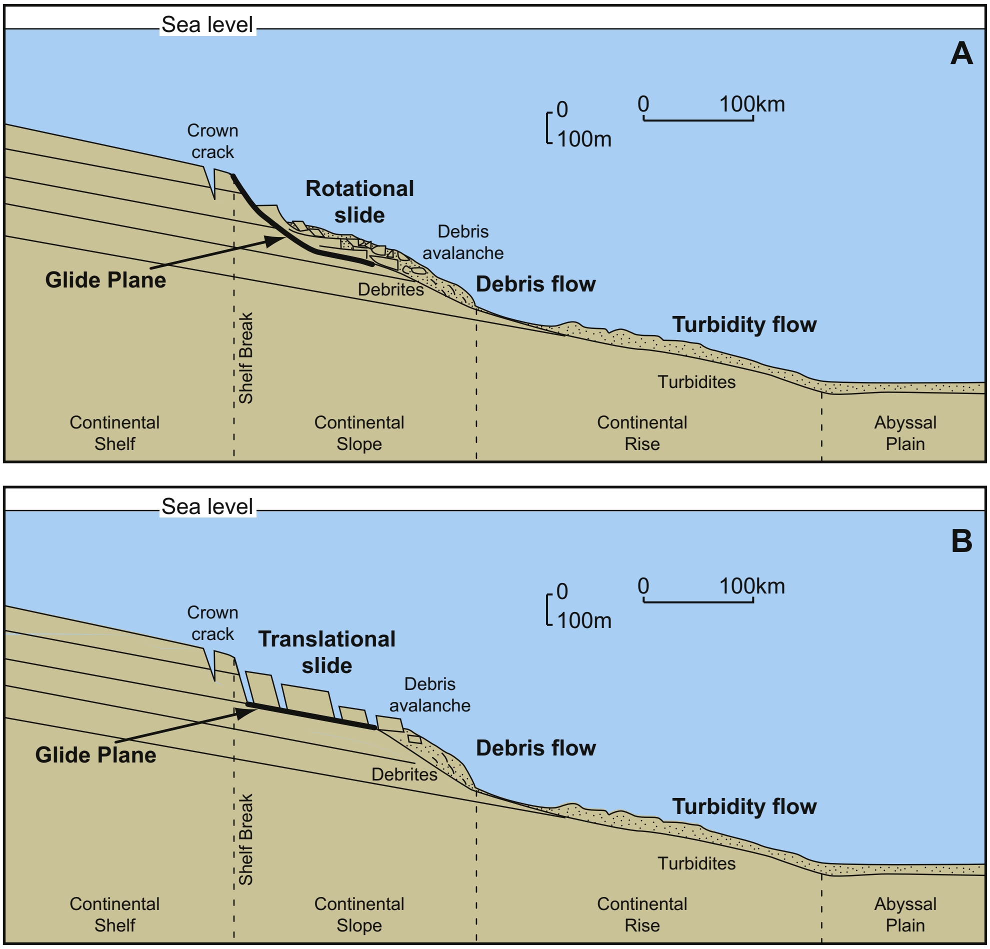

Fig. 1. Schematic diagram showing the main features to be found in a submarine mass failure. A: rotational slide; B: translational slide. Pelagic, hemipelagic and contourite deposits, which may occur throughout the failure, are not specifically identified. Based partly on Nisbet and Piper (1998).

hemipelagic deposits (deep water fine grained deposits containing organic remains) as well as contourites (deposits from bottom currents moving parallel to the slope). Failures are often retrogressive, the head of the failure area developing towards the adjacent coastline.

Some mass failures are particularly large: the Agulhas Slump, a largely rotational slide off the south-eastern coast of South Africa, involved a volume of up to 20,000 km^3 (Dingle, 1977), although it is uncertain whether a single event was involved and further studies are awaited (Tappin, 2010), while the Holocene Storegga Slide, the most recent of several slides in the Storegga area off south-western Norway (e.g. Jansen et al., 1987; Bugge et al., 1988; Solheim et al., 2005), involved a maximum volume of 3200 km^3 and an area of 95,000 km^2 (Haflidason et al., 2004). Initial slide speeds can be very high, dependent upon the nature of the material involved and the slope. Beyond many slides, the flowage of sediments can be both rapid and extensive. After the Grand Banks earthquake of 1929, the timing of the breakage of cables in the path of the turbidity flow indicated that it had travelled at up to 65 kph (Heezen and Ewing, 1952). Run-out distances of slide sediment have been shown to have reached several hundred kilometres in some cases. Talling et al. (2007) reported submarine debris flow deposits extending for 1500 km from submarine mass failures off Northwest Africa. In terms of the areas affected, submarine mass failures can be some of the largest depositional features on the surface of the Earth.

3. Submarine mass failures: summary of causes

In describing the processes involved in submarine mass failures, authors commonly identify preconditions, or the characteristics of the sediment which predispose it to failure; and triggers, which initiate the failure. Preconditions include variations in the stratigraphy and texture of adjacent horizons (e.g. Laberg et al., 2002); the slope of the sediment surface underlying the sediments in which the mass failure occurs (e.g. Chaytor et al., 2007; Twichell et al., 2009) including slope steepening due to the growth of diapiric structures; the presence of gas hydrates within the sediments (e.g. Rothwell et al., 1998; Vorren et al., 1998; Maslin et al., 2004; Meinert et al., 2005); and overpressure in the sediments. The roles of gas hydrates and overpressure have been considered at length in the literature. Gas hydrates, sometimes termed methane hydrate or methane clathrate, comprise methane gas molecules in a “cage” of water molecules at low temperature, comprising methane ice. If circumstances allow the methane to develop without being extensively vented, the stability of sea floor sediments can be compromised. Overpressure, or fluid pressure in excess of hydrostatic pressure at a given depth, involves an increase in confining pressure within the sediments (e.g. Osborne and Swarbrick, 1997). This will occur for example when rapid sedimentation takes place at the continental margin (e.g. Bryn et al., 2005; Flemings et al., 2008; Dugan and Sheahan, 2012); when glaciers advance across the Continental Shelf (e.g. Mulder and Moran, 1995; Lindberg et al.,